CIE 2017 October 20-28 Jeju, Korea

Smarter Lighting for Better Life

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CIE 2017 Midterm Meeting

Ramada Plaza Jeju Hotel, Jeju, Korea

October 20-28, 2017

cie

ABSTRACT BOOKLET

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Tuesday, October 24
Morning

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12:10 - 12:30	Discussion	Discussion	Discussion
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Tuesday, October 24
Afternoon

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	Presented Posters		
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Wednesday, October 25
Morning

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09:30 - 10:00	Invited paper IP05 THE LATEST IN PERFORMANCE AND DESIGN DEVELOPMENTS FOR OLED LIGHT Sae-Woong Suh, KR
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	Oral Presentations		
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11:00 - 11:15	OP39 NEW IMAGE BASED MEASUREMENTS OF REFLECTION PROPERTIES OF ROAD SURFACES Stephan Völker, DE	OP44 THE INFLUENCE OF LED LIGHTINGS WITH DIFFERENT PROPORTIONS OF BLUE LIGHT WAVELENGTHS ON HUMANS Pei-Jung Wu, TW	OP49 MEASURING THE EFFECT OF LIGHT DISTRIBUTION ON SPATIAL BRIGHTNESS James Sullivan, NZ
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Wednesday, October 25
Afternoon

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13:45 - 14:00	OP53 DOES THE VISUAL SYSTEM EXTRACT MORE INFORMATION THAN GLOSS IN THE SPECULAR DIRECTION? Guillaume Ged, FR		
14:00 - 14:15	OP54 FIELD OF VIEW CONSIDERATION TO EVALUATE DISTANCE DEPENDENCE IN BLUE LIGHT HAZARD MEASUREMENT Hiroshi Shitomi, JP	Presentations in WS 5	Presentations in WS 6
14:15 - 14:30	Discussion	WP03 CHARACTERISATION OF THE REFLECTION PROPERTIES OF ROAD SURFACES USING AN IN-LAB GONIOREFLECTOMETER Eric Dumont, FR WP04 PRINCIPLES FOR A PROTOTYPE INSTRUMENT FOR MEASUREMENT OF ROAD SURFACE PROPERTIES Dennis Corell, DK	WP05 ACCEPTABILITY CRITERIA FOR THE STROBOSCOPIC EFFECT VISIBILITY MEASURE Dragan Sekulovski, NL WP06 THE LINK BETWEEN PERCENT FLICKER AND THE FLICKER INDEX PROVIDES A SIMPLE AND POWERFUL TOOL FOR CLASSIFYING RESPONSES TO VARIABLE LIGHT SOURCES Luke Price, GB WP07 EFFECTS OF NON-VISUAL OPTICAL FLICKER IN AN OFFICE WITH TWO DIFFERENT LIGHT SOURCES Maria Nilsson Tengelin, SE
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	Workshops/Seminars		
16:00 - 18:00	WS 7 Judging the Scientific Quality of Applied Lighting Research Conveners: Jennifer Veitch, CA; Steve Fotios, GB; Kevin Houser, US	WS 5 (Part 2) Road surface photometric characteristics: measurement systems and results Conveners: Giuseppe Rossi, IT; Cyril Chain, FR	WS 6 (Part 2) Temporal Light Artefacts in Automotive and General Lighting Conveners: Chan-Su Lee, KR; Tran Quoc Khanh, DE
18:00 - 18:10	CLOSING CEREMONY		

INVITED PRESENTATIONS

IP01

CONTENTS DEVELOPMENT FOR OFFICE SMART LIGHTS

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1. Motivation and Approach

The colour and brightness of lights can be controlled by users in LED lighting system unlike traditional incandescent and compact fluorescent lamps (CFLs). This advantage is maximized by merging LED lights with IT technology. As the purchasing pattern of consumers changes from high-functioning to user-oriented products, global lighting enterprises put their research efforts to develop human centric lighting beyond energy saving. To meet such latest trends, we attempt to develop the illumination contents fulfilling office-user preferred requirements in the aspect of emotion and working performance from a huge set of psychophysical experiments using LED lighting system. These contents are inevitable factors for adding customized-value to LED, further the growth of smart LED lighting market. There are two approaches to quantify the effect of lighting surround changes on our perception and performance. The present study focuses on the visual responses rather than non-visual responses as the assessment of the non-visual pathway is limited to understand the complex requirements of users.

2. Development of the Optimized Contents for Office Smart Lights

The optimized demonstration contents are developed in the consideration of 11 scenarios from entering to office space to various behaviors such as documentation, working in front of computer monitor, discussion in a conference room, refreshment in a lounge etc. Office workers have their expected emotional and visual-performance needs about the lighting environment, which are varied dependent on their behaviors or the architectural use of space. The mathematical models are derived to predicting users' preference (and also the important emotional attributes significantly contributing to the preference) according to the change of illumination level and colour temperature. The most optimum range can be determined from the derived models by Response Surface Methodology.

The users' requirements for office lighting surrounds are classified into three main groups through the multi-variable analysis: functionality, stability, and activity. The optimum region specified by illuminanc e level and colour temperature (white tint colours) shows different trends in these three categories. Th e stability is affected more by the tint level whereas the activity by illuminance level. There exists a nar row region where users satisfy most for the functionality. All of these findings can be implemented as h uman-centric lighting solutions helping users concentrate and perform better. In addition to the static experimental condition, the dynamic surrounds are also examined in terms of concentration, fatigue, pleasantness, and alertness for the office workers who spend a whole day inside a building.

3. The Influence of Culture Deviation

Considering that users' visual and emotional needs affected by their surrounding culture, the influence of the culture deviation between Westerners and Korean on subjective responses is also investigated: (1) the viewpoint difference about important lighting-qualify factors using Kano model, (2) the different optimum ranges of two physical variables of CCT and illumination, and (3) the gap of UGR (Unified Glare Index) value that is one of the main indicators for indoor illumination surrounds. The modified version of UGR regression equation for Korean is proposed since the original UGR equation was developed mainly based on the Westerners observation data.

Comparing the cases where illuminance and colour-temperature change, Koreans prefer higher colour-temperature evoking bright/clear emotion, whereas Westerners prefer lower colour-temperature evoking comfortable/attractive emotion. 180 Koreans and 80 Westerners show different illuminance level according to the behavior type. Higher illuminance level at the same CCT is required by Koreans than by Westerners in the office tasks such as reading, typing, and conversation etc. This result is because Koreans prefer clear and bright emotion as explained.

IP02

AN OVERVIEW OF AIC ACTIVITIES AND PLANS FOR THE FUTURE

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Abstract

The Association Internationale de la Couleur (AIC) celebrates its Fiftieth Anniversary this year. The AIC was founded June 21st 1967 in Washington DC, USA during the 16th Session of the Commission Internationale de l'Éclairage (CIE). There were eight foundation members; USA - Inter-Society Color Council (Deane B. Judd), France - Centre d'Information de la Couleur (Yves LeGrand), Great Britain - The Colour Group (Robert W. G. Hunt), Spain - Comité Español del Color (Lorenzo Plaza), Sweden - Swedish Colour Group (Gunnar Tonnquist), Switzerland - pro/colore (Ernst Ganz), Japan - Color Science Association of Japan (T. Fukuda) and The Netherlands - Nederlandse Vereniging (J.L. Ouwettjes). The AIC currently has 27 Regular Members.

Since its foundation, the AIC has had a close relationship with the CIE and this continues as we meet on Jeju Island, Korea.

In 1975 the AIC at the bequest of Betty Judd in memory of her husband, the AIC established the Deane B. Judd Award to recognise outstanding work in the field of color science. The list of recipients, from Dorothy Nickerson [1900-1985] (USA) in 1975 to Françoise Viénot in 2015 represents the International elite of colour science researchers. The AIC has recently established a new award for excellence in research in Colour in Art, Design and Environment. The first of these awards will be presented in Jeju during the AIC Congress.

The AIC has active Study Groups which cover specific areas of colour application and research i.e.

- Study Group on Colour Education (CE) - Chair: Robert Hirschler (Hungary and Brazil)
- Study Group on Environmental Color Design (ECD) - Chair: Verena M. Schindler (Switzerland)
- Study Group on Color Vision and Psychophysics (CVP) - Chair: Katsunori Okajima (Japan), Secretary: Manuel Melgosa (Spain)
- Study Group on The Language of Color (LC) - Chair: Dimitris Mylonas (United Kingdom), Co-chair: Galina Paramei (United Kingdom)

The AIC website is regularly updated and Proceedings for all AIC Meetings dating back until the first AIC Conference in 1969 are now available on the website. The Journal of the AIC is also available on the website.

New initiatives

1. AIC Student Paper Awards for those in the early stages of a career in colour

The goal of the AIC Student Research Awards scheme is to encourage students to present their work at the AIC meetings and to benefit from interaction with the international colour community. Applications must be substantially related to the subject of colour, but may be based in any discipline or mix of disciplines. Both research-based and practice-based work will be considered. The best six papers, as judged by the Award's panel will be published in a special edition of the Journal of the AIC and a financial reward funded by the AIC:1st AUD 1 000; 2nd AUD 600 and 3rd AUD 400. Plus a complementary pass to the Conference banquet for the top six authors.

2. AIC Brand & Design Work Group Proposal

To form a design work group of members that are knowledgeable in the fields of branding, print and web design and social media to ensure that all initiatives that involve decisions concerning the AIC brand across all applications is consistent and adhere to developed standards.

3. Future AIC Meetings

These will be held in Lisbon, Portugal in 2018 hosted by Associação Portuguesa da Cor, in Buenos Aires, Argentina in 2019 hosted by Grupo Argentino del Color**,** Toulouse, France in 2020 hosted by Centre Français de la Couleur and the next Congress in Milan in 2021 hosted by Gruppo Del Colore – Associazione Italiana Colore. In June 2018 there will also be a special joint ISCC and AIC meeting to celebrate the Munsell Centenary. This will be held at the Massachusetts College of Art and Design in Boston.

4. International Colour Day

To increase awareness in colour in the wider community the AIC has been promoting the International Colour Day which falls on the March Equinox. This concept has been enthusiastically adopted by a number of the Regular Members. Our aim is to have UNESCO recognize the ICD but firstly we need all 27 Regular Members to take ownership of the ICD.

5. Co-operation with the CIE

The AIC membership wants to further grow the already close relationship we have with the CIE particularly in coordinating our meetings as we have done on Jeju Island and also discussing how best we can develop the relationship.

None of the above would have been possible without the support of a great team i.e. Javier Romero Immediate Past President, Tien Rein Lee Vice President, Lindsay MacDonald Secretary/Treasurer, Jinsook Lee Chair AIC 2017, Maria João Durão Executive Committee Member, Gabriela Nirino Executive Committee Member, Leslie Harrington Executive Committee Member, Stephen Westland Editor in Chief JAIC, Vien Cheung Associate Editor JAIC, Kevin Laycock Vien Cheung Associate Editor JAIC, Jose Caivano AIC Webmaster. Paula Alessi Auditor and Mentor, Frank Rochow Auditor and Mentor plus the Chairs and Co-Chairs of the AIC Study Groups, Robert Hirschler, Verena M. Schindler, Katsunori Okajima, Manuel Melgosa, Dimitris Mylonas and Galina Paramei. Also former members and officers of the AIC Executive Committee.

IP03

EXPERIENCE OF COLOURED LIGHT IN DAILY LIFE

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Abstract

1. Motivation

Probably it is the rightest moment to enjoy the benefits from the nuanced light. At home, in school, at work we spend most of the time under the artificial lighting while not fully having the best quality of it. Supported by the technical development, it becomes easy to manipulate the chromaticity and brightness and their dynamics. The real question is in human, particularly in the human desire, which is not always explicitly shown. In this presentation cases studies are presented in that the how the experience of coloured light is searched and proposed as the optimal quality.

2. Methods

Differently from conventional design artefacts, people might have a poor experience of lighting by viewing rendered picture. This is even worse when they look at pictures of nuance of lighting, because the influence of chromatic adaptation is not sufficiently accounted for. In the presented case studies, tools and methods were deliberately developed to conduct the user experience in real situation or at least 1:1 scaled lighting environment. Besides, the responses of the human subjects are assessed in a comprehensive manner that involves bodily reaction, cognitive performance, and subjective judgement. In fact, the measuring aspects are not always congruent with each other. Instead any violations between them are valuable for me to understand the nature of emotional reaction of human. Based on the empirical data designing an experience of coloured lighting is a search for scenarios between user and lighting quality.

3. Results

Not differently from the conventional design approaches, the experience of coloured lighting is to be predicted, prototyped, and proposed based on the human desire. For example, at work people are interested in the lighting under that they can more easily immersed in cognitive activities. Opening a fridge people expect to see appetizing food package, while not allowing colour distortion or poor rendering. Moreover, people get easily tired with cognitive workload required to control the lighting quantity. In sum, we expect lighting to enhance emotional quality on one side, and do not expect lighting to ask our cognitive participation.

4. Conclusions

Nuanced lighting can enrich our emotional experience. Fundamentally, the approach of coloured lighting in our daily lives is not different from how designers create artefacts. Only more proper tools and methods should be supplied from design practice and research. Ultimately, a user-centered scenario defines the research question and finally verifies the solution.

IP04

CIE 2017 COLOUR FIDELITY INDEX

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Abstract

The CIE Colour Rendering Index (CRI), defined in CIE 13.3-1995, in particular the general colour rendering index, R_a, is widely adopted and used by the lighting industry, in regulatory documents and in international and regional standards and specifications. However, limitations of the CRI have been recently addressed, especially for solid-state light sources, whereby the R_a values do not always correlate well with visual evaluation by general users. This mismatch arises, first, from inaccuracies of the CRI in its intended role as a colour fidelity index; and second, from perception-related colour quality effects beyond colour fidelity. It was determined by the CIE that, for both aspects, better colour quality characterization methods are needed to measure and specify white-light sources, and the work was divided into two corresponding tasks: (1) to develop a scientifically accurate colour fidelity index, assigned to TC 1-90, and (2) to develop one or more perception-related colour quality measures beyond fidelity, assigned to TC 1-91 for initial work.

This Technical Report, developed by TC 1-90, is a research report describing a general colour fidelity index, R_f, as a scientifically accurate measure of colour fidelity with respect to a reference illuminant, although there still remain some technical issues for further research. This colour fidelity index, based on the fidelity index of the Illuminating Engineering Society of North America, defined in TM-30-15, addresses aspects for only the first part of the limitations of the CRI – it does not address the need for perception-related colour quality measure(s) beyond fidelity. However, it does address several previously reported inaccuracies of the CRI as a colour fidelity measure. The important improvements of this measure, relative to the CRI, are the update of the colour difference calculation, in particular the object colour space, and the incorporation of 99 test-colour samples which provide a more uniform distribution of slope and curvature values as a function of wavelength and which have colour appearance values that are more widely and uniformly distributed in the three dimensions of a uniform colour space.

The general colour fidelity index, R_f, represents how closely the colour appearances of the entire sample set are reproduced (rendered) on average by a test light as compared to those under a reference illuminant. Thus, similar to the general colour rendering index, R_a, the general colour fidelity index, R_f, combines the computed colour differences for all test-colour samples in one single average index value, and is only one aspect of colour quality not considering perception/preference effects. Therefore, it is considered that such unintended uses of CRI as an overall colour quality measure for end users is not better fulfilled by the more scientifically accurate general colour fidelity index, R_f. This is because the users' evaluation is influenced by factors beyond colour fidelity such as chroma effects, and the detailed nature of specific illumination tasks. The general colour fidelity index, R_f, is therefore not a replacement of the general colour rendering index, R_a, neither for the purpose of rating and specification of products nor for regulatory or other minimum performance requirements. Replacement of the CRI will be a matter of future study and discussion that will include the evaluation of the general colour fidelity index, R_f, along with development of a harmonized set of new colour quality measures for assessing perception-related effects beyond colour fidelity and practical aspects for manufacturers and end-users.

(This abstract is a reprint of CIE Press Release, April 2017.)

IP05

THE LATEST IN PERFORMANCE AND DESIGN DEVELOPMENTS FOR OLED LIGHT

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Abstract

Ever since artificial light was developed, lighting has gone through several stages of change, and technology has played a significant role in the evolution of lighting. Initially, the focus of electric light was to produce light itself. The focus had then shifted to 'efficiency' in which LEDs provided a viable solution. At the same time, LEDs had posed certain challenges regarding blue light, glare and the like. Ever since, there has been a shift in development so that these issues can be resolved. As a result, we are seeing a significant increase on marketing messages that revolve around light quality.

OLED as a light source possesses numerous advantages that can contribute to these trends. These advantages come mainly due to OLED's physical traits and the comfortable nature of OLED light itself. Some of the better known OLED characteristics include low glare, diffused shadows, low heat emission. Certain OLED panels possess high colour fidelity levels even in its natural state. In addition to these factors, ongoing tests in Korea have revealed that using OLED lamps compared to conventional lightings result in reduced levels of inflammatory cytokine which causes eye strains. Additional test results show that there can be less retinal cell reduction with OLEDs when compared to other light sources. Based on these observations, a joint research with Boston Consulting Group has indicated that market segments eligible for initial OLED light applications may include the high-end sector of hospitality, retail, architectural, office, residential, and automotive among others.

In order to facilitate the expansion of OLED light into the mass market, efforts are constantly being made to reduce the costs for OLED panels as well. Most notably, LG Display has invested in a Gen 5 production line, and is targeted for mass production beginning in the end of 2017. The production is expected to expand to the rest of LG Display's portfolio, which includes three flexible OLED light panels, by the first half of 2018. The new products will see an improvement in performance (75~90lm/W) as well.

The rest of the presentation will focus on sharing the design possibilities of OLED lighting products. LG Display has recently developed new designs in collaboration with the likes of renowned designers Ross Lovegrove, Tokujin Yoshioka, etc. Luminaire manufacturers with strength in design, including Artemide and Foibos have also released new designs incorporating OLEDs. There have also been new product concepts that extend beyond traditional luminaires. For instance, PanelOLED has developed an OLED wall for the stage. The main inspiration for this development was that OLEDs do not blind the audience even though they are constantly exposed to the light. The intricate dimming also provides for additional aesthetic effects. Moreover, the light weight and low volume dimensions help reduce installation time and storing costs. As another example of non-luminaire developments, Swiss company Manumeta has fulfilled its vision of converging furniture and light by incorporating OLEDs into their designs.

ORAL PRESENTATIONS

Session OS1
Colour quality (1)
Monday, October 23, 10:40–12:20

OP01

THE INFLUENCE OF THE BACKGROUND LUMINANCE ON THE BRIGHTNESS PERCEPTION OF SELF-LUMINOUS STIMULI

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Abstract

1. Motivation, specific objective

The fundamental goal of Colour Appearance Models (CAM) is to provide correlates between the measured optical spectral data of both the stimulus and its surrounding and the corresponding perceptual attributes. There are three absolute colour attributes (Brightness, Colourfulness and Hue) and three relative colour attributes (Lightness, Chroma and Saturation).

Most of the existing CAMs are developed to describe the perception of related surface colours which implicitly assume the presence of a common light source illuminating both the target and background. However, at this moment, there is no colour appearance model for light sources seen in a specific self-luminous context (e.g. a traffic signal at daytime).

2. Methods

An experimental room has been set up. The room is 3 m x 5 m x 4 m and has a grey ceiling. The walls are covered by black curtains and there is a black carpet on the floor. One wall of 5 m x 4 m is composed of a large diffusor illuminated from the back by a series of dimmable TL-fluorescent tubes. A circular test stimulus with diameter D = 0.35 m is created in the centre of the wall by a RGB-LED light source encased in a cylindrical tube placed behind the diffusor.

Observers are seated in front of the wall at a distance such that the stimulus has a field-of-view of 10°. The self-luminous wall itself has a field-of-view of 70°. Both the background and the stimulus are optically characterized using a telescopic measuring head coupled to a spectroradiometer. The uniformity of the wall and the stimulus are within 10% of the mean. Care has been taken to the leakage of light from the background to the stimulus by scattering and internal reflection in the diffuser.

Magnitude estimation experiments were performed to investigate the influence of the background luminance on the brightness perception of the self-luminous stimuli. Twenty three observers (13 males and 10 females), aged between 18 and 40 years, assessed the brightness of one white (same chromaticity as the background: CCT = 3880 K) and three coloured self-luminous stimuli seen against 15 self-luminous neutral backgrounds. For all 15 backgrounds, the tristimulus values of the central stimulus remained the same while the luminance level of the background changed between 0 cd/m^2 and 960 cd/m^2. The central stimulus had a fixed luminance level of 125 cd/m^2 such that both positive and negative luminance contrast between the central stimulus and the background occurred.

The whole experiment was split up into five subsections. For a given test stimulus (one white and three coloured), observers had to assess the brightness of the test stimulus viewed against a particular background with respect to a reference stimulus identical to the test stimulus but surrounded by a background luminance of 125 cd/m^2. The reference scene was presented for 15 seconds in temporal juxtaposition before the test scene appeared for 15 seconds. In the fifth subsection of the experiment, the brightness perception of all coloured stimuli was assessed with respect to the white stimulus. This was done for three specific luminance levels of the background (0 cd/m^2, 125 cd/m^2 and 960 cd/m^2). Here, the white stimulus served as a reference and the corresponding luminance level of the background was held the same as the luminance level of the background of the test stimulus. So both, white and coloured stimulus, were presented with the same background luminance of either 0, 125 or 960 cd/m^2. The reference scene was presented for 15 seconds before the coloured stimulus appeared again for 15 seconds.

Inter-observer variability were evaluated by the coefficient of variation (CV) between each individual observer and the average observer. The results for an 'average observer' were calculated from the individual observer ratings using the geometric mean.

3. Results

The inter-observer and intra-observer coefficient of variation was 17.0 and 13.9 respectively. These values are in line with earlier experiments and with values mentioned in literature.

For a particular background luminance, all coloured stimuli, although having the same luminance, are perceived much brighter than the white one. The blue stimulus was estimated 1.83 times brighter; the red and green stimulus, 1.75 respectively 1.71 times. This is due to the Helmholtz-Kohlrausch effect, where an increase in saturation results in an increase in perceived brightness, and has been successfully modelled by the CAM15u model for unrelated stimuli presented on a dark background.

The brightness perception of the average observer decreases whenever the luminance level of the background increases. The average brightness perception can be fitted very well (Pearson r = 0.99 and R^2= 0.96) by a model that subtracts the luminance of the background raised to the power of 1/3 and multiplied by a constant from the brightness prediction of the CAM15u model.

When the luminance level of the background approaches the luminance of the coloured test stimuli, the brightness variation with background luminance levels out. Within this luminance region, it seems that observers are not very sensitive to the impact of small differences in background luminance on the brightness of the coloured stimulus. Differences in chromaticity probably become dominant over differences in luminance. However, for the white stimulus, which has the same chromaticity as the background, a direct comparison with the background luminance is possible. This makes it easier to notice any luminance contrast and hence to judge the impact on stimulus brightness.

4. Conclusions

For all four stimuli, the average brightness perception decreases when the background luminance increases. The decrease of brightness as a function of the background luminance can be fitted very well by a model that subtracts the luminance of the background raised to the power of 1/3 from the brightness prediction of the CAM15u model, although some deviations occur near the transition range between positive and negative luminance contrast.

OP02

USER PERFORMANCE AND PREFERENCE STUDY UNDER VARIOUS PHOTOMETRIC AND COLORIMETRIC PARAMETERS OF EXISTING LIGHT-EMITTING DIODE LAMPS IN INDONESIA

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Abstract

1. Motivation and specific objective

The lighting system based on Light-Emitting Diode (LED) technology has grown rapidly in the last decade; as well in Indonesia as the fourth most populous country in the world. The consumption rate of lighting products (in this case are the compact lamps) had reached to around 500 million units in 2014, with the growth of LED lamps consumption is about 40 to 80 million units from 2013 to 2014. Therefore, LED lamps have the potential to shift the trend toward utilities of lighting system in the country.

Nevertheless, studies on user acceptance of LED lighting in the Indonesian local context have never been conducted so far, while there are presumably significant differences between Indonesia and other countries. Measurements of various domestic LED lamps were therefore conducted in this study. The specific objectives are to know the effects of varying photometric and colorimetric parameters on visual perception and to determine the users' preference of those parameters under LED lighting in Indonesian context. The defined photometric and colorimetric parameters were as follows: lamp luminous efficacy was varied from 46 to 162 lm/W; correlated colour temperature (CCT) was varied between 3000 K, 6500 K and 8000 K; and colour rendering index (CRI) was varied from 72 to 88. Visual assessments with users were performed under the combination of those parameters.

2. Methods

The visual assessments were conducted using viewing booths in a dark chamber. The assessments consisted of subjective performance and preference tests. The performance tests focused on the subjects' acuity in reading text and ability to discriminate hue, saturation, and brightness (HSB) of Macbeth colour checker. The scores obtained in each test were normalised to 1 (the best). In the preference test, the subjects were asked to rate lighting level, colour clarity, colour appearance, and visual comfort in the viewing booth; using Likert scales ranging from very good (1) to very bad (6), except for colour appearance, which ranges from very warm (1) to very cool (6). Analysis of Variance (ANOVA) was performed to find significant correlation between the stimuli and the responses.

The booths were set in two scenarios: (1) six booths having the same illuminance (320 lx) and CCT (6500 K), but CRI was varied as 72, 74, 76, 78, 84, and 88; and (2) nine booths in combination between illuminance (250, 350, and 450 lx) and CCT (3000 K, 6500 K and 8000 K). There were 43 participating subjects in the first scenario and 41 in the second. All subjects were Indonesian and mostly were 20~30 years old.

3. Results

In the first scenario, the mean normalized score of the acuity test is found to be 0.87; but the score varies from 0.89 (CRI 72) to 0.97 (CRI 88) in HSB test. CRI yields a significant effect on the users contrast sensitivity (F=18.8; p=0.0). Meanwhile, the preference tests yield the following mean Likert scales: [a] lighting level: from 1.56 at CRI 74 (very good – good) to 2.72 at CRI 76 (good – moderate); [b] colour clarity: 1.86 at CRI 78 to 2.58 at CRI 76; [c] colour appearance: 2.46 at CRI 76 (warm – neutral-warm) to 4.21 at CRI 78 (neutral-cool – cool); and [d] visual comfort: 2.12 at CRI 88 to 2.93 at CRI 78. From statistical analyses, it is found that CRI yields significant effect on colour appearance (F=8.63, p=0.0) and lighting level (F=7.56, p=0.0), but not on colour clarity (F=3.025, p=0.011) and visual comfort (F=2.93, p=0.014). It is also noted that the lamp at CRI 76 has Duv +0.00463 (green-yellowish) and –0.00923 at CRI 78 (bluish).

In the second scenario, the mean normalized score of the acuity test is 0.88; but varies from 0.89 (250 lx, 3000 K) to 0.96 (450 lx, 8000 K) in HSB test. Illuminance yields significant effect on the HSB test (F=11.72; p=0.0), but not on acuity (F=0.96; p=0.38); while CCT yields significant effect on both performance tests (F=11.04; p=0.0 for HSB and F=3.22; p=0.04 for acuity). Both parameters can be considered statistically independent based on the ANOVA.

The preference test in the second scenario yields the following mean Likert scales: [a] lighting level: 1.45 (at 450 lx, 8000 K) to 4.12 (at 250 lx, 3000 K); [b] colour clarity: 1.62 (at 450 lx, 8000 K) to 2.98 (at 350 lx, 3000 K); [c] colour appearance: 2.07 (at 350 lx, 3000 K) to 4.57 (at 450 lx, 8000 K); and [d] visual comfort: 2.07 (at 350 lx, 6500 K) to 3.74 (at 250 lx, 3000 K). Illuminance yields significant effect on lighting level (F=63.2; p=0.0), colour clarity (F=5.94; p=0.0), and visual comfort (F=4.07; p=0.02); but not on colour appearance (F=0.08; p=0.92). Meanwhile, CCT yields significant effect on all perception criteria: [a] F=59.87, p=0.0; [b] F=32.1, p=0.0; [c] F=142.9, p=0.0; and [d] F=27.1, p=0.0. Interaction between illuminance and CCT yields significant effect on visual comfort (F=2.17; p=0.07) and colour clarity (F=1.36; p=0.25), but not for lighting level (F=0.71; p=0.58) and colour impression (F=0.34; p=0.85).

4. Conclusions

Variation of illuminance, CCT, and CRI of various existing LED lamps in Indonesia has been found to yield significant effect on user performance and preference. Variation of CCT also yields more significant effect on colour clarity and visual comfort. On lighting level, variation of both illuminance and CCT yields more significant effect compared to CRI. On colour appearance, variation of CCT yields more significant effect compared to CRI, while illuminance gives no effect. Moreover, the participating subjects in this study preferred higher CRI value for visual comfort (also at illuminance 350 lx and CCT 6500 K), but preferred higher illuminance and CCT for good lighting level and colour clarity.

OP03

WHITE LIGHT CHROMATICITY LOCUS FOR NATURALNESS

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Abstract

1. Motivation, specific objective

One of the colour quality of white lights is naturalness, which was judged by the appearance familiar objects similar to the memory colours. It associated with chromaticities at the Planckian locus. In 2013, Ohno and Fein first investigated the naturalness of white light. They found that perceived natural white locus is located at about -0.015 Duv units, much below the Planckian locus. Wei and Houser then questioned the reliability of their results due to poor control of colour fidelity property. In 2015, Ohno and Fein repeated the experiment with improved control of colour fidelity property and further confirm the position of the locus.

With the above in mind, we like to conduct an independent study by strictly controlling all other colour quality parameters including CCT, colour fidelity, gamut shape and chromatic adaptation. The goals are to seek the effect of backgrounds to scale natural / colourful / preferred, to establish their loci of naturalness / colourfulness / preference, and to explore the relationship among the three perceptions..

2. Methods

A series of psychophysical experiments was carried out using a multi-channel LED lighting system. All judgments were performed by normal colour vision observers while viewing a grey interior of a double cabinet in a darkened room. The grey wall had an L*, a*, b* values of 78.44, -0.33 and -0.08. Each stimulus was presented one at a time having a viewing/illumination geometry of 0/45. The luminance of light sources was 500 cd/m^2. Samples were placed in the center of cabinet floor, including fruits, vegetables, rose and skin tone, which were familiar objects to observers.

Seventeen observers were the students and employees at the Zhejiang University. They had an average age of 24 ranged from 21 to 40.

Experiment I was conducted at 4800K having seven different Duv levels (-0.02, -0.015, -0.01, -0.005, 0, 0.005, 0.01). The colour fidelity IES TM30-Rf, the gamut IES TM30-Rg and the chroma difference ΔC^* for CQS 15 samples were strictly controlled within 85.1$\pm$0.4 and 104$\pm$0.2 respectivey and they had very similar gamut shape oriented in red and green direction for each light source. All stimuli were inter-compared in pairs. Therefore, there were 21 comparison pairs in total for each CCT assessed by seventeen observers.

Observers first adapted to the illumination at Duv=0 for one minute. For a given pair, each observer did adaptation and observed the appearance of two sources successively, then judged which light source appears to be more natural, colourful, or preferred, one session at a time. For a given session, observers were presented 21 randomly arranged comparison pairs.

The above procedure was repeated in the double-cabinet whose interior walls were covered by black cloth which had an L*, a*, b* values of 3.21, 0.01 and -0.06, respectively.

Experiment II was conducted at seven different Duv levels (-0.03, -0.025, -0.02, -0.015, -0.01, 0, 0.01) at two CCTs (3500K and 6000K). The procedure was the same as that in Experiment I, only against the grey background. All the other parameters were again carefully controlled. In total, 1428 assessments were made, i.e. 21 pairs x 2 CCTs x 2 questions (Naturalness & Colourfulness, and Preference) x 17 observers.

3. Results

The mean results were calculated for each attribute. The inter-observer variability was first analysed. The results were presented in terms of z scores for naturalness, colourfulness and preference respectively.

In Experiment I, It was found that the results in grey and black backgrounds were similar. Grey and black background results had correlation coefficient (r) value of 0.93, 0.97 and 0.85 for naturalness, colourfulness and preference respectively

The results showed that for naturalness, perceived natural white sources were at Duv=-0.012 in grey background and at Duv=0.017 in black background; for preference, perceived preferred white sources were at Duv=-0.019 in in grey background and at Duv=0.015 in black background; for colourfulness, light sources at the lower Duv appeared more colourful.

The above results indicated that the two backgrounds gave very similar results within 0.005. The chromatic adaptation due to different background can be ignored. Experiment II was conducted using grey background same as that used by Ohno and Fein.

In Experiment II, for naturalness, perceived natural white sources were at Duv=-0.012 in 3500K and at Duv=-0.016 in 6000K; for preference, perceived preferred white sources were at Duv=-0.018 in 3500K and at Duv=-0.023 in 6000K; for colourfulness, light source at the lower Duv appeared more colourful.

Naturalness and preference results were also compared. They had an r value of 0.73 in 3500K and 0.90 in 6000K. This confirmed again that these two scales had a good agreement. So, the naturalness prediction should give a good estimation to the preference. Naturalness and colourfulness results had an r value of 0.31 in 3500K and 0.70 in 6000K. Preference and colourfulness results had an r value of 0.81 in 3500K and 0.92 in 6000K.

4. Conclusions

Experiment was conducted for assessing natural / colourful / preferred ranges of Duv of white light for indoor illumination. From the above results, the following conclusions were drawn:

- The chromaticities of light sources below the Planckian locus (around Duv≈ -0.013 on average) were perceived as the most natural in the CCT from 3500K to 6000K. This finding agrees well with the Ohno and Fein's finding.
- The naturalness prediction could give a good estimation to the preference.

OP04

A PROPOSAL FOR CHARACTERIZING SURFACE WHITENESS UNDER AN ARBITRARY LIGHT SOURCE

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Abstract

1. Motivation, specific objective

Whiteness is an important colour appearance attribute for surface colours. Fluorescent Whitening Agents (FWAs) are added in many natural and man-made materials to simultaneously increase the brightness and introduce a blue tint by absorbing the ultraviolet and violet radiation in the illumination, enhancing the whiteness appearance of the objects. Thus, the spectral power distribution (SPD) of a light source plays an important role in exciting the FWAs and rendering the whiteness appearance of the objects. The CIE whiteness index, however, only characterizes the whiteness under CIE standard D65 illuminant. Based on three psychophysical experiments, this paper proposes a new whiteness formula, together with a whiteness boundary, to characterize surface whiteness under an arbitrary light source. It is aligned with CIE Research Strategy.

2. Methods

Three psychophysical experiments were conducted to investigate the whiteness appearance of various nominally white samples (FWA and non-FWA samples) under different lighting conditions. In Experiment 1, eight observers evaluated 50 samples under 12 lighting conditions. In Experiment 2, 12 observers evaluated 55 samples under 6 lighting conditions. In Experiment 3, 20 observers evaluated 88 samples under 4 lighting conditions. The SPD of the lighting conditions were carefully adjusted and produced using a 14-channel spectrally-tunable LED lighting system, whose channels covered 350 to 700 nm and the intensity of each channel can be individually adjusted. The lighting conditions covered four different levels of CCT (3000, 4000, 5000, and 6500 K). In each CCT, different UV levels were applied. All the samples were specially prepared to have different amounts of FWA.

3. Results

The evaluations made by the observers reading the whiteness percentage of each sample (i.e., 100% means a pure white and 0% means no trace of white) were combined and used.

It was found that the samples were perceived to be less white under 3000 K, though the viewing conditions (e.g., illuminance, experiment protocol, viewing booth, the amount of UV contained in the illumination) were identical. The performance of six whiteness formulas, such as CIE whiteness formula and Uchida whiteness formula, were compared by evaluating the correlation between the calculated whiteness values and the visual evaluations made by the observers. It was found that the CIE whiteness formula with the CAT02 chromatic adaptation transform, $W_{\mathrm{CIE,CAT02}}$, had the best performance in predicting the surface whiteness, with a correlation coefficient of 0.797. Especially for the FWA samples under the non-UV illuminations, the inclusion of CAT02 increased the correlation coefficient from 0.471 to 0.829.

The lower whiteness of the samples under 3000 K was likely due to the incomplete chromatic adaptation under a low CCT level. An optimized degree of adaptation factor D of 0.98 in CAT02 for the 3000K lighting conditions was able to increase the correlation coefficient.

The combined dataset also allowed us to derive ellipsoids as a new whiteness boundary to classify whether a surface colour can be regarded as white. For different CCT levels, the ellipsoids have a similar shape, but different center.

4. Conclusions

Based on the analyses, the boundary to classify whether the surface colours are white or not was defined. If the chromaticities of the surfaces are within the identified boundary, the CIE whiteness formula, together with the CAT02 chromatic adaptation, is proposed to characterize the whiteness appearance. Further studies are needed to investigate the effect of chromaticity of adapting field on chromatic adaptation and colour appearance, especially for lower CCT levels.

OP05

COLOUR QUALITY ASSESSMENT UNDER LED TUNEABLE SOUCES WITH VARYING GAMUT SIZES AND SHAPES

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Abstract

1. Objective

Colour Quality of lighting, usually defined as colour fidelity (naturalness), colour gamut (colourfulness) and preference, was investigated in many previous studies during years. Numbers of colour rendering indices (CRIs) based on colour gamut and colour preference of familiar objects were developed, such as GAI, MCRI, Qg (CQS), Qp (CQS), ∆C* (CQS) and Rg (IES-TM-30). Most of the previous studies designed the experiments comparing lightings with different colour gamut sizes but without precisely control of the other parameters such as CCT, duv, luminance, colour fidelity and colour gamut shape. The reason is that they usually used combinations of white lightings and an RGB lighting system to render different test lights, which had limitation in chromaticities and gamut shapes. The present experiment was designed to study the naturalness, colourfulness and preference of lightings using a tuneable multi-channel LED system to render different gamut size as well as gamut shapes under strict control of other lighting parameters.

2. Methods

Using a multi-channel LED ceiling lighting system, five series of lightings with four CCT (3600K, 4500K, 5600K, 6600K) and two levels of Rf (71 and 87) were tested in the experiments. All the lightings had duv value about -0.002 and luminance about 140 cd/m^2. In each series, the Rg values of lightings ranged from about 90 to about 115 having both red-green and yellow-blue gamut shapes, with CCT differences smaller than 100K below 6000K and smaller than 250K above 6000K, duv differences smaller than 0.0035, Rf differences smaller than 2, and luminance differences smaller than 1 cd/m^2. Totally, 39 kinds of lighting were used.

In a living room environment, 18 kinds of samples (familiar fruits, vegetables and Pepsi) and Macbeth 24 colour checker chart were placed on a table covered with a black tablecloth. Categorical judgment was used to scale three perceptions, naturalness, colourfulness, preference. For an example, very unnatural, unnatural, a little unnatural, a little natural, natural and very natural had scores of -3, -2, 1, 1, 2, 3 respectively. Note that during the experiment, scores of -4 or 4 appeared when the observer judged the light to be extremely (un)natural/colourful/preferred. Observers were asked to follow the following experiment procedure: (1) to be given instruction to evaluate one of the three perception scales; (2) to adapt in a light having same CCT as the series of testing light with zero duv and highest colour fidelity (Rf>95) the system can achieve for 1 min; (3) to observe the samples under a light in this CCT series following a random sequence; (4) to give the visual scores of the perception; (5) to repeat steps 3 and 4 until the completion of all the light in this CCT ; (6) to repeat the above steps until all the perceptions were finished. Finally, 24 observers participated in the experiment.

3. Results

The result scores were transformed into z-scores for each observer and each perception. Different from the previous studies, the naturalness scale having a smaller magnitude than colourfulness and preference, due to that the colour fidelity of lights was controlled in the present experiment. Except that the high colourfulness (z-score>0.5) provided low naturalness and preference while colourfulness lower than reference sources (z-score<0) might cause low preference under some CCTs, these three scales had weaker correlation of each other comparing to the previous studies. It indicated that the observer though these three perceptions to be clearly different in the present experiment.

Colour gamut based or colour preference based CRIs were tested with the present experiment results. MCRI, Qg, Qp, ∆C* and Rg all showed good prediction for colourfulness. Qg, ∆C* and Rg show

negative relationship with naturalness. MCRI performed better than ΔC* and Rg for preference. The results showed that both gamut size and gamut shape affect the colour quality of lightings. The most natural and preferred gamut sizes are around 100-105 Rg values (corresponding to 0-1 ΔC* values) and 105-110 Rg (1-2 ΔC* values) values respectively. The lightings with red-green gamut shape were judged much more colourful than those with yellow-blue shape, while the gamut size was control to be similar in terms of Rg or ΔC* values. Therefore, it can be concluded that only a single gamut size index, such as Rg or ΔC* cannot predict the colourfulness well. The gamut shape should be taken into consideration.

In the present result, Rg and ΔC* both had problem for evaluating colourfulness under low CCT (3600K) lightings. When CCT = 3600K and the Rg value < 100 (ΔC*<0), the lower the Rg / ΔC*, the higher the z-score of colourfulness, and also the higher the MCRI value. Note that the MCRI performed well in all region for colourfulness. It indicates that gamut size metrics could not predict colourfulness well below a certain CCT.

The colour shifts of experiment samples under different lightings with various gamut sizes and shapes were plotted in CAM02-UCS. It was found that whatever the gamut shape, red-green or yellow-blue, an increase of gamut size would stretch some colours in red-green direction and blue samples to have a big hue shift towards purple. Comparing with yellow-blue gamut shape, under a lighting with red-green gamut shape the red samples' chroma increased largely while the blue samples shifted towards to green. Again, not only the gamut size but also the gamut shape of the lighting affects the colour appearance.

Models and their testing details will be shown in full paper.

4. Conclusions

An experiment was designed to study the naturalness, colourfulness and preference of lightings using multi-channel LED system to render different gamut sizes as well as gamut shapes under well controlled of other lighting parameters. The results show the most natural and preferred gamut sizes are around 100-105 Rg values and 105-110 Rg values respectively. The lightings with red-green gamut shape are judged more colourful than those with yellow-blue shape while the gamut size are similar. Rg and ΔC* both have problem evaluating colourfulness under low CCT lightings. The models in the previous studies were tested and a new model was built.

Session OS2
Metrology for photometric and radiometric devices (1)

Monday, October 23, 10:40–12:20

OP06

GLOBAL INTERLABORATORY COMPARISON OF GONIOPHOTOMETER MEASUREMENTS USING LIGHT EMITTING DIODE ARTEFACTS

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Abstract

1. Motivation, specific objective

The International Energy Agency's (IEA) Energy Efficient End-use Equipment (4E) Solid-State Lighting (SSL) Annex is conducting a global interlaboratory comparison test for goniophotometers. Called Interlaboratory Comparison 2017 (IC 2017), it is designed in compliance with ISO/IEC 17043 to serve as proficiency testing for those laboratories seeking for testing laboratory accreditation for goniophotometers using CIE S 025 (or EN 13032-4) or other regional test methods.

All types of goniophotometers are acceptable, including goniophotometers with photometer head, gonio-spectroradiometers, far-field and near-field goniophotometers. Near-field goniophotometers and non-standard goniophotometers that rotate the operating position of the luminaire with a correction technique (allowed in CIE S 025) will also be covered in this interlaboratory comparison, and their results may be used for the validation requirement for such goniophotometers in CIE S 025 or to assist in an accreditation application.

IC 2017 is led by the National Institute of Standards and Testing (NIST, USA) with the Korea Institute of Lighting Technology (KILT, Korea), Laboratoire national de métrologie et d'essais (LNE, France) and National Lighting Test Centre (NLTC, China), which have all established measurement equivalence with NIST for measurement of SSL products.

The SSL Annex is supporting IC 2017 as part of its intergovernmental work promoting harmonised approaches to LED performance specifications and testing. The IC is intended to build capacity in test laboratories in support of the use of CIE S 025.

2. Methods

Participating laboratories will be asked to measure a set of four SSL product artefacts: (1) a narrow-beam LED directional lamp, (2) an indoor LED panel luminaire, (3) an indoor linear LED batten luminaire with lens, and (4) an LED street lighting luminaire. Measurements of luminous quantities will be made using a goniophotometer and measurements of colour measurements will be made using either a gonio-spectroradiometer or integrating sphere. The fourteen quantities that will be measured include electrical quantities, total luminous flux, luminous efficacy, colour quantities (spatially-averaged), luminous intensity distribution, partial luminous flux, centre-beam intensity, beam angle, and angular colour uniformity.

Participants will be asked to use CIE S 025 as the test method but those who are not in full compliance with the CIE test method and/or those who do not measure all the quantities above will also be accepted as participants. After completion of all participants' measurements, each participant will receive an individual test report that could serve as a proficiency test (PT) report, as well as a preliminary IC 2017 final report at the end of the comparison that will analyse all the results anonymously for a technical study.

This new interlaboratory comparison will study the equivalence of different types of goniophotometers, e.g., near-field goniophotometers and far-field goniophotometers, and investigate the measurement variations and the capability of participating laboratories using goniophotometers to measure SSL products.

The IC will be conducted as a star-type comparison. The set of artefacts will be measured and shipped from the Nucleus Laboratory to each participant for measurement, and then returned to the Nucleus Laboratory for a closing measurement. The assigned values will be determined as the average of the two measurements by the Nucleus Laboratory, with an analysis of artefact stability. The artefacts will be calibrated by the Nucleus Laboratory using CIE S 025 and in compliance with the accredited and/or peer reviewed procedure with the determination of the uncertainties of measurement results.

3. Results

At the time of the CIE conference in Jeju Island, Korea, IC 2017 will be conducting its second of three rounds of testing with participants. Thus, no participant results will be available at this time of the conference, however the reference laboratory comparison using the same four types of artefacts will be presented in this paper, as well as any observations and comments on the findings from the first round of testing.

The SSL Annex is expecting more than sixty laboratories to participate in this comparison, with interest expressed in a ‘pre-registration’ period from 20 countries around the world. Some of these laboratories will have more than one instrument on-site, which would potentially lead to a large set of data for the final analysis in 2018/19. This data can then also be fed back into a possible future revision of CIE S 025 and some of the findings may also be useful in the work of CIE TC 2-74 and TC 2-78.

4. Conclusions

The paper will offer summaries of the IC 2017 generic protocol, the IC 2017 quality policy, the reference laboratory intercomparison and the interim findings associated with IC 2017. The overall objective of this task is to continue promoting a harmonised and effective global product testing regime of photometric measurements for SSL, especially where current standards and practices provide insufficient coverage.

OP07

LIGHT SOURCE CHARACTERIZATION AND AIR MOVEMENT UNDER CIE S 025

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Abstract

In this paper we describe methods to perform accurate and traceable measurement of air flow in accordance with the specification in CIE S 025. Further, we investigate the influence of airflow on various LED based devices under characterization. This is done by simultaneous measurement of the forced airflow surrounding various luminaires and the photometric quantities measured under those conditions.

1. Motivation, specific objective

CIE publication S 025/E:2015 (S 025), has a number of requirements for the laboratory conditions under which accurate and reproducible measurements of LED lamps, modules and luminaires are to be performed. Due to the thermal sensitivity of many LED lamps and luminaires, strict requirements are given for the thermal conditions relating to the device under test (DUT). Airflow in the immediate surroundings of a DUT may cause cooling, which in turn may change the operational temperature of the DUT and, depending on the temperature sensitivity of the light output of the DUT, may therefore alter the performance of the DUT. Therefore, S 025 stipulates a maximum ambient airflow of 0.25 m/s, including the uncertainty in the measurement of the airflow. The uncertainty of the airflow measurement must therefore be significantly smaller than 0.25 m/s. However, accurate and traceable measurement of airflow in this domain of values is not readily available without significant expense.

The airflow in a laboratory space is tightly connected to the air temperature via the ventilation/temperature control system. For a room where air change is used as the main method of removing excess heat, the air has to be changed with a certain rate, which will induce an air velocity. A laboratory working under S 025 may require a non-negligible airflow to avoid temperature build-up in the room.

2. Methods

We will present two investigations of airflow and its relation to photometric measurements of LED lighting devices.

2.1 Measurement in the required air speed range

In this study, “hot-wire” anemometers are used to measure airflow. This type of instrument measures the change in resistance of a thin heated wire induced by the cooling from airflow, compared to the resistance of a reference wire that is shielded from airflow. Commercial products exist that can measure airflow values in the range needed in this context, which means producing measurements at speeds of and with an uncertainty significantly lower than the threshold value of 0.25 m/s. This type of probe is normally used to measure airflow relating to human comfort. A probe of this type is set up in the photometric laboratory at DTU Fotonik at Technical University of Denmark. This setup is used to measure corresponding values of forced airflow below the S 025 threshold, and the photometric quantities of typical lamps and luminaires.

2.2 Measurement outside of the air speed range

In this study, a rotary vane anemometer is used to measure air speeds above the limit stated in S 025. The rotary vane anemometer has a minimum speed of around 0.3 m/s, and furthermore within Australia it is not possible to have an anemometer calibrated at a speed below 0.3 m/s so it is not possible to measure an air speed within the required parameters with a proper traceable calibration. Additionally, in the laboratory space it was not possible to set up a constant air flow due to the return circulation of the air interfering with the air flow onto the DUT. So in this case the air speed was set to approximately 0.9 m/s ± 0.3 m/s and the effect of this air flow on the front side and the back side of

three different types of LED lamps was evaluated. It should be noted that the usual condition in the laboratory was considerably less than this air speed – the airflow encountered around the laboratory's goniophotometer was so slow that it didn't make the anemometer's vane rotate and it is believed that the laboratory's condition would actually satisfy the standard quite comfortably. However, to firmly establish this an actual traceable evaluation needs to be undertaken.

2.3 Corrections and uncertainty

If the air speed exceeds the specified threshold then, according to S 025, the test result would need to be corrected back to the equivalent result with an air flow that meets the standard condition, and the measurement uncertainty needs to take this correction into consideration. However, this approach would be impractical for many situations. Another approach would be to test a large number of lamps and luminaires and see the worst case that is encountered. This worst case, inflated to take into account "unknown other" DUTs, could then be incorporated into the uncertainty budget with an assumed correction factor of 1.000 (i.e. no correction).

3. Results

Preliminary tests were done on three LED lamps tested outside the air speed range exhibited sensitivities of between 4.1 and 5.4 % / (m/s) which is consistent with Appendix C.3.3 of S 025.

Further test results and a comparison of the results from the two studies will be included in the final paper, including measurements at different air speeds on the same DUT to study the linearity of air flow effects and also measurements of the air flow effect on some types of luminaires.

4. Conclusions

The limitation on airflow in CIE S 025 is imposed to ensure that DUTs are not overly affected by the cooling caused by unintended forced convection. However different DUTs will in many cases be affected differently by a given air flow. As it will rarely be practically possible to measure the sensitivity of every DUT that is to be characterized in a laboratory, some generalizations and rules of thumb will have to be applied. Preliminary results for the tested LED lamps show a sensitivity of around 5 % / (m/s) on light output.

OP08

ONLINE MEASUREMENT OF LED JUNCTION TEMPERATURE FOR LIFETIME PREDICTION

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Abstract

1. Motivation, specific objective

The p-n junction temperature is one of the main factors that affects the lifetime of high-power light emitting diodes (LEDs) and their wide application to energy-efficient lighting. With an extended use of the LED, its internal quantum efficiency may decrease and a larger part of the electrical driving current is transformed to heat increasing the junction temperature without producing photons as intended. High junction temperature may damage the chip and thus manufacturers state upper limits for the junction temperature which need to be followed by the luminaire manufacturers for optimized LED lifetime. Monitoring the junction temperature in a luminaire is challenging because of limited mechanical and electrical access to the light sources. An optical measurement method providing junction temperature information based on intrinsic features of the emitted spectra would greatly facilitate the thermal management task and LED lifetime prediction.

The forward-voltage method with pulsed driving current is the standard procedure for junction temperature measurement. Various optical methods for determining the junction temperature from the emission spectrum have been studied, but they always require at least one calibration measurement using the forward-voltage method.

2. Methods

We have developed two alternative methods to derive the junction temperature directly from the measured spectrum of an LED. We have also studied the possibility to estimate LED lifetime from the junction temperature. Finally, we have an ongoing experiment of LED lamps ageing since 2011, used for studying LED lifetimes and how the junction temperature changes as a function of time. Together these results reveal relationships between the junction temperature, emission spectrum, and ageing of LEDs.

Earlier methods for optical junction temperature determination need at least one spectrum at a known temperature, typically derived using the forward-voltage method for an LED in a thermostatic bath. We have first studied a straightforward way to derive the LED spectrum in normal conditions at room temperature by driving the LED with a pulse-width-modulated electrical current and changing the modulation ratio. The electrical power, causing heating of the junction above room temperature, reduces as the modulation ratio decreases. Based on our experiments, 1 kHz is a good selection for the modulation frequency since frequencies higher than 1 kHz may severely distort the rectangular waveform. For example, a 1 kHz rectangular waveform signal with 0.5% duty cycle corresponds to 5 µs pulses. The spectrum at the junction temperature equal to the ambient temperature is constructed by extrapolating changes of spectral irradiance at each wavelength to the duty cycle of 0%. This method is suitable for characterization of LEDs in a luminaire, if the individual spectra of LEDs can be measured separately and the luminaire electronics allows driving the LED at low modulation ratios.

The second method that we have studied takes advantage of a recently found temperature-invariant energy value in the LED emission spectrum. With this method the junction temperature can be determined, without any forward-voltage calibration, by emission spectrum measurements at a few known ambient temperatures. The normalized emission spectra at different junction temperatures intersect at a unique energy value. The existence of the invariant intersection energy is a general feature of normalized LED spectra, including white LEDs, because almost always LEDs have linear temperature dependence of the energy gap and peak energy over a limited temperature range around

the operating temperature. For the junction temperature determination, a derived spectral shape is fitted to the measured normalized spectra close to the peak intensity and the temperature-invariant intersection energy with the junction temperature as a fitted parameter. This method is suitable for characterization of LEDs in a luminaire, if the individual spectra of LEDs can be measured separately and the luminaire can be operated at a few different ambient temperatures deviating by at least 10 °C. No access to luminaire electronics is required.

3. Results

In test measurements of the first method with red InGaAlP-based LEDs, the emission spectrum at one reference temperature was known and the junction temperatures over the range 30 to 125 °C were determined and compared with the reference results obtained with the forward-voltage method at each temperature. The mean absolute difference was 1.8 °C over the whole temperature range studied, and the maximum difference was 4.4 °C. This experiment shows that a reference spectrum obtained at room temperature is sufficient, avoiding the need of using a thermostatic bath for the LED temperature control.

The second method of using the temperature-invariant intersection energy was tested with red InGaAlP-based LEDs and with infrared GaAs and GaInP LEDs. Agreement with the forward-voltage method was achieved within about 5 °C for the red LEDs. For the infrared LEDs, the results were also consistent within about 5 °C.

We have six years of ageing data available for a set of LED lamps. These data can be used to study effects taking place in the spectra as the lamps age. We have observed that the junction temperature increased by about 0.001 °C per an hour of ageing time. Results on the correlation between the LED junction temperature and the decay rate of luminous flux will be presented in the conference.

4. Conclusions

Our results show that it is possible to derive the junction temperatures of LEDs from measured emission spectra, even for LEDs inside luminaires. One of the developed methods requires access to the luminaire driving electronics and the other needs measurements at different ambient temperatures. Luminaire manufacturers can use the developed methods to confirm that the specified junction temperatures of LEDs are not exceeded. Long-term ageing tests of LED lamps indicate that the junction temperature rises as the lamp ages, making the optical measurement methods useful for lifetime prediction of the LEDs.

OP09

LED-BASED STANDARD LAMP FOR REALIZATION OF PHOTOMETRIC UNITS

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Abstract

1. Motivation, specific objective

Incandescent lamps have been used as standard sources of luminous intensity and illuminance in calibration of photometric equipment. Due to the development of solid-state lighting and energy saving related legislation, incandescent light sources are phasing out. Manufacturing of incandescent standard lamps may end in the near future, so incandescent standard lamps need to be replaced with LED-based standard lamps in order to continue photometric calibration work.

As most of the light sources measured at test laboratories and in the field are nowadays based on LEDs, using reference devices calibrated against incandescent sources yields additional spectral mismatch errors. The additional uncertainty due to the spectral mismatch between the incandescent based calibration source and the device under test can be removed by using an LED-based standard light source in calibration of photometric instruments.

2. Methods

We have developed a new LED-based luminous intensity standard lamp to be used as a photometric transfer standard lamp. The mechanics of the device were designed to be compatible with existing measurement setups. The device comprises an electronic control unit, a temperature controlled heat sink, and a replaceable LED unit. Due to the temperature sensitivity of intensity and spectral properties of LEDs, temperature stabilizing electronics are required to keep the luminous intensity stable. The control unit stabilizes the voltage over the constant current driven LED unit by controlling the temperature of the heat sink. Stabilizing the voltage over the LED stabilizes also the electrical power consumption, and thus the luminous intensity of the LED module, assuming that the luminous efficacy depends only weakly on temperature. The cooling unit is based on a thermoelectric module (TEM) which is mounted on a heat sink. In addition to the temperature stabilization electronics, a typical laboratory DC current source is used for driving the LED unit. High quality shielded cables are used to interconnect the LED mounting base and the temperature control electronics unit. Two separate cables are used to prevent the crosstalk between the high power TEM current wires and the signal wires for the voltage and temperature measurement.

White LED lamps can be roughly divided into two different categories, "warm white" and "cold white", based on their correlated colour temperatures (CCT). The spectral mismatch between the calibration source and the device under test can be minimized by choosing a correct spectral distribution for the calibration source. Due to the requirements set by different types of LED modules, the LED unit attached to the heat sink can be removed and replaced.

Several test measurements were performed with the new LED standard lamp. The short-term stability of the device was tested by measuring the change of the luminous intensity of the source during a typical operating time of 75 minutes. The LED source was measured for spectral and angular distributions and an ageing test over an ageing period of four months was performed for ten samples of the LED modules used.

3. Results

The stability, spectral irradiance, luminous intensity, and angular distribution of the LED standard lamp were compared to the presently used Wi41/G and FEL lamps in order to study if the LED standard lamp was a suitable successor for the incandescent standard lamps in the visible wavelength range.

The experiments show that the LED standard lamp is as stable as a WI41/G type lamp and about three times more stable than an FEL type lamp. Due to the possibility of using LED modules of

different types, the spectral errors influenced by the difference between the calibration spectrum and the spectrum of the test device will be greatly reduced, as compared to using incandescent lamps in calibration of photometers. The driving current of the LED unit was chosen to produce illuminance and irradiance levels equaling the levels of a typical FEL lamp adjusted to the CCT of 2856 K. The white LED modules used in the source emit most of their light in the wavelength range between 400 nm and 800 nm.

The measurement results showed that the angular distributions of the Osram Soleriq LED modules used are close to Lambertian, while the output of the Wi41/G lamp is limited by the painted window. The standard deviations of the measured illuminance for two stabilized incandescent standard lamps, calculated using data recorded between 10-75 minutes from the beginning of the measurement, were 1.14 times higher for the Wi41/G and three times higher for the FEL, as compared to the developed LED standard lamp. A test calibration of an integrating sphere using the new LED standard lamp as an external source showed that the LED-based lamp works as well as the FEL lamp, providing similar signal levels and calibration spectrum better compatible with measurement of LEDs.

The switched ageing test (2 h 45 min on / 15 min off) performed during an ageing period of 2880 hours showed no decrease in the average luminous intensity of the LED modules used. The ageing period of 2880 hours already corresponds to at least five times the typical lifetime of an incandescent standard lamp.

4. Conclusions

An LED-based luminous intensity standard lamp for photometric calibrations was designed, built, and characterized. The device has potential to complement or replace incandescent standard lamps used in photometric calibrations. The optical properties, excluding the emission spectrum, of the developed LED standard lamp were chosen to be comparable with the incandescent standard lamps allowing reduced uncertainties in measurements of LED products with similar colour temperature. The stability and stabilization time of the LED standard lamp were measured and compared to Wi41/G and FEL lamps. According to the comparison results, the LED standard lamp performs at least as well as the Wi41/G standard lamp and better than the FEL standard. The LED modules used in the lamp can be driven with a current producing output intensity level comparable to FEL type lamps. The switched ageing test during an ageing time of 2880 hours showed no decease in luminous flux of the LED units.

OP10

PROPOSAL FOR A NEW GENERAL V(λ) MISMATCH INDEX

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Abstract

The accepted General V(λ) Mismatch Index, (f'_1) was defined for a general description of the photometric performance of photometers. This index is widely-used in Photometry, and it is very relevant for selecting photometers for low-uncertainty photometric measurements. It quantifies the mismatch between the spectral responsivity of a photometer and V(λ), but we proved that it does not involve that this index correlates well with the photometer performance. Our thesis is that a low value of f'_1 is not enough for a good photometer performance, but it also depends on the way in which V(λ) differs from the spectral responsivity of the photometer. We propose an alternative general V(λ) mismatch index, defined as the variation of the spectral responsivity with respect to V(λ) once the high-frequency variation is filtered. This proposed index correlates, unlike f'_1, with the empirical photometric performance of seven photometers.

1. Motivation, specific objective

The photometric performance of Illuminance and Luminance Meters (hereafter, just photometers) should be adequately assessed by providing quality indices. These indices are defined by the Commission Internationale de l'Eclairage (CIE) in the International Standard CIE S 023/E:2013, and provide information about the V(λ) mismatch, the UV or IR responses, the cosine response, the linearity, the temperature dependence, the spatial non-uniform response, and others. Among them, index f'_1 is widely-used in Photometry, and it is very relevant for selecting photometers for low-uncertainty photometric measurements.

The spectral responsivity of a photometer should match the spectral luminous efficiency function for photopic vision V(λ), in order to avoid using correction factors of the luminous responsivity according to the spectral power distribution (SPD) of the source under measurement. The General V(λ) Mismatch Index, f'_1, was defined for a general description of a photometer performance, regardless the kind of source to be evaluated, and it cannot be used for correction. It is basically defined as the integral of the absolute differences between its normalized spectral responsivity and V(λ) at wavelengths covering the visible range and spaced at least 5 nm.

We agree that this index is quite reasonably defined to quantify the mismatch between the spectral responsivity of a photometer and V(λ). But, this does not mean, as we will show in this contribution, that this index is well-correlated with the photometer performance, where a good photometer performance means here a luminous responsivity with small dependence on the spectral power distribution of the source to be measured. Our thesis is that a low value of f'_1 is not enough for a good photometer performance, but it also depends on the spectral way in which V(λ) differs from the spectral responsivity of the photometer.

In this contribution we will propose an alternative to the so-called General V(λ) Mismatch Index, which, in our opinion, assess better the general photometric performance of photometers.

2. Methods

It can be mathematically proved that the distribution of the spectral variation (SVB) of the spectral responsivity of a photometer with respect to V(λ) plays a very important role in the constancy of its luminous responsivity against the SPDs of lighting sources. Therefore, that spectral variation should be included in the definition of a general V(λ) mismatch index for assessing the photometric performance of photometers. Spectral responsivities differing from V(λ) with a smooth spectral variation will have a worse performance than those with a fast variation and a similar amplitude on the difference, since the deviations that they produce in their responses with respect to an ideal photometer are compensated with high probability when using broadband illuminants.

We propose a new General V(λ) Mismatch Index (f''_1), whose definition has been based on the Fourier transform of the SVD and on a set of illuminants composed of 9 blackbody illuminants and 9 phosphor-based white LEDs at different CCTs, and on the spectral responsivities of seven high quality photometers.

3. Results

For these seven high quality photometers, we have compared both the accepted general V(λ) mismatch index (f'_1) and the here proposed index with (f''_1) with an empirical index (δ) calculated as the disagreement between the photometric responses and the expected photometric quantities. The correlation coefficient between f'_1 and δ is -0.06 (completely uncorrelated), whereas between f''_1 and δ is 0.82, with a p-value (probability of getting a correlation as large as the observed value by random chance, when the true correlation is zero) of just 2.3 %.

4. Conclusions

It has been proven that a low value of f'_1 is not enough to ensure a good photometric performance of a photometer, but that it also depends on the distribution of the spectral variation between the spectral responsivity of the photometer and V(λ). An alternative general V(λ) mismatch index, based on distribution of the spectral variation of the spectral responsivity with respect to V(λ), is proposed. To compare both indices, it has been calculated an empirical photometric performance of seven photometers using a set of illuminants composed of 9 blackbody illuminants and 9 phosphor-based white LEDs. Whereas the values of the accepted general V(λ) mismatch index f'_1 of the seven photometers is completely uncorrelated with their empirical performance, the proposed new index f''_1 is clearly correlated. Therefore, we consider that the use of this new index for the assessment of the general performance of the photometers would contribute in great extent in the general improvement of the photometric measurements.

Session OS3
Glare
Monday, October 23, 10:40–12:20

OP11

GENERIC GLARE MODELS FOR PREDICTING NON-UNIFORM AND COLOURED LED SOURCES

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Abstract

Three experiments were carried out to accumulate glare perception data from luminaires having different uniformities and spectral power distributions. Two generic glare models were proposed to predict glare perceptions caused by them. And they all achieved much better performances than traditional glare model.

1. Motivation, specific objective

Distinct features of LED sources include multiple colour, high intensity and small size. A major issue concerning LED lighting applications is discomfort glare, which is the focus of the present study. Although there are some models predicting discomfort glare, they are mainly concerning glare produced by large size and uniform white sources. They cannot work well with LEDs. Firstly, LED lights are generally non-uniform because of its small size and high intensity, even with the inclusion of lenses or diffusers. Secondly, LED sources can have variety of spectral power distributions (SPD). Many researchers have found that the above two properties (uniformity and SPD) could have large impacts on glare perception, while most existing glare models do not take them into consideration.

The goals of the present study were a) to collect experimental data of glare perception caused by LEDs having different uniformities or SPDs, b) to establish new definition of luminance or brightness to consider the effects of uniformity and SPD on glare perception, and c) to develop new models based on the new definition of luminance or brightness.

2. Methods

Three experiments were completed. For Experiment 1, the influence of uniformity on discomfort glare was studied. It included four types of LED luminaires, i.e. raw LED matrix (RLED), LED matrix covered by lens (HLED), LED matrix covered by diffuser (DLED) and raw LED patterns (PLED). The experiment was conducted under two different ambient environments, at two different positions of glare source. Observers rated glare using a seven-categorical scale, .i.e. imperceptible (1), just perceptible (2), perceptible (3), just discomfort (4), discomfort (5), intolerable (6), totally intolerable (7). In total, 5040 ratings were obtained (3 RLED×5 luminance level+3 HLED×4 luminance level+3 DLED×4 luminance level+6 PLED×4 luminance level)×2 background×2 position×20 observers).

Experiment 2 was conducted to study discomfort glare caused by LEDs having different SPDs. It included three groups of LEDs, i.e. coloured LEDs (CLED), metameric white lights having different density of blue lights (MWLED), and white lights formed by the same RGB LEDs but different correlated colour temperatures (CCT) (CWLED). The experiment was only conducted under dark ambient but still at two positions of glare source. In total, there were 2240 rating (5 CLED×4 luminance level+ 4 MWLED×4 luminance level+5 CWLED×4 luminance level)×2 position×20 observers).

Experiment 3 was designed to investigate the uniformity and SPD simultaneously. The glare sources had three different uniformities and four SPDs. It was only conducted at one position and under dim ambient. In total, 720 ratings were collected (3 uniformity×4 SPD×3 luminance level×20 observers).

3. Results

Experiment 1 results showed that average luminance (L_{ave}) cannot take the influence of uniformity on glare perception into consideration. A more non-uniform glare source will lead to a higher glare perception. Furthermore, a modified luminance (L_{UNI}) was proposed to be based upon the product of a contrast factor and L_{ave}. And the authors also built a modified brightness scale (Q_{UNI}) by multiplying a contrast factor with the brightness calculated from CAM15u colour appearance model. Both L_{UNI} and Q_{UNI} could predict all the glare perceptions accurately.

Experiment 2 results showed that luminance calculated from photopic sensitivity function *V(λ)* performs badly in predicting the influence of SPD on glare perception. Blue light produces more glare than red and green lights at the same luminance. Moreover, a shorter peak wavelength of blue LED leads a stronger glare. A new luminance (L_{SPD}) based on glare sensitivity function $V_{DG}(\lambda)$ was applied. $V_{DG}(\lambda)$ had a higher value in the shorter wavelength range, meaning weighing the effect of blue light more than *V(λ)*. Besides, the brightness from CAM15u was modified again (Q_{SPD}) to take into account the Helmholtz-Kohlrausch (H-K) effect. Both these glare indicators markedly outperformed than luminance basing on *V(λ)*.

Moreover, L_{UNI} and L_{SPD} were combined to obtain a modified luminance L_M. And Q_{UNI} and Q_{SPD} were combined to achieve a modified brightness Q_M. Both L_M and Q_M considered the effects of uniformity and SPD simultaneously. They were then integrated with background, position and size of glare source to form two final glare models mUGR and QUGR. These models were tested using Experiment 3 data. It showed that they had similar performance and both performed much better than UGR.

4. Conclusions

Three experiments were conducted for evaluating glare affected by uniformity, SPD and their combination. The former two experiments were used to develop two generic models, mUGR and QUGR, based on new defined luminance and brightness respectively. Both gave much more accurate predictions than UGR. The mUGR was similar to the traditional UGR since they were both empirical formulas. While QUGR was based on colour appearance model, in other words, it is the first time we can bridge the glare perception and human visual model. Therefore, it is more promising to be applied in evaluation of LED lighting quality in the future.

OP12

DISCOMFORT GLARE FROM DAYLIGHTING: INFLUENCE OF CULTURE ON DISCOMFORT GLARE PERCEPETION

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Abstract

1. Motivation, specific objective

Energy efficiency and well-being are both major challenges in construction nowadays. In order to profit from the benefits of daylight, whether they are related to energy, occupants' performance, or well-being, office buildings tend to have wider windows. But a larger surface of glazing implies an increased risk of discomfort glare. If daylight becomes irritating or disturbing, occupants will most probably use shading devices and turn on artificial lighting. When daylighting conditions return to a comfortable situation, occupants often forget to open the shading devices, canceling all the benefits of daylight.

To consider this growing issue of discomfort glare from daylight, recommendations to limit glare will be part of the new European daylight standard (prEN17037). These recommendations use the Daylight Glare Probability (DGP) as a reference index, prescribing a threshold value that DGP should not exceed more than 5% of usage time. Concerning discomfort glare from artificial lighting, CIE recommendations are mainly based on the Unified Glare Rating (UGR) index.

However, these indices cannot properly explain the high variability existing between individuals' discomfort glare perceptions. One assumption for this is that some of the factors influencing discomfort glare perception are still unknown. A potential influencing factor might be the culture. The culture is defined in this case as the climatic and indoor conditions to which a subject has been accustomed during the major part of his life, his behaviour towards this indoor environment, and his expectations about it. Discomfort glare indices have indeed been developed through experiments involving particular populations. Until now, no study has examined that these indices could be used analogously for subjects having different cultures and living in different parts of the world. Several observations have been made in the last 20 years suggesting that subjects from different cultures would have different sensibilities towards lighting, and especially towards discomfort glare.

This study aims to determine the existence of differences between the perceptions of discomfort glare of people from different cultures. The main objective is therefore to assess whether or not the influence of culture on discomfort glare perception is real.

2. Methods

A field survey is being conducted for three populations having distinct culture; the Chileans, the Belgians, and the Japaneses. These countries have been chosen because of climate and cultural requirements and given the local presence of competent teams in the field of daylighting.

The field survey consists in collecting objective and subjective evaluations of visual discomfort, and more specifically of discomfort glare, in real office buildings. Although field surveys have the disadvantage of not being totally controllable, this option has been chosen for several reasons. Amongst them, there is: the difficulty to recreate the same office-like cell in different parts of the world; the necessity to take into account the differences that might exist between office environments; the ambition to induce the least modification possible to subjects' day-to-day situation.

On the one hand, the objective evaluations of discomfort glare are obtained from Daylight Glare Probability (DGP), Daylight Glare Index (DGI), Unified Glare Probability (UGP), and other glare indices values, which are calculated on the basis of a luminance map of the subject's field of view. These luminance maps are created by the use of High Dynamic Range (HDR) images calibrated with

luminance and illuminance values measured in-situ. On the other hand, the subjective evaluations of discomfort glare are collected from the subjects answering a questionnaire. The questionnaire includes demographic information, visual task completion, and visual comfort assessment.

Since the objective and subjective evaluations have to be made for the exact same daylit scene, the HDR image is captured right after that the subject finished answering the questionnaire, with the camera located at subject's eyes position. Moreover, the survey is only conducted under stable skies to ensure that luminous conditions do not change between the subjective and objective evaluations.

The discomfort glare survey was carried out in Chile in March 2017 and a sample of 80 subjects was collected. The authors will conduct the survey in Belgium from May to August 2017, and later in Japan in March 2018. Additional samples of around 160 and 60 subjects should be collected, to achieve a total of 300 discomfort glare evaluations in real offices using daylighting.

3. Results

A first comparison between the Belgian and Chilean populations will be done for the CIE Midterm Meeting. The comparison consists in observing the difference in discomfort glare perception (subjective evaluation) between Chileans and Belgians for each value of a discomfort glare index (objective evaluation). These comparisons will be made through inferential and descriptive statistics such as t-test and prop-test. Furthermore, several discomfort glare indices, such as the DGP, the DGI, the UGP, or the vertical illuminance at eye level (E_V), will be examined against the subjective evaluations in order to confirm or infirm the trend of a divergence in discomfort glare perception between the two populations.

4. Conclusions

If the hypothesis of a difference in discomfort glare perception between subjects of different cultures is verified, current discomfort glare indices need to be reviewed and adapted according to the population to which they are applied. Moreover, the influence of culture would help explain a part of the high variability existing between individuals' discomfort glare perceptions.

If, contrariwise, this hypothesis is rejected, the cultural factor can be deleted from the list of factors influencing discomfort glare perception. It would therefore be acceptable to gather samples collected from different parts of the world to create a larger dataset in order to study discomfort glare perception.

However, regardless of the conclusion reached from the Belgian-Chilean comparison, it will be necessary to validate this conclusion with the Japanese sample.

OP13

AGEING EFFECTS ON DISCOMFORT GLARE SENSATION AND THEIR MECHANISMS

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Abstract

1. Introduction

To evaluate discomfort glare in interior lighting, the CIE (1995) established the Unified Glare Rating (UGR) system. The UGR rates the degree of discomfort caused by high-luminance light sources based on the luminances ($cd \cdot m^{-2}$), sizes (sr), and positions of the light sources, as well as the luminance of the background ($cd \cdot m^{-2}$). Unfortunately, the UGR has not taken into account the ageing effect on glare sensation.

The luminance contrast of a light source against its background is the basis of the UGR formula. As the luminance contrast increases, the degree of discomfort also increases. Light scatter in the eyes increases with age, and therefore the luminance contrast between the light source and the background is reduced. Then, the degree of discomfort may also be reduced. However, light scatter may directly increase the degree of discomfort glare by increasing the apparent size of the light source. Due to such conflicting mechanisms, studies showed mixed results with regard to the effects of age on discomfort glare.

As is known, the Borderline between Comfort and Discomfort (BCD) has an ageing factor. To obtain it, Bennett (1977) quantified the effect of age on discomfort glare and found that older adults were more sensitive to high luminance stimulus than young people. However, Rex and Franklin (1960) found no correlation between BCD luminance and age. Several other studies found that older people were less sensitive to glare than young people (Mochizuki et al., 1998; Theeuwes et al., 2002).

A common finding in the above-listed studies was that there were larger individual deviations in glare sensation for older subjects than those for young subjects. Therefore, we thought that it was inappropriate to simply average discomfort glare evaluations, especially derived from older subjects. We decided to first examine each individual's visual characteristics, and then carefully investigate the relationship between the visual characteristics and glare evaluations for each individual, so we can investigate the mechanisms of the ageing effects on glare sensation.

2. Methods

This study consists of two parts; (1) measurements of visual characteristics and (2) glare evaluations. In this study, six young subjects ranging between 22 and 23 years old and 18 older subjects ranging between 65 and 80 years old participated. All the subjects had healthy eyes appropriate to their ages.

(1) Measurements of visual characteristics

All subjects received eye examinations in University of Fukui Hospital. In the examinations, ophthalmologists first conducted health screening for various eye diseases such as cataract, glaucoma, and macular degeneration. Then, they measured visual characteristics; i.e., visual acuity, pupil size, and transmittance of crystalline lens for each of the subjects.

(2) Glare evaluations

The experiment was conducted by using an experimental setup in a laboratory. The experimental setup was composed of a 0.6 m wide, 0.6 m high, and 0.15 m deep glare box and a dimmable flood light. The glare box contained 16 fluorescent lamps, and had a square opening with a translucent acrylic panel. The square opening provided a glare source to

subjects. The luminance of the surface of the glare source was changed by using neutral density filters. The dimmable flood light was used to maintain the background luminance as about 40 cd·m^{-2} for all experimental conditions.

The independent variables were the size and luminance of the glare source. The sides of the square glare source were 2 cm and 60 cm while 700 cd·m^{-2}, 5000 cd·m^{-2}, 10 000 cd·m^{-2} and 20 000 cd·m^{-2} for the glare source luminance, so the total number of conditions was eight. Glare evaluations were done by using a nine point glare scale ranging from (0) no glare to (8) intolerable.

In the experiment, each subject was seated on a chair at a distance of 0.8 m from the glare source which was assigned to one of the conditions. After adapting to the brightness of the glare source for one minute, the subject evaluated the degree of discomfort caused by the glare source. The presentation order of the experimental conditions was randomized.

3. Results

Generally, the results of this study confirmed the existing finding that older subjects had larger individual deviations in the degree of discomfort caused by high luminance glare sources than young subjects. We also found larger deviations in visual characteristics in older subjects than those of young subjects.

First, to compare the glare sensitivities between young and older subject groups, the degrees of discomfort were averaged under each condition for each age group. The results showed that the averaged degree of discomfort evaluated by the older subjects was higher at low luminances (< 13 000 cd·m^{-2}), but lower at high luminances (≥ 13 000 cd·m^{-2}) than those of the young subjects.

Second, to understand the reasons of the older subjects' larger individual deviations and to understand the mechanisms of discomfort glare sensation, we examined the correlation between BCD luminance and each of the visual characteristics, e.g., visual acuity, pupil size and lens transmittance. The results found a poor correlation (R^2<0.1) between visual acuity and BCD luminance. On the other hand, the results found much better correlations between retinal illuminance and BCD luminance, i.e., R^2=0.85 and R^2=0.68 for the larger and smaller light sources respectively. The retinal illuminances were calculated by the combination of pupil size and lens transmittance. In other words, the higher the retinal illuminance the higher the BCD luminance. This implies that as pupil size decreases and light scatter in lens increases with age, discomfort caused by a high-luminance glare source may also become more serious.

4. Conclusions

This study found that people feel more serious glare as the pupil size decreases and the light scatter in lens increases with age. This implies that the total amount of light reaching the retina does not determine the degree of discomfort, but the light scatter causing light veil over the visual field may annoy people, by increasing the apparent size of the glare source. More details on the mechanisms of the age effects on discomfort glare sensation will be shown in the final conference paper.

OP14

STUDY ON GLARE DURING PLAYING BADMINTON IN GYMNASIUMS USING LED AND HID FLOODLIGHTS

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Abstract

1. Motivation, specific objective

LED lighting technology has been advancing quite rapidly and it has been used in sports facilities. Some LED retrofit projects, however, have been the target of complaints regarding glare which prevents players from being able to follow targets such as balls and shuttlecocks when they pass directly in front of the luminaire. Since the lines of sight of the players move to follow the targets during the game, players sometimes look at the luminaires directly. In such a case, we call it 'obtrusive glare' since it is different from both disability glare and discomfort glare.

In our previous study, subjective experiments were carried out in three gymnasiums (two gymnasiums with LED floodlights and a gymnasium with electrodeless discharge floodlights). However, it was difficult to find obvious relationship between photometric quantities and degree of obtrusive glare. Therefore, the purpose of this study is to model the physical lighting conditions associated with obtrusive glare in gymnasiums.

2. Methods

The subjective experiments were carried out in eight gymnasiums (four gymnasiums with LED floodlights and four gymnasiums with HID floodlights) by using the same method as our previous study. The height of the celling of the gymnasiums ranges from 6.4m to 16.5m. The position of the subject and the shuttlecock were arranged so that the subject's eyes, the shuttlecock and the floodlight were in a straight line. The subjects sat on the chair at three different points to fix their eyes at the height of 1,2 m from the floor. The shuttlecock was set at a height of 3,0 m from the floor. The subject's line of sight was set at a 40, 60 and 80 degree angle. In order to identify the effect of the optical focus of the subject on glare sensation, two conditions (with shuttlecock and without shuttlecock) were evaluated for each angle. More than ten students participated as subjects in each gymnasiums. The subjects evaluated "glare from the floodlight", "the visibility of the shuttlecock in front of the floodlight" and "the acceptability of the lighting environment". The luminance distribution of subject's visual field was measured by using a digital camera system (Nikon D3300). The candidate variables which can predict degree of obtrusive glare include the average luminance of the glare source, the average luminance of the background, the solid angle of the glare source and UGR. To extract the glare source area, threshold luminance between the glare source and the background should be determined. In this study, three threshold values (10^3, 10^4 and 10^5 cd/m^2) were adopted. Therefore, three sets of the average luminance of the glare source, the average luminance of the background, the solid angle of the glare source and UGR were obtained.

3. Results

Granularly the larger the angle of the subject's line of sight from the horizontal plane, the lager the degree of the obtrusive glare from the floodlight and the lower the visibility of the shuttlecock in front of the floodlight. The result of the discriminant analysis showed that "the acceptability of the lighting environment" mainly affected by "glare from the floodlight" in case without shuttlecock. Using the degree of obtrusive glare as a dependent variable and the candidate predictor variables as independent variables, a multiple regression analysis was carried out. The multiple correlation equation was obtained and its multiple correlation coefficient was 0.78. The equation includes the solid angle of the glare source multiplied by logarithm of the average glare-source luminance and a logarithm of the average glare-source luminance divided by the average background luminance

(threshold luminance between the glare-source and the background is 10^3cd/m^2). This equation shows that increasing the reflectance of the ceiling can reduce the degree of the obtrusive glare.

4. Conclusions

In order to find the relationship between photometric quantities and degree of obtrusive glare in gymnasiums, the physical lighting conditions associated with obtrusive glare were modelled. Using the degree of obtrusive glare as a dependent variable and the candidate predictor variables as independent variables, a multiple regression analysis was carried out and the multiple correlation equation was obtained. This equation shows that increment in both the amount of light from glare-source and the contrast between the glare-source and background increases the degree of the obtrusive glare during playing badminton.

OP15

EFFECTS OF TASK AND VIEWS ON DISCOMFORT GLARE FROM WINDOWS

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Abstract

1. Motivation, specific objective

Research into the effects and underlying processes of discomfort glare has been on the agenda of lighting and vision researchers for many years. The main variables that affect the experience of discomfort glare have been established. They are the luminance of the glare source, the luminance of the background, the angular size of the glare source, and the relative position of the glare source in relation to an observer's focal point. However, recent studies suggest that window glare depends on more factors than the four main variables. Actually it cannot be denied that indices predicting subjective response to light environment sometimes ignore the psychological and physiological state of occupants, because conventional stimuli-response researches have avoided dealing with the other factors which cannot be measured and expressed in physical quantities. Although the draft of the CIE TC 3-56 "Assessment of discomfort glare from daylight in buildings" report pointed out that there are various possible factors like type of task, view through the windows, power spectral density of glare source, time of day, age of the observers, etc., their effects on glare evaluation have not been clearly identified. The objective of this study is to indicate the effects of the type of task, the direction of view from the observer to the window, and the view through the window on discomfort glare evaluation.

2. Methods

Subjective experiments were carried out in a test chamber with a virtual window and two rooms with real windows. The solid angle of the window from each subject's position was set to keep 0.46 sr in both the test chamber and the actual rooms. In the virtual window experiment, the average luminance of the virtual window (illuminated by LED light) with venetian blinds was set to 2000, 4000 and 8000 cd/m^2. For the real windows, the blind slat angle was set to avoid direct sunlight. The reflectance of the blind slat ranged from 0.69 to 0.76. Also, the real windows had different views, one included adjacent building blocking the horizon while the other included a distant view of trees. In both experiments, two different tasks (VDT/paper) and two different directions of view from the observer to the window (perpendicular to the window plane or oblique angle) were examined.

Twenty students participated as subjects in the virtual window experiment, while 146 students participated as subjects in the real window experiment. In both experiments, the subjects entered the room and worked on VDT task or paper task for three minutes. Then they looked at the window and assessed the glare using the Glare Sensation Vote (GSV) scale. Luminance distribution was measured by using a HDR camera system ((Nikon D3300 and Sigma 4.5 mm, 1:2.8 EX DC circular fisheye) and the glare indices, Daylight Glare Probability(DGP), Daylight Glare Index (DGI), CIE Glare Index (CGI), Predicted Glare Sensation Vote (PGSV), and Unified Glare Rating (UGR) were calculated with Evalglare.

3. Results

The results of the virtual window experiment showed that the difference in glare indices between the tasks (VDT task and paper task) and between the directions of view from the observer to the window (perpendicular to the window plane or oblique angle) were negligible. Although the correlations between the glare indices were generally strong, e.g. correlation coefficient between DGP and PGSV was 0.975, CGI showed lower correlation coefficient with the other indices. It was found that these glare indices except CGI showed strong correlations with GSV judged by the subjects. The correlation coefficient between GSV and these indices except CGI ranged from 0.808 (DGI) to 0.960 (PGSV) while that between GSV and CGI was 0.485.

As a result of the virtual window experiment, the normality test (Kolmozov-Snmilnov test) showed that the GSV judged by the subjects for the 4000 or 8000 cd/m^2 window had normal distribution, while that for the 2000 cd/m^2 did not. For windows with 4000 and 8000 cd/m^2, the VDT task resulted in significantly higher GSV than the paper task, when the line of sight of the subject was perpendicular to the window plane. However, no significant difference in GSV was found between the VDT task and the paper task, when their line of sight was at an oblique angle to the window plane.

The results of the real window experiment showed a larger individual difference in GSV. No significant difference in GSV was found between the two different views seen through the windows. Moreover, the type of task and the direction of view from the observer to the window had significant effect on GSV. For the conditions with 0.45<DGP<0.55, GSV from the real window was lower than that from the virtual window

4. Conclusions

Subjective experiments were carried out to identify the effects of the type of task, the direction of view from the observer to the window, and the view through the window on discomfort glare evaluation. The virtual window experiment showed the VDT task resulted in significantly higher GSV than the paper task, when the line of sight of the worker was perpendicular to the window plane. However, the real window experiment showed no significant difference in GSV between the VDT task and the paper task. The effect of the direction of view from the observer to the window on GSV was not found in both experiments. It was found that the view through the windows had the possibility to relieve discomfort caused by glare from windows.

Session OS4
Colour quality (2)
Tuesday, October 24, 09:40–10:40

OP16

LIGHTENING DIFFERENT TRADE-OFFS WHILE DEVELOPING A UNIFORM COLOUR SPACE

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Abstract

1. Objective and Motivation

The display industry is going through a major evolution. Brightness and contrast of displays have improved in recent year and will continue to improve further. International Telecommunication Union has recommended Rec.2020 gamut for future displays. A computationally inexpensive colour space is desired which can uniformly encode high dynamic range (HDR) and wide colour gamut (WCG) image signals. It should also be able to accurately predict visual colour differences with least cross-contamination between Lightness, Chroma, and Hue. State of the art colour spaces include CIELAB, CIELUV, CAM16-UCS (revision of CAM02-UCS), IPT, and IC_TC_P (Dolby's proposal for HDR and WCG). These colour spaces have some pros and cons. Tireless-efforts have been done to develop a colour space to be perceptually uniform in wide gamut, linear in iso-hue directions, and can predict both small and large colour differences, and lightness in the high dynamic range, with minimum computational cost. Keeping above in mind, current study aimed to develop a simple colour space for perception-based image processing (including HDR and WCG images). Different versions of a colour space were developed and trade-offs between lightness-constancy, hue-linearity, and local and global uniformity are discussed here.

2. Test Data and Metrics

A comprehensive range of experimental data was collected to test the performance of proposed colour space compared with state of the art spaces. Combined visual data (COMBVD) (previously used to develop CIEDE2000) and OSA data were used to test performance for prediction of small and large colour differences, respectively. COMBVD ellipses and MacAdam's JND ellipses data represent small and large gamut data, respectively, to test local and global uniformity. Hung & Berns, Xiao *et al.*, and Ebner & Fairchild data were used to test performance for hue-linearity. Considering HDR applications, performance to predict wide-range lightness (above and below diffuse white) was also tested using lightness scaling data generated by Fairchild *et al*. Real samples of Munsell Colour Order System were used to test performance of each perceptual correlate of test spaces.

Quantitative results for prediction of perceptual colour/lightness differences are presented in terms of STRESS. Ellipse parameters were used to obtain quantitative results for uniformity. To compare performance for hue-linearity, average standard deviation (SD) of hue was computed. Whereas, to test lightness-constancy, chroma-ratio metric (%) was used i.e., ratio of chroma of the CIE D65 white point to the mean chroma of vertexes (red, green, blue) of sRGB gamut.

3. Results and Discussions

Performance of CIELAB, CIELUV, CAM16-UCS, IPT, and IC_TC_P was investigated in the preliminary study. It was found that CIELAB and CIELUV have zero cross-contamination between lightness and chroma but are not hue-linear, and also cannot accurately predict perceptual colour differences i.e., they are lacking of local and global uniformity. CAM16-UCS can accurately predict perceptual colour differences and is best known colour space for perceptual uniformity but cannot avoid problems with lightness-constancy and hue-linearity (especially in blue region). Both IPT and IC_TC_P were intended to prevail lightness-constancy and hue-linearity but could not accurately predict perceptual colour differences. Among above mentioned colour spaces, only IC_TC_P was intended for HDR and WCG applications.

Different versions of a colour space were developed and performance was compared with state of the art uniform colour spaces. In our preliminary study, a colour space, zIC_aC_b, was developed using the structure similar to IC_TC_P. The model was optimized for uniformity with an aim to achieve uniformity as accurate as CAM16-UCS by using a much simpler model. The results showed that local and global uniformity of zIC_aC_b is very similar to CAM16-UCS but the model could not avoid problems with lightness constancy and hue linearity. It was observed that hue-linearity (particularly in blue region) decreases with improvement in uniformity. This phenomenon has been also previously reported by other researchers such as Lissner *et al.,* and Froehlich *et al*. A new model was then intended to minimize this trade-off. A linear equation was integrated into the structure of zIC_aC_b to improve hue linearity while preserving uniformity. And another non-linear equation was also integrated to improve performance for prediction of wide-range lightness data. This model was named as $J_za_zb_z$. Different trade-offs were observed while improving performance for lightness-constancy, hue-linearity, and uniformity.

The final version of $J_za_zb_z$ achieved a satisfactory compromise between uniformity, hue linearity, and lightness constancy. Lightness-constancy was achieved with chroma-ratio of less than 0.1%. For the Hung & Berns data, average hue-linearity and blue-hue linearity for $J_za_zb_z$ (SD=2.7,2.7) was obtained similar to IPT (SD=2.7,3) which was found best available space for hue-linearity. CAM16-UCS, CIELAB, and CIELUV were found to have unsatisfactory contamination between chroma and hue in blue region with SD values of 9.9, 13.8, and 6.2, respectively. Similar performance was found in prediction of other iso-hue data. The new model performed second best to predict small colour difference data (STRESS=38) following CAM16-UCS (STRESS=30) and best for large colour difference data (SD=19) similar to CAM16-UCS. For local and global uniformity (tested using COMBVD ellipses), it again gave second best performance (STRESS=32,35) following the best CAM16-UCS (STRESS=27,33). It also predicted most accurate for local and global uniformity (SD=26,35) in wide area gamut (i.e., prediction of MacAdam's data) followed by IPT for local uniformity (STRESS=33) and IC_TC_P for global uniformity (STRESS=38). Furthermore, the new model was also found best to predict lightness differences similar to CIE L* and IPT with STRESS values of 1, and 7 to predict Munsell value and wide-range lightness data, respectively. CIELAB and CIELUV showed worst performance for uniformity. IC_TC_P gave overall worst performance, particularly to predict perceptual lightness.

4. Conclusions

A colour space was developed by achieving minimum trade-off between perceptual uniformity, hue-linearity, and lightness-constancy. The newly developed colour space either performed best or similar to the best to predict comprehensive range of experimental data. The results showed that the new model is a strong candidate for performing perception-based image processing including HDR and WCG signals. Best prediction of MacAdam's data also means that it can be reliably used to predict self-illuminant colours. Its performance was demonstrated using image compression and gamut mapping algorithms.

OP17

EVALUATION OF GAMUT COMPRESSION ALGORITHMS WITH DIFFERENT NEUTRAL CONVERGENT POINTS IN DIFFERENT COLOUR SPACES

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Abstract

1. Objective

Nowadays, displays of wide colour gamut (WCG) and high dynamic range (HDR) are becoming popular. Here comes the problem: how to achieve successful cross-display colour reproduction from a new display to a traditional one, for which both of them having large differences in colour gamut and luminance range. Hence, this paper will investigate this problem in 2 aspects: 1) the fidelity performances of different gamut mapping algorithms (GMAs) from DCI-P3 to sRGB gamut, and 2) whether GMAs are applicable to the newly developed HDR-UCS colour space. In terms of colour spaces in which gamut mapping is to be performed, the state-of-the-art colour models, CAM16-UCS by Li et al. and HDR-UCS by Safdar et al. were endorsed. The former one is adjusted from the CIE recommended colour appearance model, CIECAM02 and was further elaborated to give more uniformity. The latter is specially developed for the HDR images. It can accurately predict the colour appearance of any colour having a luminance up to 100,000 cd/m^2.

2. Methods

The whole experiment was carried out following the guideline provided by the CIE TC8-03 technical report entitled 'Guidelines for the evaluation of gamut mapping algorithms' in 2004. An EIZO CG277 display was used in a darkened room with a luminance set at around 100cd/m2 and a CCT at approximate 6500K. The GOG model was implemented to give a performance of 0.8 units in CIELAB space which is an average from the 24 colours in the Macbeth ColourChecker chart.

The GMAs adopted in this study mainly concerns with different neutral convergent points. Five types of mapping convergent points were investigated. They include 1) black point for L* at the minimum, 2) medium grey for L* of the CUSP, 3) light grey for L* of 80 and a dark grey for L* of 30, 4) white point for L* at the maximum and 5) adaptive L* according to the device or imaging gamut. Here, Algorithms 1 and 4 were newly proposed to maintain vividness and depth based on Berns's new scales, referred as VP and DP, respectively. Colours were converged to the black point and white point, respectively. Algorithm 3 was adjusted from Kang's algorithm in 2000, where the constant hue plane was divided into three regions (upper, medium and lower regions). Colours in the upper region will converge to the light grey, colours in the lower region will converge to the dark grey and colours in the middle region will converge to the lightness axis. Algorithm 5, named TOPO, was proposed by MacDonald in 2001 to construct a set of mapping chords and performed the gamut mapping along these chords. In addition, CIE guideline recommended two GMAs as anchors, which were known as the chroma-dependent sigmoidal lightness mapping followed by knee scaling toward the cusp (SGCK) and the hue-angle preserving minimum □E*ab clipping (HPMINDE). The former one was just the same as mentioned in Algorithm 2 and the latter was included as a reference "to make it possible to reconcile the different interval scales used in different experiments".

Five images containing a range of different types such as pictorial contents, tonal and chroma variations were adopted in this study. The five test images were named 1) Fruit Basket, 2) Graphics, 3) Musician, 4) Colour Patch and 5) Picnic. Many memory colours such as skin, sky and fruits were included in Images 3 and 5. Lightness changes were investigated in Images 2 and 5. Image 4 was included for testing hue linearity and colour fidelity and Image 1 was to test saturated colours. Hence, 60 images were produced in total including 6 GMAs and 2 colour spaces.

The paired-comparison method was used. Ten observers, half males and half females with a mean age of 24 ranged from 22 to 27, took part in the experiment. Three images were presented side by

side within a scene, with the source image in the middle and two reproduction images on each side. Observers were asked to make a decision on which one appears to be more similar to the original one. Each observer was therefore required to make 66 pair-wise comparisons per image. Hence, a total of 330 comparisons were made.

As for colour spaces, a pilot study was first conducted ahead to investigate the performances of CIELAB, CAM02-UCS, CAM16-UCS and HDR-UCS. Four observers from the ten participants did this pilot study and it was found that CAM16-UCS and HDR-UCS performed best. So, they were finally selected.

3. Results

The raw results were first calculated as probability data and then transformed into z-scores, following the Case V of Thurstone's Law of Comparative Judgment.

Overall, HPMINDE was the best among all GMAs and VP performed the second best. DP was ranked the highest for the Picnic image, in which it preserved the depth rendering better than the other algorithms, especially for the skin and grass colours. TOPO performed better for the image of Colour Patch due to its high fidelity of chroma.

As for colour spaces, HDR-UCS performed slightly better than CAM16-UCS. This is mainly because the latter had a slight colour shift for neutral colours and also caused a small blue hue shift, which were found in Images 3 and 5. Apart from these, some defects appeared in images processed in CAM16-UCS.

4. Conclusions

Overall, the HPMINDE performed the best and followed by the newly proposed VP algorithm, which outperformed all the other convergent points based GMAs.

CAM16-UCS did not perform better than HDR-UCS due to its blue hue shift problem and the grey scale convergent issue. In addition, HDR-UCS offers a comparative colour uniformity compared with CAM16-UCS, indicating it can be a promising uniform colour space for gamut mapping.

OP18

STUDY CHROMATIC ADAPTATION VIA NEUTRAL WHITE ASSESSMENT IN DIFFERENT VIEWING CONDITIONS

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Abstract

1. Objective

Chromatic Adaptation (CA) can be defined as that observers will judge perfect white objects (with unity spectral reflectance) under any illuminant to be neutral after full adaptation. Based on the above definition, Chromatic Adaptation Transforms (CATs) were built by predicting corresponding colours which are a pair of colour stimuli showing same colour appearance under two different illuminants. However, a recent study showed the over-prediction of CA. A modified function of the effective degree of adaptation (D_{eff}) in CAT02 was developed according to the chromaticity of adapting illuminant. The more colourful the illuminant is, the less the observer will adapt to it, but the D_{eff} falls less rapidly along the daylight locus and towards the blue direction. For example, since D_{eff} values under CIE illuminant A are lower than that under CIE illuminant D65, the perfect white objects under illuminant A will always appear to be yellowish rather than neutral as it may be under D65, regardless the adaptation time. Note that this study was based on the visual data in a viewing condition of high luminance (800cd/m^2) projector.

On the other hand, a concept of 2-step CATs was proposed in the previous study to replace the present 1-step CAT in order to clearly define the degree of adaptation. An illuminant representing the baseline states between the test and reference illuminants for the calculation was involved. In the first step the test colour is transformed from test illuminant to the baseline illuminant, and it is then transformed to the reference illuminant. Degrees of adaptations of any other illuminants should be calculated relative to the baseline illuminant. Therefore, this illuminant is expected to produce a neutral adaptation field according to the concept of CA. That is, the chromaticity of neural white under the baseline illuminant is equal to the chromaticity of the baseline illuminant.

Using both surface colours and self-luminous colours, the present experiment collected visual results of neutral white under a very large range of white illuminants, aimed to explore the baseline illuminant and to test D_{eff} model in different viewing conditions.

2. Methods

Inside a viewing cabinet equipped with a spectrum tuneable LED lighting system, the experiment illuminants were rendered as 58 phases with 9 CCT levels (3000K, 3500K, 4000K, 4500K, 5000K, 6000K, 6500K, 10000K and 15000K) and 7 Duv levels (-0.025, -0.0175, -0.0125, -0.0075, 0, 0.0075 and 0.015) at constant luminance of 270cd/m^2. In the experiment, the observers had viewing angles of 70° and 3° for the adapting and target fields, respectively.

In Part-1 experiment of surface colours, the NCS (*Natural Colour System*) colour patches with blackness of 5 and chromaticness from 2 to 10 were placed in the cabinet as a 7 by 7 array according to NCS hue (red on the right, yellow on the up, green on the left, and blue on the down) and chroma (neutral on the centre and high chroma around outside) direction. Under each test illuminant, the observers were first adapted to the illuminant for 1min. Then s/he were instructed to identify a colour on the colour patches array appeared most neutral (defined as no trace of hue). The observers used a black mask to cover the neighbouring patches when s/he observes a patch to avoid background effect.

In Part-2 experiment of self-luminous colours, a calibrated mobile phone display with luminance of 300 cd/m^2 covered by a black mask as same size as Part-1. After 1-minute adaptation, the observers controlled the colour shown on the display and navigated CIELAB a* and b* controls with constant

lightness to find the neutral white using a keyboard. The starting chromaticity under each illuminant was set equal to the chromaticity of that illuminant.

Each part of the present experiment collected results from twelves observers with normal colour vision in total.

3. Results

The visual results of neutral whites under low CCT illuminants shifted to blue directions away from the chromaticities of those illuminants, while results under high CCT shifted towards yellow. The neutral whites under illuminants with either positive and negative Duv shifted towards black body locus away from the chromaticities of the illuminants. The vector from the chromaticity of an illuminant to the visual result of neutral white under this illuminant was the prediction error of CA. These vectors converge to a single point close to 6000K at black body locus for the surface colours, while the convergent point was around 9000K at black body locus for self-luminous colours. The results were similar both in CIE 1976 u'v' diagram and CAM02-UCS. The convergent points were supposed to be the possible chromaticities of the baseline illuminant of the 2-step CAT. Detail discussion will be showed in the full paper.

The global D_{eff} of the self-luminous colours are much lower than those of the surface colours. The self-luminous colours result had similar trend to the D_{eff} model in the previous study: illuminants with low CCT (<5000K) would had lower D_{eff} values. However, the adaptation is stable over CCT for the surface colour. Illuminants with positive duv provide slightly higher D_{eff} values for surface colours but lower D_{eff} values for self-luminous colours.

4. Conclusions

Using both surface colours and self-luminous colours, an experiment was conducted to collected visual results of neutral white under white illuminants (3000K < CCT < 16000K, -0.03 < Duv < 0.02). The baseline illuminants of the 2-step CAT was found with different CCTs for the surface colours (6000K) and self-luminous colours (9000K) respectively, at black body locus. Models of effective degree of chromatic adaptation were tested and compared with that found in the previous study.

Session OS5
Road lighting (1)
Tuesday, October 24, 09:40–10:40

OP19

NIGHT TIME VISIBILITY OF ROAD SIGNS WITH MODERN HEADLAMPS

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Abstract

The work on improving traffic safety and decreasing the number of fatal accidents is often of highest importance for governments and public authorities all over the world. For example, in 1997 the Swedish government took a decision that the national work in this area should strive towards zero traffic accidents with lethal outcome. This so called “zero vision” is still of current interest, although of course very hard or even impossible to reach. Since many accidents occur during the dark hours of the day, measures have been taken to improve road safety at night with increased night time visibility of the road, its immediate surrounding and traffic signs. Development of new vehicle lamps, including light sources and optics, and high performance retro-reflective materials on road signs are believed to contribute in this respect.

When driving, it is important to accurately and from a distance be able to detect and properly identify road signs. The distance need to be far enough so that there is time to make decisions and adapt the driving to the information provided. Since the colour of the sign is a crucial part of the message and contributes to fast decision making, it is essential to investigate the night time chromaticity of the road sign. Another problem with night time traffic safety is glare, and therefore it may be a problem if retro-reflective road signs do produce too high luminance and thereby disturb the drivers’ vision.

The aim of this study is to investigate whether modern vehicle light sources such as LED and Xenon influence the visibility of road signs compared to traditional halogen lamps, with focus on colour recognition and glare. Retro-reflective material used on road signs must generally fulfil requirements according to international regulations and testing is performed against relevant standards such as EN 12899-1 in Europe or ASTM D4956 in the US. However, in the current version of EN 12899-1 (2007) there are no requirements regarding night time chromaticity and while ASTM D4956 states such requirements, they are based on using an incandescent light source (CIE standard illuminant A). Furthermore, according to these standards, the requirements for the coefficient of retro-reflection are based on conditions with incandescent light sources.

Other studies have indicated that disturbing glare could arise from road signs with high retro-reflectivity but generally relevant test standards do not set an upper limit on the coefficient of retro-reflection. However, some standards in adjacent fields (e.g. DIN 74069) have acknowledged this potential problem by imposing requirements regarding the maximum allowed retro-reflection. Although similar studies have been performed previously, the present work is motivated by continuous and rapid development in both retro-reflective materials as well as in vehicle lighting technology.

For this study an existing goniometer was modified in order to make spectrally resolved retro-reflection measurements on a selection of new retro-reflective sheets from different manufacturers. The system is normally equipped with a standard photometer and used for testing retro-reflectivity of various products and materials. It is fully automated in terms of the observation angle ($0° \leq \alpha \leq 3°$) and the full range of incidence and rotational angles of the sample ($\beta 1$, $\beta 2$ and ε according to CIE 54.2). The evaluated materials included several grades of both micro-prismatic and beaded sheetings in the most common colours (white, red, blue, green and yellow). Also, some older and worn materials were included for comparison.

A total of 35 samples were measured in a traditional way, i.e. with a photometer, in selected standard geometries using a small halogen lamp. After this initial characterization the photometer was replaced with a spectrophotometer and the standard halogen lamp was replaced with commercially available vehicle headlamps (halogen, LED and Xenon). All samples were measured in 20–25 different geometries using the halogen lamp, with observation angles between 0,33° and 2,5° and selected incident and rotational angles. Based on the spectral distribution of the lamp, the relative spectral retro-reflection responsivity was determined for each sample. These responsivities were used to

calculate night time chromaticity and worst case luminance for typical LED and Xenon vehicle headlamps, assuming spectra and intensities within acceptable regulatory limits (i.e. ECE R48).

The results from the modified setup were compared to the initial measurements made with the well-validated standard setup, while the method and calculations were verified with retro-reflective measurements made using the vehicle LED and Xenon lamps respectively. The standard measurements agree fairly well with the modified setup. However, some differences are noted which can be attributed to the physical extension of the actual vehicle lamp used.

Results from spectral retro-reflective measurements in the above mentioned geometries show variations in CIE 1931 x and y chromaticity coordinates from 0,01 up to 0,07 for the halogen lamp, which is in line with previous studies. The full paper will present an analysis of the colour variation for all tested geometries as well as for different spectral distributions that can be found in modern vehicle headlamps. In addition to this, calculations of worst case scenarios regarding possible disturbing glare from road signs will be presented assuming different types of headlamps, position relative to and distance from the sign, and also taking into account other influencing factors.

OP20

INFLUENCE OF AMBIENT LIGHT LEVEL ON PEDESTRIAN ACTIVITY AND ACCIDENTS ON PEDESTRIAN CROSSINGS

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Abstract

1. Motivation, specific objective

Road lighting in subsidiary roads is intended to promote conditions in which people feel it is safe to walk after dark. Lighting is expected to do this because it can enhance the ability to detect hazards, to recognise the apparent intentions of other people and to feel safer.

One way to investigate whether lighting promotes a feeling of safety amongst pedestrians is to ask them how they feel in different conditions of illumination. This is a quantitative subjective approach. It is known, however, that this approach can be easily influenced by factors other than lighting: asking for a rating compels a participant to make an assessment of something they perhaps would not otherwise have considered to be of importance; quantitative evaluations are likely to be significantly affected by context, for example, the range of stimulus magnitudes that the participant is asked to evaluate.

In this article we report analyses of the impact of ambient lighting on objective data – the frequencies of walking and the frequencies of collisions with pedestrians on pedestrian crossings. Using natural data removes the bias associated with subjective evaluations. Analysis by ambient light means a contrast between daylight and after-dark (night-time) and is reported here as a first step in analysis of variations in road lighting conditions.

2. Methods

These analyses were carried out using the daylight savings clock change method. Consider the period of approximately 5pm to 6pm (but more precisely chosen according to latitude). In the period immediately before daylight clock change in spring this period tends from twilight to darkness; after the clock change, however, this same period tends from daylight to twilight. Comparing road user behaviour between these periods provides an analysis of the effect of changes in light whilst other potential confounds are held approximately constant (e.g. purpose of travel, driver demographics and level of alcohol consumption).

To improve the robustness of conclusions an Odds Ratio (OR) approach was used. This means that in addition to the case hour in which ambient light would change before and after clock change, we also examined changes in behaviour in a series of control hours for which the ambient light would remain the same before/after clock change (e.g. continuously daylight or continuously dark). These control hours hence provide a benchmark against which to consider any changes found in the case hour.

The effect of ambient light on the frequency of walking was examined using data recorded by automated pedestrian counters installed in an inner suburb of a major city in the USA. This is an area of 26 square miles within which there were 19 pedestrian counters, recording pedestrian volumes at 15-minute intervals. These data are openly available for independent analysis. For the current analysis we used the Spring and Autumn daylight saving clock changes between November 2011 and March 2016, thus giving ten clock-change events. For each event, data were extracted for the case and control periods for the 13 days (Monday of week one to Saturday of week two) before and after the clock change.

The effect of ambient light on collisions at pedestrian crossings was determined using data from STATS19, the UK record of road traffic collisions (RTCs) that are reported to the police. These data are also openly available for independent analysis. For the current analysis we used RTCs reported between 2005 and 2015. Of the 1.78 million RTCs in this period, there are 289,923 separate incidents that involved a pedestrian casualty. The current analysis considered those which occurred for the 13-

day periods before and after each of the 22 Daylight Saving Time transitions that occurred between 2005 and 2015. Two control hours were used (daylight, 14:00 – 14:59 and dark, 21:00 – 21:59). Three types of crossing were considered: unsignalled (zebra) crossing, signalled (pelican) crossing, and crossings associated with signalled road traffic junctions.

3. Results

An odds ratio of 1.62 was calculated for the pedestrian count data, meaning there was a 62% increase in pedestrians in the case hour when it tended towards daylight than when it tended towards dark. This increase is statistically significant ($p<0.001$).

For RTCs on crossings, the odds ratio averaged across all types of crossing was 1.7. This suggests using a pedestrian crossing after-dark presents a significantly greater risk of being involved in an RTC than during daylight ($p<0.001$).

Odds ratios provide an indication of effect size: odds ratios of 1.22, 1.86 and 3.00 have been equated to Cohen's small, medium and large effect sizes respectively.

4. Conclusions

These results show the importance to pedestrians of ambient light conditions. First, we have shown that light encourages people to walk rather than use other forms of transport, and this active mode of travel is of importance in improving public health. Second, we have shown that light reduces the risk of involvement in a road traffic collision whilst using a pedestrian crossing, and this contributes to international targets for reducing pedestrian fatalities.

In this analysis, ambient light was identified only as daylight or after dark. The next step of this research will be to discriminate between different conditions of light after dark to establish the impact of changes in lighting.

OP21

COLOUR TRANSITIONS IN ROAD LIGHTING

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Abstract

1. Motivation, specific objective

Although it has been possible to produce coloured road lighting for a long time, the use of colours other than yellow and white, has never been widespread. Since the introduction of LEDs, also other colours are being used in road lighting. These include single colour LEDs and fixed or dynamic combinations of multiple colour or white LEDs. Practical cases have shown that the use of certain colours can lead to a sharp increase in accidents. Another concern which is raised more often concerns viewing or actually turning into a side road which is lighted using a different colour, where people often report a lack of visibility. Where current recommendations give guidance on transitions in light level along a road, such guidelines do not exist for transitions in colour. Experimental evidence to underpin such recommendations seems very scarce. The aim of this work is to investigate the influence of temporal transitions in monochromatic road lighting on the visual performance of road users in mesopic driving conditions. We explicitly exclude colour preference or liking as these are typically very personal. As a secondary research question we want to look at both objective visual performance as well as the subjective rating of visibility by the test subjects themselves. The latter is often used as a measure in this type of research, but it is unclear, even doubtful, whether the subjective rating really matches the actual performance of people.

2. Methods

The test subjects were seated in front of a 1:20 scale model of a road, with their head on a chin rest, keeping their eyes at a scale height of 1.45 m. Such a scale model can provide a good balance between the high experimental control and low environmental validity of a laboratory setup, and lower control and high environmental validity of a real driving situation. Experience and an initial test indicated that this method yielded similar results as a natural and realistic outdoor experiment.

Participants were wearing a pair of glasses equipped with mechanical shutters in front of the glasses. Once they were wearing the glasses with shutters closed, they were adapted for 90 seconds to one of the adaptation light colours using coloured LEDs fixed inside the glasses. A random time after the adaptation time, the shutters flipped open, making the road visible. In front of the participants, two pedals were attached to the floor, mimicking a gas and brake pedal. The participants, having been asked to depress the gas pedal from the start of each test run, were instructed to press the brake pedal as soon as an object was seen on the road. The response time needed to press the brake pedal was registered and used as the dependent variable. After each test run, the subject was also asked to rate the visibility of the target on a numerical rating scale between 1 and 10.

The experiment had a 12 (colour transition) x2 (luminance level) within-subject design with response times and subjective ratings as dependent variables. The colour transition starts with four levels; monochromatic red, green, blue or amber. These colours all have a transition from and to white. A single white-white transition is added as control condition. Also, a red-to-blue transition is added, which as two opposites colours in the human visual system, could provide larger effects than the other, more conventional road lighting transitions to white.

A total of 27 participants were recruited, aged between 23 and 31 years (mean age 27, s.d. 2.6) and 56 % male and 44 % female. Due to technical issues in two test series, the reaction time results of two subjects could not be used.

Based on scenarios that represent real-life coloured lighting situations, the road luminance was chosen according to a M3 or P3 class, at either 1 cd/m2 or 0.1 cd/m2. This gave a total of 24 transitions in the experiment. The objects on the model road, which the test participants had to detect, were positioned between a luminaire at 4-meter distance (80m in real-life) and a luminaire 1.15 meter

(23m) further away. The difference in distance of the object positions on the scale model was not more than 10-15 cm.

3. Results

Coloured light did give lower subjective ratings and higher objective response times, and it did play an important role in what can be seen under mesopic conditions at night. Compared to white-to-white transitions with an average break reaction time of 877 ms, white-to-red (1009 ms, +15%) and white-to-green (1061 ms, +21%) transitions do add important time in dangerous situations. Even worse, it could more than double to 2197 ms in low white-to-blue light transitions. At 50 km/h, stopping distances would be 31 meters (for the 877 ms response time) and 49 meters (for the 2197 ms response time). This is a 60% increase in stopping distance, which can have enormous implications for accident rates in urban areas. The claim that coloured lights positively influences object detection and perform equally or better than regular white light, is not reflected in these results.

The effect of colour transition on brake reaction time depends on the colours, with blue being associated with worst performance, the direction of the transition, with transitions towards blue being worst, and of the light level, with lower performances at the higher light level. A Bonferoni corrected significance analysis showed that when compared individually, only the blue-to-white and white-to-blu transitions where significantly different, with a RT difference of at least 900 ms to the other colour transitions. Although the number of targets which were not seen was really low, the highest number of these occurred at transitions towards blue. Surprisingly, the amber-to-white transition resulted in a number of missed targets comparable to that of the white and blue transitions.

Based on our data, it seems unlikely that people can accurately predict how well they see under different types of coloured light. Nonetheless, subjective measures may still be important to take into consideration, as they might have influence on feelings of control, confidence and driving ability for some users when assessing road situations.

4. Conclusions

Road lighting installations with coloured light, and particularly the use of blue LED light can lead to situations where road users with normal vision can experience visual difficulties, potentially leading to dangerous situations.

Session OS6
Interior environment and lighting design (1)

Tuesday, October 24, 09:40–10:40

OP22

ON THE ENERGY EFFICIENCY OF "SMART" CONNECTED LIGHTS

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Abstract

1. Motivation, specific objective

Smart lighting is a broad term recently coined for connected lamps and luminaires, sometimes embedding sensors (e.g. motion, presence, and daylight), processors, and ancillary non-lighting features.

In the office, smart lighting products may improve energy efficiency (e.g. by automatic dimming based on daylight availability), visual comfort (e.g. by using colour correlated temperature tuning), monitoring and maintenance (e.g. by maintaining the flux constant over lifetime), and data delivery (e.g. Li-Fi).

The consumer market is also thriving and innovative smart lighting appliances are regularly put forward. Examples of products are the ambiance lamps, which have dimming and colour tuning capabilities, loudspeaker lamps, aroma diffusion lamps, presence detection lamps, smoke detection lamps, CCTV lamps, etc.

There is however a growing concern that some of these products may consume more energy than their traditional counterparts. Standby mode, in particular, is scrutinized. In connected products, a communication channel (e.g. Wi-Fi, Bluetooth, Zigbee, DALI, 6LoWPAN, infrared) has indeed to be maintained online even when no light is provided.

Assessing the energy consumption of smart lighting products is challenging because they often have several operating modes (e.g. lighting, ancillary feature, standby), non-trivial electronic circuitry (which may cause stabilization issues), non-reproducible setting points (e.g. when the interface mimics an analogic control such as a colour wheel), and because they are associated with innovative usage scenarios.

The aim of this research is to assess the energetic impact of the recent smart lighting trend in residential and office sectors; then to propose recommendations for policymakers and product designers.

2. Methods

Relevant products were identified, classified and sampled. Some photometric and electrical properties were measured. In the next stage, energy consumption indicators will be computed.

Forty products were selected from the office and residential markets. The office products were luminaires, drivers, sensors, controllers and gateways. They were equipped with the digital addressable lighting interface (DALI). The residential products were stand-alone smart lamps (ambiance lamps, loudspeaker lamps, CCTV lamps, etc.), sensors and gateways. They were controlled using either a smartphone or a remote control unit.

The measurement protocol consisted in measuring spectral power distribution, electrical power and luminous flux, under standard conditions, as close as possible to those defined in CIE S205. On a product by product basis, other measurements were made (e.g. properties of sensors, photobiological safety, goniophotometry, temporal light modulation).

In the upcoming stage, an existing building simulation engine will be adapted to compute relevant energy consumption indicators. The simulation will rely on data-based models of the smart lighting devices, scriptable usage scenarios, and on daylight contributions throughout the year, using a climate-based daylight modelling approach (CBDM).

3. Results

The data gathered have yet not all been processed; some products still have to be measured; and the building simulations still have to be realized. It is hoped that this work will be achieved by the time of the article submission. Some raw results so far obtained are as follows.

In dimmable products, the consumption was usually not proportional to the emitted flux. More surprisingly, for some products, the power maximum did not match the maximum light output. Dimming this device could therefore result in a higher consumption.

Stabilization of light output and power draw was an issue for many products, likely due to the complex smart lighting electronic circuitry.

Residential products were, in the general case, not meant to be interoperable. The situation was more contrasted for office products: although the DALI protocol is open, some vendors added proprietary layers, which could limit interoperability or features.

The settings of ambiance lamps were not always reproducible (e.g. the colour was set on a colour wheel without numerical value) or physically-based (e.g. vendor defined "mood settings"). A new measurement method had thus to be devised: Between ten and fifty colours and dimming settings were selected on the controller. For each colour, spectrum and power were measured. The spectrum was projected on the CIE XYZ colour coordinates space. A discrete mapping from colour coordinates to power was thus constructed. Smooth interpolation then reconstructed power for every colour coordinate. A gradient descent was ultimately performed in order to locate power minima and maxima.

The average standby power on the residential samples was approximately one third of a watt. One particular appliance consumed nearly two watts when lighting was OFF, and ten watts when it was ON. The appliance then consumes more energy on standby mode than on providing light if the lighting mode is ON less than four hours a day.

As a dedication to open science, data acquired during the project are made available to other researchers.

4. Conclusions

This paper presents an ongoing work on the assessment of the energy efficiency of smart lighting products, in the residential and tertiary sectors.

Preliminary results show that, for some products, more energy may be spent on standby mode than on actually providing light. This argues in favour of the new requirements of a maximum of half a watt standby mode, present in the latest US ENERGY STAR revision and in the upcoming EU lighting regulation (to be issued in 2018).

The emergence of smart lighting also impose to re-think some lamps and luminaire metrology methods. Ambiance lamps, for instance, cannot be characterized by a single measurement, as their performances depend on the particular settings of the lamp.

New usages have also to be taken into account. In the next stage of the project, energy consumption indicators will be computed using measurement-based models of the devices, scripted usage scenarios, and CMBD building simulations.

OP23

TRANSITORY BUILDINGS - LASTING EFFECT: AALTO'S EXHIBITION DESIGNS: PARIS WORLDS' FAIR, LAPUA FORESTRY PAVILION, AND NEW YORK WORLDS' FAIR

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Abstract

"The magic of light and architecture is nowhere more eloquently expressed than in the work of Alvar Aalto."

This paper will look at the architectural and luminous design of 3 modest buildings that Alvar Aalto designed relatively early in his career, 1936-1939. After a short existence, all were demolished, yet during their lives were seen by many people from many countries, and represent an important phase in Aalto's career, and in the evolution of his attitude towards employing daylight in his buildings. The first of these, the Finland Pavilion at the Paris World's Exposition, incorporated what might be called a "modernist" approach towards daylighting. The second pavilion, the Forestry Pavilion at a regional agricultural exhibition in Lapua, Finland in 1938, had an irregular distribution of skylights that both washed the walls and illuminated the floor below. The third, the Finland Pavilion at the New York World's Fair, also incorporated an irregular distribution of rectangular skylights. These skylights directed light towards an undulating wall.

Aalto's design for the daylighting of the major space in the Paris Pavilion incorporated a regular grid of 30 circular skylights. The lighting for these was carefully controlled by Aalto's design for a shading device shaped by the sun angles of Paris in June. Aalto designed a modest pavilion located in the Lapua in Western Finland. As this was located in a provincial town for a national agricultural exhibition, little was written about it at the time, and it has remained in relative obscurity since. This pavilion itself had an undulating form. The simple rectangular skylights illuminated the exhibits below. For the New York World's Fair pavilion Aalto developed an undulating design. The large, canted wall of wood dominated the space. Skylights were located to respond to the position of the wall, and included louvers to control the light. The three pavilions together provide an opportunity to develop a better understanding of the use to which Aalto put daylight in his buildings, and the way in which his design strategies evolved. In these works, Aalto revealed a growing technical mastery of innovative lighting strategies and a poetic interpretation of atmospheric phenomena. Their timing demonstrated Aalto's decisive move away from a strict Modernist approach, to an architecture that engages nature and what has been called a phenomenological approach to lighting and shaping space, that he used throughout the remainder of his career.

Such a significant phase in Aalto's architecture deserves to be better known and understood. In the design of buildings for exhibition, lighting plays a key role. Although It is perhaps not as exacting as that needed in a permanent museum setting, it is critical for both the functional display the artifacts, and for the creation of the overall experience of place. Aalto's lighting design in these international expositions is an integral part of the architecture and demonstrates his sophisticated evolution of methods and ideas.

UNDERSTANDING THE DISTRIBUTION OF THE LIGHT

Using documentation from the Aalto Archives, we created a digital model of each of pavilion. These were then evaluated using Diva4Rhino. The results demonstrate the both the divergence and the effectiveness of each lighting strategy. The use of digital models based on Aalto's drawings allows us to recreate these buildings and adds quantitative information to the qualitative evaluations that we can derive from photographs.

LUMINOUS SPACE IN SUBSEQUENT BUILDINGS

After 1939, Aalto designed Baker House at Massachusetts Institute of Technology. The form of the building took on the undulating line of the wall of New York at a urban building scale. Here he again

used a circular skylight, again in a grid pattern, in the design of the dining commons that stands in a separate pavilion to the south of the main building. Other buildings that follow this type of uniform lighting are the Rautatalo Building, and the Enzo-Gutzeit Building, both of which use a grid of circular skylights over central atrium-like spaces. In small library in the National Pensions Building also uses a grid of circular skylights.

The correspondence between the undulating wall and staggered skylights, which he used in the Lapua pavilion and developed in New York, became an integral part of Aalto's architecture and its complementary light and space. A similar composition of sloped and undulating wall and focused lighting is found in the Aalto Museum in Jyväskylä. The roof monitor that lifts the ceiling at Mount Angel library complements the dropped floor that leads down to the lower level may have been foreshadowed in the sloping site of Paris. The use of wood slats on the ceiling above the circulation desk at Mount Angel was used around the light court in Paris, while the segmented northern wall of the library might be seen as an adaption of the undulating wall of the Lapua and New York pavilions.

CONCLUSION

Though the pavilions were demolished, the lessons learned in their design endured. After these designs, Aalto manipulated light and space in concert that he had not demonstrated previously. He composed buildings by manipulating the shape of surfaces, the location and type of aperture, the use of plaster, wood and glass, movement and stasis, drama and repose, and light and dark. He developed a system or language of "light-giving devices" that he used in harmony with the manipulations of space and form. As he dropped the floor, to create reading wells in his libraries, he manipulated the ceiling to enhance the lighting. He orchestrated sequences of movement to bring one from the exterior, through foyers and passages to major interior rooms. These were finely crafted compressions and expansions of space reinforced with diminution and enhancement of the light. He used material to absorb or reflect light. In neatly summarizing these strategies Aalto remarks, "Rooftop lighting, clerestories, screened windows and lighting scoops are quite consciously made major design elements. They are used to crown or accent spaces, to denote movement from place to place in light, or to punctuate activities in controlled light. Light was always carefully considered in relation to the human functions it illuminates."

OP24

READABILITY AND VISUAL COMFORT FOR READING ON A DISPLAY WITH VARIOUS AMBIENT LIGHTING SETTINGS

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Abstract

Ambient light sensor has been popular in modern displays to make automatic brightness adjustments on the display based on current lighting conditions. Although the technology for ambient light detection has been available and widely used, a drawback has been that the sensor is normally located on only one side of the display, normally on the front face of the screen. This may result in measurement of ambient light in only a specific direction. It is unclear whether such a one-direction approach can provide a sensible measurement and make a satisfactory brightness adjustment for various types of ambient lighting. In other words, do user feel the same in terms of readability and visual comfort, when the ambient lighting is produced in different ways? To answer this question, the present study used four settings of ambient lighting in a room where the observer was asked to assess the readability and visual comfort for reading on a laptop display.

Methods

The experimental room was 3.5m (width) by 2.5m (depth) by 2.3m (height) in size, where a 15-inch Asus laptop was placed on a table in the middle of the room. The room had three grey walls and a brown wood veneer floor. The ambient lighting was generated by indirect lighting from the three walls, the background wall behind the laptop and the two side walls. Three liner LED light bars recessed in the ceiling were used to down light the background wall, and were called W1 in this study. Each light bar (36.9W, 1360lm) was 1m in length. Two sets of light bars, called W2 and W3, each consisting of two light bars, were installed on the floor to up light the left and the right walls, respectively. All lights used in this study had CCT = 3000K and were all provided by TONS Lightology Inc.

Four settings of ambient lighting were used in this study. Setting 1 used all W1, W2 and W3 to provide ambient lighting of all directions except the front face direction to avoid indirect glare. W1, W2 and W3 were all dimmable and this was done simultaneously by changing the currency at the same rate by 6 steps: 100%, 80%, 60%, 40%, 20% and 0%. Setting 2 used only W1 to provide ambient lighting from the back of the display. Setting 3 used both W2 and W3 to provide ambient lighting from both sides of the display. Setting 4 used only W3 to provide ambient lighting from right side of the display. Settings 2 to 4 all adopted the same dimming strategy as described for Setting 1. The sequence of the four ambient lighting settings and the dimming rate was randomised in the experiment for each observer. Throughout the experiment, the display brightness was kept constant.

Twelve observers, 6 females and 6 males, all Taiwanese university students, participated in the experiment. More observers will take part in this study and the results will be reported in more detail in the full paper. All observers had normal colour vision. During the experiment, each observer was seated individually in front of the laptop, of which the screen showed a document with black text on white background. The observer was asked to rate the screen in terms of “readability” and “dazzlingness”, followed by assessment of the entire room in terms of “brightness” and “comfort”.

Results

Experimental results indicate that the observer responses tended to show similar trends for Settings 1 and 2, which were different from those for Settings 3 and 4, while the responses for Settings 3 and 4 tended to be similar. For instant, for “readability” on the screen, Settings 1 and 2 show similar tendencies in observer response, i.e. the higher illuminance level of ambient lighting, the lower readability. This seems to make sense as bright ambient lighting tend to make content on the screen feel too dark to read. Nevertheless, Settings 3 and 4 show the opposite trend, i.e. the higher illuminance level of ambient lighting from either side of the display, the higher readability.

For “dazzlingness” on the screen, Settings 1 and 2 show similar tendencies, i.e. the screen felt most dazzling when the illuminance level of ambient lighting was close to, if not equal to, either 100% or 0%. Settings 3 and 4, on the other hand, both show a different trend, i.e. the higher illuminance level of ambient lighting from either side of the display, the less likely it was that the observer found it dazzling.

The observer response for “comfort” of the room was highly (and negatively) correlated with the response for “dazzlingness”, and thus the two groups of tendencies as described for “dazzlingness” also apply to “comfort” but in the opposite way.

The only scale that shows the same tendency for all the four settings of ambient lighting was “brightness”, indicating that the observer’s assessment of perceived brightness was not affected by where the ambient lighting came from.

The above experimental results reveal interesting findings regarding the influence of the direction of ambient lighting on readability and visual comfort. The most striking finding was that the observer responses for Settings 3 and 4 in terms of “readability” had a tendency opposite to that for Settings 1 and 2. The findings of this study can contribute to development of more advanced approach to ambient light detection.

Session OS7
Exterior lighting
Tuesday, October 24, 11:10–12:30

OP25

TESTING A MESOPIC ADAPTATION SIMULATION METHOD WITH SIMPLE LUMINANCE DISTRIBUTIONS

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Abstract

1. Objective

The mesopic photometry system recommended in CIE 191:2010 defines the mesopic luminous efficiency functions, the shape of which changes depending on the observers' adaptation luminance. Determining the adaptation luminance is a key issue for implementing the mesopic photometry system to lighting applications.

Previously, Uchida et al. (2016) proposed an adaptation luminance simulation method, which derives an adaptation luminance from a luminance distribution, to CIE JTC 1. Currently, adaptation field definitions are discussed in JTC 1 based on some contributions including the adaptation luminance simulation method. The method takes three factors other than the luminance distribution into account – eye movements (EM) of observers, the area of measurement (AOM) in the luminance distribution, and the surrounding luminance effect (SLE) caused by the veiling luminance. Even though the simulation process was designed based on a reasonable understanding for the interactions among those factors, it has not been verified empirically.

On the other hand, Terai et al. (2017) conducted a series of vision experiments to measure the veiling luminance at various peripheral points in mesopic ranges. Although the main subject of the experiments is characterization of the veiling luminance, the results also provide sets of a luminance distribution and an adaptation luminance. Such data sets are available to verify the simulation method.

Thus, the subject of this study is to verify the adaptation luminance simulation method by using the data sets provided by the vision experiments.

2. Method

The basic idea of this study is to compare the adaptation luminance simulated from the luminance distributions used in the vision experiments with the empirical adaptation luminance. The vision experiments provide totally 18 adaptation luminances (at nine task points × in two luminance distributions with different glare source intensity). In this study, the data for three task points of them were employed because those are more likely in AOM for real lit scenes than the others. Those positions were 10°, 20°, and 30° left from the fixation point. Thus, totally six adaptation luminances (at three task points × in two luminance distributions) were employed.

The simulation method intends to set AOM as the design area of the lighting. Since the vision experiments' luminance distribution does not mimic any specific lit scenes, it is necessary to assume a geometric condition to set AOM. In this study, the ground surface was divided into 2 m long × 5 m wide rectangles, the baseline of which is the line of sight vertically projected on the ground. The fixation point was assumed at a point on the baseline, the distance from the observer was 15 m or 55 m distance from observer. Observer's height was assumed 1.5 m. Then, a rectangle was set as the AOM for each task point.

Two SLEs were used for the simulations: one is based on the veiling luminance model by Uchida and Ohno (2016) and another is based on the model proposed by Terai et al. (2017) based on the vision experiments. In the vision experiment, observers were asked to look at a fixation point moving in a 2° × 5° elliptic field. Thus, the EM was assumed that a uniform distribution in the same size ellipse. Totally four simulations (two AOMs × two SLEs) for each empirical adaptation luminance were conducted.

3. Results

The relative trends of the simulated adaptation luminances are consistent each other and also with the empirical adaptation luminances. However, a significant difference on the adaptation luminance level is observed depending on the SLE. The simulations based on the Uchida-Ohno model gives about 60% lower adaptation luminances than the empirical adaptation luminance while those based on the Iwamoto et al. model derives about 10% lower adaptation luminances. Overall, the simulations with Iwamoto et al. model give closer results to the empirical adaptation luminances. The simulated adaptation luminance is relatively less sensitive to the AOM than to the veiling luminance model employed for the SLE. The difference caused by the AOM is less than 10% for both SLEs.

4. Conclusions

The comparison between the simulated and the empirical adaptation luminances gives some suggestions.

Firstly, the simulation method can estimate the adaptation luminance for simple luminance distributions provided that the SLE is modelled adequately. The significant difference between the two veiling luminance models is a big question because those models were developed based on experiments with similar conditions.

Secondly, the size of AOM is not critical for the adaptation luminance simulation when the local luminance in AOM can be considered uniform. This is because the veiling luminance changes gradually enough and the EM also averages the change of the veiling luminance in AOM.

Although this study shows that the simulation method can estimate the adaptation luminance sufficiently for simple luminance distributions, it is still questioned if it can provide sufficient estimations for the adaptation luminance for real lit scenes. Testing the simulation method with such real luminance distributions is a further issue.

OP26

FIELD SURVEYS OF REASSURANCE IN TWO EUROPEAN CITIES USING BOYCE'S DAY-DARK APPROACH

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Abstract

1. Motivation, specific objective

There are plans across the globe to increase the frequency of walking. This is to promote health through physical activity and to reduce the risk of motor vehicle collision with pedestrians. We know that people are more likely to choose to walk if they feel safer. Here we examine the contribution of road lighting to that decision.

Reassurance is the confidence to walk that a pedestrian gains from road lighting, a similar emotional reaction to perceived safety. Potential risks to pedestrians include tripping over uneven pavement surfaces, being the subject of negative behaviour by other people, and not being seen by motorists. Lighting is expected to affect all of these risks.

While it has been shown that the presence of road lighting enhances reassurance, it is not yet known how much light (e.g. what illuminance) is optimal. Many studies have examined this but do little more than conclude that more light is always better. In other words, the higher of the illuminances examined in any one study tends to receive the higher rating of perceived safety, regardless of the range of illuminances included.

What past studies did was to evaluate reassurance only after dark. While this may appear a sensible approach to evaluating the effectiveness of road lighting, it fails to account for underlying variations in the reassurance of different locations. An alternative approach was proposed by Boyce and colleagues in which reassurance-type ratings were recorded in daytime as well as after dark. Boyce then used the difference between these ratings as a measure for the effectiveness of changes in illuminance. This method revealed an optimum horizontal illuminance (10 lux), above which further increase in illuminance had negligible further reduction in the day-dark difference.

The Boyce et al survey was conducted in car parks in the USA, these having higher illuminances (up to 50 lux) than used in European subsidiary roads (2.0 to 15 lux). This article describes two field surveys carried out, using the Boyce et al method, in two major European cities. The objective was to validate the method by repetition and seek evidence for demonstrating an optimum light level for pedestrians.

These studies also measured a range of values (horizontal, hemi-spherical, cylindrical and semi-cylindrical illuminances) to evaluate the conclusion from Boyce et al these other metrics did not offer better characterisation than horizontal illuminance.

2. Methods

Evaluations of reassurance were captured using category rating. These were brief surveys that included critical questions (when translated into English): *How safe do you think this street is?* and *How risky do you think it would be to walk alone here at night?* Responses were given using either a 6-point or 11-point scale, ranging from very dangerous to very safe (Q1) and not at all risky to very risky (Q2).

City 1: Ten locations in a residential area were surveyed by 24 people (aged 18 to 38 years), day and dark, in a repeated measures design. The illuminances ranged from approx. 4 to 65 lux and lighting was provided by a mixture of high pressure sodium and LED sources. The survey was completed the 18th and 30th November 2016. Of the ten locations, eight were residential roads, one was a pedestrian underpass and one was the path through a public park.

City 2: Ten roads in a mixed residential and commercial area were surveyed by 40 people, day or dark, in an independent samples design. Their ages ranged from 20-35 years old and was an even gender split. The illuminances ranged from approx. 11 to 34 lux and all locations were lit using high pressure sodium lamps. The surveys were carried out between the end of September and the beginning of November.

Horizontal illuminance (and other measures) were captured using a measurement grid similar to that described in EN 13201-3:2015 with the arithmetic mean used to characterise average quantities.

3. Results

City 1: Plotting the after-dark ratings of reassurance against horizontal illuminance revealed a general trend for higher illuminance to be considered safer (r^2=0.21, n=9, underpass data ignored) but this is clearly not a dependable trend for all circumstances. Plotting the day-dark difference against horizontal illuminance revealed an exponential relationship (r^2=0.52 n=9). For day-dark differences of 0.5 or 1.0 units on the 6-point scale would require horizontal illuminances of 6.5 lux or 4.5 lux respectively. There was a high degree of linear correlation between the three illuminance measured (e.g. for horizontal and semi-cylindrical, r^2=0.83, n=9).

City 2: Plotting the after dark reassurance against mean horizontal illuminance of the sidewalk showed a general trend for higher illuminance to be considered safer (r^2=0.46, n=10). Plotting the day-dark difference against the horizontal illuminance revealed an exponential relationship (r^2=0.79, n=10). For day-dark differences of 0.5 and 1.0 units on the 11-point scale would require horizontal illuminances of 22 and 10 lux respectively. There was a high degree of linear correlation between the three values of illuminance (e.g. for horizontal and cylindrical, r^2=0.76, n=10).

4. Conclusions

1) There is a general trend that higher illuminances lead to a higher after-dark ratings of reassurance, although that is not a certain trend for any two locations.

2) The day-dark approach leads toward an asymptote illuminance. For a day-dark difference of 0.5 units on the respective response scales, these data suggest illuminances of 30 lux (Boyce et al), 6.5 lux (city 1) and 22 lux (city 2). Further work is ongoing to determine an explanation for these variations.

3) Data from both cities confirmed the Boyce et al finding of a high degree of correlation between horizontal and cylindrical illuminance.

OP27

NOTICEABILITY OF ILLUMINATED ROUTE SIGNS FOR TSUNAMI EVACUATION BY SOCIAL EXPERIMENT IN MINAMI-AWAJI CITY

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Abstract

1. Motivation, specific objective

The death toll from the tsunami associated with the Nankai Trough Earthquake is estimated to be 230,000 in the nighttime winter season, and it is predicted that the damage will expand more than the 190,000 people in the daytime. That is why the evacuation behaviour start is often delay if an earthquake occurs at night and why the evacuation speed tends to decline due to poor visibility of one's feet. So improvement of the evacuation environment at nighttime is very important.

In this study, illuminated route signs are installed experimentally and the guidance effect of illuminated route signs is verified through nighttime tsunami evacuation experiments.

2. Methods

We conducted three experiments to clarify the above-mentioned object.

At the first step of this study, we installed a prototype of illuminated route signs for tsunami evacuation in a coastal town area called Minami Awaji City during resident evacuation drills, where tsunami damages are predicted. We confirmed the situation of residents' evacuation drills and noticeability of illuminated route signs.

Evacuation drills were conducted early in the morning (November 1, AM 8: 00) and at night (November 22, PM 7: 00), and a questionnaire survey was conducted after training.

We conducted an evacuation behaviour survey using GPS (Wireless Global Positioning System Logger) in 33 people who participated in early morning and night training. And we analysed walking route, walking distance and walking time for each subject by GPS data from the start point to the end point to the primary school gate or west gate.

The target area was divided into two areas located in the south of the evacuation area. West area has no illuminated route signs, and East area has illuminated route signs.

In the next experiment, evacuation behaviour experiments of tourists were conducted in the same experimental environment as the residents. Six subjects who visited for the first time were regarded as tourists. Evacuation behaviour experiments were conducted assuming that a tsunami occurs at nighttime. The first experiment was conducted in the western area with no illuminated route signs and the second experiment was conducted in the eastern area with illuminated route signs. The behaviour of each subject was observed and recorded by three experimenters (video recording, behaviour observation, safety confirmation). After the experiment, the experimenter interviewed the subjects.

Finally, In order to solve the problem of the illuminated route signs clarified from the experiment result of Minami-Awaji City, we created four route signs and analysed noticeability through evacuation experiments.

3. Results

The results obtained from the first experiment are as follows.

More than 60% of the people were walking speeds of horizontal movement of 1 m / s or more. On the other hand, 20% of the people did not reach the walking speed of the elderly, 0.8 m / s.

In the night training, there was a subject with correlation between the mean road illuminance and the walking speed. However, as a whole, no correlation was found between the mean road illuminance and the walking speed.

According to a questionnaire survey after residents evacuation drills, 90% (37/41) of the subjects noticed a route sign along the road. Subjects belonged to one of the regions in which 41 people were equipped with route signs. Furthermore, 57% (21/37) of the subjects who noticed the pathway sign felt psychological sense of safety from the pathway signs through training. The attention degree of the route marker was good for the inhabitants because it was familiar with the target area.

We clarified the luminance distribution of the light environment in which the experiment was conducted. It is conceivable that the lights of urban security lights and vending machines etc. have an effect on evacuation guidance lighting awareness. Regardless of the presence or absence of light in the surroundings, it is necessary to make it more noticeable.

As a result of the second experiment, the subject(1／6) who noticed the illuminated route signs arrived at the evacuation place according to the illuminated route signs from the departure place to the evacuation site, so the induction effect was confirmed. However, since the other five subjects（5／6） did not notice the existence of a illuminated route signs. It is necessary to make them more noticeable for tourists .

The result of the third experiment was that more than 70% of subjects noticed it when the route sign had 800 lm flashlight. In addition, 90% of the subjects noticed the route signs and the flashlight was 1,600 lm.

4. Conclusions

In the night training, we clarified the relation between the mean road illuminance and the walking speed. Most subjects noticed signs, and more than half of the subjects had a sense of safety by noticing the signs.

However, the evacuation behaviour experiments of tourists clarified the issues of luck of noticeability installed prototype.

And we made clear the requirement of route signs for tourists tsunami evacuation.

OP28

EXTERIOR LIGHTING OF PUBLIC STAIRWAYS

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Abstract

1. Motivation, specific objective

The navigation of stairways is a hazardous exercise, which demands coordinated body movements supported by acute perceptual capabilities. It is essential that lighting is strategically designed to adequately illuminate stairways for safe ascent and descent. Presently, there is limited guidance for the lighting of stairways in International Standards. Research into the lighting requirements for public exterior stairways entailed surveying sites, developing computer models, and analysing human factors.

2. Methods

At specific sites, staircase lighting was measured to analyse average horizontal illuminance, point horizontal illuminance, illuminance horizontal uniformity, and point vertical illuminance. For the comparison of data, computer models were created based on photometric specifications including luminaire type, nominal wattage, dimensions, shape, envelope finish, and lamp operating parameters.

In the design of public lighting for staircases, it is of utmost importance to consider the human factors associated with ambulating a staircase. To safely descend stairs, a person must be able to successfully step and balance in the act of a controlled fall. Whilst moving, the body's balance is unsteady and dynamic as the centre of gravity shifts in relation to the base of support. It is the vigilance of human sensory systems to detect spatial orientation in relation to posture that allows for stability and balance. The innate ability to control sway by correcting posture is highly intuitive with a real-time sense of gravitational axis and spatial location. It is the combination and coordination of human vestibular (ears), visual (eyes), and somaesthetic (skin & muscles) systems that provide this critical information. To balance, sensory input from tissues and organs are analysed at the brain stem, together with stored information from the cerebellum and cerebral cortex. The cerebellum provides the ability to automatically perform tasks learnt through repetition. Meanwhile, the cerebral cortex recalls contextual information on how to strategically move and remain balanced.

3. Results

During the descent of staircases, there is the hazard of over or under stepping, which results in the loss of balance and often an uncontrolled fall. In the case that the leading foot slides over the edge of the lower tread, the person loses balance. In contrast, if the leading foot does not sufficiently step over the top landing or tread and instead intercepts the edge, the person will be thrown off balance. It is therefore crucial that pedestrians are able to accurately perceive the presence and length of the next tread platform. In addition to, the edge of the tread that must be safely cleared. In accordance, the visual capability known as contrast sensitivity is required to distinguish between shades of light and dark across the length of the staircase. When safely navigating stairs, a person identifies the contrast of the tread edge, and discerns the length of the following riser and tread. The contrast sensitivity of human eyes is influenced by the object appearance, visual adaption, and lighting. If the staircase colour, texture and pattern is consistent, the detection of the tread edges can be challenging. This issue is compounded if the user is in a state of visual adaptation from having walked from a bright to dark environment, or vice versa. Accordingly, it is of utmost importance that each tread is adequately illuminated. Moreover, the person is to be aware of fellow pedestrians ascending and descending the staircase. An adequately large stride provides stability for the body as it is balanced between the base of support. Moreover, maximising the frictional resistance between shoes and the ground enhances both stability and mobility. It is also evident that increased body weight provides greater stability. By

providing more points of contact with supporting surfaces, the human body has added stability. This is exemplified by the added support provided by a handrail when ambulating stairs.

4. Conclusions

If a light is positioned behind a person, a shadow will be cast upon the staircase and inhibit the view of the treads. Since the frequency and severity of injuries are greatest upon descent of staircases, it is most prudent to place a public streetlight at the base of the staircase that extends the full height of the staircase plus three metres to accommodate for the height of tall pedestrians. Nonetheless, the light is to be suitably diffused and angled to minimise glare and enhance uniformity. There are supplementary measures to promote the safe navigation of staircases which include: applying reflective friction tape at the edge of each tread, installing lights that extend the full horizontal distance of the staircase on both sides, publicising hazard signs that notify users of an upcoming staircase and advises the use of the handrail, creating a prominent appearance of staircase landings to attract awareness, and extending tread nosings that make the dimensionality of the stairs more consistent and safe.

Session OS8
Metrology for photometric and radiometric devices (2)

Tuesday, October 24, 11:10–12:30

OP29

FISHEYE CAMERA SYSTEM FOR DETERMINING SPATIAL CORRECTIONS IN LUMINOUS EFFICACY MEASUREMENTS WITH INTEGRATING SPHERES

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Abstract

1. Motivation, specific objective

Continuous development of solid state lighting products necessitates accurate ways of measuring their energy efficiency, which is described in terms of luminous efficacy (lm/W). The total luminous flux (lm) is often measured using an integrating sphere photometer, while the active power (W) consumption is measured using a power meter. Reaching low uncertainties in luminous flux measurements with integrating spheres, especially in the case of lamps with directional radiation patterns, requires a correction factor to account for the spatial non-uniformity of the integrating sphere. Depending on the sphere and the lamp under test, the magnitude of the spatial correction can be up to a few percent. Traditionally, obtaining the spatial correction factor has involved a time consuming measurement of the relative angular intensity distribution of the lamp with a goniophotometer. Test laboratories who do not have a goniophotometer available for the measurement may need to omit the correction. If the correction cannot be determined, the uncertainty of the measurement is increased.

2. Methods

A quick and convenient fisheye camera system is presented for resolving the relative angular intensity distributions and spatial corrections for lamps during luminous flux measurements with integrating spheres, without any need for a goniophotometer. The original idea of the method was presented by Y. Zong (NIST) at the CIE Session in Manchester 2015. After studying the challenges of the method, a functional and practical fisheye camera system was developed including automated measurement software. The system is compatible with typical integrating spheres and baffle configurations. Using the developed system, one can obtain the spatial correction for the lamp under test in a period of minutes.

The developed fisheye camera method determines the spatial non-uniformity correction factor from the intensity distribution of a fisheye camera image captured via a port of an integrating sphere. The resolved distribution is used together with the mapped spatial responsivity distribution function (SRDF) of the sphere to calculate the spatial correction factor. The SRDF is typically obtained using a commercial sphere scanner that is required also in the case of goniometrically measured intensity distribution of the lamp. Before measuring the lamp under test, a reference image is taken through a port of the sphere while the sphere surface is illuminated by a lamp with nearly omnidirectional radiation pattern. This reference image is used for processing actual measurement images to collectively diminish the impact of the non-idealities of the integrating sphere and the camera hardware.

After the image processing routine, the three-dimensional inner surface of the integrating sphere is mathematically reconstructed in order to take into account the camera perspective and lens distortion. By deducting the ambient light level inside the sphere from the reconstruction, the intensity values of the sphere surface directly illuminated by the lamp are resolved. The intensity values of the reconstructed sphere correspond to the relative angular intensity distribution of the lamp. For lamps with a symmetrical radiation pattern about their optical axis, the median values can be used to represent each step of deviation from the beam centre. This increases the robustness of the method to residuals of the image processing stage.

3. Results

The functionality of the new fisheye camera system was verified against a goniphotometer by determining spatial correction factors for thirteen LED lamps of different types using a 1.65-m

integrating sphere with coating reflectance of 98 %. The spatial correction factors for the lamps ranged from 1.0029 to 1.0211. The differences in correction factors obtained using the fisheye camera method and the goniophotometer ranged from −0.15 to 0.15 %, the average of the differences being 0.06 %. For the utilized sphere and the tested LED lamps, omitting the correction factor would lead to a maximum error of 2.1 % in the measured luminous flux and luminous efficacy.

Lamps with directional angular intensity distributions tend to have a more prominent contrast between the primary reflection and the diffuse ambient illumination level inside the sphere. This effectively leads to a better signal-to-noise ratio in the image, the noise being the ambient illumination inside the sphere. On the other hand, small deviations in determined angular intensity distributions tend to lead to larger errors in spatial correction factors for lamps with directional radiation patterns.

The limit for resolving the angular distributions of lamps from fisheye camera images is set by the ratio of the ambient illumination inside the sphere and the intensity values of the regions illuminated by the direct light from the lamp. For nearly omnidirectional lamps, the ambient illumination may constitute over 97 % of the signal from the area also directly illuminated by the lamp. Additionally, the non-uniform angular distribution of the lamp used for capturing the reference image of the sphere has a more severe impact on the results for lamps with wide beam angles.

4. Conclusions

A fisheye camera system for determining relative angular intensity distributions and spatial non-uniformity corrections in luminous flux and efficacy measurements with integrating spheres was developed and validated against a goniophotometer. In the developed system, the angular properties of the tested lamp are resolved from an image captured through a port of an integrating sphere using a fisheye lens camera controlled by automated measurement and analysis software.

The fisheye camera system was validated by measuring thirteen LED lamps with different angular intensity distributions. The maximum deviation in the obtained spatial correction factors between the fisheye camera and the goniophotometer was 0.15 %, the average difference being 0.06 %. The tentative expanded uncertainty ($k = 2$) of the spatial non-uniformity correction obtained using the fisheye camera method was evaluated to be 0.2 %. The fisheye camera method offers a quick and convenient way for test laboratories to determine the spatial correction factor during the luminous flux and efficacy measurements with integrating spheres.

OP30

DETERMINATION OF STRAY-LIGHT AND INTERREFLECTION AT A TABLE-TOP NEAR-FIELD GONIOPHOTOMETER

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Abstract

1. Motivation, specific objective

The traceable calibration of a goniophotometer requires knowledge about numerous contributions to measurement errors and uncertainties. Those are difficult to elaborate in particular regarding ray data calculated from luminance measurements in a near-field goniophotometer which employs an Imaging Luminance Measurement Device (ILMD).

Near-field goniophotometry also enables an evaluation of the far-field characteristic, e.g. the luminous intensity distribution, with an economic setup which requires less space than a conventional goniophotometer and can be installed in a smaller room. But thereby several surfaces, e.g. mechanical components and detectors, are located quite close to the object to be measured (DUT). This increases the amount of stray-light interfering the measurement by reflection or scattering into the ILMD objective, creating a parasitic contribution to the measurement. The ray-data are therefore not only representing the original emission characteristic but also the interaction with reflections from the measurement environment.

In several near-field goniophotometers the ray data obtained using an ILMD is scaled to the luminous flux evaluated from the illuminance distribution measured by a photometer, bypassing the necessity for an absolute calibration factor of the camera. Beside deviations of their V(λ)-function mismatch this scaling fidelity suffers from the different angular sensitivity, aperture size and position of the two detectors. In particular their sensitivity regarding stray light components differs typically by several orders of magnitude.

We therefore target the demonstration of a route to experimentally determine the impact of stray-light (to the photometer) and interreflection between the environment and the DUT.

2. Methods

Measurement results of LED-based transfer standards performed in a near-field goniophotometer will be compared with the luminous flux and luminous intensity distribution measured by a traceable calibrated far-field goniophotometer using the same thermostatic controlled lamp holder. These transfer standards are based on either a single colour LED or a converted-white CoB-LED.

In addition, the stray-light characteristic is evaluated by comparing the measurement deviation of transfer standards with different emission directionality (luminous intensity distribution), e.g. by means of a wide or small beam.

Regarding a stray-light corrected scaling of ray-data with respect to the total luminous flux the sensitivity to stray-light from the environment can be eliminated by adapting the cosine characteristic of the photometer head. Therefore the view-field of the photometer is adapted to the view field of the ILMD by using a stray-light tube with different apertures which limits the view-field of the photometer. An iris diaphragm in this aperture tube can be used for gradually adjusting the view-field to the emitting area of the object.

The amount of stray-light from the environment including the room (wall, ceiling, and floor) evaluated from test measurements with different view-fields and simulation will be presented. In addition, an insertion of parasitic elements with certain reflectivity is demonstrating the impact of reflectivity and position (e.g. distance) of distinct surfaces to stray-light and its parasitic contribution to the ray-data with respect to luminous intensity distribution of the lamp.

3. Results

A commercial table-top near field goniophotometer is used to carry out the measurements discussed above. In this setup the ray data are normalized to the luminous flux obtained by a conventional photometer which view-field differs from those of the camera.

External light and constant light sources can be treated as an offset obtained from a dark measurement of the same track; But the stray-light and hence the impact of the surrounding reflectivity strongly depend on the luminous intensity characteristic of the DUT. Due to this stray-light the total luminoux flux also depends on the solid angle (e.g. in directions with narrow luminous intensity) of the measurement which might be reduced with respect to measurement time, too.

By using an aperture tube in front of the photometer, its sensitivity to stray light is subsequently reduced. By removing or covering reflective parts of the measurement setup and environment which reflect or emit light (e.g. by reflectivity or phosphorescence) back to the DUT the interreflection of stray-light is reduced, too, which can also be demonstrated by evaluating the ray-data.

4. Conclusions

The discussed measurements demonstrate the impact of stray-light and interreflection, which in particular increases the luminous intensity distribution and luminous emittance assigned to the DUT.

As stray-light cannot be neglected in a near-field goniophotometer, its calibration regarding luminous flux depends also on the emission directionality of the reference lamp. Therefore, when characterizing lamps with an emission distribution or self-absorption (housing) different to the reference, a stray-light analysis is necessary and needs to be corrected or included in the related uncertainty budget.

OP31

METROLOGICAL CHARACTERIZATION OF ILMD FOR SMART LIGHTING APPLICATIONS

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Abstract

This paper presents the method used to characterize instruments based on ILMD detector for applications in road and tunnel lighting applications.

In the first application the device measures the road surface luminance for controlling smart adaptive road lighting systems. The range of luminancies the instrument shall measured is between 0,1 cd m^{-2} and 5 cd m^{-2} and the measurement distance is about 80 m or more (see EN 13201-4). In the second application the instrument measures the atmospheric luminance, the equivalent veiling luminance and calculates the veling luminance for controlling the lighting level in the entrance zone of the tunnel. The range of luminancies the instrument shall measured is between 100 cd m^{-2} and 20 kcd m^{-2} or more at a distance that can be as high as 250 m. In both cases the instruments should have low cost, a great stability and repeatability, and a low sensitivity to climatic conditions (for example temperature differences between winter and summer). Last but not least their calibration procedure shall be simple and possible in conditions that are completely different from the conditions the instrument will find in applications and the measurement uncertainty as low as possible because this uncertainty influence the controlled light level (EN 13201-4).

The research aim, outlined in this paper, consists in the instrument metrological characterisation and in its behaviour verification, simulating typical operative conditions, with the final objective to evaluate the measurement uncertainty. The instrument calibration, executed with the traditional procedure for luminance meters, is a necessary but not sufficient condition to adequately characterize the instrument for on-site measurement applications. Usually luminance meters are calibrated using an illuminant A reference diffuse source (an integrating sphere port or a lambertian diffuser) framed at a fixed distance of some meters. It is obvious that in road applications illuminant A is not a source representative of actual sources and the device spectral sensitivity plays a relevant role. As well the geometrical condition of measurement application are completely different from the geometrical laboratory set-up: in road lighting the ILMD frames the road from an observation point above and far from the measuring surface, while during laboratory calibration the distances are reduced and usually the camera is on axis. For these reasons the European Standard EN13201-4 proposed an on-site calibration (set measurement), but to evaluate the actual measurement uncertainty of the device, the procedure suggested in the GUM shall be followed. The measurement model for the measurement uncertainty evaluation must include the characterization parameters describe in the ISO-CIE standard 19476. Therefore relevant parameters like: the instrument linearity, instrument noise the spectral influence of the incident radiation, the directional responsivity, the influence of luminous sources outside the given or measured field (ghost images) shall be considered and evalauted

The procedure described in the paper is proposed for the two aforesaid specific applications considering the typical technical characteristics of ILMD devices on the market. The characterisation was performed considering requirements highlighted in the European standard EN 13201 series (i.e. road lighting class) and in the Italian tunnel lighting standard (UNI 11095) for luminance in the entrance and transaction zones of tunnel.

Considering these specific applications the suggested procedure envisages the evaluation of:

- linearity and working range;
- noise and pixel sensitivity;
- influence of the incident radiation spectrum;
- influence of the luminous sources, the ILMD does not frame;
- influence of the framed luminous sources that are not in the measured directions;

The measurement uncertainty is given as a function of the calibration uncertainty and conditions too. This improves the feasibility of the proposed method. The measurement uncertainty has been evaluated considering all the components attributable to the device and not these due to the measurand (i.e. variability of emitted flux of road lighting sources) or to the measuring conditions (e.g. influence of the environmental and /or geometric parameters of lighting set-up) as required by the European Standard and suggested by CIE 194.

OP32

NEW OPTICAL APERTURE AREA DETERMINATION METHOD FOR LED PHOTOMETRY

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Abstract

1. Motivation, specific objective

The measurement uncertainty of illuminance and, consequently, luminous flux and luminous efficacy of LED lamps can be reduced with a recently introduced method based on the predictable quantum efficient detector (PQED). One of the most critical factors affecting the measurement uncertainty with the PQED method is the determination of the aperture area.

In an optical method for direct determination of the aperture area, a superposition of equally spaced Gaussian laser beams is used to form a uniform irradiance distribution over the aperture. Due to small acceptance angle of the PQED, differences between the diffraction effects of an overfilling plane wave and of a combination of Gaussian laser beams at the circular aperture need to be evaluated in the determination of the aperture area.

2. Methods

We present an upgrade to the optical method for direct determination of aperture area where the superposition of equally spaced Gaussian laser beams is used to form a uniform irradiance distribution. In practice, this is accomplished by scanning the aperture in front of an intensity-stabilized laser beam. In the upgraded method, the aperture is attached to the PQED and the whole package is transversely scanned relative to the laser beam. This method has the benefit of having identical geometry in the laser scanning of the aperture area and in the actual photometric measurement. Furthermore, the aperture and detector assembly do not have to be dismantled for the aperture calibration.

The PQED trap structure has an effective transverse size of 10 mm × 10 mm, in front of which the aperture is placed. We have applied the Rayleigh–Sommerfeld (RS) diffraction integral to this geometry. The RS diffraction integral enables relatively fast numerical evaluation, as the diffraction integral can computed using Fast Fourier transform (FFT). Calculations were further streamlined by utilizing the angular spectrum method, where the analytical solution to the transfer function of the RS diffraction integral is used in combination with the numerical FFT. The reliability of numerical diffraction calculations was assessed by applying the calculations to some special cases for which the analytical solution is known.

The studied cases were a plane wave overfilling the aperture and the superposition of equally spaced Gaussian laser beams. Even though the laser beams effectively form a uniform irradiance distribution, the sum of diffraction patterns may deviate from the diffraction pattern of the plane wave, as the laser beams are not entering the aperture simultaneously. Calculations were performed for various aperture diameters and aperture-to-detector distances of 20 mm and 33 mm. In addition, the wavelength dependence of the diffraction loss was calculated for an overfilling plane wave.

3. Results

The remarkable finding of the calculations was that with both cases – the plane wave and the combination of laser beams – virtually all intensity seems to fall on the detector. Moreover, despite of having considerably different diffraction patterns at the central parts of the aperture, remaining intensities in the shadow area of the detector are almost identical for both cases. For the aperture-to-detector distance of 20 mm, the diffraction losses are less than 0.001% for aperture diameters up to 6 mm. For the distance of 33 mm, apertures in the range from 3 mm to 6 mm have higher diffraction losses of up to 0.01%. However, still the difference between the diffraction losses of the combined laser beams and plane wave diffraction is less than 0.0001%.

For the aperture-to-detector distance of 20 mm, the wavelength dependence of the plane wave diffraction is insignificant for most of the visible wavelength range. At the distance of 33 mm, the diffraction losses increase rapidly for wavelengths longer than 600 nm; at wavelengths around 800 nm the diffraction losses are around 0.01%. In such cases, the obtained results can be used to correct the small diffraction losses.

4. Conclusions

The upgraded method for aperture area determination is very beneficial in cases where the PQED is used with the aperture, as in photometric measurements. The method does not require removing the aperture from the PQED. Such dismantling and separate measurement would produce a significant risk of either dust contamination of the PQED or damaging of the sharp aperture edge.

Using the original laser scanning method in 1997, a standard uncertainty of 0.013% has been demonstrated for the area determination of an aperture 3 mm in diameter. This uncertainty was dominated by the uncertainty of the length scale in the linear translator movement. Since then improved linear translator resolutions and smaller uncertainties for length scales have become available. With improved length scale, a standard uncertainty below 0.01% is anticipated for the area determination of a 3 mm aperture using the upgraded laser scan method.

For the illuminance measurements of white LED lamps, a standard uncertainty of 0.13 % has been demonstrated. Here the area of the aperture was one of the largest uncertainty components. Using the upgraded method, the aperture area would be scanned in identical geometry as compared with the illuminance measurement arrangement. The numerical calculations indicate that if the distance between the detector and the aperture is around 20 mm, the diffraction losses are insignificant in both cases, and for longer distances they can be corrected. Therefore, one can safely assume that a standard uncertainty of around 0.1% could be achieved for illuminance measurements using the PQED.

Numerical calculations were performed for the PQED and aperture geometry. However, the method is only limited by the conditions for the accuracy of the RS approximation. Thus, the method can be applied to a large variety of commonly used detector-aperture arrangements.

Session OS9
Interior environment and lighting design (2)

Tuesday, October 24, 11:10–12:30

OP33

LIGHT, EMOTION, AND INTERACTION

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Abstract

With the rapid development in LEDs and lighting control technology, this study sees the potential to shift the focus of modern workspace lighting design from providing visual needs with some accent on decorative lighting towards ambiences that are fully tuneable to people's emotional needs. In this context, human emotion (or affect state) could become a primary component of the lighting design process as well as the assessment of quality. However, the current literature in the area often shows inconsistent results with the dominant usage of the Positive and Negative Affect Schedule (PANAS) model, which describes emotional state by positive affect and negative affect. In contrast, this study set the key parameters of emotion as 'pleasantness' and 'activation', derived from the circumplex model of affect and aims to explore the two parameters by various lighting designs. The study then considers at the impacts of such designs on various psychological responses to investigate relationships between lighting design and human emotion.

A detailed research programme, consisting of two separate phases, was carried out. In the first phase of the field study, five experienced lighting designers were invited to devise two sets of lighting design concepts, referred to as 'lively' (pleasing and with high arousal) and 'relaxing' (pleasing and with low arousal). The main objective of this phase was to first identify potential lighting design elements that are associated with positive emotion and therefore to replicate the essence of such design elements in a controlled experiment, which was the second phase of this research. In the second phase, a total of fifteen different light settings were set up, consisting of ten designers' inspired settings (5 'lively', and 5 'relaxing') and another five settings, which were developed based on the literature to verify and compare the effects of lighting design on emotional changes. Overall, forty participants were invited to assess the settings by subjective rating of their visual perceptions of the space and their emotional states. Each setting was subjected to a full photometric and colorimetric survey.

The results from the controlled experiment indicate a number of useful findings. First, modifying Correlated Colour Temperature (CCT) or illuminances alone did not have an impact on pleasantness level of human affect states but only influenced activation scale, which explains why much of the literature with PANAS model has shown inconsistent results as the both positive affect (PA) and negative affect (NA) are associated with pleasantness level. Second, a significant effect of the lighting designs on an increase in pleasantness was found. Five out of ten designers' settings have resulted in the participants' judging the setting to be more pleasant. However, the characteristics of such design elements were neither expressed nor categorised by commonly used photometric and colorimetric values. In the 'lively' settings, it was found that design approaches involves saturated blue and cyan colours to make a directional light pattern in the field of view was particularly effective in increasing both pleasantness and activation level of the human affect state compare to the other settings. A factor analysis of the visual perceptions of a space showed two primary component factors in describing the visual perception. Factor 1 includes the subject scales of Dim/Bright, Confined/Spacious, Nonuniform/Uniform and Warm/Chilly whereas Factor 2 consisted of Uninteresting/Interesting and Diffused/Dynamic scales. A strong correlation between the Factor 1 and perceived activation level was found as well as a less strong correlation between the Factor 2 and the perceived pleasantness level.

In conclusion, the study successfully explores the possibilities of an emotion-based lighting design approach and explains their impacts by the controlled experiment. The result also provides an in-detail understanding of human affect by lighting stimuli. The findings work as a fundamental step to promote human psychological well-being in workspaces by fulfilling various human needs and demonstrate the potential of smart lighting technologies to deliver these environments.

OP34

AN EXPERIMENTAL PROTOCOL TO CHARACTERIZE DISCOMFORT GLARE USING PHYSIOLOGICAL MEASUREMENTS

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Abstract

1. Motivation, specific objective

Discomfort glare remains an important topic in lighting design: new problematics are tackled in the literature and have mostly emerged with the development of LEDs (non-uniformity of luminaires, spectral effects...). Most studies about discomfort glare rely on psychophysical experiments, in which observers analyse their own perception: ratings on semantic or numeric scales, source luminance adjustments… But only few have tried to use physiological measurements to collect objective data. Investigations with physiological measurement tools can be divided into two categories: studying the relation between discomfort and physiological data, or using directly such data to give conclusions on the discomfort provided by a visual scene. Our study belongs to the first category. Indeed, a capacity of objectively characterizing discomfort glare would have many applications in research. Besides, contrary to disability glare, the underlying phenomenon behind discomfort glare is not well-known. Development of such tools could benefit the understanding of its perception. But one criticism could be raised: would the range of stimuli required to observe a physiological response be representative of standard lighting conditions? The aim of this study is to design experimental physiological procedure and set-up which would conciliate controlled laboratory parameters and real lighting situations. In such conditions, the physiological measurements could give information about practical lighting applications. A protocol was then elaborated to investigate the relevance of physiological measurements to characterize discomfort glare in such conditions.

2. Methods

The present study focuses on two types of physiological measurements: infrared pupillometry (collected via an eye-tracking device) and electrography (for example, electroencephalography). A set of physiological measurement tools have been defined to measure such data.

In order to anchor the experimental set-up into near-real conditions, the set-up is based on three points: a photopic illumination, a glare source located outside the center of the visual field (since none observer stares at luminaries in real life), and room dimensions close to those of an office.

3. Results

Set-up

A real-size white room has been built (octagonal shape with eight walls of 1.1m width surrounding the observer, 5m², 2.6m height). The octagonal shape of the room has been chosen to provide a uniform background illumination. In the centre of the room, the observer can sit on a chair and look at a target located on the wall in front of him. Two LED projectors provide a photopic background luminance while the luminous flux of two other LED projectors is sent into a box to produce a circular diffuse glare source off-centered above the observer's line of sight on the front wall. These four projectors are 7-channel spectrally tuneable, enabling a great diversity of spectral power distributions (SPDs). Intensity and SPD of each the glare source and the background of the room can therefore be controlled.

Protocol

An experimental protocol has been designed to study if and how the physiological data are influenced by glare. The different stimuli of this experiment were designed to provide non-glaring and glaring situations.

In this protocol, the SPDs of the projectors providing the background illumination are classic white LED SPDs. The luminance of the walls is set to 20 cd/m². Two glare stimuli are studied: these glare

stimuli are metameric (according to CIE 10° Standard Observer 2006), which means they provide the same chromaticity with different SPDs. Each SPD differently excites intrinsically photosensitive retinal ganglion cells (ipRGCs). Indeed, it seems relevant to compare two SPDs which produce different levels of melanopsin excitation (photopigment of the ipRGC) because the ipRGCs drive the pupillary steady-state response and activate differentially cerebral regions. A relaxing sequence (peaceful sound) and a stressing sequence (annoying sound) is also added to investigate the range of influence of the lighting stimuli on EEG data in comparison with other environmental stimuli. In the same purpose, a totally dark ambiance and fully lit ambiance is added to measure the range of the pupil diameter. No psychophysical procedures is used during this experiment: the observers do not think about their perception of discomfort, preventing any influence on the objective measures. However, it is asked to the observers if they perceived glare or not.

An experiment based on this protocol is planned in the future, to conclude on the relevance of physiological tools to characterize discomfort glare in classical lighting conditions.

4. Conclusions

Physiological measurements could help to understand and analyse the influence of light source on human being. In order to investigate the applicability of such measurements for discomfort glare characterization, an experimental set-up and a protocol with physiological measurement tools have been designed. Attention was paid on balancing controlled lighting parameters and near-real lighting conditions, to investigate the relevance of those tools for interior lighting experimental procedures.

OP35

COMPARISON OF LUMINANCE BASED METRICS IN CHANGING LIGHTING CONDITIONS

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Abstract

1. Introduction

User assessment studies on daylight-induced visual discomfort for application mainly in office buildings have been conducted more extensively in recent years. These studies are proposing metrics to describe discomfort caused by the luminance distribution in the field of view. However, in several cases only minimum change has been considered in the luminous environment at the experimental set up, hence limiting the applicability of the metrics to a broader range of luminance destitution. The question is if the proposed metrics will perform in lighting conditions that are significantly different than the initial lighting conditions where they are developed.

Among the developed metrics for predicting daylight-induced discomfort glare risk, Daylight Glare Index (DGI) has an early attempt to address this phenomenon which was developed under artificial light far from real daylight conditions. Daylight Glare Probability (DGP), was the first metric developed under real daylight conditions where user assessment data were acquired in office like test rooms. In recent years several new metrics have been developed, namely, modified daylight glare index (DGI_m), average luminance in the 40°band (L_{av40}), standard deviation of window luminance (L_{winstd}), Unified Glare Probability (UGP). These metrics have been developed either by experimental user assessments in test rooms or in case studies.

2. Objectives and Method

In this study we do a (cross-)evaluation of the mentioned metrics using statistical analysis methods where we compare them with the user's glare ratings. Besides the newly proposed metrics, photometric quantities such as average luminance in the field of view (FOV) L_{av}, the position index weighted average luminance L_{avpos} and the vertical illuminance at eye level E_v will be compared to the subjective data. These values are all derived from calibrated high dynamic (HDR) fisheye images captured in three different experiments conducted between 2003 and 2013 at two different geographical locations. Although the head and camera position are assumed fixed and the room geometry is not changing, the variations of shadings and window sizes created different lighting condition with a large variation of luminance distribution. This variation was created by including varying window sizes (25%, 50% and 90% glazing fraction) in combination with five shading systems (white venetian blinds, venetian blinds with mirror finished top side of the slats, two types of textile fabric roller blinds and a transparent foil system). The acquired data set contains 656 independent data points from 232 different subjects. Part of this data (348 data points) has been used to develop the Daylight Glare Probability DGP. Therefore, in order to compare all glare metrics with non-development-data, the data is split up into two parts. The statistical analysis contains Spearman correlations, logistic regressions and Hosmer-Lemeshow tests (goodness of fit of the logistic regressions) is done on all three datasets: the complete dataset and the two data-parts. The Spearman correlation is applied to the metric-value and the user's glare rating (dependent variable) on a Likert 4-point scale. This scale is assumingly not linear and therefore does not allow using Pearson correlation. For the logistic regression the users' glare ratings are transferred into dichotomous data (binary: disturbed – not disturbed) before being applied to the metrics

3. Results and Conclusions

The Spearman correlations show that all investigated metrics have a significance value smaller than 0.0005, which means they all pass this first statistical test. Moreover, the correlation values between the metrics differ and give a first indication of the performance of the metrics when applied to conditions that were not part of the metric's development or the so-called non-development data. More specifically, the non-development data correlations show that, the L_{winstd} has the lowest correlation (ρ=0.340), thus the weakest performance for all conditions. L_{av}, L_{avpos} and E_v indicate high correlation values (ρ=0.493-0.505). DGP shows the highest correlation (ρ=0.549), where UGP (ρ=0.434), DGI_m (ρ=0.454) DGI (ρ=0.433) and L_{av40} (ρ=0.467) are in a mid-range.

The Hosmer-Lemeshow tests on the three data-sets are aligned with the previous findings in most cases - only here, some metrics failed to pass the test. These results show that while DGP, DGI_m and L_{avpos} are clearly passing all the tests on all data-sets, Ev, L_{av40} and L_{av} have a significance level only between 0.05 and 0.10 for one of the data-sets. DGI failed the test on one data-set, UDP and L_{winstd} failed for two of them.

Not all metrics passed all the applied statistical tests for all three data subgroups. The Spearman correlation with the user's glare ratings shows the performance differences between the metrics and is an indication of their sensitivity to the experimental conditions or different luminous environments. This sensitivity could even lead to non-significant results for some of the metrics. Finally, DGP and L_{avpos} showed the most robust results in this study.

In future steps a more comprehensive (cross-)evaluation study of glare-metrics can be envisioned by adding data from other locations, research groups and luminous conditions. Such (cross-)evaluation study can help making a selection of metrics with reliable and robust results that can be applicable for broader lighting conditions.

OP36

A TYPOLOGY FOR LIGHT QUALITY IN SPATIAL CONTEXTS

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Abstract

1. Motivation, specific objective

The study is conducted within the research project Swedish Research Project on Perceptual Metrics for Lighting Design that aims to develop definitions of quality of light based on the visual and emotional aspects of light experience. The project is implemented in cooperation between Lund University in Sweden, Research Institutes of Sweden and fifteen companies within the lighting and the real estate business. The purpose of the study is to develop a typology of lighting quality in spatial context based on our knowledge of visual perception and practitioner's principles of qualitative lighting design.

Lighting recommendations have been developed to support the lighting design in public and commercial environments. They are formulated primarily to ensure basic needs for visual comfort, but as a tool to create good light environments, they are not sufficient. The key to understand vision is contrast as the eye's receptors react to contrast between light and shade and different colours rather than light intensity. Differences in contrast is what makes a room possible to perceive. Vertical surfaces are central to the visual perception of space and the light experience is also affected by the surface properties. Since the recommendations only specify illuminance levels in the horizontal plane, the measurements cannot be sufficient to describe the overall experience of a light environment. The recommendations have created practices for lighting design that rewards even illumination and high light levels, which may affect both wellbeing and energy use negatively. There is a need to increase awareness of how light creates the experience of the room. The typology for light quality that is developed in this study could be a useful tool in the communication between designers, architects, clients and users. The aim of the typology is to create a structured collection of examples that can illustrate how different combinations of light and colour affect the experience of a light environment.

2. Methods

The basis for the typology has been created by several different methods. Interviews with experienced lighting designers and literature studies of both theoretical works on lighting design and visual perception have created an important basis for the work. The research project is based on a collaboration between researchers from various scientific disciplines and practitioners with different types of experience of lighting design. This cooperation takes place both through meetings and workshops where methods and concepts are tested to further develop definitions of light quality for both light sources and light environments.

The typology is developed through a scale model study, based on the materials developed within the research project. The material has provided a basis for a number of basic definitions for quality of light that can be arranged in scales. The definitions examined in the study are e.g. *Contrast* from diffuse to distinct lighting, *Light level* from low to high and *Colour contrast* from low to high regarding interior surface colours. Combinations of definitions provide a basis for the typology which are then processed by comparisons with principles of lighting design. The practical implementation involves the construction of a number of scale models with systematically varied surface colours. The lighting is done using fibre optics and LED strips so that various steps in the range described above can be visualized and photographed.

3. Results

The study results in a systematic visualization of different combinations of light and colour that will have at least two potential uses. It can function as a communication tool for different actors responsible for lighting design and planning. They can facilitate communication by illustrating how the different principles of light and colour affect both the contrast ratio and the experience of the light environment. Practitioners involved in the project has proved that there is a demand for such. The

typology will also serve as a basis for further studies in the project, which aims to measure the visual experience of different light environments, using subjects and by methods drawn from other research disciplines as sensory science and environmental psychology.

4. Conclusions

The aim is that the results of both the sub study and the entire project will culminate in definitions and scales that describe light quality based on both visual and emotional values that can be used as a tool both in research and practice. It is also hoped that the result will ultimately be able to contribute to raising awareness of light and light experience.

Session OS10
Road Lighting (2)
Wednesday, October 25, 10:30–12:10

OP37

A NEW DIMMING CONTROL SCHEME OF LED STREETLIGHTING LUMINAIRES BASED ON MULTI-DOMAIN SIMULATION MODELS OF LEDS IN ORDER TO ACHIEVE CONSTANT LUMINOUS FLUX AT DIFFERENT AMBIENT TEMPERATURES

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Abstract

Temperature dependence of LED operation is often not fully considered during the design of solid state lighting products. If temperature dependence is not carefully considered, solid-state lighting products are typically overdesigned to be too robust enough to fulfil the requirements under any possible environmental conditions. Temperature dependent nature of LEDs though, could even be a new benefit if properly considered. Overdesign means designing for the worst case that is the highest possible environmental temperature when LED efficiency/efficacy is low. With a control scheme resulting in constant emitted total luminous flux significant electrical power saving can be achieved since at lower temperatures, due to increasing efficiency/efficacy less electrical power, thus, lower forward current levels are sufficient. We present the new, so called iso-flux control scheme and its implementation in an actual smart luminaire. The actual control scheme was designed with a multi-domain LED model and the results were validated by simulation.

1. Motivation, specific objective

Temperature dependence of LEDs' operation has always been seen as harmful, since with increasing junction temperatures energy conversion efficiency as well as efficacy of LEDs, thus, that of LED based luminaries decreases. This means, that in order to fulfil lighting requirements e.g. in streetlighting, the worst case, i.e. the highest allowed junction temperature needs to be considered. Since the usual driving mode of LEDs is applying constant forward current, this design approach at junction temperatures lower than the allowed maximum results in higher LED efficiency/efficacy, thus results in more "hot lumens" then required by the application. With our work we targeted energy saving by applying a new LED driving scheme in which instead of applying a constant forward current we concentrate on maintaining the luminous flux at constant level with a temperature dependent regulation of the applied forward current. We call this new control scheme *iso-flux control*.

2. Methods

To find the proper parameters of the iso-flux control scheme we built a multi-domain simulation model of the LED luminaire + LED packages + LED chips such that its multi-domain simulation could be performed by a Spice like electro-thermal circuit simulator. (The luminaire contained 48 LEDs.) With such a simulation we established the relationship between the applied forward current of the LEDs and the ambient temperature that assured to maintain the prescribed total emitted luminous flux of the luminaire (13500 lm in our particular example). By simulations the different luminous flux – forward current relationship of the luminaire obtained under iso-thermal conditions between T_A = -30 °C … +30 °C ambient temperatures from which the required iso-flux characteristic was identified. With the same simulations the electrical power taken by the luminaire was also calculated this way the electrical power consumption with the iso-flux control of the luminaire was also identified.

3. Results

With the above outlined simulations we established the $I_F(T_A)|_{\Phi v=const}$ relationship and implemented the corresponding, temperature compensated current driving control scheme in the smart streetlighting luminare that we develop. The emitted total luminous flux of the luminaire obtained with the above outlined multi-domain luminaire model and obtained during our first field measurements with a "breadboard" physical sample of the smart luminaire were compared. We found satisfactory agreement between the simulation results and the preliminary measurement data. More precise

measurements of the luminaire under laboratory conditions by using an appropriate climate chamber are in progress now.

4. Conclusions

Streetlighting luminaires are designed to fulfil requirements of lighting standards under any possible environmental conditions during the whole operation lifetime, making the designs too robust. In this paper we suggested an approach for keeping the light output values at the desired level despite temperature changes and elapsed product life time: a smart adaptive system could realize the so called iso-flux operation through a controlled current source which drives the LEDs in the luminaire with an ambient temperature dependent forward current which assures constant emitted total luminous flux of the luminaire. Data sets needed for the implementation of such a light output control can be generated from the results of multi-domain luminaire level simulations. Preliminary field measurements with this model based iso-flux control show good agreement with our simulation results. By applying the simulation model to historical records of temperature data of the Hungarian city of Szombathely we estimated the energy saving potential of this new control scheme Based on our preliminary calculations an average 5% … 10% additional energy saving can be expected when this new LED control scheme is applied.

OP38

DETERMINATION OF ROAD LIGHTING AUTOMATION STRATEGIES CONSIDERING DRIVING SAFETY BASED ON VISIBILITY CONCEPT

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Abstract

1. Motivation, specific objective

Road lighting automation systems, by which the luminous flux of the luminaires can be adjusted according to the conditions, seems to be a significant way to save energy. However, there is not enough research yet on how the reduction of luminous flux will affect the visual performance, safety and comfort conditions of drivers. So there are contradictory approaches when determining control strategies and dimming scenarios. Therefore, tests on real road conditions and more research about driving safety must be carried out, as much as possible, before determining the automation strategies and applications.

2. Methods

Istanbul Technical University (ITU) and ISBAK Istanbul IT and Smart City Technologies Inc., developing a common project, with the support of Ministry of Science Industry and Technology, established a test road in Istanbul, ITU Ayazaga Campus where different road conditions and scenarios can be practiced in order to assess and measure the visual performance of drivers. According to the measurements and experimental results which will be held on the test road, it is aimed to develop a "road lighting automation system" working with correct dimming scenarios.

In order to be able to determine dimming scenarios correctly, driver's visibility performance should be evaluated based on the time-varying parameters, such as traffic intensity and vehicle speed on the road. For this purpose, the measurements of the visibility levels (VL) and tests on the road are carried out for the fixed observer, located 60 meters behind the calculation area, which is used in the calculation of the road surface luminance in current standards and recommendations. The VL measurements are repeated for the moving observer positioned at the safe stopping distance, which is the distance that the driver can see the target on the road and stop safely.

3. Results

From the measured VL's minimum VL values are found by experiments which were carried out under laboratory conditions. In this paper, laboratory experiments to find the minimum VL values and the field tests with observers to verify these minimum VL values are explained. After this verification, visibility tests are carried out with moving observers from safe stopping distance according to permitted vehicle speeds for related road lighting class. From the results of moving observer experiments based on visibility level measurements and evaluations, road lighting automation strategies considering driving safety are determined.

4. Conclusions

Technically, it is possible to adjust the luminous flux of luminaires with LED light sources at desired levels. However, when traffic safety is considered in real road conditions, the lack of information about the time and amount of dimming is the biggest obstacle in the application of road lighting automation systems in existing or newly installed road lighting. This paper describes the studies which are carried out in order to determine the effect of dimming on the visibility performance of the drivers, in terms of driving safety.

OP39

NEW IMAGE BASED MEASUREMENTS OF REFLECTION PROPERTIES OF ROAD SURFACES

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Abstract

A lighting planner designs the installation with the help of the illuminance level if road's reflection properties are unknown. This can result in luminances too high or too low, incalculable luminance distributions and therefore lower safety and/or energy efficiency. The reflection properties are relevant to the research and development community as well, as the quality rating of street lighting scenes, for example by means of visibility level and through revealing power methods, requires an exact simulation of luminance distributions on pavements. In addition, with this knowledge they would be able to fully exploit the potential of new LED optics.

The established measurement method for determining reflection properties of road surfaces is taking a drill core sample out and making precise measurements in the laboratory. The resulting r-tables contain reduced luminance coefficients for defined viewing angles and light incidents. Other, non-destructive in situ measurement methods which use closed boxes and calibrated light sources have not been asserted themselves. Cheap, easy and non-destructive methods are desired by lighting and urban planners.

Hence, the authors are investigating a method where luminance image processing is used to calculate relevant reflection properties of a street lighting scene. It uses a calibrated additional luminaire to eliminate the lack of knowledge about all other light sources and several luminance camera images taken of the measurement field. The reduced luminance coefficient in all relevant points of the measurement field is calculated by dividing the illuminance, caused by the light sources, by the luminance, seen by the standard observer. In this way the measurement and calculation process provides luminance coefficients for the relevant measurement field. The results are compared to simulations where precise measured r-tables and measurements were available. The presented method generates r-tables which provide sufficiently well simulated street lighting scenes.

Finally, this article shows the further need to improve this method to eliminate measurement uncertainties. It also provides ideas of further simplifications of the required measurements and calculation process for planners.

Keywords: Exterior lighting, street surface, reflection properties, luminance coefficient, r-tables, image processing, luminance image, measurements

OP40

MEASUREMENT SYSTEM AND METHOD FOR REFLECTION PROPERTIES OF WET ROAD SURFACES

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Abstract

The reflection properties of wet road surfaces that influence the quality of road lighting are quite different from dry ones. CIE47-1979 has established a description system for wet road surfaces' reflection properties, based on measurement data from Swedish and Danish road surfaces, as well as their weather conditions. To update the standard data, and perhaps also the description system, CIE TC 4-50 "Road surface characterization for lighting applications" included the wet road surfaces, and call for input and data from related studies.

Based on our previous work for dry road surfaces' studies, a measurement system for wet road surfaces has been setup, which mainly consists of a 2-Dimensional rotating platform, an imaging luminance meter, a collimated light source, a PC and a simulating rainfall apparatus. The 2-Dimensional rotating platform realizes the scanning of incident (0-85.2°) and observing (0-180°) angles. At 1° observing angle standardized by CIE, the target area of the luminance measurement is linear-shape with relative small width. Therefore, it is quite challenging for using spot luminance meter to do the precise measurement. To improve the measurement accuracy, an imaging luminance meter was used to serve for special requirements of the measurement. One of the main challenges of the measurement is from the extremely high dynamic range of luminance of the measured sample surface when getting wet. The simulating rainfall apparatus was also built to splash wet onto the road surface sample, which is applied wetting process defined in CIE 47-1979.

The other challenge, solved by our study, is about developing the measurement process of wet samples whose ‘wet level’ changing with time rapidly. According to our study, the reflection property changes along the time and saturate after about 2 hours in the laboratory settings. However, the complete measurement of one r-table costs roughly 6 hours which is obviously un-applicable for reflectance measurement of ‘wet surface’. Therefore, a segmented measurement process was defined and applied. The measurement of a complete r-table was basically divided into 10 groups with two angles in the neighbouring of C plane. Each measurement group took 30 minutes roughly. Then, the sample will be left to dry naturally and prepared for the next round of measurement.

After 6 months' measurement, 20 road samples with four situations (dry, 0, 30, 60 minutes' drying) have been measured. Results show that for these wet samples, most of them gather within the W1 and W2 classifications. The reflectance property of the wet surface at different wet levels are addressed and analysed.

OP41

COMPARISON BETWEEN LABORATORY AND ON-SITE MEASUREMENTS OF ROAD PHOTOMETRY

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Abstract

1. Motivation, specific objective

The characterization of pavement photometric properties is defined in the joint technical report CIE-PIARC 66. This document describes the methodology to perform laboratory measurements on road sample with a goniophotometer. But in the last decade, new prototypes have been developed, aiming measurements on real roads. Some were presented during the CIE Symposium on Road photometry organized in Turin in 2008. Most of these new devices measure limited angular distributions and extrapolate the full r-table according to various methods.

The CIE does not propose any recommendations for this on-site metrology (how to measure, where to measure, how to extrapolate…)

There were several studies in France, where samples of road were extracted and both on-site and laboratory measurements were performed. The study consists in comparing these results.

2. Methods

The data base contains various photometric measurements done on different types of pavements:

- Measurements on samples (according to CIE metrology reference) done with a laboratory goniophotometer,
- Portable-device measurements on these samples,
- Portable-device measurements on roads, considering the treads and the centre of the lane.

The method consists in comparing the r-tables, Q0 and S1 parameters between the various measurements performed for each pavement. A comparison of these data with the reference CIE Standards is also done.

3. Results

Measurements on site can fit or sometimes largely differ from the one performed on the sample extracted from the road.

The reasons of the differences are explored; they include:

- The heterogeneity of the road (the sample itself and over the lane)
- The sample extraction that could lead to a possible modification of the photometric properties.

There is also a confirmation that the CIE Standards, shall imperatively be used by adapting the Q0 value.

4. Conclusions

The database and the results of the analysis illustrate:

- the need to improve the sampling extraction methodology (where…),
- the importance of framing and giving guidelines for on-site measurement devices,
- the open-discussion to have with the experts on how to interpret the multiple data, especially when on-site characterizations differ from laboratory ones,
- the need to revise the CIE Standards.

This proposal could contribute to the work going on in CIE TC4-50.

Session OS11
Lighting and health
Wednesday, October 25, 10:30–12:10

OP42

SUNLIGHT EXPOSURE: DO WE GET ENOUGH AND SHOULD WE CARE?

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BACKGROUND: Sunlight is still the primary source of light and radiation for the majority of life on earth, but has become less dominant for human lifestyles as lighting technology has provided us with ever increasing options for alternative sources of visible light. However, vision is not the only biological effect of sunlight on human health and well-being. Other direct effects resulting from exposure of eyes and skin include circadian entrainment, seasonal affective disorder, cataracts, sunburn and skin cancer, skin ageing, vitamin D synthesis, plus related or indirect effects of these photobiological responses. There are further benefits to be gained from being outdoors, including fresh air and exercise. However, it is recognised that being outside, sunlight availability and solar exposure, while related, are not indicators of activity and nor are they interchangeable measures of photobiological efficacy. The effects of "being in the sun" will depend on location, weather, timing, duration, skin type, dress (including eye wear) and behaviour. Here we use a series of studies performed at a northern European location to first explore the time spent outdoors in each of the four seasons by different sectors of the population, and then assess that with respect to the skin mediated outcome of vitamin D synthesis, and alternative sources of the nutrient.

METHODS: The population groups studied were adolescents (13 -15y), working age adults (20 - 60y) and adults past standard retirement age (65y +). For adolescents and adults the behaviours of two different groups, white Caucasian and South Asians (skin type V) were recorded. Diaries for each participant provide the time of day and duration of outdoor activity, allowing this to be put in context of both the actual solar radiation available during the study days (from a local monitoring station), and the typical exposure that might have resulted from the same behaviour in average or climatological conditions (from detailed climatological modelling of the region).

Dosimeter badges (total dose) tell us the amount of radiation that reached each person, adding a level of personal behaviour to the diary exposure durations and timings (e.g. was a person sitting in a park under a tree, or in full sunlight?). Then exposure diaries provide information on dress and other sun protection (sunscreen and cosmetic use) that further modifies the degree to which unprotected skin/eyes are exposed to sunlight. It is usually the final, unprotected exposure that elicits the largest photobiological response for biological effects. For skin mediated effects, for which we are predominantly concerned with the UV part of the spectrum, photons have to reach the skin to elicit a response.

The skin response chosen as a marker of exposure outcome is vitamin D synthesis, which also incorporates the impact of skin type on the response to exposure. Seasonal venous blood samples from all volunteers were analysed for 25 hydroxyvitamin D by high performance liquid chromatography.

Finally, we consider the alternative artificial source of ultraviolet (UV) radiation, as it might be used to reach the same endpoint of vitamin D synthesis, and place this in the context of the lifestyle exposures to sunlight.

RESULTS: We illustrate the wide range of sunlight exposures achieved by the different population groups living in the same region under the same climate, and the subsequent biological responses that are also influenced by personal characteristics and behaviour. Common findings were the very limited periods outdoors for the majority of those studied, and the importance of weekend exposures in determining overall dose received and biological response. Skin type and cultural practices were strong indicators of the biological response, best illustrated by the adolescents with similar and structured exposures during the school day.

CONCLUSIONS: Our free-living volunteers represent the time outdoors and sun exposures obtained in real life, and show that, at least for the endpoint of vitamin D synthesis, limited time outdoors means

that exposure is insufficient for some, in particular those with constitutive skin pigment. The implications for other aspects of health and well-being, and alternative sources of UV radiation and vitamin D will be discussed.

OP43

PRELIMINARY STUDY ON SPECTRAL CHARACTERISTICS FOR IDENTIFICATION OF SKIN COLOUR UNDER CIRCULATORY DYSFUNCTION USING ARTIFICIAL SKIN SAMPLES

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Abstract

1. Introduction

In disaster situation, it is necessary to judge correctly if the victims rescued from debris has fallen into circulatory dysfunction, and to apply appropriate medical treatment accordingly, in order to enhance the survival ratio. Also in non-disaster medical lighting environment such as hospitals, which are shifting rapidly from conventional lightings (such as fluorescent and incandescent lamp) to LED lights, the development of LED light sources enabling the medical staffs to judge on patients' conditions more accurately than conventional light sources is needed.

We have developed database of circulatory dysfunctional skin colours taking consideration of age and gender by using Japanese subjects' skins which are artificially shocked or congested in part of upper arms. Also, we have conducted a simulation to extract the theoretical spectral power distributions (SPD) which make maximum colour differences between healthy skin and shocked/congested skin under LED light sources for each group.

This time we report the qualitatively identification of urethan skin sample's conditional changes under the theoretical LED light source in the previous paper. Skin-coloured charts (Colour Chart) made of paper which is commercially available have quite different SPD from real skins' with 580nm SPD and higher. Therefore, we particularly developed urethan skin samples for our experiment taking into considerations of skin's visual appearance, texture, structures of real skins.

2. Methods

Just like the previous paper (CIE proceedings of 2016 Prague), we used NIST Spectrally Tunable Lighting Facility (STLF). We produced spectra as close as possible to the theoretical SPD and the reference light (daylight D65 and incandescent light) using STLF's 25 channels. As our goals include the development of the experimental methods to evaluate the theoretical SPD in order to distinguish conditional changes about circulatory dysfunction, we conducted two experiments. Experiment (1) was using the same procedure in the previous paper, and its purpose was to judge the most appropriate Duv conditions under certain light sources. Experiment (2) directly compared the theoretical LED light .and the reference light which were same Duv value (from -0.025 to +0.01) and the correlated colour temperature (CCT, 2700K and 6500K).

We used urethan skin samples of four groups (age and gender) and three states (healthy, shocked and congested) as evaluation targets. The samples were 5mm thick, with the size of 100mm×70mm, and their surface was unlevel, made to look like real skins. We included also the paper colour charts with the same values of Munsell colour system with young female's skin colour, and real human skins (subject's back of the left hand). Although there were some not exactly matching with real skins' SPDs, L*a*b* values roughly fit, and colour differences between real skins and urethan skin samples were small. Therefore we judged that these urethan skin samples satisfied the standard of visual experimental targets.

The subject was one female with full colour vision in the 40s. This subject was well acquainted with Experiment (1) in the previous paper, and trained thoroughly until she showed stable evaluation as for Experiment (2). The subject was exposed to adaptation state for five minutes (later one minute). Then she was shown to the two light conditions, and asked to answer which was her evaluation for the next four questions.

Q1: “Which light presents your skin colour of the back of hand more natural?”

Q2: “Which light presents the paper colour charts more distinguishable?”

Q3: “Which light presents the urethan skin samples more natural?”

Q4: “Which light presents the urethan skin samples of three states more distinguishable?”

In Experiment (2), the subject also answered the degree of naturalness or identification from five evaluation scales.

3. Results

In Experiment (1), results indicated that there was appropriate Duv condition for each light source. For instance, the naturalness of real skin’s best condition was Duv=-0.005, the naturalness of urethan skin sample Duv=-0.005. The identification of urethan skin samples had it peak at Duv=-0.005 for the 6500K reference light like the previous paper. However, for the theoretical LED light (both 6500K and 2700K) and 2700K reference lights, the identification became easier with lower Duv (Duv<-0.025). Because the results were similar to those of the previous paper, the reproducibility was confirmed.

In Experiment (2), results showed that the direct comparison produced more stable evaluation than the judgment of degree. For both 6500K and 2700K, the reference lights produced more natural than the theoretical LED lights in the case of the naturalness of real skin colour. Both theoretical LED (6500K and 2700K) produced more distinguishable than the reference light in the case of the identification of paper colour charts. In the case of the naturalness of urethan skin samples, the evaluation was not stable, especially with 2700K. In the case of the identification of urethan skin samples, the two CCT had different tendency. 6500K had threshold around Duv=0. The 6500K reference light produced more distinguishable than the theoretical LED when Duv was higher than 0.005. If the Duv was lower than 0, the 6500K theoretical LED light produced more distinguishable than the reference light. The 2700K results showed that the reference light consistently produced more distinguishable than the theoretical LED.

4. Conclusions

Our overall results show that 6500K theoretical LED has ideal spectral distribution for identification of circulatory dysfunctional skin colours. But we experimented qualitatively the tendency of only one subject, so further examination with more subjects is called for. Experiment (2) indicates the difficulty of judgement of degree, so more refined experimental methods are needed, like the experiment environment enable us to compare simultaneously the two different light conditions.

Also, our urethan skin samples do not have enough match of spectral reflectivity, so we need to better the quality of the samples in this regard.

OP44

THE INFLUENCE OF LED LIGHTINGS WITH DIFFERENT PROPORTIONS OF BLUE LIGHT WAVELENGTHS ON HUMANS

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Abstract

Nowadays, people are under the environment of high pressure, high competition and long working hours. According to the survey, office workers spend 1/3 of a day staying indoors. Therefore, providing/offering a suitable and comfortable working place for them is an important issue. However, what is the appropriate and comfortable working environment? The priority condition is the sufficient lighting. In this study, depending on the light characteristics (such as colour temperature, spectrum, illumination, etc.), we find out the physiological effects from different light sources.

In this study, except for the colour temperature and illumination of different light sources, the effects of distinctive light sources on work efficiency are evaluated by objective assessment. This experiment light conditions contain two kinds of colour temperature (400K and 6000K), three kinds of basket light wavelength (420nm / 460nm / 480nm), and two kinds of illumination (400lx / 700lx). The subjects are 12 people, including 6 male and 6 female. Also the experiment time is at 9 am, 1 pm, 3 pm respectively. The tasks cover reading (30 minutes), GoNoGo (12 minutes), and proofreading (18 minutes). During the whole course of the experiment, the instruments are used to record changes about physiological signals. Thorough EEG, ECG and EOG, the heart rate variability (HRV) and the number of blinks are analysed to obtain the subjects' work efficiency and feelings of fatigue from different light sources. It is expected to improve the work efficiency and reduce the feelings of fatigue of office workers. Furthermore, to promote people's working efficiency, we could use this light source in an office.

OP45

CHARACTERISATION OF DAYLIGHT'S SPATIAL AND SPECTRAL DISTRIBUTION TO ASSESS ITS IMPACT ON HUMAN BEINGS

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Abstract

Daylight is effective in fulfilling psychological and physiological lighting needs in the built environment. It differs from electric lighting in several aspects. The dynamics in light levels and the spectral power distribution, with a strong short wavelength component, are said to be specific beneficial characteristics of the natural light source. Additionally, directionality of light is an important quality. Daylight from windows causes a spatial light distribution in indoor spaces, which results in higher illumination of vertical surfaces. Increased luminance of walls positively affects room appearance and user well-being, and higher vertical illuminances at eye level are associated with less fatigue in office spaces.

Inferior and nasal illumination is said to be more effective in inducing non-visual effects. Vertical illuminances or irradiances at eye level, typically used in research on non-visual effective lighting, do not properly reflect the effective radiant flux to stimulate ipRGCs, as their arrangement on the retina is not properly considered.

To evaluate the impact of daylight on human beings and support healthy lighting design, a proper and detailed description of daylight provision in the room and at the eye is required. This includes information about intensity and directionality, as well as spatial and spectral power distribution. All parameters are influenced by sun position and the prevailing sky conditions, which provide the specific dynamics for all considered aspects.

At present, daylight planning considers a minimum daylight coefficient, a constant ratio, or the course of the daylight coefficient on a horizontal plane in the room, not reflecting the dynamics or absolute lighting levels, nor considering spatial light distribution. The correlated colour temperature of the light is usually set to 6500K, or colorimetric characterization of daylight is based on measurements combining diffuse (skylight) and direct light (sunlight), even though research has shown that the spectral power distribution of specific regions of the sky can vary largely.

The paper will show a differentiated view on characterisation of daylight provision using spectral information of many sky patches and the quantification of light direction. The spectral information is based on spatially resolved spectral power distribution measurements of daylight with a sky scanner. The quantification of light direction is based on measurements and simulations, and includes information about intensity and origin of the light. The paper will include examples that show how this characterisation can be used to evaluate non-visual effectiveness of the light, to assess this aspect of daylight's impact on human beings.

OP46

METHODS TO QUANTIFY THE EFFECT OF DIFFERENT LIGHT SPECTRA IN HUMANS AND THEIR APPLICATION ON TWO STUDIES

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Abstract

1. Motivation, specific objective

To quantify the effect of different light spectra, EEG Data, pupillometry data and self-rated sleepiness have been collected in two studies funded within the German BMBF NiviL Project. Since there is no agreed standard of EEG data evaluation, an universal approach for spectral analysis is presented. Pupillometry data is evaluated using the PUI (Pupillen Unruhe Index) as well as spectral analysis.

2. Methods

The first study carried out in winter 2015/16 aimed to investigate the effects of red and blue light on people with bipolar affective disorder (19 women, 14 men, mean age 44 years) in comparison to healthy participants (36 women, 21 men, mean age 39 years). All participants came to the lab for three nights with one random light condition for each night (dark, red and blue). At 9 pm participants pupils were dilated and eyepatches were applied to create complete darkness The Light condition started at 11 pm and lasted for 30 minutes. Number of photons was 1,6*10^13 per second and cm². LEDs with peak wave-length of 475 nm (blue) und 624 nm (red) was used, full width at half maximum was 25 nm (red) and 18 nm (blue). This created light levels of 8 lux for blue and 9,2 lux for red at eye level of the participant.

In this study around 1200 hours of EEG data was collected and analysed. Due to the fact that there is no scientifically agreed EEG data evaluation standard, the paper describes an universal approach.

The second study carried out in winter 2016/17 aimed to investigate the phase shift of the circadian clock induced by two hours of bright blue light on people with bipolar affective disorder (21 women, 20 men) in comparison to healthy participants (33 women, 25 men). Participants came the lab at three consecutive nights, the first and third night with eye patches for no light administration. In the second night they sat in front of a half sphere (diameter 50 cm) and received a light dose from 9pm to 11 pm. Phase shift was measured with melatonin blood sampling. In this study, pupils were not being dilated. Instead a camera measured participants pupil size. To equalize the light dose for every participant , a self developed control scheme adjusted brightness while light administration in the sphere depending on pupil size (maximum 1200lux blue with 1,6mm pupil, minimum 120 lux blue with 5mm pupil diameter).
Pupillometry data was sampled with 30 Hz and stored for evaluation. EEG Data was collected in the second night as well as the Karolinska Sleepiness Scale self rating every half our in all nights. As a hypothesis, it should be possible to notice the shifted circadian phase also in EEG and pupillometry data.

3. Results

In the paper, the control scheme for the light administration with pupil size correction is presented and methods for data evaluation from pupillometry will be described. Participants arousal status can be obtained by frequency analysis of EEG, from pupil size deviations as well as the KSS score. Within EEG data and pupillometry, good artefact rejection is the key to small standard deviations. Since there is no standard procedure, the methods used will be described. First results show correlation between Theta waves as well as Alpha waves to the KSS score in the first study.

4. Conclusions

In summary, data analysis and outcomes of the KSS scale, EEG data and pupillometry of both studies are presented and, if possible compared.

Session OS12
Visual perception in interior lighting
Wednesday, October 25, 10:30–12:10

OP47

EVALUATING VISUAL COMFORT IN OPEN-PLAN OFFICES: ON-SITE ASSESSMENT VIA IMAGE ANALYSIS

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Abstract

1. Motivation, specific objective

Although daylighting as a design strategy can reduce energy use and increase productivity in buildings, it may also increase the risk of discomfort glare for building occupants. Discomfort glare has become a major challenge for architects, as resulting occupant dissatisfaction can lead to unwanted adjustments to the environment (such as over-use of blinds) that offset designed gains in building performance. The experience of discomfort glare is subjective, and can be influenced by a range of person factors other than illuminance or luminance in the visual field. As such, examining visual comfort in real-life office settings is important for developing our understanding of its assessment and prediction. This study presents original data captured in a field setting with long-term occupants of a green building in a subtropical climate, and examines established glare metrics and subjective glare ratings of building occupants.

2. Methods

Participants were 40 office-worker occupants of an open-plan office located in Brisbane, Australia (latitude 27° 28' S, longitude 153° 1' E). Site visits were completed from late November to early December 2016 and consisted of measurements of the light environment at individual occupant workstations.

Participants sat in their usual working position and answered a series of questions relating to the current lighting, time spent at their workstation, work tasks, use of corrective lenses, and current alertness and mood. Participants rated the overall visual comfort of their current light environment, and whether they perceived any bright light in their visual field, as well as its level and severity. After capturing subjective ratings, we used a data collection cart to capture objective measurements of the lighting from seated eye height (120cm) for each workstation. We completed measurements of luminance, illuminance, CCT and CRI associated with the lighting conditions, and captured a series of images using a calibrated Canon EOS 5D fitted with a 180-degree fisheye lens.

For each workstation, nine images taken at a range of exposure values were used to generate high dynamic range (HDR) images and luminance maps (using Photolux Version 3.27). Glare indices (including daylight glare index, visual comfort probability and unified glare ratio) were calculated from luminance maps of individual workspaces and compared to occupants' subjective glare ratings, alongside simpler measures of the luminous scene including vertical illuminance at the eye and simple luminance ratios.

3. Results

At the time of assessment, 17.5% of occupants reported uncomfortable bright light in their visual field, and the same percentage rated their workstation to be visually uncomfortable or very uncomfortable. Correlations assessing the relationship between glare indices and occupants' subjective ratings of visual discomfort were calculated. Preliminary analysis suggested that existing glare metrics based on images of the entire scene both under and over-estimated the proportion of occupants that reported experiencing visual discomfort.

4. Conclusions

This study assessed reported visual discomfort and a range of glare indices in long-term open-plan building occupants. Results suggest a need for further development of strategies to predict discomfort glare in this setting. Approaches using image analysis and simulation should be validated in field settings to assess their ability to differentiate between comfortable and uncomfortable light in real work environments across a range of locations, contexts and applications.

OP48

THE APPLICATION OF MEAN ROOM SURFACE EXITANCE INTO LIGHTING DESIGN PRACTICE

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Abstract

Current lighting design practice related to most indoor environments has basically been achieved through the same design methods and guidelines, using horizontal illuminance as its main metric, for many decades. This is because present methods have proven simple to implement and have resulted in reasonably satisfactory outcomes for many years; but the visual needs of people in modern way of life are evolving. Self-illuminated screens of computers, televisions, tablets and smart phones have changed the relationship between people and their environment. Changing demands for a different illuminated environment and lower energy use create pressure for new lighting design methods.

In 2010, an alternative exitance-based lighting design method was suggested by a New Zealand researcher with the intention of proposing better quality lighting. Perceived Adequacy of Illumination (PAI) and Illumination Hierarchy (IH) criteria are at the basis of this new method. There are two metrics associated with these criteria: Mean Room Surface Exitance (MRSE) and Target-Ambient Illuminance Ratio (TAIR).

Research undertaken in Dublin Institute of Technology through multiple PhD studies is exploring this new paradigm. The research investigates whether an MRSE approach is better than one based on horizontal illuminance and whether it can be easily designed using software and easily measured. These issues have been investigated as the first part of the research described above and published in the SLL Lighting Research & Technology journal. These findings will be briefly described before presenting follow on and current research, which is mainly focused on evaluating MRSE levels and their adequacy and on illumination hierarchy in the indoor environment.

The MRSE metric has been examined with a view to determining the suitability of this approach for application to general lighting practice. Studies curried out have provided data about spatial brightness and MRSE levels in a real life experimental office. They were mainly based in a small room, furnished with a work desk and two chairs. The room was completely shielded from natural light.

This present study builds upon the previous work and sets out to evaluate an appropriate level of MRSE for specific office-based activities. Participants were asked questions provided in random order related to the subjective spatial brightness rating in relation to different light scenes with varying levels of MRSE. An evaluation scale from very dim to very bright was used.

Since the start of this research, a number of key findings have been produced that centred on how occupants react to various levels of MRSE.

This paper will:

- Describe experimental results that demonstrate how occupants have reacted to various levels of MRSE within mocked-up office environments.
- Demonstrate how MRSE can be measured using HDR images technology and calculated using scripting and an open source lighting computation engine.
- Display survey results carried out in real offices to determine the actual level of MRSE in specific workplaces.
- Describe the process to date and outline a number of pilot studies for future research that investigates how people react to various changes in Target Ambient Illumination Ratios.

PhD research on MRSE/TAIR shows that MRSE performs better then horizontal illuminance as a metric to evaluate occupant satisfaction. Duff has also shown that MRSE can be easily designed and measured using software and camera technique using HDR images.

One of the purposes of this experiment was to refine the range of values found so far to establish a scale of MRSE from very dim to very bright, that could form the basis of recommendations for lighting codes and guides. Whilst work is ongoing, the initial data suggests that a value of about 75 lm/m2 may be acceptable to most of interviewed subjects. This will be clarified and evidenced in the final paper.

Future research will be based on analysis of illumination hierarchies and particularly on the ratio between areas of emphasis requiring concentrated light with MRSE levels of the related surrounding areas. Some data from pilot studies will be presented.

OP49

MEASURING THE EFFECT OF LIGHT DISTRIBUTION ON SPATIAL BRIGHTNESS

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Abstract

1. Motivation, specific objective

A number of studies have suggested that the luminance distribution in a space affects its apparent spatial brightness. In particular, they highlight the effects of uniformity, and the effects of where the light is placed (e.g. the importance of peripheral illumination). However, compared to other areas, such as the effects of spectral power distribution, there is a limited amount of research on the subject. Moreover, due to the common use of subjective rating scales, it is often difficult to evaluate the practical magnitude of the effects (e.g. the effective change in light level).

Previously, we reported the results of a pilot study looking to measure the effects of light distribution more accurately using a brightness matching task. This study indicated that non-uniform spaces appeared brighter than uniform spaces. This contradicted the majority of studies in the area which have generally found the opposite effect, but agreed with the one other study that used brightness matching. This raised the possibility that the disagreement in the literature could be the result of differences in methodology.

2. Methods

To test this, we repeated the previous experiment with using both side-by-side brightness matching (n=10) and magnitude estimation (n=24), examining 8 different light distributions at 3 different light levels. A null condition was used to account for biases. Light distributions were measured using HDR luminance mapping with a fisheye lens.

3. Results

The results confirm the results of the previous study, with the non-uniformity again having a positive correlation with spatial brightness. The size of the effect is substantial, with the differences in light distribution amongst the conditions causing differences in brightness equivalent to as much as a 67% increase (or 40% decrease) in mean luminance.

With the hypothesis that the difference between studies was caused by a difference between subjective ratings and brightness matching being unsupported, the next best hypothesis is that it is a result of a failure to “correctly” describe the light distribution. i.e. that the commonly used simple metrics such as uniformity ratio are not properly capturing the true effect of light distribution on spatial brightness, and that if we knew the correct way to measure it, then the studies would all align with each other. With this in mind, we compare and evaluate the brightness effects predicted by using various common uniformity metrics, and discuss their theoretical implications.

4. Conclusions

There exists a substantial unexplained discrepancy in the research into the relationship between light distribution and spatial brightness. Some studies show non-uniformity to have a negative relation, whilst others (such as this one) show it to be positive. This disagreement does not appear to be caused by differences in methods of assessing brightness between studies, but may be an artefact of incorrect measurement of the light distribution. Commonly used metrics such as uniformity ratios may be theoretically unsound, and have poor empirical performance. There is a need to further test and develop metrics of light distribution, and to determine what aspects of the light distribution such metrics would need to capture.

OP50

BRIGHTNESS PREDICTION METHOD BASED ON BRIGHTNESS MATCHING EXPERIMENT IN REAL LIGHTED INTERIORS

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Abstract

1. Motivation, specific objective

Predicting perceived brightness of objects or surfaces in an interior is quite beneficial especially for energy-saving lighting. A large number of studies of relationship between luminance and brightness have been carried out, and certain relations like Fechner's law (1860) and Stevens' law (1961) have been obtained. Today, the general model of brightness/luminance that covers a range of background luminances, proposed by Bodmann et al. (1994), is recognized reliable enough for predicting brightness of a circular object seen against a uniform background, with parameters of the object size, its luminance and its background luminance. For surfaces in an interior, Marsden (1970) proposed a brightness predicting model with a parameter of maximum luminance in the interior, but its relation to Bodmann's model is unclear. On the other hand, capturing a luminance image of an interior is not so difficult today, and when specifying the center of an object contained in the image, the object size, its luminance, and its background luminance can be extracted by use of Nakamura's contrast profile method (2000). This suggests Bodmann's model can be applied to an object in an interior when a luminance image that contains the object is obtained. This study examined this possibility by conducting brightness matching experiment in a real lighted interior.

2. Methods

Perceived brightness of varied visual objects set in an office-like room with common ceiling luminaires were estimated by subjects with haploscopic brightness matching method. The subject saw the target object in the real lighted room with his/her left eye, and saw uniform luminance OLED panel with his/her right eye, and was asked to match those brightness by adjusting right panel luminance in two ways, one in ascending order and the other in descending order. The answered luminance of the subject was assumed to be the mean of the two luminance, and the median of all the answered luminance of all the subjects was assumed to indicate the perceived brightness of the object. 8 students, 4 male and 4 female, participated following three experiments.

EXPERIMENT 1: BRIGHTNESS MATCHING OF CIRCULAR OBJECT SEEN AGAINST UNIFORM BACKGROUND

The subject was ask to see a circular paper object set on a paper background. The background were 45 degrees wide and 36 degrees high in visual angle and attached on a vertical panel. The experimental parameters are object size (5 conditions; 1, 2, 4, 8, 12 degrees), object luminance (12 conditions; from 2 to 190 cd/m^2), and background luminance (12 conditions; from 2 to 190 cd/m^2). The luminance of those conditions were set by spot luminance meter reading on the center of the object and on several points of the background. Luminance images of all the conditions were captured.

EXPERIMENT 2: BRIGHTNESS MATCHING OF CIRCULAR OBJECT SEEN AGAINST COMPLICATED BACKGROUND

The subject was ask to see a circular paper object set in various positions of 3 rooms. The selected positions were dark area of a shelf, on a sofa, and under a light stand for example. Two ceiling lighting level, bright and dark, were adopted. Object luminance were varied from 1 to 235 cd/m^2, and object size were varied appropriately to the set positions. The contrast between the object and the background were set to be positive in almost half conditions and to be negative in the rest conditions. Total number of conditions were 46. Luminance images of all the conditions were captured.

EXPERIMENT 3: BRIGHTNESS MATCHING OF INDETERMINATE FORM OBJECT SEEN AGAINST COMPLICATED BACKGROUND

The subject was ask to see specific part of various objects in the same rooms as in the experiment 2. Specified parts were a part of spine of a book, a corner of a sofa, specific area of the wall, a part of a doll face for example. By changing lighting level, the contrast between the object and the background were set to be positive in almost half conditions and to be negative in the rest conditions. Total number of conditions were 45. Luminance images of all the conditions were captured.

3. Results

EXPERIMENT 1: Object luminances and background luminances were first extracted from captured luminance images of all the conditions by use of contrast profile method. Comparison between the values extracted and spot meter readings showed high correlation (R2=0.96). Using the parameters extracted from luminance images, brightness magnitudes of all the objects were calculated based on Bodmann's model. The answered luminances of all the condition obtained in the experiment were compared to the predicted brightness magnitudes calculated. The results showed the two values were highly correlated (R2=0.90), which suggested the values extracted from luminance images based on contrast profile method could predict brightness.

EXPERIMENT 2: Although the backgrounds of the objects in this experiment had luminance distribution, background luminances could be extracted from captured luminance images by use of contrast profile method. Extracted values from luminance images applied to Bodmann's model and brightness magnitudes of all the objects were obtained. The answered luminances of all conditions obtained in this experiment were again highly correlated to the Bodmann's brightness magnitudes (R2=0.835). This result suggested the values extracted from a luminance image by use of contrast profile method could directly predict answered luminance value obtained in the experiment.

EXPERIMENT 3: The same procedure as in previous experimental results was applied and the same result obtained, namely the answered luminance were well predicted by the values extracted from a luminance image by use of contrast profile method (R2=0.879).

4. Conclusions

All the results suggested that brightness of various parts of a real lighted interior could be predicted when a luminance image captured and contrast profile method applied. Finally the prediction formula was obtained by applying regression analysis to the result of experiment 2 and 3 (R2=0.876).

OP51

CONTRAST AND BRIGHTNESS PERCEPTION OF ILLUMINATION PATTERNS IN PHYSICALLY-BASED RENDERED SCENES

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Abstract

1. Introduction

Functional lighting design requirements and standards are currently formulated in terms of certain hard lighting quality criteria such as illuminance, illuminance distribution uniformity or colour rendition. While complying with such standards may well eliminate lighting designs which fail to meet a minimum quality threshold, this does not, however, guarantee a unique or attractive lighting scene, but rather an 'average' lighting concept. Most lighting standards employ traditional 'illuminance-based' lighting design whereas utilizing 'luminance-based' lighting designs would offer greater possibilities insofar as realizing more suitable lighting quality and visual comfort.

A first possible step towards converging to a 'luminance-based' lighting design concerns the ability to determine several visual characteristics of a room and its lighting, such as brightness and contrast, based on a luminance map. A previous study has already investigated the predictive performance of various contrast metrics (algorithms that estimate perceived contrast present in an image). Results indicated that for simple circular stimuli contrast perception increases as central luminance and edge smoothness increase and decrease, respectively. However several underlying factors were unclear and the stimuli did not resemble illumination patterns created by real lighting and thus lacked realism.

The impact of systematically varied realistic illumination patterns and intensities on the apparent brightness and contrast of an empty, context-free room and on the apparent brightness, contrast and perceived edge transition sharpness of the resulting lighting distributions visible on the room's rear wall, is investigated.

2. Methods

Given that such a systematic study requires a careful and adequate sampling of the parameters domain impacting physical lighting distribution characteristics, the use of virtual, but physically-based, rendered scenes has been selected. In addition, virtual scenes are more easily generated and controlled with little to no extra cost compared to real settings.

Employing LuxRender, a physical-based rendering engine, 135 virtual scenes were generated with full HD resolution (1920 x 1080). Each scene consists of an empty, context-free room of dimensions 8m (width) by 8m (length) by 3m (height) with uniform reflection coefficients of 30%, 65% and 80% for the floor, walls and ceiling, respectively. The observer's point of view is centrally located at a distance of 7m from the back wall.

Each virtual room is lit with one to three (N) point sources (light beams) with a theoretical Luminous Intensity Distribution (LID) resembling that of a spot luminaire. The LID was modelled by a Butterworth function with three parameters controlling the: LID's luminous intensity (I_0), beam width (θ_c) and beam edge sharpness (n). Luminous intensities I_0 were specifically chosen for each scene such that three maximum luminance values on the back walls were achieved: 23, 76 and 180 cd/m². The maximum luminance value of 180 cd/m² was selected within the display's dynamic range to minimize tone mapping issues. A CIE 1931 tristimulus map was obtained for each rendered scene. Scenes were displayed on a calibrated ColorEdge CG246 LCD monitor, capable of high precision output (10 bits per colour channel).

Experimentation took place in a darkened room with no active light sources apart from the monitor. Observers were seated at a distance of roughly 80cm from the monitor, resulting in an approximate 40° scene field of view. In total 14 unique scenes were randomly selected, 6 of which were repeated,

thereby resulting in a total of 20 scenes. Each observer rated the selected scenes on brightness and contrast for both room and lighting pattern, whereas edge diffusivity was rated for the lighting pattern alone, resulting in a total of 5 questions per scene.

Scene presentation was programmed in Matlab employing the Psychophysics toolbox. Observers logged their estimates via a slider positioned below the scene on the monitor. No explicit definition for any of the visual aspects was given to the observers and they alone exclusively determine how they would evaluate the visual aspects. The experiment consisted of two similar sessions: in session A observers rated one question at a time for all scenes sequentially while throughout session B observers rated all questions sequentially per scene. All observers completed both sessions, with each observer's first session being randomly assigned. Ten observers – five male and five female – of ages 24-41 years old (and an average of 30 years old) participated in the experiments. At the end of both sessions observers were asked to rank the questions on difficulty, which session they preferred and the criteria they employed when assessing the visual aspects.

3. Results

A preliminary analysis has indicated that observers were capable of consistently estimating room brightness and a high correlation was found (R^2=0.85) with average scene luminance, whereas lighting pattern brightness correlated less with average scene luminance (R^2=0.64). Results also indicate that some observers interpret brightness estimation for both room and lighting pattern on the same scale whereas others estimate these on separate scales.

Room brightness and edge diffusivity were the easiest factors for observers to estimate, while room and lighting pattern contrast proved the most challenging. Observers judged room contrast in various ways, some observers found dark scenes with only a single light source very contrasting whereas for other these had almost no contrast.

The average response time for each question in session A was 5 seconds and 7 seconds for session B, possibly indicating that observers prefer the questioning order in session A over B, whether this is of statistical significance has yet to be determined although this indication is consistent with observer feedback.

A detailed analysis is provided in the full paper, providing an account of observer variability and possible correlations between visual aspects and the LID parameters.

4. Conclusions

Observers estimated brightness consistently and primarily correlated it with average scene luminance (R^2=0.85). Observers found contrast difficult to estimate and had varying criteria in terms of its estimation. Average response times indicate observers prefer to estimate visual aspects separately. A future study will estimate several visual aspects – for typical commercial available scenes of lighting – in a real room environment to validate current results in a real setting.

Session OS13
Eye-related metrology
Wednesday, October 25, 13:30–14:30

OP52

REFINING THE EFFECTIVE INTENSITY MODEL AT THRESHOLD AND SUPRA-THRESHOLD FOR USE IN MARINE VISUAL SIGNALS

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Abstract

1. Motivation, specific objective

Ground-breaking experiments have been conducted over the last few years in order to refine the effective and apparent intensity models that are key to understanding how visual signals are perceived by mariners. Such refinement means that a visual signalling service can potentially be provided in a more efficient manner without unduly underestimating its performance. The presentation will discuss the experiments, the results and the consequences of the refinement for users, authorities and industry.

Note that since the term 'effective intensity' is only valid at the threshold of perception, the term 'apparent intensity' is used to quantify supra-threshold conspicuity applicable to marine aids-to-navigation usage.

2. Methods

The experiments measured precise illuminance levels at which flashes of various shapes and lengths were perceived by an observer. The observer was required to compare the brightness of a flashing light with that of a fixed light of known illuminance - the brightness matching method. Results from several sets of experiments were used to gauge the suitability of currently recommended effective intensity models at threshold and supra-threshold levels of illuminance. Where differences occurred, changes to the models were proposed.

These precise measurements were followed by further experiments at supra-threshold light levels with the purpose of verifying the apparent intensity models proposed. A number of brightness comparison tests between two different flash shapes were made, and these were compared against the visual system response models currently in use and being proposed.

3. Results

In order to obtain normalised effective (or apparent) intensity values from results of observer illuminance, the value of illuminance of the steady light was divided by the peak illuminance value of the flashing light with which it was compared or matched. Values of effective intensity against flash duration were then plotted and compared with similar plots from existing effective intensity models. It was noted that for supra-threshold levels of illuminance, the visual constant, *a*, needed to be refined to fit with observed results. Under current IALA recommendations, the Modified Allard Method has the value set to 0.2 s for night time observations with an observer illuminance of 0.2 microlux. However, the experiments have found that a visual constant value of 0.1 s provides a much closer fit to observations. The implications of such a change is that, for shorter flashes, the apparent luminous intensity is higher than that predicted by the currently recommended value of *a*. A change in the impulse function, $q(t)$, also provided a better fit to the observed results of asymmetrical flashes.

4. Conclusions

The focus of the experiments has been on improving our understanding of the perception of visual signals in the maritime sector. However, the implications clearly are much wider than that. Both the threshold and supra-threshold experiments showed that the Modified Allard Method of calculating the effective/apparent intensity was not sufficiently accurate for some flash shapes that were tested in the experiment. A proposed change to the method would allow the effective/apparent intensity calculated to more accurately reflect observed values.

One implication of this recommended change would be that it would be possible to provide the same published level of service with lower power consumption. Alternatively, it is possible to enhance service provision with the same level of power consumption. The impacts of such changes are discussed, and it is concluded that care must be taken if any changes to service provision is based of these results alone. This is particularly important where conspicuity of an aid-to-navigation is hampered by rival lights and the intensity of the light has been determined by viewing trials. Nevertheless, the recommendation is that these changes are made in order to refine the models used to determine maritime visual signalling provision.

OP53

DOES THE VISUAL SYSTEM EXTRACT MORE INFORMATION THAN GLOSS IN THE SPECULAR DIRECTION?

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Abstract

Introduction

Gloss is a visual attribute. It plays an important part in the perception of the total appearance of a material. Gloss is implicated in the material identification, in the evaluation of the polishing level of the surface and is linked with the sensation of quality. Gloss also participates in our understanding of the environment and its coherence. It allows us to deduce geometrical cues regarding our surroundings like the position and orientation of a light source, the curvature and orientation of an object.

When we ask an observer to evaluate the gloss of a sample, he gazes in the specular direction and then rotates lightly the sample, as if he was trying to access not only the size but also the shape of the specular peak. Why does he do this? What information is expected from this action?

To answer this question, we set up an experiment where we used three different samples which exhibits the same colour and the same level of gloss measured with a glossmeter. These samples are though made of different materials and different nature of roughness. We confronted these samples over three measurement types: High angular resolution BRDF with our goniospectrophotometer ConDOR, microtopography through Coherence Scattering Interferometry (CSI) and visual assessments using our light booth dedicated to gloss evaluations. We could conclude that the visual system extracts much more information than gloss when scanning the specular peak.

Material and methods

We work on three grey satin matt samples. These artefacts exhibit close gloss indices at 60° (30 g.u, 31 g.u and 36 g.u). Nonetheless, each surface is different. Sample one comes from a commercial coated paper scale. Sample two and three are both made of hybrid silica. Roughness of sample two results from the nanoimprint of a thermally relaxed surface. Roughness of sample three is a nanoimprint copy of the coated paper scale.

BRDF of these samples have been measured with ConDOR, the only facility in the world that has an angular resolution higher than the human visual acuity. ConDOR produces BRDF measurements of specular peaks with a dynamic superior to 6 decades. It has been developed at LNE-CNAM, the French national metrological institute for radiometry and photometry.

Surface topography has been accessed with a commercial interferometer. This device has a vertical resolution of 70 nm and a lateral resolution of 1.2 µm for patches of 0.75 mm by 0.54 mm.

The psychophysical protocol was first a visual gloss ranking of our three samples, second an open questioning to describe the samples after evaluation. 11 observers between 22 and 48 years old participated. We use our dedicated light booth inspired from ASTM D4449. The roof is 1 m2 D65 diffuse light put behind a 50 mm step mesh grid. In addition, a small collimated LED is also used. Both lightings are intended to mimic “natural” sky. LED stands for the sun and fluorescent tubes for the sky. This lighting provides the sample with illuminance of 960 lx. The light booth is decorated as an office desk. The shape and weight of the artefacts were adapted to be the same so that observers could not distinguish them over edge appearance or weight. Subjects could rotate the samples.

Results

CSI mappings indicate that the respective roughness geometries of our samples are distinct. Samples 1 and 3 show similar roughness geometries on the microscopic level, with high spatial frequency. But they have a different refractive index. Sample 2 exhibits another type of roughness with less angular structures and lower spatial frequencies. It has the same refractive index than sample 3.

The BRDF measurements show three different peaks which topologies are really different. Sample 1 have a smooth shape with a small high frequency pattern. Sample 2 has a broad specular peak with another pattern of high frequency in its maximum. Sample 3 presents a more complex specular peak consisting of two individual concentric peaks, one very narrow, the other broader.

Visual measurements establish a ranking which is not consistent with the gloss index at 60° of the samples. However, the vocabulary enunciated by observers is in favour of the discrimination of the surfaces over other cues, such as subsurface effect or material recognition. Sample 1 is perceived as less glossy than the others, it is described as very uniform. Sample 2 is perceived to be the glossiest, observers often describe the reflected light as burst by the surface. Sample 3 is intermediate between the others in terms of gloss and is associated with the perception of many small luminous dots.

Conclusion

Our results don't match with the glossmeter. It is not surprising. The glossmeter averages the flux in a large angular aperture, where our sample present intentionally complex specular peak shapes. We don't have enough samples to try to find an index that can correlate with the sensation. But from the comments of our observers, we can clearly find a connexion between the shape of the specular peak and the complex sensation generated by the sample, such as small dots or subsurface comportment. This result indicates that the visual system extracts more information than just the gloss when scanning the specular peak. This information is used by the visual system to make a cognitive proposal of a coherent and natural material.

A new proposal for gloss measurement is requested today to go further than what does the glossmeter. A careful evaluation of the relation between the specular peak, the sensation of gloss and the other cognitive indices would help on the way to a better gloss metrology.

OP54

FIELD OF VIEW CONSIDERATION TO EVALUATE DISTANCE DEPENDENCE IN BLUE LIGHT HAZARD MEASUREMENT

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Abstract

1. Introduction

IEC TR62778 "Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires" is a guide document that describes methods to complement IEC62471/CIE S009 for the evaluation of blue light hazard (BLH) of lamps and luminaires. Recently, IEC TC34 has launched a new project to convert the IEC TR62778 to an international standard as a reference for their product safety standards.

The feature of IEC TR62778 is its simplicity in risk evaluation by providing some practical approaches such as transfer of risk information from a primary source to a final product. However introducing the simplified approaches seems to induce inconsistency with the IEC 62471/CIE S009 with respect to some basic conditions of the BLH evaluation, which arises strong concern of falling into the situation of double standard, leading terrible overestimation of the risk and, in the worst case, giving us totally wrong risk information.

The most serious inconsistency has been seen on the determination of threshold distance (d_{thr}). d_{thr} indicates the distance from a test source to produce the threshold illuminance (E_{thr}) that corresponds to the upper limit of RG1. Sources whose risk group is greater than RG2 are required to have a caution label. So d_{thr} has strong impact to manufacturers or users as an index to provide information on the border between RG1 and RG2. Utilizing the illuminance value instead of BLH weighted irradiance would enable us to easily access the information on the relationship between the measurement distance and the risk group of the test source, meanwhile there are two potential problems included in d_{thr}.

The primary quantity needed for the BLH evaluation is the radiance, weighted with BLH action spectrum and averaged over the specified field-of-view (FOV). However, current IEC TR62778 doesn't give d_{thr} the concept of the FOV, so what d_{thr} represents is just the distance at which the illuminance produced by all the contribution from the source is the same as the threshold value. Under that condition, it is assumed that terrible overestimation of the risk would result. In addition, it provides no clear way to determine d_{thr} value and seems to assume the calculation based on the inverse-square law using far-field photometric data. It is well known that the inverse-square law doesn't hold especially when large sources such as luminaires are evaluated, where the size-of-source effect is no longer negligible. That would lead to the concern that, in many cases, d_{thr} cannot be determined as a meaningful value for the purpose of BLH evaluation without considering appropriate FOV condition (i.e. 0.011 rad) and valid range of point-source approximation. The larger and more non-uniform a test source becomes, the more error and more serious problem we will have.

The objective of this study is to evaluate the real impact of a FOV condition in the process to determine d_{thr} and estimate the potential error d_{thr} value would have depending on methods to obtain it including one that simply based on the combination of the inverse-square law and the far-field photometric data.

2. Methods

In this study, d_{thr} values of test sources were determined by using four different approaches shown below and compared each other.

1) Using a luminance meter with a fixed FOV of approximately 0.011 rad and the threshold luminance (L_{thr}) that corresponds to the upper limit of RG1.

2) Using an illuminance meter, E_{thr} and variable aperture as a field stop to adjust the apparent source size to be approximately 0.011 rad.

3) Using an illuminance meter and E_{thr} without limiting the FOV.

4) Using the Inverse-square law and luminous intensity data.

For simplicity, all the measurements were made based on the photometric data taken by a photometer (the luminance meter or the illuminance meter) and blue light hazard efficacy of luminous radiation ($K_{B,V}$) calculated using relative spectral power distribution of the test sources. As the test sources, integrating sphere-based source with different aperture sizes and optically-patterned filters was used to mimic non-uniform light sources. The photometer was aligned with the test source on the photometric bench along with the direction of the maximum luminous intensity. Distance-dependence was evaluated by changing the photometric distance step-by-step.

3. Results

When the source size was uniform and small enough to practically satisfy the point-source approximation at the measurement distance of 200 mm where the original risk evaluated had been made, d_{thr} values determined by four methods showed consistent results. On the other hand, non-uniform and large source showed totally different d_{thr} values among four methods. Among them, method (3) or (4) usually gave the largest d_{thr} value. In some cases, more than three times difference was observed on the d_{thr} value, which resulted in providing the information on unrealistic distance for safety measures. Detail of the measurement results and comparison analysis will be presented and discussed at the conference together with a proposal to reconsider the meaning of the d_{thr} in the BLH evaluation and to introduce the method to determine it based on a fixed FOV condition.

4. Conclusions

Under the condition that the source size is sufficiently uniform and smaller than the photometric distance so as to practically satisfy the point-source approximation, using the inverse-square law and the far-field photometric data is possible for the purpose to determine distance-dependence in the BLH evaluation. When that is not the case, it is indispensable to consider an appropriate FOV condition during the measurement, and that should be 0.011 rad as a boundary condition between RG1 and RG2 as defined in IEC 62471/CIE S009. The real meaning of the distance-dependence evaluation in the BLH should be finding out the relationship between the averaged area on the source and the BLH weighted radiance for the source that doesn't satisfy the "radiance-invariance assumption".

Session OS14
Lighting and health in interior lighting
Wednesday, October 25, 14:30–15:30

OP55

MEASUREMENT AND EVALUATION OF A DYNAMIC LIGHT SOURCE WITH CLASSROOM AS EMBODIMENT

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Abstract

1. Motivation, specific objective

It is more than well known that light, air, water, and food are the essential factors for human and animals alike to evolve, grow, reproduce and sustain. It has only been the recent decade, however the significance of light in human health was brought up as a hot topic in lighting, partly due to improved understanding in the interaction between light and human physiology and behaviour, and partly due to maturing of LED lighting technologies. LED light sources offer long life time, high luminous efficacy and variability in output in terms of spectral distribution and intensity. These advantageous performance features make the LEDs be used in very broad lighting applications. The variability and controllability in spectral output can be achieved by varying the blend of phosphors with respect to the primary blue light, and by the electronic control circuit. In addition, LED light sources also offer dim ability, which means that the output intensity of light can be varied with the control circuits. All these imply that combining the understanding in the light-human interaction and the variability in spectrum and intensity of the LED light, we can provide lighting conditions according to the time of the day and the mood of the body. In other words, we can feed human body with light just as we do with the nutrition. Electrical light thus is not merely a way helping us see things in the absence of sun light, but a continuous supply of nutrition to the body. In this sense, we are talking about dynamic lighting, where the spectrum and intensity of the output of light vary in time, and provide full compliance with visual and non-visual needs of the body for a particular lighting environment. At present, there are some lighting system with automatic dimming function of the LED lights and intelligent control system, combined with dynamic lighting management software to realize the dynamic lighting, such as office dynamic lighting system.

Tradition light sources with their fixed light output provide something like “airplane food”, low quality and the same dish all the time. On contrary, the LED based light sources, or a dynamic lighting system, with specially designed control scheme to produce a lighting environment to take into account of people’s emotion, physiological rhythms, sleep, endocrine needs; will lead to positive health effects, or light nutrition. It ought to notice however, the established methods and techniques for characterizing the lamps may not apply to the dynamic light and therefore need to be critically assessed to define technologies suitable for characterizing the dynamic light.

In this contribution, a pilot dynamic lighting system is presented with a classroom as an embodiment and one of the first attempts to gradually address certain critical issues in the human or health centric lighting. Variable-output LED light sources were chosen. Relevant parameters were defined, with their quantities measured and results evaluated. Discussions are made of the results in the context of radiation safety and some non-visual effects of the lighting on human.

2. Methods

In the classroom dynamic lighting system, we set up two groups of light sources, the one for writing board (no need to consider non-visual effects), and the one for desk and room lighting. The light source chosen are LED based with two kinds of optical spectra and with built-in automatic control of light output according to the human body day and night physiological rhythms. The light sources were able to synchronize its light output with the time in the time zone where the light sources are located. Photometric and radiometric integrated sphere was used to continuously monitor the light output in 24-hour cycle to obtain measurement data on luminous flux, colour coordinates, correlated colour temperature, colour rendering index and luminous efficiency and at the same time the variation in c/p of the light sources.

The LED panels we chose have two kinds of spectral distributions with a dynamic control device, which has a smart control to control the light output in 24-hour cycle. At the same time, the control was connected to the internet to manage the light output remotely. In such a way we were able to assess all parameters and identify circadian stimulus.

3. Results

From the continuous monitoring of the light output from the LED panels, we obtained instantaneous values and variation in the parameters, such as luminous flux, correlated colour temperatures, colour rendering indices, power consumption, luminous efficiency and CS value; as well as the maximum, minimum and mean values of them. The maximum values are located at 12:00h. Based on these measurement data, we derived the variation of colour temperature versus that of black body radiation and that of the colour coordinates of the sun light. we also calculated the circadian stimulus curve and found it consistent with the one suggested by Mark Rea et al.

Complete data in form of tables and graphs will be presented in the presentation. The consideration on the distribution and uniformity of the lighting conditions are dimensioned according to The GB and DB documentations of the PRC.

4. Conclusions

The data obtained in 24-hour cycle contain very rich information. Using mean value, maximum and minimum value, we are able to extract useful knowledge. The data seem to reflect the actual behaviour of the light sources, though sufficiency is to be proved and explored. Our circadian stimulus curves follow the regime suggested by Mark Rea et al.

OP56

STUDY ON THE RELATIONSHIP BETWEEN SLEEP QUALITY, PSYCHOLOGICAL AND PHYSICAL DISCOMFORT AND OFFICE LIGHTING: BASED ON A FULL-SCALE SURVEY

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Abstract

1. Motivation, specific objective

Office employees spend most of their waking time inside the office. Recent research revealed that light has non-visual effects on human psychology and physiology in addition to its visual effects. The quality of office lighting has proved to have influence on both working people's well-being and their sleep quality, which also affect their work performance. This article presents a full-scale survey of the non-visual effect of office lighting in Beijing, and intends to further elucidate the relationship between office lighting conditions (natural and artificial lighting), lighting environment assessment, psychological and physical discomfort and the sleep quality.

2. Methods

A questionnaire containing 35 questions in Chinese, which concerned basic information of the participants' work place, office lighting environment subjective assessment, psychological and physical discomfort and the sleep quality was sent out among working people in Beijing. All participants finished the questionnaire independently. The questionnaire was divided into four parts.

The first part collected basic information of the participants, including their sex, age, visual condition, work place and work time.

The second part contained questions about basic characteristics of office space (social density, orientation, window distance, colour of the glass, view quality).

The third part asked the participants to assess five items of the lighting environment, each measured on (visual analogue scale, 0-100), and four items related to visual and thermal disturbance in the office space, each measured on a yes/no scale. The questions were taken from Hygge and Löfberg.

In the fourth part, six items taken from Pleasure-Arousal-Dominance (PAD) model, measured on VAS, was used to assess psychological discomfort. For the "physical discomfort" variable, nine items, each measured on VAS, were used. The items were selected from the TNO/RUL Chronic Fatigue and Work Questionnaire. For the "sleep quality" variable, seven items selected from a short form of the Groningen Sleep Quality Scale were used to assess participants' sleep quality during the past three months, each measured on a yes/no scale.

3. Results

In total, 842 effective questionnaires were returned. 518 (61.5%) of the final sample were men and 324 (38.5%) were women. Age was ranked on seven categories: under 18 (0.4%), 18-25 years (14.4%), 26-30 years (29.7%), 31-40 years (38.8%), 41-50 years (12.8%), 51-60 years (3.0%) and older than 60 (1.0%). 389 (46.2%) of the participants wear corrective lenses and 453 (53.8%) of them don't. All the participants have a normal visual status.

3.1 .Lighting environment subjective assessment

The statistical analysis (ANOVA, SPSS23) showed lighting environment subjective assessment is significantly relevant with office orientation, window views, distance from the window and artificial lighting time .The ANOVA analysis revealed a significant effect of office orientation on the 'lighting feels warm or cold' ($F = 9.271$, $p < 0.001$). Compared with the north orientation, the south orientation (Tukey HSD $p=0.012$) brings in a relatively warmer lighting condition. The subjective assessment is significantly higher for occupants working with a window view than those without a window view, which is 'lighting feels warm or cold' ($F = 69.462$, $p < 0.001$), 'bright or dark' ($F = 61.733$, $p < 0.001$), 'glare'

($F = 5.205$, $p = 0.023$), ‘daylighting distribution’ ($F = 22.237$, $p < 0.001$), ‘overall satisfaction’ ($F = 52.222$, $p < 0.001$). Besides, all the subjective assessment items showed relevance with distance from the window. Compared with ‘distance over 4 meters’, ‘distance less than 2 meters’ and ‘distance between 2 and 4 meters’ got higher lighting environment assessment score on every items. Similarly, artificial lighting time on account of insufficient daylighting also showed relevance with the assessment items except for ‘glare’. The less time people work under artificial lighting, the higher assessment score of the four items is received.

3.2 Lighting environment assessment and physical and psychological discomfort

The correlation analysis (Pearson, SPSS23) was implemented between the items of lighting environment assessment, physical and psychological evaluation. The results showed a significant relationship between lighting environment and psychological discomfort. Moreover, a clear link can be found between all the five item from lighting environment assessment and six items from physical discomfort (Pearson correlation > =0.281, p<0.001).However, most of the physical discomfort items such as ‘concentration problems’, ‘easily tired’, ‘dullness’, ‘bad vision’, ‘dry throat’, ‘headache’, ‘irritated skin’ didn’t show any statistically significant relevance with lighting environment assessment score (p>0.05). Interestingly, only ‘poor appetite’ and ‘dry eyes’ from the physical discomfort items showed relevance with lighting environment, which indicates that dark lighting environment associates with poor appetite and ‘dry eyes’.

3.3 Lighting environment assessment and sleep quality

The same analysis method was implemented between items of lighting environment assessment and sleep quality. The results showed a significant relevance between five items of lighting environment assessment which is listed above and items from the sleep quality,which is ‘sleep less than 5 hours’(Pearson correlation =< -0.090, p= < 0.009), ’feel refreshed’ (Pearson correlation >= 0.070, p =< 0.042), ‘lack of sleep’ (Pearson correlation =< -0.110, p=<0.001), ‘easily fall asleep’ (Pearson correlation >= 0.094, p=<0.007), ‘difficulty falling asleep when waking up’ (Pearson correlation =< -0.061, p=<0.075). Besides, energy pills were less used to fall asleep when the item ‘bright or dark’ got a higher score (Pearson correlation = -0.75, p= 0.031). The analysis of sleep quality demonstrates a clear impact of lighting environment on sleep quality.

4. Conclusions

Some findings can be drawn from the results and discussions above: 1) Office space with less artificial lighting time could achieve a better lighting environment assessment; ‘south-orientation’, ‘close to window’ or ‘with window views’ received same results. 2) Psychological evaluation is significantly relevant to lighting environment; however, little clear links can be found between office lighting environment and physical evaluation as expected. 3) The sleep quality is significantly relevant to office lighting environment assessment.

OP57

COMPARISON BETWEEN OLED AND LED LIGHTING: USER PREFERENCES AND INFLUENCE ON WELL-BEING, IN FRANCE AND JAPAN

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Abstract

1. Motivation, specific objective

During the last 10 years, LED lighting has increased its market share to more than 20% in Europe, China and North America. LED lights are now seen as substitutes for all the other light sources. However, LED technology has some drawbacks: (1) the 450 nm peak of white LEDs could potentially create retinal damage (the so called blue-light hazard), (2) being point sources with high intensities, LEDs can be glary, the materials used to reduce glare, increase optical losses and reduce the light output of LED luminaires. Organic LED technology (OLED) does not have these drawbacks, providing that its price decreases, it could challenge the choice of LED technology for indoor lighting in the future. The light emitted by OLEDs has a broader spectrum, this means a light of better quality and a light potentially safer than the one of LEDs (the 450 nm peak is divided by 2). OLEDs are surface sources, this implies that they are non-glary, so there is no need for extra diffusers, this keeps OLED sources thin and does not decrease their light output.

There are technical differences between the two technologies that we just explained, but at the end, the users will make their choice based on their visual preferences and on their feelings. This is why we decided to investigate whether subjects would prefer LED or OLED lighting and if they would feel or perform differently under LED or OLED white light. We decided to focus only on the influence of the spectrum, therefore the LED luminaires were fitted with diffuse panels and looked exactly the same as OLED luminaires. To take into account cultural differences, the experiment was done both in France and Japan.

2. Methods

The room used for the experiment was 3.4 m long, 2.4 m wide and 2.6 m high. The walls were white with a reflection factor of 0.8. In France, opaque curtains were used to fit the dimensions of the room used in Japan. The light panels (a total of 4) were placed vertically on two poles in the middle of one wall. The power supplies and the cables could not be seen by the subjects. LED and OLED panels looked exactly the same, except in depth, but the subjects could not see the difference. The setup reproduced a living room. Subjects were seated in two armchairs on each side of a living room table. Armchairs were rotated by an angle of 30° toward the light panels. Two incandescent luminaires were set next to the armchairs, they constituted the reference light condition.

In France and in Japan, 30 subjects were recruited. They were 15 men and 15 women, from 20 to 30 year old. Four lighting conditions were studied: LED panels at 3000K and 5000K and OLED panels at 3000K and 5000K. They were all set to produce in the eye of the subjects the same irradiance (around 0.185 W/m² from 380nm to 780nm) and the same illuminance (around 60 lux). Subjects came once a week during 4 weeks for an experiment which lasted one hour and a half. Their heart rate was recorded continuously.

The experiment started under the incandescent light condition. Subjects were asked to relax in the armchair and stay still for 6 minutes. This was needed to make sure that the heart rate measured during this period would not be influenced by body movements. Then, during 10 minutes, the subjects were asked to perform a series of tasks (PVT, N-back and Subtraction) to score their vigilance and cognitive performance. This was followed by a new period of 6 minutes dedicated to heart rate measurements. Then, the incandescent light was turned off and one of the four lighting conditions was turned on. After a 5 minute adaptation period, subjects were asked to fill a questionnaire to express their feelings (relax, stressed, motivated…) and judge the lighting condition. Then, they had to perform

3 tasks lasting 15 minutes each (play jigsaw puzzle, read a magazine, play with building blocks). After each task, they were asked to fill a new questionnaire which took them about 2 minutes. Finally, the lighting condition was turned off and the incandescent light was turned on again. After a 5 minute adaptation period, there was a 6 minute period dedicated to heart rate measurements, followed by the 10 minute vigilance and cognitive performance test. This concluded the experiment.

3. Results

The comparison between the scores obtained before exposure to one of the four lighting conditions and the scores after exposure did not reveal any significant difference under any of the 4 lighting conditions which were tested. In other words, a 56 minute exposure to white light either at 3000K or 5000K did not improve vigilance and cognitive capabilities.

The answers to the questionnaire right after adaptation showed that LED panels at 3000K were significantly preferred ($p<0.05$) to LED and OLED panels at 5000K. This was the case both in France and Japan. The difference between the judgment of men and women was never significant.

The answers to the questionnaire at the end of the exposure to the lighting condition did show a significant difference on the subjects' feeling of well-being between LED panels at 3000K (better) and LED panels or OLED panels at 5000K (worse). Unfortunately, this could not be confirmed by the analysis of the heart rate measured before and after the exposure to the lighting condition. There was no significant difference in heart rate reduction between the lighting conditions.

4. Conclusions

This study has shown that 3000K seems to be the colour temperature preferred in France and in Japan for reading and playing. There is no significant soothing effect coming from the white light produced by LED panels or OLED panels, at illuminance levels of 60 lux in the eye. The next step in comparing LED and OLED technology will focus on the effect of exposure to coloured light: soothing effect? acceptance?

PRESENTED POSTERS

Session PS1
Presented Posters (D1)
Tuesday, October 24, 14:00–14:40

PP01 (PO12)

COLOUR APPEARANCE OF OBJECTS UNDER OPTIMIZED SPECTRA

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Abstract

1. Introduction

The colour appearances of objects are determined by the human visual system, the spectral power distribution (SPD) of a light source, and the reflectance characteristics of objects. Objects reflect only some of the incident light on their surface, while the absorbed light turns into heat and does not contribute to visibility. This absorbed energy can be considered loss for illumination purposes.

Emerging technologies, such as light emitting diodes (LEDs), offer unprecedented control over the SPD of light sources. Since the spectral output of the new technologies can be controlled, it is possible to minimize the energy absorption, by optimizing the spectrum of a light source to the object reflectance, without altering colour appearance. In this study, the potential energy savings from optimized spectra and colour appearance of commonly found objects was investigated computationally and experimentally.

2. Methods

The colour appearance of 10 real object of different hues (a cola can and a tomato for the red hue, a mandarin and a carrot for the orange hue, a post-it note and a lemon for the yellow hue, a Granny Smith apple and a lime for the green hue, and a container of creme moisturizer and a blueberry for the blue hue) was calculated in CIE 1976 $L^*a^*b^*$ colour space. Two reference white light sources were considered: a phosphor coated LED (pcLED) and a phosphor-coated LED with an additional red peak (pcLED+red). Iteratively simulated test SPDs were generated by mixing nine narrowband LEDs of different magnitudes. Test SPDs that maintained the object colour appearance and resulted in the greatest reduction in energy consumption were selected to be tested in laboratory settings.

Two experiments were conducted to investigate the colour appearance of five of the ten real objects under optimized spectra selected from the computational study. Twenty-one naïve subjects, aged 18 to 40 years, were asked to judge the naturalness and attractiveness of the stimuli (i.e. tomato for red, mandarin for orange, lemon for yellow, Granny Smith apple for green, blueberry for blue) in two separate experiments. In a two-alternative forced choice task, objects were placed in two side-to-side black booths 1.5 m from the observers. One of the stimuli was lit by the reference light source (pcLED or pcLED+red), and the other was lit by one of the six test SPDs. The different test SPDs induced differences in the colour appearance of the illuminated objects, ΔE^*_{ab}<1.0, ΔE^*_{ab}=1-3, ΔE^*_{ab}=3-5, ΔE^*_{ab}=5-7, ΔE^*_{ab}=7-9 and ΔE^*_{ab}=9-15. These colour differences were primarily increases in chroma; hue and lightness differences were limited. Each test SPD was presented 10 times in a random order, resulting in 60 trials for each object and each reference light source. Each participant completed a total of 600 trials. Test and reference light sources alternated between the booths to reduce bias, and the luminance was constant to avoid impact from the Hunt effect and the Bezold-Brucke hue shift.

3. Results

The computational analysis showed that energy savings up to 15% are possible without shifting object colour appearance. When a slight colour difference was permitted, energy savings could increase up to 19%. Red objects resulted in the lowest energy savings, especially when the reference light source was pcLED+red, due to its spectral peak at the longer wavelengths.

The data from the experiments further suggested that spectrally optimized lighting systems could reduce energy consumption without negatively impacting object appearance. The coloured objects appeared equally natural and attractive under optimized test SPDs and reference light sources, especially when the colour differences between the objects illuminated by the test and reference

sources were low. Some increases in object chroma did reduce the perceived naturalness of the objects.

When illuminated by the chroma-enhancing test SPDs, the objects were reported to appear more attractive than natural. This is consistent with other research that suggests a distinction between naturalness and attractiveness of object colours, as well observer preference for saturated colours.

Overall, the test SPDs did not negatively impact object appearance, except for the tomato stimulus. The translucency of the tomato resulted in colour appearances that deviated from colorimetric predictions. The strongly directional light used in the experiments induced a perceived border of light between the top and bottom half of the tomato, which made judgments difficult for observers.

4. Conclusions

The computational and experimental data show that reducing energy consumption by optimizing light source spectrum to real object reflectance is possible with a caveat (i.e., translucent nature of objects). Most of the optimized spectra rendered object colours to be equally natural and attractive to their appearance when illuminated by a reference source. The results show that colour differences as high as ΔE^*_{ab}=15 can be induced in object colour appearance without reducing perceived attractiveness, which indicates that higher energy savings could be achieved without causing user dissatisfaction. However, the translucent nature of some objects may alter their colour appearance under optimized spectra. The effect of optical surface properties on the perceived colour appearance of objects by optimized spectra should be investigated.

PP02 (PO13)

CHROMATIC DISCRIMINATION UNDER DIFFERENT STATES OF CHROMATIC ADAPTATION

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Abstract

1. Motivation, specific objective

The objective of our study was to examine the effect of different states of chromatic adaptation on the adapted white point based on chromatic discrimination measurements.

2. Methods

In the study 26 normal colour observers performed the trivector test of the Cambridge Colour Test in order to measure the just-noticeable stimuli on the three confusion lines under different states of chromatic adaptation. Two states of chromatic adaptation were achieved applying colour filters. The tests were accomplished without filter as a reference.

The chromaticity of the background was shifted from the neutral point of the display towards the chromaticity points of the filters in the CIE (1976) u'v' diagram, calculated based on their transmission spectra. The test directions were set to the confusion axes towards the Protan, Deutan and Tritan points. The minimum and maximum luminance values of the pseudoisochromatic plates were set considering the spectral transmission of the applied filters in order to reach equi-luminance among the filters.

The factors (and their levels) of the statistical analysis were the followings: state of adaptation (no filter and the two different filters), analysed confusion line (Protan, Deutan and Tritan), and background chromaticity (distance from the neutral point towards the chromaticity point of the filter and in the opposite direction).

3. Results

The analysis shows that adapting to the filters affects colour discrimination depending on the background chromaticity compared to the results with the reference test. In our results we estimate the change in chromaticity of the background for best colour discrimination.

4. Conclusions

Our work may contribute to the understanding of colour discrimination issues when chromatic adaptation is involved and to the design of chromatic stimulation when the background of the adaptation differs from the neutral point.

PP03 (PO14)

HOW CHROMATICITY ALONE AFFECTS SOURCE PREFERENCE?

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Abstract

1. Motivation, specific objective

Recent studies suggested that sources with chromaticities slightly below the blackbody locus were preferred by human observers. The preferred light settings identified in these studies, however, had high values in colour fidelity and colour gamut measures. The preference was speculated to be caused by colour rendition, rather than chromaticity. This study was specifically designed to test whether chromaticity alone affects source preference by keeping the colour rendition of sources (i.e., the IES TM-30-15 R_f, R_g, and the Colour Vector Graphic) similar.

2. Methods

The light settings in this study were carefully designed using a genetic algorithm and produced using an 11-channel spectrally tuneable LED lighting device, comprising two levels of nominal CCT. Five light settings were created for 3000 K, with Duv from + 0.01 to - 0.03, Rf of 65 ± 1, and Rg of 109 ± 2. Seven light settings were created for 6500 K, with Duv from + 0.03 to -0.03, Rf of 83 ± 2, and Rg of 101 ± 1. The gamut shapes of the light settings were also maintained as similar as possible. All the light settings were calibrated to provide a uniform illumination at 300 ± 10 lux to the scene, which included an oil painting, flowers, soda cans, fruits, and snack boxes. A black felt was used as the background, trying to minimize the effect of back wall on observers' evaluations.

Twenty-three colour normal observers within the range of 20 and 24 years of age were recruited for the experiment. The pairs of light settings were presented in a rapid-sequential mode and were alternated every four seconds. Only the settings that had a same CCT level and adjacent Duv levels were compared. The observers were asked to compare the pairs of light settings and to evaluate whether there was a noticeable colour difference under the two light settings. If s/he perceived a noticeable colour difference, they were then asked to judge which light setting was preferred and which colour affected their judgement. In order to counter a possible interval bias (or order bias), each pair of the light settings were presented in two orders (e.g., AB and BA).

3. Results

For nine of the ten pairs of light settings, the colour appearances of the objects were perceived different under the two light settings, and the observers had a preference between the two light settings for eight pairs, as tested using a Chi-Square Goodness-of-Fit Test with the $\alpha = 0.05$ level. For the 3000 K pairs, the setting with a lower Duv value was generally preferred, except no preference was rated between Duv values of -0.02 and -0.03. For the 6500 K pairs, the light settings with Duv values of 0 and -0.01 were the most preferred and no preference was found between these two light settings. White was the most frequently selected colour which affected the observers' evaluations.

CIECAM02 was used to verify the similar colour appearance of the objects under the light settings, as there was a mismatch between the observed objects and the test colour samples used in the colour rendition calculation.

4. Conclusions

The result of this study suggested that sources with chromaticities below the blackbody locus were generally preferred under the investigated viewing condition and adaptation condition. Coupled with past studies, such an effect was especially strong for sources with a lower CCT level (e.g., 3000 K in this study, 2200 K and 2700 K in a past study). Further study is necessary to investigate the effect of

chromaticity on source preference under longer exposure viewing conditions and against different backgrounds.

PP04 (PO15)

A PHYSICALLY-BASED INTERPRETATION OF THE HUE OF SURFACES

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Abstract

1. Introduction

The perception of surface colour includes attributes of hue, saturation (chroma), and lightness. Among these, hue is especially useful, because unlike lightness and chroma, it correlates directly with the presence of specific colorants, and thus is diagnostic of the underlying chemical composition of a surface, indicating, for example, whether certain foods are fresh and healthy. However, hue is also the most difficult dimension of colour to define. Current definitions are merely circular (hue is defined by which hues are present) and moreover provide little insight into the physical correlates of hue. The goal in this project was to develop a physically-based interpretation of the hue of surfaces in order to explore the spectral properties encoded and represented by hue.

2. The current definition of hue and the need for improvement

The International Commission on Illumination (CIE) defines hue as the "attribute of a visual perception according to which an area appears to be similar to one of the colours red, yellow, green, and blue, or to a combination of adjacent pairs of these colours considered in a closed ring." Further, the terms red, yellow, green, or blue are described as the four "unique hues". Thus, hue is the attribute of visual perception that differs between areas that have different hues. A self-referencing definition such as this does not say what hue actually *is*. This suggests the need for a better interpretation that is simple, accurate and physically meaningful.

Ideally, this would help to explain how and why hue perception is so stable and accurate that it enables most people to discern roughly 40 different hues, largely independent of lighting conditions. Current colour appearance models, such as CIECAM02, are able to predict hue fairly accurately, but they do not explain what hue is, nor how our colour vision system is able to perceive it so well. Furthermore, such models are very complex. CIECAM02 requires the use of colour matching functions and the illuminant spectrum (at least 320 numerical values), and it comprises 14 equation groups involving 39 arbitrary numerical parameters that were adjusted to best fit experimental data. Within this context of complexity, little understanding can be gleaned as to the meaning of hue.

In contrast, the goal of this study was a physically-based interpretation of hue that is simple, accurate, and which clearly explains its meaning.

3. A simple mathematical interpretation of hue

A strong correlation is found between the perceived Munsell hue of a surface, θ_M, and a new mathematically-determined hue, θ_{math}, which is based on the ratio of the effective curvature and the effective slope of the surface spectral radiance factor $R(\lambda)$ within the visible band.

θ_{math} is calculated using just four parameters - three wavelength values, λ_c, λ_Δ, λ_m, which summarize the human visual response, and an angle θ_0 that adapts to the arbitrary zero point of the Munsell system. Notably, the calculation uses neither colour matching functions nor cone fundamentals nor an illuminant spectral power distribution.

θ_{math} is calculated in two simple steps:

(a) Over the wavelength range from λ_c-λ_Δ to λ_c+λ_Δ, a second order polynomial (i.e. a portion of a parabola) is fit to $R(\lambda)$, using the least square error method, yielding a curvature value, c, (in units of nm^{-2}) and an average slope value s (in units of nm^{-1}).

(b) θ_{math} is based on the polar angle in a dimensionless 2D plane: $\theta_{math} = \theta_0 + \text{atan2}(s\lambda_m, -c\lambda_m^2)$.

Note this approach is related to principal components analysis (PCA) in terms of representing variations in spectra by the variations in a small number of dimensions. However, our analysis differs from PCA in that the dimensions are defined theoretically rather than empirically, and because the goal is to model the perceptual correlate of the spectrum (hue) rather than to approximate the physical spectrum itself.

To evaluate its accuracy, θ_{math} was evaluated for 256 uniformly distributed Munsell colours. Over that set, the rms value of the difference (θ_M - θ_{math}) was minimized by varying λ_c, λ_Δ, λ_m, and θ_o. The optimum result was sharply defined and yielded an excellent correlation coefficient between θ_M and θ_{math} of R^2= 0.995, and an rms hue angle difference of 0.12 rad. As a comparison, the angular separation between adjacent hues in the Munsell system is $\pi/20$ (about 0.16 rad), which is barely discernible. Therefore the observed fit is about as good as could be expected for perception-based data. The four parameters were narrowly constrained by the optimization process, with the result being: λ_c = 520 nm, λ_Δ = 86 nm, λ_m = 42 nm, and θ_o = 1.41 rad.

As mentioned, θ_o has no physical meaning – it merely aligns to the arbitrary zero hue of the Munsell system. However the three wavelength parameters do have physical meaning – they arise from the centres of sensitivity of the three human cone cells: λ_L = 561 nm, λ_M = 536 nm, and λ_S = 450 nm. A recently introduced two-stage subtractive colour vision model predicts that λ_c, should be about ($\lambda_L/4+\lambda_M/2+\lambda_S/4$) and this match is found to be almost exact. The evaluation band should include most of the cone response sensitivity, and λ_m should be roughly λ_Δ /2, which is the case. Thus, θ_{math} makes sense both physically and physiologically.

4. Conclusion

A simple physically-based interpretation of hue has been developed. It accurately matches the perceptually-determined hues of the Munsell system. This is probably not a coincidence. More likely, the visual system evolved to assess the ratio of curvature to slope in a surface's spectral radiance factor, because this usefully correlates with the chemical colorants in the underlying material, largely independent of lighting intensity or colorant concentration.

PP05 (PO17)

DEVELOPMENT OF WHITENESS FORMULA BASED ON CIECAM02

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Abstract

1. Motivation, specific objective

The aim of the study was to develop a new whiteness index which correlates to perception of whiteness on textile samples. Former TC 1-77 recommend modifications of the existing CIE Whiteness and Tint Equations to extend their application to illuminants other than D65 and review the restrictions imposed on the validity of the equations to samples that are measured on the same instrument at nearly the same time, and review the colorimetric limits hitherto set. New TC 1-95 follows these recommendations, validity of CIE Whiteness formula mainly. Nevertheless, CIE Whiteness formula similarly as Ganz-Griesser linear whiteness formula are in principle two-dimensional what complicate understanding of resulting values in industry. Since CIECAM02 colour appearance model begins to be used widely, it is urgent to establish a whiteness formula in CIECAM02 that has well correlations with observers' evaluations.

2. Methods

Psychophysical experiments were conducted by a panel of 10 observers under a standard viewing condition at viewing box equipped by D65 daylight simulator (classified into category D as D65 simulator) as well as under alternative light sources such as white LEDs based on blue and violet chip. Relative spectral power distribution of the light source was obtained from spectral radiance of the plaque containing pressed certified Barium Sulphate white standard produced by Merck. Plaque was placed in the center of the bottom surface of the lighting cabinet and spectral radiance was measured by Photo Research PR-740 spectroradiometer as well as spectroradiometer OceanOptics STS-UV-L-25-400. light source is.

In the experiment was used set of 60 white textile samples, which were divided into six randomly fulfilled group each containing 10 samples. CIE Whiteness of tested samples varies from 60 till 170 and tint values were in range of -8 to +7 units.

Total radiance factor and computed luminescence factor of each sample was derived from CIBA White Plastic Scale, which was used during calibration of Datacolor SF600+ spectrophotometer in de:8° mode. For comparison and correction was measured the same sample set by using bispectral method on spectrofluorimeters JASCO FP-8600. All samples were measured also by using of X-RITE spectrophotometer ERX30 with 45°a:0° geometry and numerical method of UV adjustment. For a measurement, the sample is illuminated by white light (Xenon flash lamp, daylight) and light without UV component. Measured area is 12 mm diameter. Measured results are reported with true 1 nm spectral measurement resolution from 330 nm to 730 nm. As UV checker was used UV standard plastic plaque GM27006980, sn STD35 with CIE Whiteness SCE = 125.1, expiration date 9/2016. The recommended ultraviolet calibration routine by the manufacture was applied before measuring sequence. Every sample was measured four times.

All of the visual evaluations were conducted in completely darkened room by 10 colour normal discriminating observers with 5 replications. Method of assessment was ordering of evaluated samples from highest to lowest visually assessed whiteness and pair comparison method; when observers compare, which sample appears whiter. Together was made 45 pair comparison per each replication by one observer. On the end was used matching method, when observer choose nearest white standard from newly prepared CIBA cotton white scale. Obvious delay between replication was 1 day and ordering of samples was randomized.

Various existing whiteness indices were compared with regard to their ability to measure the perceived whiteness of whitened textile samples. The Spearmen rank coefficient, wrong decision criterion method (WDC) and STRESS was used to determine the best index for whiteness measurement.

Based on projection of measured data into CAM02 was derived new one dimensional whiteness formula allowing comparison of assessed whiteness of green and red tinted white samples.

3. Results

Analysis of the visual estimations was conducted by using of Spearman's rank correlation coefficient, which is defined as the Pearson correlation coefficient between the ranked variables. It is important to assume that Pearson's correlation assesses linear relationships; Spearman's correlation assesses monotonic relationships (whether linear or not). If there are no repeated data values, a perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other. Intuitively, the Spearman correlation between two variables will be high when observations have a similar (or identical for a correlation of 1) rank (i.e. relative position label of the observations within the variable: 1st, 2nd, 3rd, etc.) between the two variables, and low when observations have a dissimilar (or fully opposed for a correlation of -1) rank between the two variables. In order to study the limitations factor of CIE whiteness formula on the results, where highly tinted samples appear as more reddish (T<-2) and greenish (T>4) in comparison to others as 30% of all set. All observers attending in panel of observers were having tendency to separate these samples from ranked set if was used ranking method, where observers ordered samples from highest to lowest visually assessed whiteness. This is interesting result because some of red tinted samples aren't highly tinted in point of view of CIE tint. This problem was partially reduced by pair comparison method, where observers evaluate only if sample is whiter or darker. Computed Spearman's rank correlation of both assessing methods shows high consistency of panel of observers and rS = 0.93 confirms legitimacy of both methods. Last matching method was by observers most preferred method, which allows evaluation of assessed tint by grey scale method. As important result, it is necessary to point out also, that measured variability of this method was approximately twice time lower in comparison to previously mentioned assessments.

A new whiteness formula (WI CAM02) was developed by optimizing of projection the original CIE whiteness formula into CAM02 colour appearance model and it was found that WI CAM02 gave the best performance for predicting whiteness based on the colour matching and ranking visual results.

4. Conclusions

In this paper, the performance of the selected whiteness formulae was compared on set of white textile fabrics visually assessed under three different light sources. Any known tested whiteness formula correlates strongly these tinted samples. Samples slightly greener than the white scale were preferred contrary to redder tinted samples.

From experimental study, it is revealed that new CIE CAM02 based whiteness index WI CAM02 is appropriate for the prediction of whiteness of tinted textile fabric under different light sources.

PP06 (PO18)

PERCEPTION OF CORRELATED COLOUR TEMPERATURE

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Abstract

1. Motivation, specific objective

The Correlated Colour Temperature (CCT) is an important quantity for specifying the tone of white light (warm to cool) in lighting applications and others (display and photography). CCT is defined, by International Commission on Illlumination (CIE), as the temperature of the Planckian radiator having the chromaticity nearest the chromaticity associated with the given spectral distribution on a diagram where the (CIE 1931 standard observer based) u', 2/3 v' coordinates of the Planckian locus and the test stimulus are depicted. This means that the CCT is calculated using the (now obsolete) CIE 1960 u,v diagram, though the current CIE recommendation for uniform colour space is 1976 u',v' diagram. Questions are raised on why the obsolete u,v diagram is still used to determine the CCT. The distance to the Planckian locus (Duv defined in ANSI C78.377) is also calculated from u,v coodinates following the definition of CCT, which causes confusion with delta u'v' used to specify colour tolerances of light sources. Available literature does not justify the use of u,v coorinates over u'v' for CCT.

This research investigates which coordinates, (u,v), or (u', v'), agree more closely with visual perception to calculate CCT when the illumination source chromaticity is deviated from the Planckian locus.

2. Methods

A double-lighting booth with spectrally tuneable light sources was used for the experiment. The source has 16 channels of light emitting diode (LED) spectra controlled with a computer control program that allows colour settings by entering CCT and Duv values. The experiments were conducted at two CCTs, 3000 K and 5500 K, and at two Duv levels -0.015 and +0.015, therefore, four chromaticity points of test light. The inner wall surface of the booth is painted with neutral grey. A white target sheet (~28 cm x 28 cm) made of high reflectance diffuse material at the bottom of the booth so that subjects could compare the colours of the white sheet on both sides, while the surrounding area of the booth was used for subject's adaptation. The right side of the booth was set to a test light, which was 3000K with Duv +0.015 or -0.015. The left side of the booth was set for nine points on the Planckian locus, where point No.1 has the highest CCT (3384 K) and No. 9 has the lowest CCT (2773 K). The point No.5 (mid point) is at exactly the same CCT (3000 K) as the test lights based on the current definition of CCT (calculated based on the 1960 (u,v) coordinate), point No. 3 (3179 K in the current CCT definition) is at the same CCT of the test light at D_{uv} = -0.015 calculated based on the CIE 1976 (u',v') coordinate, and No. 7 (2882 K in the current CCT definition) is at the same CCT of the test light at D_{uv} = 0.015 calculated based on the (u',v') coordinate. 12 subjects having normal colour vision participated in the experiment; 8 males and 4 females, from 20 to 71 years old, 7 white and 5 Asians.

To handle chromatic adaption appropriately, two methods were used in our experiment. The first method is the *non-haploscopic method*, in which a subject directly compared different Planckian lights (left side of booth) against the Test light (right side) using both eyes. The second method is the haploscopic method, where the subject's left eye and right eye are adapted separately to the light at each side of the booth. With this method, the colours of the two lights will appear closer colours due to chromatic adaptation of each eye.

In non-haploscopic method, first, one of the Planckian point, *m* (between No. 2 to No. 8 of the 9 points), was selected. Then a subject's eyes were adapted under the adapting light at mid-point between a test light and Planckian point, m). After adaptation, the right booth was changed to the test light and the left booth was changed to the Planckian point *m*-1 or *m*+1 in random order. Each subject was asked to select which point (*m*-1 or *m*+1) looked closer to the test light. In total, there were 6

adapting points and 6 pairs of Planckian points to compare with each test light. In haploscopic method, first, the subject's left eye was adapted to Planckian point m and right eye to test light (Duv -0.015 or +0.015), then Planckian point *m*-1 and *m*+1 were presented sequentially an repeatedly. Subjects answered which point (*m*-1 or *m*+1) on left side looked closer to the test light (right side).

3. Results

The subjects' responses on which light he or she chose were sorted in the order from Planckian adaptation point No. 2 to No. 8. The percentage that subject chose higher CCT light in the pair would ideally change from zero (No.2) to 100 % (No. 8). The 50% crossover point is considered to be the point where the Planckian light was perceived closest to the CCT of test light. The experimental results followed such a trend in many cases, from the crossover CCT points were estimated, and judged whether these crossover points were closer to the CCTs from (u,v) or (u', v') coordinates. All results for 3000 K (Duv -0.015, +0.015, non-haploscopic, haploscopic) showed that crossover points were closer to those from the (u',v') coordinates. 5500 K results had some variations and the average result was considered to be between (u,v) and (u',v'). There were no clear distinctions in results between non-haploscopic method and haploscopic method, some subjects reported that judgement was easier with haploscopic method.

4. Conclusions

With limited experimental conditions (range of CCT and Duv) and number of subjects used in this experiment, the overall results show that perceived CCT agrees better with the CCT calculated from the 1976 (u',v') coordinates. Further experiments with more number of subjects and more CCT points are desired to verify the results of this experiment.

PP07 (PO19)

VISION EXPERIMENT ON CHROMA SATURATION PREFERENCE IN DIFFERENT HUES

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Abstract

1. Motivation, specific objective

It has been identified by CIE that, for accurate evaluation of overall colour quality of light sources for lighting, not only colour fidelity but also the aspect of colour quality related to preference is also critical. It is well known from previous studies that increase of chroma is a major factor for colour quality preference, and a certain level of oversaturation of chroma of objects seems to be generally preferred. To measure the level of chroma increase by a light source, gamut area measures are often used to evaluate colour preference aspects. However, the gamut area accounts for chroma increase or decrease regardless of direction of hue. Experiences in lighting indicate that the effect of chroma increase on colour preference varies significantly with hue, and one gamut area number would not indicate colour preference accurately for all cases. In particular, red is considered to be most dominant in colour quality preference, but such scientific data have not been available. This work aims to obtain such experimental data on colour preference of lighting depending on chroma increase in different hue directions, toward developing more accurate preference measures than simple gamut area.

2. Methods

Vision experiments were conducted to evaluate colour quality preference with chroma increase of illuminated objects in different hues, using a 25-channel spectrally tunable lighting facility (STLF) simulating an interior room. A coffee table was placed in the center, on which two plates of various fresh fruits and vegetables (strawberries, red apple, tomato, orange, bananas, green apple, green grapes, green pepper, lime, lettuce, purple grapes, red cabbage) and a blue package of popular snack. 19 subjects participated in the experiments. Each subject evaluated their preference on colour appearance of the target objects under illumination of 11 different spectra of different gamut shapes compared as pairs in all combinations (55 pairs total), which formed an experimental session. The experiments with fruits and vegetables were conducted at four correlated colour temperature (CCT) conditions; 2700 K, 3500 K, 5000 K (on Planckian locus) and 3500 K below Planckian locus (D_{uv}= -0.015). In addition, experiments on their skin tones (hands and face in a mirror) were conducted separately at 3500 K. The experimental session at 3500 K for fruits and vegetables was repeated to check reproducibility. Thus, six experimental sessions were conducted for each subject, requiring approximately two and half hours in total for each subject.

The 11 spectra for each CCT were set for different chroma shifts of red, green, yellow, and yellow-green Munsell samples, with -5 to 15 ΔC^*ab differences from the neutral saturation (reference illuminant used in the Colour Rendering Index). A reference light was set to be as close as possible to the reference illuminant. The CRI Ra values of all lights ranged from 63 to 98. Illuminance was set at 250 lx for all conditions. The spectra of STLF lights were tuned so that, when setting chroma shifts of one sample (e.g., green), chroma of other colours (e.g., red) was kept constant (in most cases) so that the saturation effect of only one colour could be evaluated.

The 55 pairs were presented in random order. Each pair of light was presented sequentially and repeatedly as “A” and “B”, for several seconds each, and subjects answered which light, A or B, he or she preferred (forced choice), when viewing targets in the room.

3. Results

From the raw results of 55 pair comparisons for 19 subjects, first the percentage that “A” was chosen for each of 55 pairs were calculated. For example, in a pair of ΔC^*ab = 5 (“A”) and ΔC^*ab = 0 (“B”) of a red sample at 3500 K, 89% (17 out of 19) of subjects preferred A. These data were then converted to z-scores, which provide a score in the relative scale of preference for each of 11 lights based on

statistical analysis of results of all pair comparisons – a method known in psychophysics. In this case, z-score = 0 is the mid point of the scale; positive numbers mean preferred, and negative numbers mean disliked, proportional to the magnitude of value. Then, all the z-score values were normalized to the reference light (neutral) so that preference values are shown with respect to the reference light.

The grand average of all results (fruits and vegetables at all CCTs and skin tone at 3500 K) show that normalized z-scores for red samples for ΔC^*ab = -5, 5, 10, 15 were -0.63, 0.59, 0.71, 0.54, respectively. For green samples, z-scores were -0.15, 0.07, 046, for ΔC^*ab = –5, 10, 15, respectively. For yellow samples z-scores were 0.05, 0.04 for ΔC^*ab = -5 and 5. For the yellow-green sample, z-scores were 0.00 for ΔC^*ab = 8. The results for skin tone and fruits and vegetables were similar. There were small variations among different CCTs but not significant.

4. Conclusions

The results verified that the chroma increase of red colour has the dominant effect on colour preference among all colours. The results for chroma increase and decrease of red colours agreed well with the results of previous studies. The effect of green saturation is the second, but it is much less sensitive than red, requiring a large chroma increase (ΔC^*ab=15) to be effective on colour preference. The effects of yellow and yellow-green are found insignificant.

In this experiment, it was hoped to test all hues, but chroma control was limited to only red, green, yellow, and yellow-green, partially due to the performance of STLF and possibly due to theoretical reasons. Yellow shifts were made only in small ranges, as there were significant hue shifts. Chroma control of blue (only) was not possible. Further experiments are desired to examine preference in more hue colours possibly with some other experimental techniques.

PP08 (PO20)

OPTIMAL LED SPECTRA

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Abstract

1. Motivation, specific objective

Light-emitting diodes (LEDs) have become one of the most important light sources. More and more applications of LEDs are including indoor lighting, outdoor lighting, transportation lighting, etc. Besides, the standard light sources for the measurement and the calibration of the radiometry and the photometry are also of great necessity to apply for the LED light sources. Therefore, the optic properties of the LEDs are very essential subject for the applications. Especially, how to standardize the spectrum of the LEDs must be the most urgent subject for the time being.

However, the composition of the LED spectra is complicated and not well clarified yet so far. For the most common LED light sources, it consists of a blue GaN LED die and the yellow YAG phosphor. In principle, there are at least two different kinds of mechanism for forming the emission spectra. One mechanism is the generation-recombination of the electron-hole pairs in the band structure of the blue GaN LED die. According to the basic semiconductor theory, the emission spectrum of the blue GaN LED should be able to be completely determined. Unfortunately, there might be some other unknown or some complicated hidden effects working such that the theoretical emission spectrum based on the band theory is still seriously deviated away from the practical measured spectrum. The other mechanism is the excitation-emission effect in the phosphors. The quantum single configurational coordinate model (QSCCM) proposes the Gaussian spectral function for the emission spectrum. Meanwhile, it still happens the re-absorption and the re-emission phenomena. Under such a circumstance, it is believed that the phosphor emission spectrum should be much more complicated than the one as QSCCM suggesting. Moreover, the phosphors in the applications are not limited to YAG. How to have general way to describe the emission spectra of the LED light sources becomes a practical and urgent subject to explore with. Then, the optimal LED spectra can be obtained.

2. Methods

To find the optimal LED spectra, we take two steps of analysis to approach the goal. The first step is to find an empirical function to lineate the LED emission spectrum with few characteristic parameters. As compared with a large amount of real LED spectra, the empirical spectra function is then confirmed. According to the previous reports, the candidates of the spectral functions for the blue LED dies are the sum of two Gaussian functions with 6 characteristic parameters and the asymmetric Gaussian function with 4 characteristic parameters. For the sake of the convenience and the accuracy both, we prefer to the latter one with lesser parameters but still providing with enough accuracy.

Besides, the phosphor emission spectrum follows the QSCCM suggestion. Furthermore, the suggested Gaussian spectral function for the phosphors is in term of the frequency rather than the wavelength of the light. We convert the QSCCM Gaussian spectral function into the alternative function in term of the wavelength instead. Fortunately, it is found that the re-absorption and the re-emission phenomena obey the behaviour of the alternative spectral function predicting.

In such a way, we now have a general spectral function with 10 characteristic parameters to precisely describe the full emission spectrum of a LED light source. Among them, there are 3 characteristic parameters for the center wavelengths, 4 characteristic parameters for the spectral bandwidths, and 3 characteristic parameters for the relative radiometric strengths. By appropriate tuning the 10 characteristic parameters, any one practically measured LED spectrum can be approached with high accuracy.

The second step is the optimization process. With the pre-determined CCT and the normalization to the light power, the 3 characteristic parameters for the relative radiometric strengths are thus determined, too. The rest 7 characteristic parameters are further approached by an optimization

algorithm calculation such that the merit function reach its extremes. Then, the optimal LED spectrum can be obtained. The details of the merit function can be depend on the applications. For example, the maximal CRI, the highest optic efficiency and so on.

3. Results

After the comparison with more than 1,000 various LED spectra from different manufacturers, our spectral function for the LED light sources works very well. Furthermore, it does not only work very well for the blue LED with yellow phosphor, but also even for the RGB LED combo, the UV LED with RGB phosphors, the B/R LEDs with green phosphor, etc.

For simplicity, we optimize the case of the blue LED die with yellow phosphors only. By the optimization evaluation, the corresponding characteristic parameters are found and the optimal LED spectra for the highest CRI of warm white and cool white are thus obtained.

4. Conclusions

In this work, we have successfully obtained the optimal LED spectra for the highest CRI of warm white and cool white. By developing an empirical spectral function to describe the LED spectra with high accuracy and optimizing the empirical spectral function with a specified merit function, the optimal LED spectrum can be easily evaluated. Actually, a series of the optimal LED spectra for the highest CRI of various CCTs can also be concluded. Besides, the obtained optimal LED spectra can apply for the standard light sources for the measurement and the calibration of the radiometry and the photometry.

Session PS2
Presented Posters (D2)
Tuesday, October 24, 14:00–14:40

PP09 (PO47)

LASER DRIVEN WHITE LIGHT SOURCE FOR BRDF MEASUREMENT

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Abstract

1. Objective

A bidirectional reflectance distribution function (BRDF) defines the reflectance properties of a surface by specifying the amount of radiance incident from one direction and the reflected into another direction, with respect to the surface normal. In computer graphics or other photorealistic studies BRDF measurement plays a very important role. Measurements were done to obtain the BRDF measurement of different kinds of samples based on our setup which consists of a new laser driven broadband light source (UV-VIS-NIR), spectroradiometer and sample holder stepper motor in a dark UV-protected environment. Here, we introduced BRDF measurements using a special kind of light source which has a bright, stable, broad spectral range and well collimated light output to give a very good angular resolution.

2. Method

The measurement of BRDF of a material is mainly dependent on a light source illumination and detector viewing direction. In our method, the light source used provides a bright illumination across the UV-VIS-NIR range with high spatial and power stability. In addition, the light source is well collimated by off-axis parabolic mirrors. Hence, the complete collimated light source used in our BRDF measurement consists of a laser driven light source with spectral emission between 190 and 2100 nm, collimating off-axis parabolic mirrors and a UV filter. The detector was spectroradiometer coupled with a high angular resolution collimating fibre coupler and was calibrated for visible wavelength region. We have used a stepper motor with two freedom of motion as a sample and detector mount. The whole measurement system was controlled by a LabVIEW controlled PC. The UV filter was positioned immediately after the light source in order to remove the UV-C part for safety. The measurement room was kept at a temperature of 21°C using an air conditioning system. In our measurement method, the light source is fixed during the measurement. The incoming and outgoing direction of the light is changed by the rotation of the sample and the detector. The samples we used are diffuse white sample, mirror and different anodized aluminium samples. Since the sample is mounted on a small rotating stage, its size is limited to 8cm in diameter. We have done in-plane measurements for four angles of incidences (15°, 30°, 45° and 75°).

3. Results

The complete light source consists of laser driven light source in combination with a collimating optics to give a very bright light with a broad spectral range. Results will show the properties of the light source in the BRDF setup. The spectral power distribution, spectral radiance and the stability over measurement time, and the obtainable degree of collimation using off-axis parabolic mirror will be shown. These properties of the light source give a very high signal to noise ratio and angular resolution for BRDF measurement. In addition to our light source, our detector used a collimating off-axis parabolic mirror fibre coupler with a very good angular resolution, and we managed to obtain a FWHM (Full Width-Half Maximum) as small as possible with a high signal to noise ratio. We have measured BRDFs for diffuse and non-diffuse samples.

4. Conclusions

The light source we used is optimized for high brightness, since it is radiated from a very small plasma spot and this provides a high spectral radiance. Furthermore, it is a broad-spectrum light with high spatial and power stability. This property makes it very effective for BRDF measurement especially where a very high signal to noise ratio and high angular resolution is needed. For our final paper, we will present some more measurements on different samples and present the result in relation to the light source we used.

PP10 (PO48)

CHARACTERIZING AN INTEGRATING SPHERE PHOTOMETER FOR MEASUREMENTS OF SOLID-STATE LIGHTING PANELS

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Abstract

1. Motivation, specific objective

During the recent years, solid-state lighting products (SSLs), often based on white light emitting diodes (LEDs), have replaced the majority of conventional incandescent and fluorescent lamps and luminaires used in general lighting. To accurately determine the luminous efficacy (lm/W) of new SSLs in product development, measurement of their total luminous flux (lm) is of high importance.

A common method to measure the luminous flux of SSLs is to use a 4π integrating sphere photometer, in which the lamp under test is attached in the centre of the sphere using a suitable sample holder. For accurate luminous flux measurements with integrating spheres, various spectral, spatial and geometrical correction factors are needed. Typical correction factors required in luminous flux measurements include spatial non-uniformity, spectral self-absorption and spectral mismatch corrections.

Commercial SSLs utilize LED components in various forms. Due to the small size of LEDs, building lamps and luminaires with various different geometrical properties is possible. Many new types of LEDs have appeared on the market, including large area chip-on-board, strips and filaments, as well as large-area panels built using arrays of LEDs with suitable diffusing elements or organic light emitting diodes (OLEDs). OLEDs typically have large light emitting surfaces, some of which can be transparent or even bent. As LED and OLED products have very distinctive spectral properties that often depend on the angle of observation as well, the spectral responsivity of the integrating sphere in different positions on the sphere surface may introduce additional errors in the measured luminous flux, especially in the case of directional light sources. Therefore, it is advantageous to measure the spatial responsivity distribution function (SRDF) of an integrating sphere spectrally to allow determining spectral and spatial correction factors and the related uncertainties of the measurements more accurately.

2. Methods

In this work, a 1.65-m integrating sphere with coating reflectance of 98 % was characterised for measurements of OLED panels of different sizes. Typical spectral and photometric errors, as well as uncertainties related to the measurements of large-area SSLs in different geometrical alignments were determined. In the characterisation of spectrally resolved spatial non-uniformity and spectral throughput of the integrating sphere, a commercially available integrating sphere scanner was used. The LED used in the scanner was changed to a one with higher luminous intensity and extended spectral range at longer wavelengths to reduce the noise in the calculation of correction factors for warm white LEDs and OLEDs typically found on the market. The output beam of the modified LED sphere scanner was characterised using a near-field goniospectrometer.

For the test measurements, a total of six different OLED panels, from four different manufacturers, with the areas of the emitting surfaces ranging from 37 to 81 cm^2 were measured for luminous flux by mounting them to a 2-axis OLED holder in the integrating sphere. Half of the panels had diffuse emitting surfaces, whereas the other half had more specular reflecting surfaces. To study the effect of the panel orientation on the luminous flux, the panels were measured at horizontal and vertical orientations. The relative spectrally resolved angular intensity distributions of the OLEDs were measured in a near-field goniospectrometer, and the spatial non-uniformity corrections for the panels were calculated using the measured SRDF of the integrating sphere. The uncertainties of the spatial correction factors for each operating orientation of the OLED were determined using a Monte Carlo

analysis where the horizontal and vertical rotations of the OLED in the 2-axis holder were offset up to ±10 degrees from the desired panel orientation.

3. Results

Based on the test measurements, the spatial correction factors for the OLEDs with specular reflecting surfaces varied between 1.0055 and 1.0058, when the OLED was facing either downwards or towards the auxiliary port of the sphere, located on the opposite side of the detector port of the sphere. For the OLEDs with diffuse surface the spatial correction factors varied between 1.0061 and 1.0063. For a virtual Lambertian panel, the correction factor was 1.0059 for both of the studied orientations. The uncertainty arising from the alignment of the OLED in the integrating sphere for the operating position towards the bottom of the sphere was 0.13 % (k = 2) and for the position towards the auxiliary port was 0.03 % (k = 2). The larger uncertainty for the position towards the sphere bottom is due to the higher non-uniformity on the sphere surface around that specific point.

The spatial correction factor for the SSL under measurement varies as a function of the wavelength. The largest values of the correction are located at the short wavelength range and the smallest at longer wavelengths, being in the range of 1.0035-1.0085 for all the tested panels.

The measured luminous flux values of the OLEDs after corrections differed by 0.2 % to 1.3 % depending on the operating orientation. The total uncertainty for the luminous flux measurements in the integrating sphere for a typical OLED panel was 0.9 % (k = 2).

4. Conclusions

An integrating sphere was characterized both photometrically and spectrally for the measurements of LED and OLED panels at different operating orientations. The luminous flux of six different OLED panels were measured. The relative angular intensity distributions for the OLEDs were measured using a goniospectrometer. The spectral throughput of the sphere was determined from the spectral spatial scan of the integrating sphere.

The study shows that SSL panels can be measured with integrating sphere photometers at different geometrical alignments with small uncertainties. The luminous flux values of the studied OLED panels had an expanded uncertainty of 0.9 %. The effect of the operating position of the panel on the luminous flux was up to 1.3 %.

PP11 (PO49)

DEFINITION AND DETERMINATION OF THE BEAM AXIS AND BEAM ANGLE OF COMPLEX LUMINOUS INTENSITY DISTRIBUTIONS

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Abstract

1. Motivation, specific objective

Legal regulations in many countries require the determination and indication of the beam angle of lamps and luminaires on their product. As an example, the European eco-design directive EC Regulation (EU) No. 1194/2012 defines the useful luminous flux of a lamp based on the beam angle. The value of the beam angle may therefore have a direct impact on whether a product can be put on the market or not. Therefore, a rigorous method of determining the beam angle is required that can be universally applied and which gives representative and reproducible results.

The International Standard CIE S 025:2015 *Test Method for LED Lamps, LED Luminaires and LED Modules* defines the beam angle as “angle between two lines in a plane through the optical beam axis, such that these lines pass through the centre of the front face of the device and through points at which the luminous intensity is 50 % of the centre beam intensity, where the centre beam intensity is the value of luminous intensity measured on the optical beam axis”. For ideal rotationally-symmetrical and convex luminous intensity distributions this definition can be directly applied: the measurement of the luminous intensity distribution in a single plane is sufficient to determine beam angle according to the definition. For complex luminous intensity distributions, however, the definition can’t be applied directly and more sophisticated methods are required.

This paper discusses and compares different approaches using one already-defined method and introducing three new techniques. In addition to the pure research interest, this work is also important in the context of CIE TC 2-78, which is tasked with evaluating methods of determining beam axis and beam angle and making a recommendation on the best method for the task.

2. Methods

IEC/TR 61341 *Method of measurement of center beam intensity and beam angle(s) of reflector lamps* proposes to first determine the position of the peak intensity Ip visually by titling the lamp in different directions and observing the photometer reading. In a second step, the directions where the intensity is half of the peak intensity is determined in at least 6 different measurement planes. The optical beam axis is considered to be the bisection of the direction of the peak intensity and half peak intensity. This direction defines the centre beam intensity Ic. The angle between the optical beam axis and the direction in which the luminous intensity is half of the centre beam intensity is considered to be the half beam-angle. The beam angle of symmetrical beam is then defined as twice the average of the half beam angles determined in the different measurement planes. For asymmetrical beams the individual beam angles shall be reported.

A second method is based on the determination of the optical beam axis by the centroid of the luminous intensity distribution. A coordinate transformation moves this centroid position to coincide with the reference point of the coordinate system and the half-maximum intensity positions in each of the half planes in the distribution is determined. Finally, an ellipse is fitted to these half-maximum positions using a least-squares fit and the lengths of the major and minor axes of the ellipse are considered to be the beam angles.

A third method is based on numerically fitting an ideal tiltable cos^*g* distribution to the measurement data using a non-linear least square algorithm in each C-plane. There are three fitting parameters to be optimized: the tilt angles, the centre beam intensity and the exponent g of the cos^g distribution. From this ideal distribution the beam angles in each C-plane are directly determined analytically and

the average is taken. Similar to the second method, an ellipse can be fitted in case of asymmetric beams.

A fourth method considers a direct fit of an ideal 3D tiltable cos^g distribution to the whole set of measurement data. By this the beam angle is directly obtained as a parameter of the fitting process.

3. Discussion

The first method has some limitations because it requires the photometrist to manually locate the beam maximum point and from there to move away from the maximum point within measurement planes. It doesn't provide guidance on how to make the planes "straight" and so this can only be done in a practical sense by aligning the source with the origin of the coordinate system and then using different C-planes. This may require tilting the source, which can result in errors for discharge sources whose output can change when tilted with respect to gravity.

All four methods can, in principle, be evaluated from a measured luminous intensity distribution, although in the case of the first method it doesn't provide the means for undertaking the coordinate transformation to rotate the data so that the maximum intensity point coincides with the origin of the coordinate system.

4. Results

Preliminary results indicate that for reasonably symmetrical distributions the all methods yield similar results. As the beam becomes more asymmetrical the minimum and maximum of beam widths calculated in the six planes of the first method matches reasonably well with the lengths of the long and short axes of the second and third methods, and so these methods provide a useful summary of the beam shape.

For asymmetrical beams that are poorly aimed or for complex beams with multiple peaks, a better fit to the beam can be found by performing a coordinate transformation to the centroid rather than the direction of maximum intensity.

5. Conclusion

There is no unique solution to the problem of determining the beam angle of complex luminous intensity distributions. The final paper will present more details regarding the mathematics behind the different techniques, the coordinate transformation, the centroid determination and experimental results.

PP12 (PO50)

INVESTIGATION AND ANALYSIS OF GONIOPHOTOMETER CALIBRATION

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Abstract

1. Motivation, specific objective

In goniophotometer measurement, the two important performance criteria are the spatial angle and the luminous intensity accuracies in tested direction. For spatial azimuth angle accuracy of goniophotometer, the accuracy of (C, γ) coordinate system and the rotational positioning accuracy of C and γ angle are important. But the accuracy of (C, γ) coordinate system is usually not given enough attention as the horizontal axis consistency of the C- rotation axis in the photometric plane, the vertical axis consistency of the γ- rotation axis, the verticality and the mutual deviation of the two rotation axes. Especially for the goniophotometer with large size mirror, the rigidity of the rotating arm that supports the mirror, the linearity of rotation axis, the bearing mechanism, the coaxality of drive mechanism and installation position error will all affect the accuracy of the rotation axis. Additionally, the flatness, refraction offset, etc. will also significantly affect the accuracy of spatial angle. The goniophotometer with two or more mirrors, the above deviations will become further apparent and so the multi-mirror combined system must be systematically calibrated.

For calibration of luminous intensity, using luminous intensity lamp the standard preferred method. The alternatives often used include illuminance photometer method and luminous flux lamp method. However, the latter calibration methods have some problems. And if the calibration light beam does not pass through the mirror or all mirrors in a multi-mirror combination system, it will result in significant errors in the system.

In this work, we study the calibration of goniophotometer in relevance to the spatial azimuth angle and luminous intensity distribution. Also, we analyse the applicability of the calibrated illuminance photometer method and discuss the problems of the total luminous flux calibration method. Finally, through several laboratory tests in different countries. Our results indicate that the spatial luminous intensity distributions and total luminous flux that are calibrated using the spatial angle and luminous intensity standard lamp can ensure consistent results.

2. Methods

At present, the accuracy of goniophotometer used in laboratory is better than 0.2 °. It is possible to check the axis deviation of the coaxial rotation by laser by the laser mounted on the rotation axis. In this way, we can confirm the deviation angle of the axis shake, the verticality of the two rotation axes, and the offset of the origin of the coordinate system. For the accuracy of the spatial rotation angle, we can use optical goniometer to detect it. The 14bit (or higher) optical goniometer have very small error, so the goniometer with direct coaxial installation will generate small error than others (such as gear, toothed belt, etc.). According to the EN13032-1, the intersection of two axes should be less than 10mm, the perpendicularity of axis less than 0.02 ° and the shake of axis less than 0.03 °.

The calibrated illuminance photometer method is also used sometimes as another method of goniophotometer calibration. In this method, the photometer head is calibrated on an optical rail, and the size of standard lamp is small. This results in some problems using a photometer head to test large-size luminaires in goniophotometer. We chose two luminaires with different sizes of luminous surface (a halogen lamp and an LED panel light) for the experiment and used a calibrated photometer head to measure the illuminance value at different distances. The results indicate that the deviation level of the two test were signally different at near field.

Some laboratories use the luminous flux standard lamp method to calibrate the goniophotometer. But because the uncertainty of luminous flux, measurement uncertainty of spatial light intensity distribution and stray light. The luminous flux lamp method will result in some factors of uncertainty on luminous

intensity measurement. In order to test this, we chose some flood lights for the experiment. The luminous flux of these samples are almost the same, but with different beam angles. We measured these samples on the calibrated goniophotometer that uses the luminous flux lamp and compared the results with the intensity distribution measured in goniophotometer that uses the luminous intensity lamp method. We found the deviation is changed as anticipated at the positions where the light gets weak.

3. Results

Through the careful, and precision installation and commissioning, of a high precision goniometer, by angular optical polygon and automatic collimation, the spatial azimuth angle of goniophotometer can be accurately calibrated.

For the calibrated illuminance photometer method, the results indicate that the deviation level of the two tests were different, mainly because the photometer head calibration is typically done at far field, and the lamp used for calibration usually has a small luminous surface. However, in the test goniophotometer system, the photometric distance and the size of testing luminaire are not the same, and these will lead to measurement errors.

For luminous flux lamp method, the uncertainty of the luminous flux standard lamp should be considered carefully during the calibration procedure. However, the measurement error caused by stray light is more important. Usually the luminous flux standard lamp is weaker than the luminous intensity standard lamp, so the flux calibrated goniophotometer may not be accurate enough for all types of luminaires test.

We analysed the test results of calibrated illuminance photometer method and luminous flux lamp method, and find that is possible to improve tha accuracy better than 2% uncertainty.

4. Conclusions

The azimuth angle calibration and luminous intensity calibration are critical for improving the goniophotometer accuracy. The calibrated illuminance photometer method can also be adopted when the photometric distance can be accuratly measured. For the mirror goniophotometer factors such as reflectivity and polarization of the mirror are more influential on the measurement accuracy. In the case of the luminous flux lamp method, the luminous intensity measurement error and stray light can seriously influence the measurement uncertainty, especially for the mirror goniophotometer. The mirror will change the light distribution in the space, therefore, luminous flux lamp method will result in a greater error on luminous intensity measurement.

PP13 (PO51)

HDR IMAGES FOR GLARE EVALUATION: COMPARISON BETWEEN SELF-CALIBRATED DSLR CAMERA AND AN ABSOLUTE CALIBRATED LUMINANCE CAMERA

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Abstract

1. Motivation and objectives

High dynamic range (HDR) images are being used as a simple way to measure the luminance of lighting scenes. HDR images can be made by merging several low dynamic range (LDR) images, usually taken with varying shutter speeds, into one image; sometimes also referred to as luminance maps. Each pixel in these HDR images holds information about the luminance value and can then be used for different evaluations of the lighting scene, such as luminance distribution, contrast evaluations and glare analysis.

Professionally calibrated cameras that have an absolute calibration, making good and precise HDR images, do exist, but these are generally expensive. These can resolve almost all light scenes including scenes with both high and low luminances, as well as scenes that could produce flare. These cameras are also calibrated for influences from the optical system.

It is possible to self-calibrate commercially available digital single-lens reflex (DSLR) cameras, so that they can be used to produce usable HDR images. Self-calibrated luminance cameras are being used, among others, for light research purposes, as they provide an affordable alternative to absolutely calibrated cameras. However, if care is not taken, both in the calibration process and when shooting the LDR images, the resulting luminance maps will be faulty. Self-calibrated cameras have trouble resolving light scenes with both very dark and very bright parts in them. This is emphasized if the series of LDR images are not correct or don't cover the luminance range, resulting in wrong luminance values in these parts. This happens, for example, when none of the LDRs are under or overexposed (nearly black/white) or if the shutter speed steps between the LDRs is too large. The same can happen if the wrong aperture size is used, although this usually only affect either the high or low end of the luminance range. Vignetting (light drop off at the edges of an image compared to the image center) varies from aperture size to aperture size and typically becomes more pronounced at high and low aperture sizes. It is important to have vignetting correction for each aperture, otherwise luminances at edges of the images will be too low. When there are very bright parts in relatively dark scenes, flare (light spillover between pixels) results in wrong luminance values around the pixels representing the light source. Wrong luminance values in HDR images, however they occur, results in a wrong vertical illuminance value if this is calculated from the HDR image. This in turn makes glare analysis, some of which rely on vertical illuminance, unreliable.

The objective of this study is to compare luminance maps from self-calibrated commercial DSLR cameras with luminance maps from an absolutely calibrated luminance camera and to identify the limits of the self-calibrating method when applied for glare analysis. Targets in the luminance maps will also be compared with spot measurements from a handheld luminance meter.

2. Method

Two identical commercial available DSLR cameras with identical fisheye lenses are calibrated by following the guidelines for self-calibrating luminance cameras. Briefly the method is based on four steps:

- A response curve is derived for each camera by capturing a scene containing patches of bright natural daylight and some relatively large white, grey and black surfaces.

- The HDR images are corrected for lens vignetting by applying a correction factor to each pixel value. The correction factor, a polynomial function, is obtained by measuring the light drop off that occurs when the camera is rotated around the lens nodal point.
- The images are then corrected for lens projection by applying another correction factor to the pixel values in order to account for the distortion caused by the projection method of the lens.
- Finally, a calibration factor is applied to each HDR image based on luminance values measured at points in the scene with a handheld luminance-meter.

To compare the three cameras, HDR images are made of several lighting scenes. The cameras are controlled with remote control software, so that they can make images simultaneously and without camera shake. The cameras, mounted on a tripod, cover almost identical parts of the scene. An illuminance meter is also mounted at the camera lenses for vertical illuminance measurements. The scenes consist of typical office-like environments during different sky conditions and with varying light levels in them. Luminance at specific targets located in fore-, middle-, and background of the scenes are compared across the images from the different cameras and with spot luminance measurements. Vertical illuminance is also calculated from the luminance maps and compared with the measured illuminance. Furthermore, calculation of common glare-metrics is carried out on the images and the resulting values are compared.

3. Results

The preliminary investigation and calibration process with the DSLR cameras have revealed that resolving the sun or very high luminance is problematic and can cause large differences for the glare evaluation. This study investigates the limits of the self-calibration method and aims to show its influence on daylight-glare evaluation. Improvements for the calibration of DSLR cameras are also identified.

PP14 (PO52)

STUDY ON THE POSSIBIALITY OF LED FILAMENT LAMP AS PHOTOMETRIC STANDARD

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Abstract

Incandescent lamps are phasing out by more energy efficient light source light emitting diodes (LEDs). As this trend, firstly, many types of incandescent lamp extensively used in the past as photometric standard are no longer available in the future; Secondly, the current photometric measurement system is based on CIE standard illuminant A (i.e. incandescent lamps), which is quite different from the spectral distribution of LED. Therefore, the uncertainties may increase when measuring LEDs instead of incandescent lamps. For a recent preliminary study two LED-based calibration illuminants: Lw (warm white ,2935K) and Lc (cool white,5716K) have been defined and used as calibration source instead of illuminate A for photometer that measuring LED lighting. It indicates that the measurement errors could be reduced by a factor of 3, provided that the type of calibration LED source be selected according to the type of LED source to be measured. Thus LED based photometry could reduce the spectral mismatch error in a direct way which may be the convenient methodologies to simplify the LED measurement procedure.

Standard lamps are used to maintain and transfer the unit of photometry, they should have reproducible and stable output for repeated and long-time use. LEDs have several unique properties compared to incandescent lamps, such as energy efficient, very short response time, narrow spectral bandwidth, good temporal stability, robustness, long lifetime. The four later features make LEDs prior to incandescent as photometric standard.

The developed LED standard lamps should meet the general requirements of standard lamp, but also be compatibility with general electrical connection and the existing calibration facilities, meanwhile, inexpensive and easy to be got. Based on extensive investigations of different types and different manufactures, a kind of LED filament lamp has been selected as the candidate. It have the great advantage of short warm up time 5～12 min compared to other types LED which the warm up time is as long as 30 min or even several hours.

The characteristic of a group of DC and a group of AC 4W LED filament lamp were been investigated during one year period. The reproducibility of the luminous flux was checked by measuring three reference lamps (bromine tungsten lamp) which were calibrated the luminous flux and spectral radiant flux. The reproducibility of the luminous flux is better than 0.15%, the reproducibility of colour temperature is within 2K. After burning about 7000 h, the decrease of luminous flux is 1.4%～3.5%,and the increase of colour temperature is within 14K.The storage stability of several filament lamps also have been investigated, the fluctuation of luminous flux is within 0.2% during 10 month. But this lamp is sensitive to temperature, during measurement the temperature inside the integrating sphere should be monitored, the possibility of correction the temperature dependency of luminous flux by voltage will be studied.

The studied LED filament lamp show good reproducibility and stability, as well as low ageing rate about 1/30 of incandescent lamp, robust to shock, the shortcoming of temperature dependency could be corrected by voltage. This kind of LED lamp may could be used as a kind of photometric standard , but the long time storage character should be studied in the future.

PP15 (PO53)

PERFORMANCE EVALUATION OF IMAGING SPECTROPHOTOMETER IN THE VISIBLE AND INFRA-RED REGION

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Abstract

1. Motivation, specific objective

Imaging spectrophotometer is referred to as an instrument that measures the spatial distribution of spectral reflectance and/or transmittance of a 2-dimentional sample based on the spectral imaging technique. In 2014, we reported a proto-type instrument of the imaging spectrophotometer and demonstrated its feasibility in the visible region in Metrologia. Recently, we developed an improved instrument that should provide better accuracy and higher dynamic range in the extended wavelength range. The main objective of this study is how to evaluate the key performances of the imaging spectrophotometer.

2. Methods

The instrument to be investigated is an imaging spectrophotometer based on an integrating sphere for measurement of spectral reflectance in the geometry of diffuse illumination and 0-degree detection (d/0). A monochromator-based spectral light source using a tungsten lamp is used to uniformly illuminate the test sample, which is attached to a 25-mm-diameter port of the integrating sphere. The image of the illuminated sample surface is recorded by alternatively using two digital cameras, a monochrome Si CCD camera for the wavelength range from 350 nm to 1000 nm and an InGaAs camera from the range from 1000 nm to 1600 nm. Both cameras contain the thermoelectrically cooled image sensors with a high digitizing resolution (16 bit for Si and 14 bit for InGaAs). A data acquisition software is developed to extract the spectral reflectance of a selected region of interest (ROI) from the recorded digital images.

The instrument is calibrated by using the white reflectance standard of KRISS. Once calibrated, the digital number at each pixel of the recorded image of a test sample is converted to the value of total diffuse reflectance from its ratio to the current reading of the monitoring photodiode attached to the integrating sphere. The operation conditions and parameters of the instrument such as the size of the ROI, the signal-to-noise ratio of the readings, the spectral bandwidth of the source, etc., are set in such a way that the minimum uncertainty of the spectral reflectance measurement is expected. After calibration, the performance of the instrument is evaluated by measuring a set of grey and coloured reference samples and comparing the data with the data measured by the reference spectrophotometer at KRISS. In particular, the wavelength-dependent differences between the measured data and the reference data are investigated as the reflectance level of the sample varies (dynamic range), as the position of the ROI varies (spatial non-uniformity), as the size of the ROI varies (spatial resolution), as the spectral bandwidth of the light source varies (spectral resolution), and as the surface property like BRDF of the sample varies (sample dependence).

3. Results

From the measurement data in various conditions, we first evaluate the expected uncertainty or systematic error with respect to each parameter. For example, from the measurement for the samples with different reflectance levels (grey samples), we evaluate the change of the random uncertainty and the deviation from the reference data with respect to the reflectance level. We set the target value of the relative uncertainty to be 2 % in the visible and 4 % in the infrared region, both expressed as the expanded uncertainty with k = 2. Then, we determine the dynamic range of the reflectance

measurement, in which the systematic error due to the reflectance level is less than the target uncertainty. Similarly, we determine the performance specifications of spatial non-uniformity, spatial resolution, spectral resolution, and sample dependence based on the pre-defined target uncertainty boundary. The experimental evaluation is still on-going, and the summarized results will be presented in the conference.

4. Conclusions

The results of the performance evaluation of the imaging spectrophotometer will be used to test and improve the usefulness as well as the limitation of the instrument in the application.

PP16 (PO54)

INTER LABORATORY COMPARISON OF LED MEASUREMENTS AIMED AS INPUT FOR MULTI-DOMAIN COMPACT MODEL DEVELOPMENT WITHIN A EUROPEAN-WIDE R&D PROJECT

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Abstract

The European project Delphi4LED (launched within the support of the H2020 research framework of the European Union and with the financial contribution also from the national governments of the participating consortium members) is aimed at the development of new LED compact models that can help better design LED based lighting products at all integration levels along the SSL supply chain. The compact thermal models of LED packages and the multi-domain models of the LED chips within these packages are foreseen to be identified from measured LED characteristics. When setting the targeted accuracy levels of these models one needs to be aware how accurately and with what uncertainty the required LED characteristics can be measured in an average academic and industrial testing laboratory by the application of the latest available LED testing standards. Therefore the Delphi4LED consortium decided to start an inter-laboratory testing of 5 different representative LED types. The outcome of the this round robin testing is expected to provide valuable input of the CIE TC2-84 technical committee and will be the first such testing of e.g. the most recent LED thermal testing standards and the new CIE test methods for optical measurements of high power LEDs.

1. Motivation, specific objective

There are a few bottlenecks hampering efficient design of LED based products on different integration levels of the SSL supply chain. One major issue is that data sheet information provided about packaged LEDs is usually insufficient and inconsistent among different LED vendors.

An international consortium of European SSL manufacturers including big and small companies, industrial and academic research labs and companies involved in LED test equipment manufacturing and suppliers simulation tools has recently set an R&D project with the ultimate goal of developing standardized methods to create accurate multi-domain LED compact models from testing data. Despite high accuracy expectations of end-users, model accuracy should not be defined higher than the uncertainty of LED measurement data achievable by typical test laboratories performing daily characterization of LEDs.

2. Methods

To assess the capabilities of their laboratories the consortium members with LED measurement facilities decided to carry out round robin testing of selected LED packages which have been defined as the most important ones from the point of view system level design by consortium member companies active in luminaire and lighting design.

In planning this round robin test, the outcome of earlier inter laboratory comparisons were carefully considered. The test protocol of the present round robin test is based on new measurement standards and recommendations published by JEDEC and recently developed by CIE. Our planned measurements will be the first international round robin test based on these measurement procedures.

The LED packages chosen for the round robin test are the most representative LED devices used by the consortium members include:

- a high-power phosphor converted white LED,
- a high-power blue LED package (with the same blue chip as the above white LED) ,
- a high-power red LED package,
- a mid-power green LED package,
- and white CoB LED.

The measurands to be identified at set T_J junction temperature and I_F forward current include thermal resistance, absolute spectral power distribution, total luminous flux, total radiant flux and a few further light output properties derived from the measured spectral power distributions. For a selected LED package a whole set of isothermal I-V-L characteristics will be also measured.

To reduce the possible variations of the LED samples during the whole process 500 h hours of initial ageing / seasoning of the test samples has been decided.

The huge amount of test data will be collected in a quasi-standard format and will be subject to a final statistical analysis. Regarding the data collected this round robin test is expected to provide significant input not only to the present European R&D project but also to the work of the CIE TC2-84 technical committee.

3. Results

The ageing process has been finished at the time this abstract submission and the completion of all the measurements by the seven participating laboratories is expected at the deadline of the submission of the final papers. By the time of the conference the first results of the statistical evaluation of the raw test data is also expected.

4. Conclusions

Since the work of 7 laboratories needs to be coordinated and further two research teams will be involved in measurement data post processing are involved, test data reporting is key to the success of this round robin test. So besides a better understanding of the practices and the capabilities of industrial and academic LED testing laboratories initial suggestion for LED test data reporting (with data aimed at further processing e.g. for automated LED model generation) aimed as input for the CIE TC2-84 technical committee is expected. On top of that we hope to learn how easily the latest recommendations for LED testing can be implemented in the everyday practice of average industrial and academic laboratories.

Session PS3
Presented Posters (D3)
Tuesday, October 24, 14:00–14:40

PP17 (PO75)

RESEARCH ON THE INFLUENCE MECHANISM OF THE ARTIFICIAL LIGHT ENVIRONMENT EVALUATION INDEX ON OFFICE LIGHTING COMFORT

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Abstract

People learn about the world through hearing, sight, scent, taste, and touch, and 80 % of obtained information comes from light-induced vision. Therefore, the main research topic of architectural optics has been to create a comfortable light environment to improve overall visual performance. Artificial light environment is an important component of the indoor environment; its function is to meet the physical, physiological, psychological, ergonomic, and aesthetic requirements. A comfortable and healthy light environment can not only be pleasing both mentally and physically, but it also helps to improve efficiency, as well as to avoid the type of light that may cause discomfort or potential injury. With access to relevant research results from both at home and abroad, there are still some issues pertaining to the study of a comfortable artificial light environment. First, the evaluation method of a single parameter and discrete variable lacks the consideration of the coupling effect between variables. Secondly, the evaluation process using expert and non-expert field evaluation is not easy to operate. Therefore, the only way to further improve the research within the field of lighting is the rational use of mathematical methods, which are based on human subjective evaluation experiment built on the establishment of the multi-parameter comprehensive evaluation system. Taking into account the varying types of buildings, there are differing artificial light environment requirements, so the class of buildings that has been universally studied should be chosen. For the standard office building, the building space is relatively simple, people stay longer, and the artificial light environment has specific requirements; therefore, a small office space should be chosen for the study.

This paper mainly adopts the research method of subjective evaluation experiment, and explores the effects of artificial light environment based on the comfort of the lighting. First, a typical office space is built, the walls are light, brushed with white latex paint, and the window is shaded with a curtain cloth. Following the foundation of this area, the lamp is configured. Experimental straight fluorescent lamps were selected as experimental lamps, and configured with a dimmable ballast for the controlling the brightness of the lamp during the experiment. Furthermore, this experiment has developed a set of adjustable light control systems, and prepared a dimmable control program used to record the experimental conditions set in advance. The experimental conditions are then set. As an indicator of artificial light environment, the illumination (100l x, 200l x, 300l x, 400l x, 500l x), colour temperature (2700 K, 4000 K, 6500 K), colour rendering index (high colour group: 96, 91, 90; low colour group: 70, 61, 49), and illumination uniformity (0.4, 0.7) were selected. In ensuring the experimental method and procedure are reasonable, the combination of the index levels selected for each parameter should be arranged according to the above four lighting physical quantities, obtaining 36 kinds of artificial light environment conditions. Finally, the settings for the questionnaire and the experimental subjects. There are ten experiments in total, each questionnaire survey necessitates three subjects. The questionnaire provided two questions: “What do you think of the overall room ambient light comfort?” and “What do you think of the current light environment?” The questions were evaluated by scoring according to the degree of seven levels, respectively, from very uncomfortable to very comfortable and from too dark to too bright.

After the end of the experiment, the investigational questionnaire was entered and the results were statistically analysed. It is found that in the case of low illumination, the light environment created by the high colour light source is obviously more comfortable than compared with the low colour light source in the same situation. Colour temperature in the 2700 K low colour temperature light source to created a more comfortable light environment than using the same conditions but replacing it with a high colour temperature light source. In the case of high illumination, the colour temperature ranging between 4000 K and 6500 K or so in the high colour temperature light source created a higher degree of light comfort, where the 4000 K colour temperature of the light source had the highest comfort. In

the low colour temperature, the light environment is less comfortable. By using the results of the comfort questionnaire, the influence of illumination, colour temperature, colour rendering index, and illumination uniformity on the degree of comfort and brightness were found to further study the quantitative effects of individual physical environment on visual comfort. Combining the questionnaire statistics and experimental data correlation analysis, the correlation does not exist in interactions between independent variables; followed by a multivariate linear regression analysis by SPSS software, the mathematical model of artificial light environment is established. Further, a quantitative evaluation of the effects of various optical environment parameters on visual comfort in artificial light environment was conducted.

The model integrates a number of artificial light environmental evaluation indexes, taking into account the influence of parameter coupling. At the same time, the model is based on subjective evaluation, which eliminates the cumbersome evaluation of field scoring and has the reliability and convenience of optical environment comfort evaluation, as well as provides the basis for the establishment of the artificial light environment evaluation system. In addition, it also explores the relationship between the artificial light environment evaluation index by mathematical method.

PP18 (PO76)

MEASUREMENT OF ILLUMINANCE SATISFACTION REGARD TO DUTIES AND NEW CONTROL METHOD OF INTELLIGENT LIGHTING SYSTEM USING SATISFACTION LEVEL

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Abstract

1. Motivation, specific objective

In order to clarify the range of the preference illuminance that the office worker believes is easy to perform office, we examine the relation of satisfaction degree to the illuminance of the office worker. Next, in the conventional Intelligent Lighting System, there are cases where the target illuminance cannot be realized due to the physical characteristics of the illumination when the target illuminance of the adjacent office worker is greatly different. In this case, the illuminance determination is performed using a policy relating to illuminance determination such as giving priority to high illuminance, giving priority to low illuminance, providing average illuminance. Then, we decide the illuminance to provide to the officials based on physical indicators for both policies. However, in this method, problems such as extremely low satisfaction of a specific office worker occur. Therefore, based on the satisfaction level which is a psychological indicator of each user rather than a conventional physical indicator, all workers We propose a method that can obtain high satisfaction. Finally, since satisfaction with illuminance can be considered to change with season, physical condition, time, consider the learning function to estimate satisfaction level while doing daily work. We introduce this learning function to the Intelligent Lighting System, above mentioned, which maximizes satisfaction.

2. Methods

We propose a new intelligent lighting system that all officers can obtain high satisfaction. Then we propose a learning function to estimate satisfaction while doing daily work.

3. Results

When the illuminance close to the target illuminance was gained, a high level of satisfaction was obtained, and when the illuminance far from the target illuminance was gained, the satisfaction level decreased. Next, Intelligent Lighting System that introduced satisfaction compared to the standard Intelligent Lighting System could provide an illumination environment where all office workers can obtain high satisfaction. Finally, the Intelligent Lighting System that introduced satisfaction compared to standard intelligent lighting system has a small difference in satisfaction among each office worker, and it is said that all the officers have obtained similar satisfaction.

4. Conclusions

It was found that the degree of satisfaction got higher near the illuminance preferred by the office worker and the satisfaction level decreased when leaving the preference illuminance. In addition, we found that the relationship between illuminance and satisfaction level differs for each worker. Next, by measuring the degree of satisfaction of the office worker in advance, it is possible to calculate the degree of satisfaction for each office worker for the illuminance realized by the Intelligent Lighting System. Then, by performing control to maximize the total satisfaction level of the satisfaction of all office workers and dimming each lighting, the average satisfaction level of all office workers is higher than that of the conventional Intelligent Lighting System, and further We propose a new Intelligent Lighting System control method with less variability of satisfaction degree obtained by all office workers. Finally, while the office worker performs daily work, entering satisfaction with respect to the illuminance at that time enables learning the relationship between the illuminance to be provided to the office worker and the degree of satisfaction to the illuminance. Moreover, by inputting satisfaction degree every day, it is possible to learn appropriate degree of satisfaction for each office worker over

time, so that the proposed Intelligent Lighting System change to provide better illumination for each worker.

PP19 (PO77)

FIELD MEASUREMENT OF NET-ZERO ENERGY RENOVATION BUILDING

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Abstract

1. Motivation, specific objective

In Japan, buildings are responsible for more than 30% of primary energy usage and 32% of CO2 emissions to the atmosphere. One of the goals in the energy performance of buildings is achieving Net-Zero Energy Buildings (NZEB). In recent years, the renovation of office buildings to NZEB have proceeded. For NZEB renovation, photovoltaic panels, daylighting, natural ventilation, highly efficient HVAC, and replacement of conventional lamps by LED lighting are all recommended.

NZEBs should keep the comfort of their occupants as a priority. For the visual environment, well-controlled daylight and electric light are effective to reduce electric consumption and to keep occupants comfortable. An office building in an urban area near Tokyo was renovated to an NZEB. In this paper a field survey and subjective assessment of the visual environment of an NZEB renovation were carried out.

2. Methods

In the subject building LED task-ambient lighting and automated venetian blinds were used. The LED task-ambient lighting is controlled to keep the desktop illuminance around 300 lx. This electric light control requires input from the ceiling sensors. In addition, ceiling light fixtures protruding from the ceiling surface to provide ambient light to the ceiling surface. The automated venetian blinds in the northwest and southeast sides are controlled so that their slats cut direct sunlight (cut-off angle control).

The field survey and subjective assessment investigated (1) winding up the automated venetian blinds during periods of no direct sunlight, (2) the lighting environment produced by the protruding fixtures, and (3) the subjective assessment of brightness level.

The field survey was carried out in the subject NZEB renovation office for three days in sunny and cloudy conditions. The field survey conditions included two ambient lighting controls (dimming control based on desktop illuminance and without electric light) and three blind positions (horizontal angle of the slats, wound up, and closed). Desktop illuminance, luminance distribution, and brightness image (proposed by Nakamura) for each condition were measured from the 8 desk positions of the workers. Luminance of the ceiling surface and the glare index for daylighting (PGSV) for each condition were measured from the center of the office by HDR images.

A subjective assessment was carried out at the same time as the field survey. The subjective assessment conditions included the three blind controls with dimming light control on the assumption that subjects were working. After four subjects observed the room and the desktop, they assessed the brightness of each on a 5-point brightness scale. They repeated this for three different desk positions.

3. Results

The results of the field survey show that the illuminance of the desktop was kept at a minimum of 300lx, when the ambient lights were controlled automatically.

The comparison of blind positions (horizontal and wound-up) shows that wound-up blinds provided more daylight, while glare index value only increased slightly. The ceiling luminance with wound-up blinds on the southeast side was greater than that with wound-up blinds on the northwest side. The average spatial brightness values were higher than 6, which is the average recommended brightness level for work places.

The subjective assessment shows that subjects evaluation about room and desktop brightness were neutral (neither bright nor dark), when the northwest side blinds were both horizontal and wound-up. On the other hand, when blinds on both sides were closed, the brightness of the desktops on both window sides were assessed as dim. In addition, the southwest side of the room was assessed as dim in the same conditions.

4. Conclusions

In the absence of direct sunlight winding up the blinds increases the luminance of the ceiling, increases the brightness of the room, and saves energy while only slightly increasing glare. When light fixtures protrude from the ceiling surface the luminance of the ceiling is higher than before. of Brightness was considered to be comfortable in all cases except when the blinds were closed. Subjective assessment of brightness for desktops closer to the windows is more difficult to satisfy.

PP20 (PO78)

EVALUATION OF VISUAL ENVIRONMENT IN AN OFFICE WITH NOVEL LED LIGHT FIXTURES

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Abstract

1. Motivation and objective

LED lighting has become wide-spread in office spaces in Japan. First, LEDs have substituted fluorescent lamps in conventional light fixtures and LED light fixtures have gradually become more widespread. LED lighting is expected not only to reduce electricity consumption but also to improve lighting quality. Since LED lighting has high directionality, a small amount of light is emitted to the ceilings or walls. In order to avoid dark ceiling and wall, a point-source-type LED light fixture emitting direct and indirect light has been developed. The fixture is designed to use the direct light as task light and the indirect light reflecting on the ceiling as ambient light. Since the LED lighting is small in power and size, seven fixtures are required per 2 m^2 of floor area (one fixture per square 533 mm). It is expected that an office space with this LED lighting system increases workers' alertness and cognitive performance. On the other hand, there are concerns that this system may cause discomfort glare. Although UGR is an index to evaluate discomfort glare from electric lighting, recent research shows that UGR cannot accurately predict discomfort glare from LEDs.

The purpose of this study is to evaluate the visual environment in an office using the direct-indirect LED lighting system. Luminance distribution, subjective impression, workers' alertness, brightness and discomfort glare are measured and evaluated.

2. Methods

Field measurements and subject experiments were carried out in two office spaces; one used the point-source-type LED light fixtures and the other used conventional light fixtures with fluorescent tubes. The point-type LED light fixture which has a special lens to change the direction of light emitted from LEDs has direct light and indirect light. The desk illuminance in the office with the LED lighting system was set at 400, 750 and 1000 lx, while that in the office with the conventional light fixtures was 750 lx. The luminance distribution of the visual field was measured for each condition. Subjects assessed the visual environment using evaluation scales including brightness sensation, glare evaluation etc. Twenty-four university students participated as subjects. In addition, a subjective experiment was conducted using three 1/10 office scale models to cancel the effect of the interior of the office on evaluation. The scale models have conventional light fixtures for tube lamps, light fixtures for diffused point lighting and light fixtures for narrow-beam point lighting respectively. For the conventional tube lighting, thirty fixtures per 100 m^2 is necessary while 400 fixtures for the diffused point lighting and 350 fixtures for the narrow-beam point lighting. The horizontal illuminance in the models was set at 400 lx and 750 lx. Twenty university students participated as subjects in the scale model experiment.

3. Results

The luminance distribution of the visual field shows that the light fixtures positioned nearer to the subject show higher luminance in the office with the conventional light fixtures. However, in the office with the point-source-type LED lighting system, the light fixtures positioned farther away show higher luminance. In the field experiment, the subjects judged that desk surface illuminated by the LED lighting system was brighter than that illuminated by the conventional light fixtures, when the desk illuminance was 750 lx. The subjects judged that the visual field with the LED lighting system was brighter than that with the conventional light fixtures. The subjects felt that the office with the LED lighting system was vivid and the office with the conventional light fixtures was sombre. The subjects

could read the manuscript illuminated by the LED lighting more easily than that illuminated by the conventional light.

To calculate UGR, the threshold luminance between the glare source and the background should be determined. It was found that the effect of the threshold luminance on UGR was small when the threshold luminance was between 500 and 5000 cd/m^2. The UGR of the office with the LED lighting system was around 23 which was higher than that for the office with the conventional light fixtures. However, glare sensation evaluated by the subjects in the office with the point-source-type LED lighting system is “just acceptable” while that with the conventional light fixtures is “perceptible”.

In the 1/10 scale model experiment, the subjects judged that the space illuminated by the diffused point lighting was brighter than that illuminated by the conventional light fixtures for tube lamp in the case of 750 lx of desk illuminance.

The result obtained from the scale model experiment showed that UGR of the office with narrow-beam point lighting resulted in UGR higher than 23, however, glare sensation evaluated by the subjects was lower than “just acceptable”.

It was suggested that the UGR possibly overestimated glare from narrow-beam point-source light fixtures in high density arrangement.

4. Conclusions

In the office with the point-source-type LED lighting system, the light fixtures positioned farther away show higher luminance, while the light fixtures positioned nearer to the subject show higher luminance in the office with the conventional light fixtures. The subjects judged that the visual field and desk surface illuminated by the narrow-beam point-source LED lighting system was brighter than that illuminated by the conventional light fixtures. Also, the result of the typing test in the field experiment, the workers’ performance in the LED lighting system was higher than that in the conventional light fixtures. It was suggested that the UGR possibly overestimated glare from narrow-beam point-source light fixtures in high density arrangement.

PP21 (PO79)

DISTRIBUTION OF REFLECTANCE ON WALLS AND CEILINGS AND THEIR INFLUENCE ON LIGHTING PARAMETERS

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Abstract

1. Motivation, specific objective

Design of interior lighting systems is often made under simplified assumptions. Inputs for calculation of lighting parameters comprise data as such as room geometry, luminous flux distribution of luminaires, arrangement of luminaires and reflectance of ceiling, walls and floor. Depending on room geometry, reflectance of main surfaces may have very significant influence on resulting parameters of illumination. It is not only about the maintained illuminance but also background luminance created by large surfaces in field of view and also energy performance which benefits from better utilization of luminous flux. For energy efficient lighting it is, therefore, important to use bright colours of walls and ceilings and to maintain these surfaces clean enough to keep the high reflectance value. Influence of the floor is less important, although not neglectable as well.

In the stage of designing the lighting system it is seldom known how the furniture is arranged and what reflectances are to be taken for calculations. The room is usually calculated for the empty state where reflectances of walls are assumed as average values that take into account some average but uniform distribution of reflectances. Indicative values of main surfaces are proposed also in international standards like e.g. in the European standard for interior workplace EN 12464-1. In particular, 0,5 to 0,8 is recommended for walls while 0,7 to 0,9 is recommended for ceiling. Painting used for walls and ceiling are normally of the same kind. Therefore, drop in the value of walls reflectance is due to objects covering the walls. The standard requires usage of light colours for main surfaces and in this point of view low values of reflectances do not satisfy this approach.

It is obvious that distribution of reflectance on walls is significant. However, it depends on light distribution from luminaires, their arrangement in space and the shape factor of the room how much this distribution affects the luminance distribution on working area. For example, luminaires with double-parabolic louvres when placed on ceiling quite near the walls, will direct light on usually upper part of walls where normally no objects are covering the surface. Bottom parts of walls where darker furniture is placed are less affected. It can be supposed that taking into account the division of walls to zones with different reflectances may lead to better adjustment of lighting design, still keeping the situation simple enough (in comparison to 3D modelling, for instance), and having in result better energy performance. Aim of the investigation is to show that using simple zoning can be a better method of simple lighting design.

2. Methods

Following the objectives of this study, first, common reflectance distributions in typical rooms in administrative, educational buildings and in similar applications have been acquired and analysed. Selection of room types cover cell offices, classrooms, corridors and storage rooms. Reflectances of objects have been measured in real installations. For the installed lighting system also illuminance on the working area and on walls have been measured. Reflectance have been measured by the luminance/illuminance method assuming the lambertian nature of reflectance of diffuse surfaces. The focus was put on reflectance of the painting which was, where possible, checked for uniformity and depreciation. Based on measured data, typical reflectance distribution schemes have been composed.

In the second part of the study, room models have been created in the calcuation sofware. The combinations comprise: different room shape factors, different light distributions from luminaires and different reflectance distributions on surface of walls including the uniform wall reflectance. Discovered transparent windows transmitting the light outside the room have also been regarded.

3. Results

Results of the analyses showed that applying the proposed zoning of walls may bring 10 % to 15 % gain in illuminance on the working area in average and even more in places closer to the walls, if work places are specifically placed in such areas. Large window areas must be covered during night-time hours by light colour curtains to avoid light tresspass through windows what may cause significant losses. The paper will publish more detailed results for different situations, discussing the differences and concluding recommendations for practical lighting design and calculation.

4. Conclusions

It can be concluded that instead of using a single figure for wall reflectances it is more appropriate do divide the walls into zones, one being two thirds of the room height and the upper part being one third of the height. Then calculated values of illuminance on the workplane using simplified method match better the real values.

PP22 (PO80)

THE USE OF COLOUR-TUNEABLE LED LIGHTING FOR RESIDENTIAL APPLICATIONS

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Abstract

1. Motivation, specific objective

The development of solid-state lighting has brought a revolution to electrical lighting, changing LEDs from sources for indicators to those for general lighting. Especially, the development of control technologies makes it easier to adjust the intensity and colour of LED sources. Past studies have suggested the effectiveness of allowing individual adjustment of lighting system in enhancing productivities and satisfactions in commercial buildings. This study was purposely designed to investigate individual adjustments of LED lighting in a residential space.

2. Methods

A full-scaled space was built to mimic a typical bedroom setting in China. Thirty-one participants, between 18 and 26 years of age, were recruited to adjust the colour and intensity of a bedside lamp. The colour of the light is limited within the gamut enclosed by (0.1411,0.702), (0.6702, 0.3033), and (0.1334, 0.0715) in CIE 1931 chromaticity diagram.

Each participant was seated in a sofa which was around 0.5 m away from the table lamp, and was asked to adjust the colour and intensity of the table lamp for four different purposes—reading, waking up, relaxing, and atmosphere—through a smart phone. The order of the four purposes was randomized for the participant. Before the start of the adjustment, the participant experienced a wash-out (or adaptation) period for 5 minutes, during which the lamp was providing 32 lx at the calibration point on the desk with a chromaticity of (0.4527, 0.3943). When adjusting the lighting for the purpose of reading, the participant was given a book; for the other purposes, the participant was asked to make the adjustment based on the appearance of the entire space. After the participant adjusted the lighting for each purpose, the experimenter recorded the spectrum, the illuminance measured at a fixed point on the desk, and the luminance measured at a fixed point on the luminaire, as dependent variables.

After finishing the adjustments for all the purposes, the participant was asked to finish a questionnaire about his or her habit and preference for using the table lamp at home.

3. Results

Based on the analyses that have performed, reading mode had the highest light level, followed by waking up, atmosphere, and relaxing. The reading mode also had the highest variation among the participant, while the relaxing mode had the smallest variation. The adjustments made the participants also corroborated the results from the questionnaire. Interestingly, we found the females generally needed a higher light level than the males for reading and relaxing modes; but males needed a higher light level for the other two modes.

White light was generally needed for the reading mode, but most light settings adjusted by the participants had chromaticities above the blackbody locus. For the relaxing and atmosphere modes, wide variation in terms of chromaticity existed among the participants. For the waking-up mode, most participants needed a white light with a low CCT level.

4. Conclusions

This study provides valueable information for us to design a good lighting system for residential applications, especially with the popularity of spectrally-tuneable LED lighting and smart control. The results here suggested that a good scene control and fine-tuned light setting can provide high-quality

and comfortable luminous environment to human beings. Further studies are necessary to compare the results obtained from a laboratory experiment and from a field study.

PP23 (PO81)

RESEARCH ON PREDICTIVE EQUATION OF SPATIAL BRIGHTNESS CONSIDERING COLOUR EFFECT

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Abstract

1. Motivation, specific objective

There are many recent studies on the predictive equation of spatial brightness. Nevertheless, there are only a few that consider colour effect, which is a vital element in space. Previous studies have pointed out that colours have influence towards perception of brightness; for example, it is known that as purity of the colour stimulus increases, and as the colour is closer to blue, perception of brightness becomes stronger. Considering these results and its influence on spatial impression, colour effect must be considered when examining perception of brightness.

It has been reported that there is a neural mechanism that maintains the perceived colour balance when adapting to spectral distribution of the visual environment. Although no exclusive relationship is identified between a specific cone response and a specific hue, it is suspected that a relationship between XYZ distribution and cones exists. As XYZ colorimetric system is an improved version of RGB colorimetric system, it is clear that colour-related information is incorporated. Specifically, Y holds the information on brightness, and when combined with X and Z, the colour can be identified.

The predictive equation designed in the previous research only used Y distribution as luminance, which was derived by the imagery analysis of luminance camera, and the arithmetic average and standard deviation of the logarithm of luminance distribution were calculated. Based on this, the following hypothesis was formed; colour effect can be considered into perception of brightness by including X and Z distribution values into the predictive equation. This research aims to adjust the predictive equation of luminance and spatial brightness, and the previous experimental conditions were re-measured using CCD camera and software, which can output and analyse X, Y, and Z distribution from a measured image.

2. Methods

In the previous research, adjustment method was applied for an experiment using two boxes with the eyehole. The interior is covered by white paper, and the front surface is covered by white paper that is curved in semi-circular (cylindrical) form, so that the edge of the box is not seen. A stimulus box is lighted with a colour lighting system with the following 28 colours and purity levels; nine colours (blue, cyan, blue-green, green-blue, green, yellow, orange, red, and magenta) with respectively three colour purity levels (10%, 30%, and 50%), and white. An adjustment box is lighted with a white lighting system, and subjects were asked to adjust the power until the brightness of the two boxes are the same. There were minimum of 18 subjects for each set (Due to significant number of sets, the experiment was split into a couple of days. Number of subjects for each set may vary because some sets were measured several times, in order to maintain a stable benchmark.). Coefficients of X and Z were identified by measuring luminance distribution under a reproduced experimental condition. In order to preserve measuring conditions of the previous research, luminance distribution area was fixed to 104 degrees horizontally and 76 degrees vertically.

The following analysing steps were taken using the measured distribution of X, Y, and Z. As a hypothesis, synthetic distribution was formed with the following coefficients in order to adjust the predictive equation; alpha for X, 1 for Y, and beta for Z. Several combinations of alpha and beta were tested, and the predicted brightness of the stimulus and adjustment were calculated for each combination. The first four testing combinations of alpha and beta were selected to observe general tendency; (alpha, beta), (1, 1), (1, -1), (-1, 1), and (0, 0). The ratio of predicted brightness of the

stimulus (denominator) and predicted brightness of the adjustment (numerator) was calculated, and optimum values of alpha and beta were verified using the ratio for each combination of each colour.

3. Results

As a result, optimum values of alpha and beta varied by colour. Tendencies were divided into two groups; warm colours, namely orange, red and yellow as one, and other colours as the other. Generally, as values of alpha and beta were smaller than 1, (0.5, -0.5) were added to the testing combinations. The optimum values of alpha and beta were derived by regression analysis.

As a result of ANOVA, which set adjustment value as the objective variable, and “light colour” and “subject” as factors in order to identify personal differences of the subjects, statistical significance was evident in both factors. Previous research also suggested that differences are caused by light colour, and optimum coefficients may differ by colour. In order to clarify different tendencies among colours, the average of the ratio of the adjusted value was calculated for each colour, which was used in the regression analysis to output values for alpha and beta. Results of the regression analysis, which input all data, were compared to identify general tendencies. As a result, excluding warm colours, there was no statistical significance in the value of alpha. Statistical significance in the value of beta was observed in most colours, but the values varied by colour.

In addition, regression analysis was applied to each subject in order to identify personal differences among subjects. Contrary to differences among colours, statistical significance was identified for alpha, but not for beta. Although none of the subjects admitted to have a defective colour vision when the experiment took place, colour perception may vary by subjects. Therefore, subjects were divided into groups, and results of the analysis were compared with the general tendencies.

4. Conclusions

Using the data of re-measuring the experimental conditions of brightness experiment using light colours with a device that outputs X, Y, Z distribution, predictive equation that considers the effect of colour is being formed. For further consideration, similar experiments will be held to examine whether similar tendencies are observed when using surface colours, in order to adjust the predictive equation

PP24 (PO82)

LIGHTING ENVIRONMENT CONSIDERING THE COMBINATION OF Duv OF THE LIGHT SOURCE AND INTERIOR MATERIAL

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Abstract

1. Motivation, specific objective

In recent years, LED luminaires have becoming much popular to correspond for the demands of energy saving or the diversity of requests for lighting environment. LED can realize a variety of luminous colour by using multicolour LED. In JIS Z 8725: 1999, it can be expressed as the same correlated colour temperature in the cases with the chromaticity distance from Planckian locus (Duv) within about ±0.02. Chromaticity coordinates of the most present light sources, such as incandescent lamp, fluorescent lamp or non-dimming type LED bulbs, are almost on the Planckian locus. However, the chromaticity coordinates of toning controllable LED tends to be located on the negative side of the Planckian locus because the most of the current toning controllable LED is composed with 2 types of LEDs with different wavelength and the chromaticity coordinates changes linearly by toning control. It has been pointed out that LED sometimes causes unnatural colour appearance due to the chromaticity distance from the Planckian locus (Duv).

In this study, subjective experiment was conducted to identify the effects of Duv of the light source on the impression of the lighting environment with consideration of the difference of room inner surface. This paper reports the combined effects of Duv of the light source and inner surface material on brightness evaluation.

2. Methods

Subjective experiment was conducted by using scale model (W: 600×D: 600×H: 600). All 15 university age students participated in the experiment as the subjects (Male:10, Female: 5, 21.4 years old in average). The experiment was conducted in two ways. In the first way, the subjects compared the brightness of a pair of scale models with different condition (paired comparison experiment). In the other way, the subjects evaluated the lighting environment in the scale model using a subset of the 14 semantic differential ratings (SD evaluation experiment). The subjects adjusted their eyes to 150 lx during the experiment.

The scale model was illuminated by the luminaire set in the centre of the ceiling. The lighting condition was set with illuminance, correlated colour temperature (CCT) and Duv. LED bulbs with different CCT (3000 K and 5000 K) were used as the source. The illuminance was set at 2 levels for each CCT by using ND filter. Duv was set at 3 different levels ranging from -0.023 to +0.0096 with 3000 K of CCT and ranging from -0.013 to +0.019 with 5000 K of CCT by using colour filter. The inner surface of the model was finished with 7 different interior materials with the reflectance ranging from 0.14 to 0.82. All 84 conditions combined with 2 conditions of CCT, 2 levels of illuminance, 3 levels of Duv and 7 types of interior material were evaluated.

3. Results

In the paired comparison experiment, the subjects evaluated the brightness in the model with each condition comparing with the standard model finished with white vinyl wallpaper (78% of the reflectance) set at 300 lx with 5000 K at Duv=0. The results showed that the subjects sensed the model lit by luminaires with Duv=+0.019 much darker than Duv=0.0034 in the case with the same interior material, the same illuminance and the same CCT. From the results of SD evaluation experiment, it was certified that the lighting environment lit by the light source with negative Duv was brighter than positive Duv and Duv=0 for each CCT and each interior material. Wilcoxon signed-rank tests were conducted to identify the significant difference in brightness evaluation between Duv=0 and positive/negative Duv. The results showed significant difference between Duv=0 and negative Duv in

the case with the whitish interior material of rather higher reflectance, and between Duv=0 and positive Duv in the case with the brownish interior material of rather lower reflectance.

In addition, the percentage of the subjects who judged the lighting environment uncomfortable never fell below 20% in the cases with negative/positive Duv.

4. Conclusions

The effects of Duv of the light source on brightness evaluation and impression of the lighting environment were analysed. It was identified that brightness evaluation was significantly different when the chromaticity coordinates was off the Planckian locus even when the correlated colour temperature of the light source was classified as the same by JIS. It was also shown that the effects on brightness evaluation differs depending on the combination of interior material and which side the Duv shifts (Duv>0 or Duv<0).

Session PS4
Presented Posters (D4, D6)
Tuesday, October 24, 16:15–17:00

PP25 (PO99)

FLICKER EFFECTS IN TUNNEL LIGHTING

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Abstract

Flicker is when a light source varies its emission. CIE defines flicker as *"impression of unsteadiness of visual perception induced buy a light stimulus whose luminance or spectral distribution fluctuates with time",* [definition 17-443] in the International Lighting Vocabulary. Usually all traditional lighting sources flicker because of the AC voltage power input, but subjects are usually unaware of the flicker: sources flicker at 100 (120) times in a second, a frequency above the critical flicker frequency, i.e. *"the frequency of alternation stimuli above which flicker is not perceptible":* the human visual system is unable to detect it. Besides with old and not more sealable incandescent lamps the filament thermal mass was also able to smooth the flicker effect due to power supply and these lamps emit light with negligible flicker. With fluorescent lamps only power supply technologies working at high frequencies helped in reducing the flicker perception in the most sensitive subjects. SSL (Solid Light Source) can work with AC/DC drivers and AC/AC drivers. According to the driver type or power supply implementation flicker can be very low (i.e. it is due to the ripple in the output current for example 5 % in the low frequency range, i.e. 70 Hz – 1 kHz and 15 % in the high frequency range) or the LED can go dark every mains half-cycle when its voltage is at or near to 0 V.

Current a lot of researches and normative works are focused on the problem of how much flicker is acceptable, but in these researches the starting point is the flicker associated to power supply, as a direct consequence of power supply techniques or because of dimming conditions. In outdoor lighting, road and especially in tunnel lighting there is another situation in which flicker exists. It is when the observer drives *"through spatially periodic changes in luminance",* as CIE TR88-2004 said. CIE recognize that discomfort from flicker depends upon four main factors: the flicker frequency (i.e. the number of luminance change per second), the duration of the experience, the ratio between the two peaks (i.e. between light and dark condition) and the steepness of the increase. In CIE TR88-2004 is recognized that for flicker frequencies, i.e. the time between the passage under two different luminaires at the given speed, between 4 Hz and 11 Hz, subjects can experience discomfort if exposed to stimuli for more than 20 second; 20 seconds at 100 km/h is about 600 m.

CIE TR88-2004 suggests these conditions without providing a solid metrological background. By reason of this and the recognized problems in evaluating flicker effects (due to observer motion) the last revision of Italian National Standard UNI 10095 on tunnel lighting do not gives flicker requirements while they are suggested in its previous edition and in CIE TR88. In EU there is not a reference standard (only a Technical Report was published by CEN) and the Italian tunnel lighting standard has a great impact on lighting installation cost because in Italy we have a very high number of tunnels and more the 1500 km of the highway network are in tunnels.

New researches consider flicker due to source fluctuation because of several problems faced with electronic driven technology of some LED sources as well the applications on LED dimmer techniques and stroboscopic effects viewing moving vehicles but studies on flicker due to observer motion in road lighting are very limited. This paper presents the results of a research work carried out as a task of the European funded project EMRP ENG62 MESAIL, "Metrology for Save and Innovative Lighting". The effects of flicker in tunnel lighting due to passage of drivers trough different luminaires inside a tunnel lit by LED luminaires is investigate with subjective experiment on site (during driving in a road tunnel lit by LED technology) and on laboratory using an Eye tracker system to evaluate physiological eye parameters like pupil diameter and fixation times.

During subjective experiment in laboratory the visual acuity of several selected subjects has been tested using a Landolt ring table, and the physical parameters of pupil and the time for completing the test were measured too. During driving in tunnel lighting, fixation point and pupil parameters were measured too. In laboratory the Landolt ring table was lit using LED sources driven under DC voltage

(steady on) and at different frequency to simulate AC flickering (50 Hz) and different frequencies of 20 Hz, 5 Hz, 3 Hz, 2 Hz and 1 Hz the lowest values to simulate motion flickering due to the passage under different luminaires during driving in a tunnel. Considering the common distance of 10 m between consecutive luminaires in the internal zone of a tunnel the last tested frequencies correspond to an average speed of 100 km/h, 70 km/h and 36 km/h. Subjects had also to answer to a questionnaire regarding the discomfort they experienced at the different flickering frequencies. The results and influences of flicker will be discussed in the paper as well as future implementations in the UNI tunnel lighting standard and suggestion for future work in CEN and CIE working group.

PP26 (PO100)

VISUAL EXPERIENCES AND NEEDS OF AGEING DRIVERS

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Abstract

1. Motivation, specific objective

With advancing age, visual and motor performance tend to decrease. In higher age cohorts more people experience problems in driving and these problems also become more serious. This is often connected to the increase in crash risk for older drivers. But apart from crash risk, a perhaps even bigger issue is the economical, social and personal consequences of not being able to drive anymore. Research and surveys have shown that even among the healthy elderly, a large part refrains from driving, or at least adapts its driving behaviour. Due to its particular challenges, night driving is most often avoided, by up to 50 % of the 60+ population. Research also suggests that in the majority of these cases, problems with vision are the reason to stop driving at night.

The visual tasks related to (night) driving have been identified. There is also a lot of information on how these relate to visual functions and lighting conditions. If we want to explore what role road lighting could play to support ageing drivers, we first need to know which of these tasks and functions are related to the reported increase in visual problems, so that we can approach this in a focussed way.

In order to have a differentiated view on the experiences of drivers, they were categorized in four different subgroups. The normal driver still drives and does not change his driving behaviour even if he might experience problems while driving. Other drivers might still drive in daylight and at night, but self-regulate their driving behaviour when experiencing problems and are therefore called regulators. The subgroups of the restrictors are defined by two aspects, not driving at all (general) and not driving in the dark (night). In general, this project is focusing on the problems regulators experience and the reasons why restrictors stopped driving.

2. Methods

To achieve this, a literature review on the visual problems of ageing drivers and their reasons to refrain from driving at night was performed. Additionally, a survey was held under ageing drivers in three countries, the Netherlands, the United Kingdom and Germany. Recruitment of participants was done via social media and organizations for the elderly and relevant interest groups.The survey was conducted online using Vovici.

3. Results

Up to now, 301 people participated in the survey. 16 % from Germany, 25 % from the UK and 59 % from the Netherlands. As there were no significant differences between the answers from these different countries, we treated the results as one group in our further analysis.The mean age of the respondents was 71 years (ranging from 50 to 99 years), with 54 % females.

For more than 67 % of restrictors, the feeling not being able to see good enough is the reason to self regulate their driving.

Looking at the combined results from the night regulators and restrictors, we see six visual functions which are most cited as being the (main) reason to self regulate. These are related to contrast sensitivity (e.g. being able to discern a pedestrian who is wearing dark clothing, or low contrast obstacles on the road); glare from road lighting luminaires and from the headlights of oncoming cars; adapting to darkness coming from a brighter lighted road and noticing (sudden) differences in relative speed and detection of low contrast obstacles. Comparing the answers of the participants to the results of similar research, we get the impression that they are in general in better health and more active than the average elderly. There is very likely a bias towards the better performing elderly in our

recruiting largely via organizations which cater for the active seniors, such as third-age universities and motoring clubs.

The subjective results of our survey compare quite well with the conclusions from our literature survey. Also here, apart from glare sensitivity, deterioration in contrast sensitivity and dark adaptation are found as the major sources of problems. This causes a decline in visibility and conspicuity of other road users and obstacles, which in turns leads to longer perception-reaction-times, a smaller useful field of view, underestimations of relative speed and overestimation of distances and time-to-contact in potential collision situations.

4. Conclusions

From both scientific literature as from our own survey, dark adaptation, contrast sensitivity and glare sensitivity come forward as the three major factors causing issues for ageing drivers. Further research should now be directed at filling the gaps in the characterization of contrast sensitivity and dark adaptation for elderly under lighting conditions relevant for night driving. With this knowledge, it should be possible to suggest improvements in our road lighting recommendations to better meet the visual needs of the ageing driver. Special attention should be given to cyclists, as these have been almost completely neglected up to now, but are increasingly important in modern traffic.

We will discuss the latest overview of the survey, which is still running, as well as a more detailed overview of the relationships between the ageing visual functions and the driving performance of our ageing drivers.

PP27 (PO101)

CHANGES IN ROAD SURFACES AND WALLS INSIDE TUNNELS OVER TIME

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Abstract

The road surface and the walls of a tunnel are crucial elements that determine the luminance caused by the lighting inside a tunnel. The reflectivity of these surfaces undergo changes once the tunnel is opened to traffic and as cars are driven through the tunnel. Such change in reflectivity depends on tunnel's structure, surface material, and amount of traffic. Considering these changes during the designing stage of tunnel lighting to predetermine the appropriate reflectivity level, ensures that the design is accurate, while guaranteeing safety for drivers as well as economic feasibility of the tunnel lighting.

Our research team measured reflectivity of road surfaces and walls from 97 of 600 tunnels located throughout local highways in Korea. These measurements were then analysed with respect to the total number of automobiles that had driven through each tunnel since their openings, thus enabling us to predict the changes that take place. Further analysis were made to determine which value, among those changes, would be most economical as far as installation and operation of the tunnel lighting is concerned.

PP28 (PO102)

METHODS TO CONTROL OBSTRUSIVE LIGHT IN CONSIDERATION OF URBAN STRUCTURE AND OUTDOOR LIGHTING USAGE IN ASIA

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Abstract

Obtrusive light is a general term used for various problems such as light trespass, sky glow, and glare arising from outdoor lightings. Obtrusive light creates adverse living conditions for the residents and causes energy waste. In order to minimize these problems, CIE and IES have created standards applicable to outdoor lightings and are recommending that the designers as well as installers of outdoor lightings employ these standards in their works. In addition, matters to be considered in selection and installation processes of the outdoor lighting are also being suggested.

As economies grew sharply in the recent years, many Asian cities also expanded rapidly. And especially with the advancement of LED, various lighting equipment are being used all over the roads, public squares, and stores. The placement as well as the type of obtrusive light from the outdoor lighting in these Asian cities are very much different from those in the US or Europe, due to differences in shape and layout of the roads and residential buildings, and different ways of using advertisement lightings at retail stores, etc. Moreover, lightings that use new methods, which could not have been imagined when existing light sources were used, are continually being developed and applied.

It is therefore very difficult to control obtrusive light in these Asian cities just by applying existing regulation methods. In this report, different types of outdoor lightings in Asian cities are categorized and their problems associated with obtrusive light are identified. In resolving these problems, problems with existing standards are revealed, while new forms of standards to be proposed are presented.

PP29 (PO16)

POSSIBLE HEALTH IMPLICATIONS OF LOW INFRARED LEVELS IN INDOOR ILLUMINATION

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Abstract

1. Introduction

The spectral power distribution of indoor illumination can extend beyond the band of visible wavelengths, into both the near-ultraviolet (NUV) and near-infrared (NIR). By definition, radiation in the NUV and NIR bands provides no direct visual benefit to building occupants, but it does have the potential to influence health, since radiation in these bands can interact with human tissue in ways that can be beneficial, harmful, or both.

In the case of the near-ultra-violet (NUV) band of radiation, the associated photons have enough energy to break molecular bonds, thus potentially damaging cells, and this can have negative health consequences. However, NUV radiation can also be beneficial – for example by killing potentially harmful bacteria and enabling the body to produce vitamin D. There is an important trade-off between these aspects, and therefore, not surprisingly, this topic has garnered considerable attention.

With the visible band, there is also considerable interest in non-visual effects of light which depend on how the spectral power distribution of the light varies throughout the day, involving, at least in part, absorption of light by intrinsically photosensitive Retinal Ganglion Cells.

The situation is very different for the near-infra-red band (NIR), roughly from 700 nm to 900 nm. Unlike NUV and visible radiation, there has been little, if any, discussion about possible health effects of NIR radiation in ambient illumination. In general, manufacturers of electrical light sources try to minimize the emission of NIR radiation, not because it is harmful, but because it does not contribute significantly to visual perception and is therefore viewed, to some extent, as a waste of energy.

2. Evidence from the medical field of photobiomodulation

NIR radiation is however of growing interest in medical treatment – especially in the field now known as photobiomodulation. Medical Subject Headings defines photobiomodulation as "*a form of light therapy that utilizes non-ionizing forms of light sources, including lasers, LEDs, and broadband light, in the visible and infrared spectrum. It is a nonthermal process involving endogenous chromophores eliciting photophysical (i.e., linear and nonlinear) and photochemical events at various biological scales. This process results in beneficial therapeutic outcomes including but not limited to the alleviation of pain or inflammation, immunomodulation, and promotion of wound healing and tissue regeneration*." In particular, it is believed that NIR radiation is absorbed by the enzyme cytochrome c oxidase (often abbreviated COX) which plays a key role in energy production within cell mitochondria. Since NIR wavelengths readily penetrate several cm into human tissue, NIR in ambient radiation can reach many parts of the body. In particular, it easily reaches the retina, since it passes through both the pupil and the sclera. The effect of NIR radiation on cells is generally beneficial – improving the ability of tissue to withstand and recover from oxidative stress.

These observations have given rise to a number of well-established treatment techniques for various medical conditions, as established in numerous randomized double-blind placebo-controlled clinical trials. Particularly intriguing are animal models in which retinal harm from exposure to blue light can be reversed by concurrent exposure to NIR light.

Since NIR radiation is abundant in natural daylight and typical natural cumulative daily doses of NIR are comparable to those that have had therapeutic benefits, it seems reasonable to consider whether these ideas may be related. It would not be particularly surprising for organisms to have evolved

biochemical uses for naturally occurring NIR photons, and for the known therapeutic effects of NIR to operate via those same mechanisms.

This raises a question that appears not to have been broadly asked: Is it possible that a significant health factor could be a person's daily NIR exposure, or the ratio of their NIR exposure to that of blue light? For example, perhaps the retina can benefit from absorption of a certain number of NIR photons for each absorbed blue light photon, in order to help counteract, to some extent, blue light damage.

3. Estimating NIR content in common illumination settings

From this perspective it is interesting to consider the ratio of NIR radiance to luminance in various settings. A fairly high ratio is found in three common settings - viewing a fire (about 20 mW/lm), viewing sun-lit leaves, which reflect mainly in the NIR band (about 8 mW/lm), and reading paper under an incandescent lamp (about 8 mW/lm). In comparison, two settings have a much lower ratio – sun-lit barren ground (2 mW/lm) and reading under a typical LED lamp (0.3 mW/lm).

An interesting possibility is that even though people cannot see NIR radiation they may nevertheless sense its presence unconsciously, and perhaps this could explain why people often choose NIR-rich settings such as sun-lit vegetation, fire-light, and incandescent light. If NIR light in ambient illumination is indeed healthful, such a preference could have naturally evolved.

Certainly there are other possible explanations for a correlation between fractional NIR content and the appeal of an illumination setting; clinical trials will be essential to better understand this. Fortunately, because NIR radiation is invisible, it is straightforward to carry out truly double-blind experimental protocols. For these reasons, new research along these lines is highly recommended.

4. Conclusion

It is proposed that the possibility of health benefits arising from NIR radiation in illumination (and conversely the possibility of harm in its absence) warrants careful investigation. This seems especially appropriate considering two worldwide trends: First, a growing fraction of people are spending a greater portion of their time indoors under electrical illumination, and second, lamps that emit very little NIR radiation are rapidly displacing NIR-rich incandescent lamps and high efficiency windows are removing much of the NIR radiation from the daylight entering buildings. Thus, overall NIR exposure is being greatly reduced for many people. Fortunately, if NIR is found to be needed for healthful lighting, it can readily be provided by incorporating inexpensive, highly efficient NIR LEDs into the design of electrical light fixtures.

PP30 (PO109)

LIGHTING EFFECT HEALTH TEST AND EVALUATION METHOD BASED ON PHYSIOLOGICAL INDEX OF HUMAN VISUAL SYSTEM

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Abstract

1. Motivation, specific objective

Eyes are human organs of great importance, which play vital role in the living, learning, working and growing of human being. They function by dealing with visual activities, thus enabling people to obtain information from eyesight, and affect various physiological operations inside human body. Surrounding light transports image information outside to brain through eyes, and meantime more or less exerts an influence upon the visual system containing eyes and the brain. When exposed in poor lighting environment, visual functions of human eyes are inclined to be seriously harmed with an increasing level of visual fatigue. Moreover, undesirable lighting is likely to damage the rhythm of human body to some extent. In the last decades, studies on the health effect of lighting aroused wide attention of people. And a growing number of researchers devote to the study of health lighting recently. As far as lighting products are concerned, lighting effect on visual physiological as well as brain load function conditions display rather obvious distinctions with different optical parameters, such as luminance, illuminance, colour temperature, colour rendering index, peak spectral and flicker. It is found that there exists a certain relationship between physical parameters of lighting products and the condition of physiological functions of human body, thus providing guidance to lead the development direction of healthy production within lighting products field. This prompts lighting health study to be a key part in the future researches of international lighting industry. In the process of lighting, eyes are direct receptors of light. As a result, human eyes act as the main researching object in studies on visual health and visual comfort of lighting products. However, previous researchers tend to assess the visual comfort degree of products relying on subjective sensations of the product users. Few credible indices are provided for quantification, making their results controversial in stability and accuracy. Consequently, these researching results can hardly meet the “healthy and comfortable” aim of lighting products design. Several objective physiological indices related to human eyes are widely employed to reflect visual condition of human eyes, yet any single one of them without accompanied by other indices is far from competent to accurately and completely describe the visual fatigue degree of eyes after enduring lighting process from products. It is also inappropriate to select all these indices as a combined group to quantitatively describe visual fatigue degree of human eyes, since they are not independent of each other. Given a suitable parameter could be inferred based on all these physiological indices, it would be hopeful to achieve objective quantitative assessment of human eyes visual comfort.

2. Methods

Nonlinear Regression Analysis (NRA) is a widely used tool to transform multiple parameters into one by fitting curve model. However, this method is not ideal when it comes to the conversion aiming at obtaining a new index to assess the visual comfort of human eyes, as it requires quite complicated process for constructing nonlinear regression equations, which are full of uncertainty with the changing of tested samples and measurement scope. Artificial Neural Network (ANN) method brings a novel thought for constructing the quantitative assessment index model. This method simulates the neural network of human brain by making a large number of processing units connect with each other and constitute a large scale nonlinear self-adaption system. It analyses the potential regulation according to the input and output parameters provided by researchers. This potential regulation enables researchers to set multiple physiological indices as input parameters, and transform them into one index for assessing visual comfort. In the present study, target test people were given enough time to experience the lighting products after a rest in dark room and vision function test to ensure the sample availability. Then a total of six objective physiological indices were collected from the target people as

the input parameters for describing the visual condition of eyes: refractive status (RS), axial length (AL), keratometric refraction (KR), higher order aberrations (HOAs), modulation transfer function (MTF) and the ratio of accommodative convergence to accommodation ratio (AC/A).

3. Results

This study also designed the test on visual contrast standard based on the space frequency and time frequency of human eyes vision. Combined with subjective assessment, a psycho-physical scale was formed as the output parameter to reflect the visual fatigue degree of tested people. Back Propagation Neural Network Analysis (BPNNA), which is a convincing tool to analyse the potential regulation between input layers and output layers using error backpropagation algorithm, was carried out in the present study on the purpose of investigating the relationship between input parameters and the output parameter.

4. Conclusions

This method optimizes real output of network to be more close to the ideal output by continuously adjusting interlayer weight, thus successfully constructing the visual comfort algorithm model, and generating the VICO Index (Visual Comfort Index) which proves to be effective for visual comfort assessment of human eyes. Nearly ten thousands of physiological parameters of human eyes were collected in this study to construct the database of parameters characterizing visual function of human eyes. The VICO index inferred from our algorithm model is available for the quantitatively classified assessment of lighting and displaying products.

PP31 (PO06)

BLH, LEDs AND CCT EQUIVALENT MELANOPIC ILLUMINANCES

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Abstract

1. Motivation, specific objective

It has been suggested that LED lighting provides more blue light than other lighting technologies. This perception persists despite the range of available correlated colour temperatures (CCTs), and needs to be regularly debunked. Nevertheless, increased efficiency, reduced sizes and the ability to produce affordable display screens with LEDs is likely to have increased exposure to artificial light, and changed typical circadian exposure profiles.

CCT is a widely recognised and established metric to describe the appearance of a light due to its relative spectrum. Different spectra can share the same CCT, but other human responses to lights with the same CCT may vary according to other aspects of the spectrum. The aim was to investigate the use of CCT as a guide to certain human responses.

2. Methods

This study builds on two previous studies, one concerning the potential blue light hazard (BLH) for both a range of screens, and another on human responses to LEDs and other lighting technologies. For each of the sources in these studies, the spectral irradiance was measured.

From this data the CCT and illuminance were calculated. A reference illuminant was defined as the blackbody that matched the source CCT and illuminance.

The ratio of the equivalent melanopic illuminances was then calculated (as $E_{z,source}/E_{z,ref}$). Finally, an adjusted colour temperature was determined in order to set this ratio to 1. This is referred to as the correlated melanopic temperature (CMT).

This was repeated to find the BLH ratio ($E_{B,source}/E_{B,ref}$). The adjusted colour temperature required to set this ratio to 1 is referred to as the correlated blue light temperature (CBLT).

More correlated equivalence temperatures (CETs) were found in the same way for other short-wavelength weighting functions related to the human eye.

3. Results

The CBLT values for these white light sources were generally lower than but reasonably close to CCT, although the accuracy reduced for high CCTs over 6000 K (CBLT/CCT = 0.92 ± 0.07).

The CMT values were also generally lower but less correlated with CCT (CMT/CCT = 0.83 ± 0.11). For CBLT and CMT, where the CET exceeded CCT, this was by no more than 12%.

CCT was not an entirely reliable proxy for either CET (CBLT or CMT), but CCT appeared to give a reasonably prudent prediction of the CIE's proposed blue light hazard factor of luminous radiation, $a_{B,v}$, which is closely linked to CBLT.

CCT uses a colour space to determine the correlated temperature whereas CET effectively uses the weighted efficacy of luminous radiation. To investigate why CCT did not predict CET, the CET using the 1931 2-degree standard observer colour matching function z was calculated (CET/CCT = 0.99 ± 0.05).

This shows the difference in approach immediately adds small unpredictable discrepancies. This level of variation was even present within a fairly homogeneous sample of blue LED plus phosphor lighting LEDs.

The non-visual cyanopic weighting function relates to the short wavelength cones in the peripheral retina. Cyanopic CET might be expected to be similar to those using the colour matching function z. However, the cyanopic CET values were more variable than expected, and the CCT values needed moderate adjustments (CET/CCT 0.98 ± 0.06). The change from colour space to hazard ratio correlation and the change of weighting function both contribute similar amounts towards this 6% variability.

The CBLT/CCT and particularly CMT/CCT ratios were quite varied for the LEDs. The change from colour space to hazard ratio correlation accounts for less of the variability than the changes in the weighting function. Similar results apply to the rods, regardless of whether the scotopic function V'(λ) or the rhodopic weighting function is used.

As well as exactly describing the melanopic content, the CMT values provided a useful rule-of-thumb description for predicting the rhodopic content of the light sources.

4. Conclusions

No evidence was found to support the hypothesis that LED technology is generally leading to potentially harmful lighting spectra when compared with other familiar lighting types. Based on these results, CCT might provide a useful rule-of-thumb description of a range of white light sources for cyanopic and BLH purposes. However, this should first be tested with a wider variety of illuminants.

For blue-LED driven phosphor LED lighting, the spectral dip between the peak of the blue LED and the longer wavelength peak(s) leads to a deficit in both melanopsin and rhodopsin stimulus when compared to a daylight or incandescent reference spectrum with the same colour appearance. There was, however, a similar result for the fluorescent sources tested. This is reflected in lower CET values for melanopsin (CMT) and rhodopsin.

The data demonstrate the power and limitations of describing white light spectra other than blackbody radiation in terms of colour temperatures.

Further discussion

As previously shown, the display screens are between 2.4 and 3.4 orders below the blue light hazard safety threshold for any exposure duration, and the threshold itself includes a substantial safety margin.

As also previously shown, none of the lighting sources presented a blue light hazard in normal use. Although LED street and panel lighting had moderately high CCTs, low CCTs are widely available for LED domestic lighting, and tended to predominate. The domestic lamps available suggests people prefer warmer CCTs and low radiance lamps.

There is a mismatch between the BLH function and the colour matching function z used in the CCT. This means CCT can theoretically understate the BLH-weighted radiance for some spectra. For white LED lights that would only be the case if there were a significant component around 420 nm. However, using LEDs below around 440 nm for these lights would be inefficient, which explains why CCT actually overstated the BLH-weighted radiance for all the LEDs measured.

PP32 (PO110)

LIGHT EVALUATION IN HIGH AND LOW MOOD STATES

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Abstract

1. Motivation, specific objective

Experiments were conducted to elucidate the relation between a person's light environment evaluation and mood states. The lighting level was changed from dark to light, or from light to dark during experiments. Subjects were divided into high and low mood state score groups. Then lighting evaluation was compared between the groups. Subjects' mood states of tension–anxiety, depression–dejection, anger–hostility, vigor, fatigue and confusion during the preceding week were used to divide the subjects.

2. Methods

2.1 Experimental methods

Experiments of two types were conducted. In one experiment, a subject entered a chamber with a lower level of illuminance (1-DARK). Lighting was changed to a higher level (2-LIGHT) for the latter part of the experiment. In another experiment, the reverse order of the illuminance levels was used (1-LIGHT and 2-DARK). Lighting evaluations were reported before the change of the lighting level and at the end of the experiment. Each experiment continued for 25 min; the lighting level was changed at about 15 min from the time of entry into the chamber. Six subjects entered the experimental chamber, sat around a table, and filled in questionnaire sheets according to the instructions. The mean horizontal illuminance at the center of the table was 340 lx at the lower level and 2200 lx at the higher level. The experiments examined 471 high school student participants.

2.2 Items of evaluation

Evaluation items of the light environment were brightness, glare, comfort, preference, and performance. The mood state during the preceding week was asked during the time for adaptation to the test environments. Six Mood state factors were measured using several rating scales. Then scores were calculated for each factor. Basic personal attributes, living habits such as regularity of living time and turning off unneeded lighting, and consciousness of environmental issues such as preference for natural light, needs for 24-hr shops and needs for brighter streets at night were also asked.

3. Results

Lighting evaluation was compared between high score and low score groups of subjects for the mood state score. Limits of division were 25, 50, and 75 percentile scores.

3.1 Tension–Anxiety (TA) and glare evaluation

Results show that TA-75%-high evaluated 2-DARK as more glaring than TA-75%-low ($p<0.0001$), although both evaluated 2-DARK as less glaring than neutral. Also, TA-25%-low evaluated 2-DARK less glaring than TA-25%-high ($p<0.15$). We infer that 2-DARK was evaluated as more glaring for high tension–anxiety subjects and as less glaring for low tension–anxiety subjects.

Furthermore, TA-75%-high evaluated 1-DARK as more glaring than TA-75%-low ($p<0.05$), although no difference was reported between TA-25%-high and TA-25%-low in the evaluation of glare of 1-DARK. We infer that 1-DARK was evaluated as more glaring for high tension–anxiety subjects, although 1-DARK was not always less glaring for low tension–anxiety subjects.

3.2 Tension–Anxiety (TA) and comfort evaluation

TA-25%-low evaluated 2-DARK as more comfortable than TA-25%-high ($p<0.05$). However, no difference was reported in the evaluation of comfort of 1-DARK between TA-25%-low and TA-25%-

high. We infer that 2-DARK was evaluated as more comfortable for low tension–anxiety subjects, but that 1-DARK was not always more comfortable for low tension subjects.

3.3 Vigor (V) and evaluation of brightness, comfort and preference

Results show that V-75%-high evaluated 1-LIGHT as brighter ($p<0.05$) and more comfortable ($p<0.05$) than V-75%-low. However, no difference was reported in brightness or comfort of 2-DARK between V-75%-high and V-75%-low. No difference was found in brightness and comfort evaluations of 1-LIGHT and 2-DARK. We infer that 1-LIGHT was evaluated as brighter and more comfortable for high vigor subjects. No relation was found between vigor and the evaluation of brightness and comfort for 2-DARK. Low vigor subjects did not always evaluate 2-DARK or 1-LIGHT as less bright and less comfortable.

Also, V-25%-low evaluated 1-DARK as brighter than V-25%-high ($p<0.05$). However, no difference was reported between V-25%-high and V-25%-low in the evaluation of brightness of 2-LIGHT. V-25%-low evaluated 2-LIGHT as less comfortable ($p<0.05$), less preferable ($p<0.05$), and less performable ($p<0.01$). It can be said that low vigor subjects evaluated 1-DARK as brighter than high vigor subjects. However, no relation was reported between vigor and brightness evaluation for 2-LIGHT. Low vigor subjects evaluated 2-LIGHT as less comfortable and less performable. No difference was found in the evaluation of comfort, preference, or performance of 1-DARK between V-25%-high and V-25%-low.

3.4 Anger–Hostility (AH) and glare and performance evaluation

AH-25%-low evaluated 1-LIGHT as less bright ($p<0.01$) than AH-25%-high. AH-25%-low evaluated 2-DARK as less glaring ($p<0.05$) and more performable ($p<0.05$) than AH-25%-high. We infer that low anger–hostility subjects evaluated both 1-LIGHT and 2-DARK as less glaring than high anger–hostility subjects did. Low anger–hostility subjects evaluated 2-DARK as more performable than high anger–hostility subjects.

3.5 Depression-Dejection (D) and brightness and glare evaluation

Finally, D-75%-high evaluated 1-DARK as more bright ($p<0.05$) than D-75%-low did. No relation was reported between depression and brightness evaluation for 2-DARK. D-25%-low evaluated 1-LIGHT as less glaring ($p<0.05$) than D-25%-high did. Also, D-25%-low evaluated 2-DARK as less glaring ($p<0.01$) than D-25%-high did. Results show that high depression subjects evaluated 1-DARK as brighter but no relation was found between depression and the evaluation of brightness for 2-LIGHT. Low depression subjects evaluated 1-LIGHT and 2-DARK as less glaring than high depression subjects did.

4. Conclusions

Some mood states were found to be related to some lighting environment evaluations; tension–anxiety was related to the evaluation of glare and comfort; vigor was related to the brightness, comfort, preference and performance; anger-hostility was related to the glare and performance; depression was related to the brightness and glare. However, mood states of fatigue and confusion were apparently unrelated to the evaluation of light environment.

Session PS5
Presented Posters (D2)
Tuesday, October 24, 16:15–17:00

PP33 (PO55)

ANALYTICAL MODELS FOR PHOTO-EMISSION SPECTRA OF SINGLE COLOUR LEDS

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Abstract

1. Motivation, specific objective

LEDs are a rapidly developing key component in a wide range of modern lighting applications. Important tools for developing LEDs and assessing their properties are reliable simulations of their physical properties.

In this paper we present an *a priori* analytic model for the photo-emission spectrum of single colour LEDs. The model establishes a close connection between the spectral properties of LEDs and the underlying solid state physics and can in principle be used to predict the photo-emission spectrum of an LED from only a few of its semiconductor properties. The full model is compared to a more simple, empiric, model that turns out to be well suited for good quality fitting of real LED spectra.

2. Methods

The presented LED model is based on the Lasher-Stern-Würfel equation that allows calculation of the photo-emission spectrum of a direct bandgap semiconductor from its energy dependent absorption coefficient. The later is routinely measured for many semiconductors, but can also be calculated *a priori* if the band structure of the semiconductor is known. The model requires only five input parameters and includes in particular the effects of so called band tails in the density of states that are responsible for photoemission at energies below the band gap.

3. Results

The analytic model is verified by using it as a fit-model for various real LED spectra and good agreement is found. Previously, similar agreement with experimental data has been achieved by using an asymmetric gauss distribution as fit model. Based on the analytical model the connection of the empiric fit model to the underlying physics of the LED is explained and its general applicability as a fit model is confirmed.

4. Conclusions

An analytic physical model for the photo-emission spectra of single colour LEDs is presented and validated against experimental data. The model can be used either as a fit-model for experimental data or as a tool for predicting the photo-emission spectra of single colour LEDs *a priori*. The full model provides justification for using a more simple asymmetric gauss model for fitting experimental data. Because the analytic model provides a clear connection between the photo-emission spectra of LEDs and their semiconductor properties, the model can facilitate the simulation of more complex situations involving single colour LEDs like the properties of luminaires or of phosphor converted white LEDs.

PP34 (PO56)

NOVEL METHOD FOR ANGULAR CHARACTERISATION OF GONIOPHOTOMETERS WITH A PATTERN GENERATING ARTIFACT

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Abstract

1. Motivation, specific objective

A precise measurement of luminous flux and luminous intensity on a goniophotometer requires a precise characterisation of all angles set by the measurement system. According to the international standard CIE S 025 describing the test method for solid state lamps, luminaires and modules, several mandatory requirements addressing the angular resolution and adjustments of goniophotometers are listed. One specific requirement mentioned in the standard is the angular reading resolution of 0.1°. This parameter depends on the device hardware implementation and cannot be corrected for. Whereas the second angular criteria concerning the angular aiming of a device under test being adjusted and maintained during a measurement within ±0.5° can be addressed by applying a specific correction and should be disclosed in the uncertainty budget of the measurement device. Therefore a precise characterisation of the angular properties of a goniophotometer system is needed and can be performed with the here presented newly developed approach of using an illuminated sliced half sphere.

The different steps for a goniophotometer angular characterisation based on C-plane measurements are presented and described. The results might be used for an angular correction to comply with the angular requirements of the international standard.

2. Methods

For the investigations a commercially available luminous flux goniophotometer was used where a single warm white temperature controlled LED source is mounted in the optical centre of the system. The main emission direction of the point light source is heading to the side. The optical axis of the LED is oriented perpendicular if the measurement arm with the photometer head is at position 90°. Furthermore the light source is covered with a structured object which is made with additive manufacturing (3D-printing) and has the shape of a sliced half sphere centred on the LED source. Thus the illuminated seven incisions in the cap covering the LED are generating a periodical shadow/light pattern. The light distribution curve of this geometrical structure is measured by acquiring single C-planes at different measurement speeds and measuring/moving directions.

To analyse the angular precision of the different acquiring modes the edges of the periodical structure in the light distribution curve are analysed and fitted with linear slopes. A measure for the system angular precision can be found by comparing these linear slopes of the different acquiring modes. As a parameter of interest the angular shift between the linear slopes and a predefined reference mode is calculated. This reference mode is defined as a C-plane acquisition in the direction top/down in the slowest possible moving speed of the goniophotometer measurement arm.

As the stability of the light source might be an issue for this kind of analysis it can be tracked by assessing the light intensity levels of the centre part of this structured object. The stability criteria of the international standard CIE S 025 are applied.

3. Results

By comparing the reference mode to the specific angular shifts of the extracted linear slopes acquired with slow moving speeds it revealed that for the present system the moving direction (bottom up/top down) has no influence on the angular precision. For all analysed slopes the angular shift was negligible.

However a significant direction dependent angular shift can be found for fast moving speeds of the measurement arm close to the allowed limit of the device. Compared to the reference mode, the

top/down movement direction results in an underestimation of the angle as the calculated angular shifts are negative. On the other hand the angular shifts showed positive values for the bottom/up movement of the measurement arm with fast moving speeds resulting in an angular overestimation.

The analysis of stability of the chosen light source showed a good agreement with the specific requirement described in the standard.

4. Conclusion

In summary it can be concluded that this method allows for characterising the angular properties of a goniophotometer by analysing C-plane measurements of different operating modes. The standard measurement mode is defined by scanning the light source by moving the measurement arm top/down and after rotating the gamma-axis moving the arm bottom/up. The here presented method was able to detect an angular position mismatch between the two different arm movements. If the angular deviations are beyond the specified values defined in the standard a correction can be applied on the angular values. Furthermore this procedure allows to report the angular precision in the uncertainty budget of the measurement setup.

PP35 (PO57)

SPECTRAL NONLINEARITY MEASUREMENT OF ARRAY SPECTRORADIOMETERS FOR COLORIMETRY

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Abstract

1. Introduction

Array spectroradiometers constructed with a charge-coupled-device (CCD) or an arrayed photodetector have been widely used in the fields of photometry, radiometry, and colorimetry. Array spectroradiometers have several advantages for use in these fields, such as short-time spectral measurement, compact structure, and easy-to-use functionality. Taking these advantages, the measurement system with an array spectroradiometer, e.g. sphere-spectroradiometer systems and gonio-spectroradiometer systems, have been used for the accurate testing of total luminous flux and chromaticity of lighting products based on light emitting diodes (LEDs) and laser diodes (LDs) and displays.

To reliably evaluate the total luminous flux and chromaticity by using an array spectroradiometer, the operation stability, the wavelength accuracy, and its spectral responsivity are fundamental factors. The response of the array spectroradiometer needs to have a linear response over wide range of optical power level, because the optical power of a test lighting product is larger or smaller in several orders of magnitude than that of a reference standard used for calibration. In addition, spectral nonlinearity would distort the measured spectral power distribution that directly affects the error in the source colour measurement. However, almost all optical detectors have more or less nonlinear properties accompanied by wavelength dependence. Therefore, evaluating the spectral nonlinearity of the array spectroradiometer is important.

In this study, we report on the nonlinearity of array spectroradiometers and its wavelength dependence, and discuss the potential error attributed to them in the source colour measurement.

2. Methods

Nonlinearity of two types of array spectroradiometers in the visible region was measured based on the flux-addition method with several laser diodes. In this study, two commercial array spectroradiometers with CCD, the array spectroradiometer A and B, were selected. The measurement wavelength ranges of the array spectroradiometers A and B were 300 nm to1110 nm and 350 nm to700 nm, respectively.

Each laser beam was divided into two optical paths, Path-A and Path-B, by applying a polarization-beam-splitting (PBS) cube. Before irradiating to an irradiance head of the array spectroradiometer, the divided beams were aligned to the same spot by adjusting two plane mirrors and another PBS cube. The power balance between each beam was adjusted with an optical attenuator. By blocking the beam from one of the optical paths alternatively and opening both beams using two mechanical shutters, the output counts, CA, CAB, and CB, of the array spectroradiometer were measured in a time-symmetrical sequence. The linearity factor was calculated by CAB/(CA+CB). By increasing the laser power multiplicatively, the nonlinearity of the array spectroradiometer was obtained by summing up successive linearity factors.

As the light sources in the flux-addition method, three Fabry-Perot laser diodes (FPLDs) and a diode-pumped solid-state (DPSS) laser were used. To evaluate the wavelength dependence, the incident laser wavelengths were chosen as 405 nm, 460 nm, and 660 nm for the FPLDs and 530 nm for the DPSS laser, respectively. The spectral bandwidths of the lasers were 1 nm for the FPLDs and 2 nm for the DPSS. Laser intensity drift of approximately 0.03 % and wavelength drift of less than 0.01% were attained for all the lasers by the stabilization with thermoelectric coolers whose temperature variation was controlled within 0.01 K. These lasers were operated with a constant current source at

room temperature. Each beam was adjusted with a collimating lens to obtain a near-Gaussian spectral shape and a 1.0 mm beam in diameter.

3. Results

The spectral nonlinearities at four wavelengths—405 nm, 460 nm, 530 nm, and 660 nm—for the two array spectroradiometers were evaluated. For all the measurements, the exposure time was set to be 20 ms and the normalized output count was chosen to be the indicated output count of 1. For the two array spectroradiometers used in this study, the nonlinearity values decreased so that the output count was lower, and the nonlinearities did not show spectral dependence. The spectroradiometer A showed the nonlinearity of 4% in the output count range of three orders of magnitude, whereas of the spectroradiometer B showed that of 25% in the output count range of two orders of magnitude, respectively. This nonlinear behaviour can be explained by the difference of floating diffusion nonlinearity when detecting the charge at the CCD and a lowering of charge-transfer efficiency of the CCD with the increase of the output count. Additionally, Different nonlinear behaviour depends on the type of the CCDs in the spectrometers.

To investigate the influence of the nonlinearities observed for the array spectroradiometers when they are used for source colour measurement, the change of chromaticity coordinates (x, y) by spectral power distribution of light sources with and without correction with respect to the nonlinearity was compared for each spectroradiometer. Three light sources based one white LED (blue LED+ yellow phosphor), tricolor LEDs (blue, green, and red), and tricolor LDs (blue, green, and red), all of which were adjusted to have the correlated colour temperature of 3025 K, were selected for these comparison. The comparison between the corrected and uncorrected conditions showed that the nonlinearity of 25% in the spectroradiometer B gave the maximum differences of 0.2 and 0.1 in x and y values, respectively.

4. Conclusions

Spectral nonlinearity measurements of two commercial array spectroradiometers were performed in the visible region. Different nonlinear behaviour was observed depending on the performance of the CCDs in the spectroradiometers, whereas no clear wavelength dependence was observed for both spectroradiometers. Using the observed nonlinearities, their potential error for source colour measurement was evaluated by using ofthree types of common spectrum (a blue-YAG type white LED, R-G-B tricolor LEDs, and R-G-B tricolor LDs).

PP36 (PO58)

COMPARISON OF GONIPHOTOMETRIC METHODS FOR OLED

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Abstract

1. Motivation, specific objective

OLEDs are innovated light sources which are still undergoing major improvement. This new technology in the lighting technology promises wide usage in the practice owing to properties of these light sources. The necessity of their characterisation for electrical, colorimetric and photometric quantities is undoubtedly very actual. However, the requirements and test methods misses in the international standards. Therefore, recently in CIE was established new technical committee TC 2-83 to create standard on test methods for OLED light sources. Simultaneously, this standard should amend recently released international standard CIE S025:2015 with the requirements for measurements of important quantities which characterise OLEDs. One of the important parameter is luminous intensity distribution curve (LIDC) to describe spatial characteristics of OLEDs to provide this information for other process in combination with statement of luminous flux from this curve. This measurement is performed by means of goniophotometer is the fundamental measurement method for the measurement of spatial distribution of the light output of light sources. Although in the science community the measurement of LIDC by goniophotometers based on various methods is very well known and sufficiently defined for OLEDs, in some international standardisation committees, prevails hesitations about using of some goniophotometric methods based on near-field goniophotometry with imaging photometers. These hesitations block implementing of this method for measurement of LIDC into the other standards what is making difficult to work for testing laboratories using this types of goniophotometers. Furthermore, this fact not allow to use references of these standards into another documents or standards. To cancel doubts about goniophotometry of OLEDs it should be underpinned by real measurements using different goniophotometers on different OLED light sources samples to validate of using various types and methods to also follow present standards.

2. Methods

This paper deals with investigation of the measurement various methods in goniophotometric measurements using various OLEDs samples with different goniophotometers e.g. two light source rotating goniophotometers, two different types of mirror goniophotometers, near-field goniophotometer with imaging photometer, goniophotometer with rotating arm with photometer and rotating light source around of OLED's axis. Cooperation between three testing laboratories having these types of goniophotometers will be presented. Previous work already done in few years ago on LED luminaires was extended to test of OLED light sources.

3. Results

Based on the measurement of different OLEDs was identified reliability of used goniophotometers and methods to measure of LIDCs of samples of OLEDs. The presentation will show

- comparison two approaches used in practice for measurement of LIDCs e.g. far-field goniophotometry vs. near-field goniophotometry for OLEDs,
- comparison various types and technologically different goniophotometers used for OLEDs
- what correction methods (if applicable), shall be applied to reach best possible accuracy for some

4. Conclusions

Comparison of goniophotometer based on near-field method need to be performed to prove ability of the measurement of this system in goniophotometric measurements of OLED light sources. The reference method was considered for far-field goniophotometers without changing working position of OLED light source in the Earth gravitational field which are based on allowed methods in the international standards and widely accepted in the standardisation community to underpin acceptance of near-field goniophotometers into the test methods of OLEDs. Even more, meassurements by goniophotometer with changing position of the light source in the Earth gravitational field with rotating light source widely used by testing laboratories was done to prove also their ability to perform measurements of LIDCs of OLEDs.

PP37 (PO59)

PARAMETERS CONTRIBUTING INTO THE UNCERTAINTY OF FIELD MEASUREMENT IN THE VERIFICATION OF REALISATION OF LIGHTING SYSTEMS

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Abstract

1. Motivation, specific objective

To have good indoor lighting system of indoor workplaces is very important for health and well-being of the persons especially for workplaces with long-term staying of persons. After installation of lighting system based on lighting design according to international standards for designing of lighting systems shall be performed verification of the lighting design. It performs by means of field measurement in the practice with photometric devices to measure various parameters which are defined in the standards. Each result of measurement should have the non-negative assigned parameter evaluated according to guide developed in BIPM (GUM). However, field measurement is not performed under laboratory conditions and lot of parameters influence the result of measurement. Furthermore, nowadays still exist doubts about expression of uncertainties for field measurement and agreement in this problem among science community is not clear. The estimation of this important parameter is undoubtedly necessary to judge if result of measurement is in the frame of desired limits defined in the standards. Until now it was not precisely defined unified guideline or recommendation at CIE or ISO level how to perform evaluation of uncertainty of measurement in the field measurement for verification of lighting systems beside on road lighting where some ideas where changed into the local standards or recommendations. In some countries is verification of lighting design one of the condition to have building commissioning of lighting system and shall be performed when new building or reconstruction of lighting system was done. At the present CIE standard S008 for indoor lighting is under revision and in the near future will be released new updated version. Also for anothe lighting systems as sports lighting or outdoor lighting standards describe necessity of measurement. In these documents are also included notes about necessity of verification indoor systems by means of field measurement which are performed by lighting designers by means of lighting calculation tools. Some discrepancies between simulations and realisation of designs were described in some papers.

2. Methods

In the research work were performed field measurements of various lighting systems in the practice based on common methods using in the stage of verification using devices properly metrologically characterised e.g. illuminance meters, luminance meters etc. Parameters which significantly contribute to the uncertainty of measurement were investigated in these measurements using guide GUM. Even more new approache for evaluation of uncertainty as Monte Carlo method were investigated and they will be presented as method for estimation of some parameters contributing to the uncertainty of measurement. For photometric quantities were evaluated from the measurements according to standards define requirements of particular lighting system. Correlations between some photometric parameters should be assumed.

3. Results

Based on the field measurements of lighting systems were identified parameters which contributes to the uncertainty listed in the uncertainty budgets for various cases and lighting systems installations. The use value of this parameter in results to be able consider how to treat with uncertainty will be presented in the paper.

4. Conclusions

The non-positive parameter shall be assigned to the result. This parameter is uncertainty and obviously minimum of investigation about this parameter was performed in the practice for verification of lighting systems so far besides road lighting. Very often evaluation process of uncertainties in the

field measurements are avoided due to lack of knowledge about parameters which contributes in the measurement. Therefore identification of all parameters contributing into the uncertainties is very important for practice by means of list of uncertainty budges similarly to measurements under laboratory conditions in combination with new approaches which appear in the process of evaluation of uncertainty of field measurements.

PP38 (PO61)

ASSESSMENT OF FILAMENT LED BULBS WITH RESPECT TO TEMPORAL LIGHT ARTEFACTS

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Abstract

Temporal light artefacts, abbreviated TLAs (including flicker, stroboscopic effect and phantom arrays), i.e. undesired time modulation in luminance from a light source, has shown to be a threat to wider SSL adoption especially related to dimming functions and low-quality LED products. This is due to the effects that both noticeable and unperceivable TLAs have on human perception and wellbeing. In the summer of 2016 the CIE TC 1-83 published a technical note (Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models) in which methods which can be used to quantify TLAs are described, e.g. the visibility measure M_v. In the present work a number of filament LED bulbs, currently available on the market, are assessed with respect to TLAs.

1. Motivation, specific objective

The objective of this work is to establish a pre-study of an overview of the state of the current market of commercial available LED lamps and put the results in relation to the recommendations put forward in some recent publications, such as the Product Performance Tiers published by the IEA SSL Annex (http://ssl.iea-4e.org/product-performance) or the IEEE Std 1789-2015. The work presented investigates filament LED products, which are a relatively new category of products where the form factor sets very tight limitations on the size of driver electronics.

2. Methods

There are a number of measures to quantify TLAs, including Flicker Index and Percent Flicker (also called Modulation depth). Together with the frequency of the modulated light, these figures can give a sufficient judgment of the TLA, however that is not always the case. Addition information is in most cases needed in order to verify the impact of the TLA on human perception. The visibility measure, M_v, is a measure of the visibility of the stroboscopic effect proposed as a standard metric by the CIE.

In the present work, a number of commercial available filament LEDs are investigated and the TLAs are quantified using both Flicker Index, Percent Flicker, the frequency of the modulated light and the visibility measure M_v. Additionally, not only TLAs are measured, but electrical, photometric and colorimetric parameters as well, such as power consumption, luminous flux, radiant flux, correlated colour temperature and colour rendering index. Regarding colour rendering, this is assessed using both the current standard of CIE CRI Ra, and the fidelity index R_f and gamut index R_g proposed in TM-30 by IES in 2015.

Some of the investigated bulbs are dimmable, and furthermore some of those are equipped with so called colour tuning, i.e. the colour temperature is decreased as the lamps are dimmed. Here the dimming properties, such as dimming range, dead-travel and occurrence of dimming introduced TLA are investigated, and the TLAs, photometric and colorimetric properties are investigated as a function of dimming level.

Regarding TLAs in combination with photometry, the integration time needs to be taken into consideration. Otherwise this can led to inaccurate results especially in the luminous flux value. To effectively avoid this issue the integration time needs to be an even multiple of the repetition period of the modulated light.

3. Results

The expected result is a comprehensive table, showing the resulting values of visibility measure M_v, CCT, CRI, luminous efficacy etc. for each of the investigated lamps. This overview will serve as a pre-

screening of the state of the current market of filament LEDs. The results will also be viewed in the context of the resent suggested recommendations regarding TLAs in SSL products.

4. Conclusion

The presented work will investigate a limited amount of a specific SSL product (LED filament lamps) with respect to TLAs, and put the results in relation to recently published recommendations regarding the both noticeable and unperceivable effects TLAs have on human perception and wellbeing.

PP39 (PO62)

BROADBAND DEEP-ULTRAVIOLET TO BLUE LED MEASUREMENTS

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Abstract

Deep-UV LEDs have low output optical power. For radiometric applications, they need evaluations and selections. Also, traditional photometric measurements in the blue wavelength range have large uncertainties because of the poor realizations of the CIE standard V(□) function in the wings. Pyroelectric radiometers with low noise-equivalent-power (NEP) and flat spectral response have been developed with NIST coordination to solve these LED measurement problems. The relative detector-response was determined from spectral reflectance measurements of the black-coating between 250 nm and 800 nm. The new pyroelectric radiometers have NEP of less than 1 nW/Hz1/2 and can be used at the output of regular monochromators. They also can accurately measure the broadband irradiance from deep-UV LEDs where the manufacturer reported output optical power is only between 1 mW and 50 mW. These pyroelectric detectors are an order of magnitude more flat in the UV-VIS range than filtered silicon detectors. An irradiance responsivity tie point for the pyroelectric detector was derived from a silicon-trap-detector. This scale transfer, was performed in the collimated irradiance of a current and temperature controlled LED of 660 nm peak. Using the tie point, the relative response function of the pyroelectric detector was converted into an irradiance responsivity function. The deviation of the response function from a constant value was less than +/- 0.2 % between 250 nm and 780 nm. This spectral flatness was validated in DC mode against a Si photodiode standard down to 350 nm. To improve the stray light in the UV, the validation was performed using an LED collimator with 368-nm peak at the input of the monochromator as an alternate source of the originally used tungsten-halogen lamp. The flat pyroelectric detector measured the integrated irradiance from deep-UV LEDs with nominal wavelengths of 265 nm, 275 nm, and 285 nm and also from high power LEDs with 365 nm, 400 nm, and 405 nm peaks. Source standards were not used in these detector-based calibrations. The broadband irradiance measurements were performed at different distances. The low-end limit of the measurements for the pyroelectric detector was 2 □W/cm2 at a signal-to-noise ratio (S/N) of 100. The spectral irradiance responsivity uncertainty of this new pyroelectric radiometer standard was 0.25 % (k=1) between 250 nm and 780 nm.

PP40 (PO63)

WAVELENGTH CALIBRATION OF SPECTRORADIOMETERS WITH PICO-METER UNCERTAINTY

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Abstract

Accuracy wavelength calibration of an array spectroradiometer is critical to many applications. We developed a method for calibration of the wavelength scales of array spectroradiometers using a tuneable kHz optical parametric oscillator (OPO) laser and achieved a wavelength uncertainty on the level of picometers; a reduction of approximately two orders of magnitude compared to those using traditional methods. This high-accuracy wavelength calibration method can significantly reduce the overall measurement uncertainties in various applications.

1. Introduction

The accurate wavelength calibration of an array spectroradiometer is critical to many applications. For measurement of optical radiation of a light source using a spectroradiometer a small wavelength error can result in a large spectral measurement error in the spectral region where the spectrum of the light source (e.g., a colour LED source) rises or falls sharply or where the spectral responsivity of the spectroradiometer changes rapidly. An array spectroradiometer is typically calibrated for its wavelength scale by measuring a limited number (e.g., 10) of narrow spectral emission lines with known wavelengths and then determining the wavelengths for the corresponding pixels near the calibrated wavelengths. The wavelengths of the rest (majority) of the pixels are obtained through interpolations, extrapolations, or curving fitting based on the small number of calibrated pixels. Using this conventional calibration approach, the wavelength uncertainty across the entire spectral range is limited to a sub-nanometer (for metrology-grade spectroradiometers) to a few nanometers (for low cost spectroradiometers). In order to reduce the wavelength uncertainty, a much larger number of spectral lines are required for the wavelength calibration. Therefore, Fabry–Perot etalons and Lyot filters were proposed to be used for wavelength calibrations, both of which produce multiple transmission maxima over the spectroradiometer's spectral range. However, such devices are not readily available, and also, their transmission maxima are typically broad which limits the wavelength calibration uncertainty.

2. Method of the wavelength calibration

In this paper, we describe a different approach for the calibration of wavelength scales of spectroradiometers that uses a fully automated, commercial kHz tuneable optical parametric oscillator (OPO) laser. A metrology-grade 1024 pixel CCD-array spectroradiometer was calibrated for its wavelength scale. The spectral range of the spectroradiometer is from 300 nm to 1100 nm with a bandpass of approximately 2.5 nm. The OPO laser was tuned across the entire spectral range of the spectroradiometer with a wavelength step of 5 nm. The wavelength of the OPO laser was measured by both the spectroradiometer and a high accuracy laser spectrum analyser with pico-meters wavelength uncertainty. The total number of measured laser lines is approximately 160. Because the wavelength calibration was fully automated, the total measurement time was within one hour.

3. Results of the wavelength calibration

The measured wavelength error of the metrology-grade spectroradiometer varies from approximately -0.2 nm to 1 nm across the spectral range and changes rapidly in some spectral regions, indicating a fine step wavelength calibration is required. Based on the large number of measured wavelength errors across the spectral range, the wavelength error of each pixel was obtained by interpolation between measured wavelengths, and a correction for wavelength error was applied to each pixel. As the result, the wavelength uncertainty of the spectroradiometer is reduced to a level of a few pico-meters.

4. Summary

High accuracy wavelength calibration of an array spectroradiometer is critical to many applications. A fast method for calibration of the wavelength scale of an array spectroradiometer is developed using a fully automated kHz OPO laser. A calibration uncertainty of wavelength on the level of pico-meters was achieved across the entire spectral range of the spectroradiometer, which is an improvement of approximately two orders of magnitude compared to those using conventional approaches.

Session PS6
Presented Posters (D1, D3)
Tuesday, October 24, 16:15–17:00

PP41 (PO27)

LUMINANCE EFFECT ON LEGIBILITY OF LETTERS PRESENTED BY A LIGHT-PROJECTION SYSTEM

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Abstract

1. Motivation, specific objective

Recently, a light-projection image technology like projection signing on buildings and roads or augmented reality devices, is rapidly progressed. Projected letters are often used in this technology and legibility of those letters is very important for safety and efficiency usage, for example. But it is difficult to define the adequate luminance of letters with regard to better legibility because background of those projected letters varies depending on the environments which affects the legibility..

The other interest of this study is to see the effect of age on the legibility for those projected letters. The projected letters are basically seen in the luminous mode and a higher luminance level than that in the reflected mode may occur. This might cause a glare sensation for which older people are more sensitive than younger people.

The purpose of this study is to investigate the effect of luminance of a projected single letter on legibility with variable background luminance. Legibility scaling of young and older adults will be measured and in addition, glare evaluation for the letter will also be investigated.

2. Methods

A Head-Up Display (HUD) system including its dedicated glass plate and a projector was used for the projection of letters in this experiment. The letter was presented as a virtual image on a real background generated by a LED Light box with a translucence diffuser the luminance of which was controlable.

Thirty five letters of a sans-serif font type (26 alphabets and 9 numerals) were used. Letter height was 0.121m, and the viewing distance was 2.5m. Five background conditions of different luminances (1.5cd/m^2, 10 cd/m^2, 100 cd/m^2, 1000 cd/m^2, 10000 cd/m^2) were employed. In each background condition, letters of nine different luminances (RGB: 255, 152, 116, 89, 68, 52, 40, 30) were projected on the virtual image plane, one at each time selected randomly. For each viewing condition, three trials with different letters were conducted. Totally, 135 letters (9x5x3) were presented to each subject.

A total of 30 older persons (mean age 70 years old) and 28 younger persons (mean age, 23 year old) were participated in the experiment. The subject was asked to try to read a letter presented and to evaluate the legibility by using a 5 point scale from 1 (very poor legibility) to 5 (very good legibility) without any restriction of time. In case the subject could not see the letter, he/she gave a 0 point. After the evaluation of legibility, the subject were also asked to judge whether he/she felt glare or not. The subject's visual acuity was corrected so as to get the best acuity at 5m distance.

3. Results

With increasing the luminance of the letter, the legibility evaluation score gradually increased from nearly 0 to up to 5 for each background condition. Comparing the legibility based on same Michelson contrast of a letter and background luminance, it is not the same but vary depending on the background luminance. When the background luminance is low, letters are less legible than the letters with high background luminance. For example, at the Michelson contrast 0.5, the score of legibility of older and young subjects is 2.5 (between moderate and bad legibility) in 1.5cd/m^2 background condition, but 4.0 (good legibility) in 10000cd/m^2. Therefore, it is assumed that the legibility of projected letters are affected not only by the Michelson contrast, but also absolute level of the letter luminance. This fact is quite different from the findings of previous studies.

Another interesting finding is the ageing effect for legibility of projected letters. In case of younger people, legibility score for high luminance letters were saturated except for the lowest background conditions (1.5 cd/m^2). In some cases, legibility of the highest luminances were worse than the moderate or lower one. Such situations were not seen in older subjects. If this reduction of legibility at very high luminance level is due to a glare of the letter, it might be more pronounced for older people. It is not the case, however.

The age-related difference is only clearly observed in the moderate luminance levels where significant difference between young and older subjects exists (legibility of young people were always better than, the older), but this difference is not seen in high and low luminance levels. ,

There were also age-related difference in the percentage of glare. Percentage of young subjects who feel glare are higher than those of older subjects at high luminance letters. Though older adults used to be considered that they feel more glare than young people, this result was considered to lead a different idea of cause of glare for older adults.

4. Conclusions

Following two points were concluded from the present study.

1) Legibility of projected letters is not simply Michelson contrast dependent. Luminance of good legibility for projected letters should be defined for different background conditions taking into account the age-related differences.
2) Two age-related differences were found in the legibility of projected letters. One is the appropriate luminance level for good visibility at moderate luminance level and the other is the percentage of feeling glare at higher luminance level of letters where young people felt more glaring effect than older people.

These findings could be applied for the design of letters which are generated by projected image technologies.

PP42 (PO28)

DISPLAY BASED METHODS FOR INTER-CULTURAL IMAGE QUALITY EVALUATION

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Abstract

1. Motivation

Image quality enhancement based on one- and two-dimensional colour attributes (e.g., chroma, lightness contrast, vividness,…) plays a crucial role for the post-productional workflow in motion picture and photographic applications. Usually, a lot of effort and money is put into the attempt to increase the image quality for a target audience or spectators group by film and photo studios all over the world without actually knowing the underlying psychophysical mechanisms leading to improved image preference. The aim of this study, therefore, is to approach the topic of image quality enhancement with respect to the observers' preference from a more scientific point of view and, as a long-term goal, to contribute to the establishment of a well-founded theory being able to describe the experimental results of image quality assessments.

2. Methods

In order to investigate the effect of one- and two-dimensional colour attributes on the perceived image quality and the observers' preference, two different but yet related display based experiments have been conducted.

For the first experiment, eight carefully chosen test images, providing a representative variety of image content, were rendered using five different one- and two-dimensional colour attributes. The one-dimensional attributes include chroma, hue, and lightness contrast, whereas the two-dimensional attributes are given by depth and clarity. For each colour attribute four distinct levels were applied leading to 21 different versions of each test image (5 attributes x 4 levels + 1 original). A paired comparison experiment was eventually performed in order to determine the corresponding z-scores of the observers' average preference ratings assuming Case V of Thurstone's Law on comparative judgements. For each test image the resulting 210 different pairs were shown to the observers in randomized order leading to a total number of 1680 comparisons, which were split into two sessions on subsequent days. Each session lasted approximately 45 minutes.

This first experiment was performed in both countries China and Germany using exactly the same experimental setup (the complete hard- and software was shipped to China and vice versa) and environmental conditions (fully darkened room with the experimental display being the only light source). In China only native Chinese observers and in Germany only native German observers were considered for participation in order to account for the cultural differences between these two observer groups and to avoid unwanted bias which could potentially be induced when mixing these two observer groups with participants having a different cultural or ethnical background. In total, assessments of 25 Chinese and 44 German observers could be gathered.

The second experiment that should be presented here can be considered as a supplement to the first one. Again, eight different test images were chosen. However, in contrast to the first experiment, no single attribute based transformations but so-called functional transformations based on colour attributes were applied to the test images including white point transformation in terms of correlated colour temperature, local and global contrast enhancement, and hue-dependent chroma transformation. In the second experiment, each transformation was considered separately, i.e., paired comparison to determine preference z-score values was only performed among images rendered with the same kind of functional transformation. Furthermore, for each test image and transformation eleven distinct levels should be applied. However, it turned out that not all four transformations were suitable for every test image and, therefore, we ended up with a total number of 1570 comparisons

instead of 1760 possible ones. Nevertheless, observers were again asked to complete the pair comparison task in two different sessions on subsequent days. Here, each session lasted approximately 40 minutes.

In order to also consider cultural differences and to compare the results from both experiments, 20 native Chinese and 20 native German observers were invited to participate in the second experiment. However, since the second experiment took entirely place in Germany one has to be careful when analysing and interpreting the experimental results, because it cannot be ruled out that the results of Chinese observers that have been living in Germany for quite a long time (>1 years) might differ significantly from those who have never left China due to cultural adaptation and bias effects.

3. Results

First results indicate that both Chinese and German observers are in favour of slightly more colourful images being in accordance with our common knowledge. For all eight test images of the first experiment and both observer groups the relation between mean preference ratings in terms of z-scores and colour attribute variation can be described by an inverted U-shaped function giving point to the conclusion that too large attribute variations – regardless of their direction – will not improve image preference. The same holds true for the transformations of the second experiment.

In both experiments it could be further confirmed that preference ratings as a function of colour attribute variations are largely influenced by the image content and, therefore, no generic image enhancement method could be derived from the results. Nevertheless, a strategy of image enhancement for a certain image content (e.g., blue sky, green grass, face skin,…) is considered to be feasible and should be presented in the final conference paper.

Regarding the cultural effects on the image preference ratings, the overall difference between the two observer groups is smaller than expected. The average correlation coefficient of Chinese and German observers reaches 0.82. Only for some specific images and transformations significant differences could be observed. The details will be reported in the full paper.

4. Conclusions

In order to investigate the cultural influences on image preference ratings two different display based experiments were performed comparing Chinese and German observers. Several different one- and two-dimensional colour attribute variations as well as more complex functional transformations were applied to the test images, which were eventually presented to the observers using the method of paired comparison. Results indicate that the preference ratings of both observer groups are mainly influenced by the image content. Therefore, a strategy of content-dependent image enhancement, where cultural differences will also be taken into account, should be presented in the final conference paper.

PP43 (PO29)

ANALYSIS OF THE LIGHTING INFLUENCE IN THE SPARKLE DETECTION BY APPLYING STATISTICAL DESIGN OF EXPERIMENTS

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Abstract

1. Motivation, specific objective

The objective of this work is to determine the light source influence in the visual perception of the sparkle texture effect on gonio-apparent materials. Sparkle texture effect is defined by ASTM E-284 as "the aspect of the appearance of a material that seems to emit or reveal tiny bright points of light that are strikingly brighter than their immediate surround and are made more apparent when a minimum of one of the contributors (observer, specimen, light source) is moved". Therefore, the influence of different lamps (with different SPD, CCT and CRI) in this appearance will be studied. In addition, three geometries mainly used in the automotive sector, 15ºx:0º, 45ºx:0º and 75ºx:0º following the CIE nomenclature, will be included in this study to evaluate its relevance on the sparkle detection distance. The motivation that has led to the development of this experiment is that there is no a previous similar work that addresses the influence of lighting in the sparkle detection.

2. Methods

A specific lighting booth for sparkle evaluation was designed and manufactured at the University of Alicante. This cabinet allow to evaluate the sparkle texture effect for any illumination angle and it is flexible to change the lamp and adapt it according to specific needs (daylight, warm light, CCT and CRI), as well as changes on the illuminance level (E in lx).

Three types of samples with different features were selected for this experiment. Firstly, a sample was chosen with a silverdollar pigment type and a large particle size (D50 = 34µm) to ensure that for any configuration we are sure that the observer is able to detect the sparkle effect. The remaining two samples (composed of Luxan® and Xirallic® effect-pigments) were selected based on the results obtained from a previous work. The behaviour of both samples was different regarding the sparkle detection for this reason it is considered interesting to see how they can be influenced by environmental conditions.

In this experiment, two light sources were selected: a warm LED lamp with a 3200K colour temperature and a daylight LED lamp with a 6500K colour temperature. For each lamp, different illuminance levels were considered: 800, 2400 and 5000 lx. Regarding the measurement geometry, the evaluation was performed in three different measurement conditions following those conventionally used in the automotive sector and available at instrumental level by the BYK-mac-i gonio-spectrophotometer: 15ºas15º, 45ºas45º and 75ºas75º.

The design of the visual experiment was based on the adjustment psychophysical method. It was consist of determining the maximum sparkle detection distance. The procedure was to adjust the maximum distance in which is perceived the sparkle texture by get closer or away from the sample. The samples were presented in a random way for each observer session. A total of 12 observers (7 men and 5 women) participated in the visual experiment with a visual acuity equal to 1. Three repetitions were performed for each lamp, illuminance level and measurement geometry. In total, each observer performed 972 evaluations for a total number of 11,664 visual assessments.

When the entire experimental phase was completed, all data related to the two lamps, three illuminance levels and measurement geometries were collected. With all these data the inter-variability and intra-variability were analysed by applying the STRESS parameter.

The analysis of the results was conducted by using the statistical design of experiments (DoE). A 3221 multilevel factorial design was selected taking into account the involved factors (CCT, illuminance level and measurement geometry) and the number of levels for each factor. It has to be in mind three levels

were considered for measurement geometry (15º, 45º and 75º) and illuminance level (800, 2400 and 5000 lx) and two levels for the lamp (3200k and 6500k). The design of experiments allows to evaluate the influence in the sparkle detection of the three factors independently as well as to analyse if there is linear or non-linear interaction among them.

3. Results

The STRESS analysis results were very good; the results of the average inter-observer variability were of 21.24 STRESS units, and an intra-observer variability of 11.05 units.

From the visual experiment it is obtained that the observer detects more sparkle for low illuminance levels and for the 45ºas45º geometry. Regarding the influence of the lamp, although the differences are not significant, the sparkle texture effect is best detected for a lamp with warm temperature.

Thanks to the statistical design of experiments (DoE) we obtain that the measurement geometry and illuminance level variables are significant (p-value < 0.05) since have been obtained p-values equal to 0.0001 and 0.0010 respectively for the sparkle detection, therefore the most relevant variable is the measurement geometry, instead the effect of the lamp type is not significant. The only significant interaction between variables is that related to geometry and the lamp type.

In resume, the statistical design of experiments has corroborated the results obtained visually in which the sparkle texture effect is detected at a greater distance for low illuminance levels and for the 45as45 geometry.

4. Conclusions

This study has shown that there are still many doubts about the sparkle perception, since as it has been verified that any slight variation in any of the variables studied, in this case environmental, causes a variation in the way in which we detect the sparkle.

In the absence of similar studies, thanks to this work and to the application of the design of experiments, some clarifications have been made on a topic, as is the sparkle visual appearance in which much work still remains. It has been concluded that the sparkle texture effect is detected at a greater distance for low illumination levels and for the 45ºas45º geometry, besides the colour temperature does not influence significantly.

It was possible to highlight the influence of the geometry variation and the illumination level when evaluating the sparkle detection distance, which extrapolated at the industrial level generates some uncertainty, since for instance it may be the case that samples that are accepted under specific illumination and observation conditions can be rejected with other measurement configurations. It should also be remembered that BYK-mac-i only performs measurements (by monochrome imaging methods and algorithms) with a fixed illuminance level and colour temperature / colour rendering general index (spectral power distribution).

PP44 (PO30)

CHROMATICITY AND EYE-MOVEMENT SPEED DEPENDENCE OF THE PHANTOM ARRAY

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Abstract

1. Motivation

The phantom array is one of the temporal light artefacts (TLA) that perform saccadic eye movement. We would like to develop a model to describe the phantom array and its threshold frequency. As a step to develop the model to explain the phantom array, we investigate the chromatic dependence of the phantom array; flicker and stroboscopic effect, which have no eye movement, shows importance of luminance variations and limited influence of the chromaticity in the TLAs.

We also examine the relationship between the threshold frequency of the phantom array and the eye-movement speed of each individual. The threshold frequency for detecting the phantom array has a large individual difference. The difference of eye-movement speed may account for individual variation of the threshold frequency of the phantom array.

2. Methods

We have developed an apparatus for the experiment of the phantom array with varying chromatic light stimulus. Red, green, and blue RGB LED bars are used in flat panel light sources in experiments. One of the light bars is controlled by DC power and the other is controlled by pulse-width modulation (PWM) with the same luminance level. The chromaticity (red, green, or blue) and the control methods (PWM vs DC power) of the illumination bars are randomly switched to remove the ordering effect from the experiment. An eye tracker with a headrest was placed in front of the participant to track the speed of eye movement during the experiment. Calibration of the eye tracker was performed in each individual at the start of each subject's the experiment.

Three luminance levels, 25 lx, 200 lx, and 400 lx, are used for the experiment. Nine college students with two females participate in the experiment. Experiments were performed in the dark chamber after dark adaptation. Each subject participated sessions: 3 chromaticity sessions x 3 luminance levels.

3. Results

The experiment results show that the threshold frequency of the phantom array is dependent on the logarithmic luminance level and linear relationship. In chromaticity, a blue LED indicates a threshold frequency lower than the green or red LED in the same luminance level. The chromatic different of the threshold frequency of the phantom array may come from the difference of L, M, S cone response time; L and M cone cell have similar shape and response time, and S cone has longer response time than L or M cone.

For the eye movement speed, each individual shows different eye movement speed. Even in the same subject, there are variations in the eye movement speed. To find out the relationship between eye movement speed and threshold frequency of the phantom array, we used average frequency of each subject and find relationship of their threshold frequency of the phantom array. The correlation between the threshold frequency of the phantom array and the eye movement speed is very high. When a subject has faster eye movement than other subjects, the subject is more likely to show higher threshold frequency of the phantom array.

4. Conclusions

Our experiments show that chromaticity and eye-movement speed are important variables for the development of the phantom array model. The temporal contrast sensitivity of the eye may also be very important factor for modelling the phantom array and other TLAs. Therefore, we further investigate the temporal contrast sensitivity during eye movement in the future.

PP45 (PO31)

VISUAL CLARITY AND BRIGHTNESS IN INDOOR AND OUTDOOR LIGHTING: EXPERIMENTS AND MODELLING

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Abstract

1. Motivation, specific objective

In indoor lighting, a wide range of illuminance levels (from the high mesopic range up to high photopic illuminances in brilliant environments) and correlated colour temperatures (from warm white to cool white) can be found. This results in very different levels of perceived visual clarity and spatial brightness impressions. Latter visual attributes are important to assure the acceptance and comfort of the built interior and also for good visual performance in relevant lighting applications (e.g. shopping, office or industrial production).

The objective of the present contribution is to define new descriptor quantities for visual clarity (*C*) and brightness (*B*) that combine the signals of multiple retinal mechanisms including chromatic components and rod and ipRGC signals by re-analysing the results of two psychophysical experiments (one on visual clarity and one on mesopic brightness) published earlier. What is meant by "visual clarity" here is defined by the psychophysical method, see Section 2.

2. Method

In the psychophysical experiment on visual clarity (published earlier), several achromatic and coloured objects were assessed according to the clear visibility of their achromatic and chromatic texture and spatial structure under different light sources (CCT=2200 K to 5000 K) at different illuminance levels (40 lx to 1000 lx). The dataset of the visual clarity scale values of the observers was considered to be re-analysed in the present paper in terms of the new descriptor *C*.

In the experiment on mesopic brightness (published earlier), one half of a >20° bipartite field was matched in brightness visually to its other half (the reference field) at three mesopic light levels between 0.1 and 1.5 cd/m^2. The test and reference field was illuminated by two different light sources of different chromaticity. Seven different light sources (including halogen, Xenon, LED, mercury vapour, sodium and metal halide lamps) were used altogether. The dataset of the resulting visually matching luminance values (together with the relative spectral power distributions of the light sources) was considered to be re-analysed in the present paper in terms of the new descriptor *B*.

The new descriptor of visual clarity (*C*) was defined from the logarithm of the prevailing illuminance plus the logarithm of a weighted sum of normalised S-cone, ipRGC, rod and L-cone minus M-cone signals of the white tone predominating in the experimental room. Signals were normalised by dividing by an integral quantity which considers every wavelength as equally important across the whole visible spectral range according to a recent idea found in literature.

The new descriptor of brightness (*B*) was defined as a product of the luminance of the stimulus and the weighted sum of normalised (in the above sense) S-cone, ipRGC, rod and L-cone minus M-cone signals of the stimulus.

3. Results

The z-scores of the visual clarity dataset of the observers correlated well (r^2=0.98) with the new descriptor of visual clarity (*C*). According to the higher illuminance levels, the weight of the rods equalled zero. The weight of the S-cones equalled 82% while the weight of the ipRGC channel equalled 12%.

The new descriptor of brightness (*B*) was used to predict the visually matching mesopic stimuli. The ratios of the B values of the matching stimuli (B_{test}/B_{ref}) were closer to unity (goodness criterion of predicting of a visual brightness match) than the ratios of the luminance values of the matching stimuli.

At the lowest mesopic luminance level (0.1 cd/m^2), (B_{test}/B_{ref}) ratios ranged between 0.93 and 1.06 instead of the broader range of the luminance ratios between 0.82 and 1.51. The ratio of the brightness predictor should equal unity for a perfect model. The 95% confidence intervals of the luminance ratios ranged between 0.05 and 0.10 at this luminance level.

At the intermediate mesopic luminance level (0.5 cd/m^2), (B_{test}/B_{ref}) ratios ranged between 0.90 and 1.05 instead of the broader range of the luminance ratios between 0.85 and 1.19. The 95% confidence intervals of the luminance ratios ranged between 0.04 and 0.10 at this luminance level.

At the highest investigated mesopic luminance level (1.5 cd/m^2), (B_{test}/B_{ref}) ratios ranged between 0.81 and 1.04 instead of the somewhat broader range of the luminance ratios between 0.79 and 1.06. The 95% confidence intervals of the luminance ratios ranged between 0.05 and 0.08 at this luminance level.

4. Conclusions

Previously obtained visual clarity and mesopic brightness datasets were re-analysed by the use of two new descriptor quantities based on the luminance, S-cone, ipRGC, rod and L-cone minus M-cone signals of the stimuli. For visual clarity, a good fit of the model to the visual data was obtained. For mesopic brightness, the model provided a better prediction than the (photopic) luminance ratios and other brightness models from literature. Further brightness matching experiments with highly variable LED spectra are currently underway.

PP46 (PO32)

PUPILLARY LIGHT REFLEX AND RECEPTIVE FIELD CALCULATION OF VISUAL DISCOMFORT FOR DIFFERENT SPATIAL FREQUENCIES AND LUMINANCE STEPS

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Abstract

1. Motivation, specific objective

Discomfort glare is defined as glare that causes discomfort without necessarily impairing the vision of objects. Researchers have been attempting to quantify the amount of visual discomfort ever since the beginning of the previous century. Some of the physiological mechanisms like the receptive field mechanism and the pupillary light reflex are known for decades. The spatial frequency and luminance distribution within the luminaire affects the perceived visual comfort. Traditional glare metrics are under discussion since they lack physiological or psychological justification and often ignore any non-uniformities in the luminance distribution.

The extended receptive field model links the luminance distribution to the neural response. In a previous study, a receptive field model was proposed as a possible alternative for traditional glare metrics. The model is extended with the pupillary light reflex. By taking the pupil area into account, a high resolution luminance map is converted to a retinal illuminance. Visual discomfort is calculated by applying the extended model on the retinal illuminance distribution. A forced choice paired comparison experiment involving non-uniform stimuli with different spatial frequencies and luminance steps illustrates the performance of the receptive field model.

2. Methods

The eye images an object plane characterized by a luminance distribution on the retina. The retinal illuminance is proportional to the pupil area and is regulated by the pupillary light reflex. In lit environments, a constriction of the iris reduces the pupil area and limits the incident light. In dimmed settings, an iris dilation increases the pupil area maximizing the retinal illuminance. An eye photoreceptor converts light into an electrical signal. In the centre-surround receptive field mechanism, the signal of one or more central photoreceptors is directly transmitted to a bipolar cell. A horizontal cell parallel to the retina connects several surround photoreceptors and relays an indirect signal to the bipolar cell. A ganglion cell combines the direct and indirect bipolar signals and relays a pulsed signal train to the brain. In an ON-centre OFF-surround receptive field, the ganglion cell is excited by the centre but inhibited by the surround signal and vice versa for an OFF-centre ON-surround. At a sharp dark-light edge, the surround (or centre) is not entirely illuminated resulting in a net signal. Receptive fields consequently act as an edge filter. The convolution of a retinal illuminance map and a centre-surround receptive field kernel produces a brain signal map representing the luminaire's visual neural response.

In a paired comparison experiment, 9 non-uniform stimuli were rear projected on a diffusor screen creating a Lambertian light source. The stimuli were composed of light emitting squares on a background. DALI controlled wall washers generated a fixed room background luminance level of 45 cd/m². In two tests, a constant stimulus surface of 33.5 cm by 34 cm observed from 3 m with an average luminance level of 200 cd/m² was maintained. In a first frequency test, if the number of squares was increased, the luminous surface per square and the spatial separation between squares was decreased. In a second test for luminance differences, the stimulus background was increased while the luminance level of the light emitting patches was decreased. 20 observers were asked to indicate the most visual discomforting stimulus in a full paired comparison forced choice experiment. Luminance maps were measured with an LMK luminance camera. A generalised linear model produced a z-score on an interval scale and a standard error for visual discomfort for each stimulus.

3. Results

A coefficient of determination of 0.90 between the observed paired comparison assessment and the extended receptive field value is obtained. For the first test, if the number of light patches is increased, the total amount of edges increases and the spatial separation decreases. The increase in the amount of edges initially results in an increase in visual discomfort. When the spatial separation of the light patches reaches the spatial eye resolving power, the light-dark edges become less clear. The human eye will not resolve any edges and the visual discomfort saturates. If the spatial separation of the light patches is further decreased, the stimuli will appear more uniform and the observed visual discomfort starts to decrease. The receptive field model also returns an initial increase when the amount of edges increases. As the spatial separation of the stimuli reaches the spatial centre-surround receptive field retinal dimension, the calculated value saturates. The model is less sensitive to the high frequency edges resulting in lower calculated values. For the second test, by decreasing the light-dark luminance step, the luminaire will appear as more uniform. In agreement with the extended receptive field model, the observer visual discomfort assessment decreases for increasing stimulus uniformity.

4. Conclusions

The pupillary light reflex is included in the extended receptive field model. Starting from the retinal illuminance distribution, the receptive field model successfully calculates visual discomfort for non-uniform stimuli varying in spatial frequency and luminance step. With a coefficient of determination of 0.90, the model is a promising candidate to replace current failing traditional discomfort glare indices.

PP47 (PO83)

COLOUR EMOTION FOR INTERIOR LIGHTING

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Abstract

The relationship between colour and observer response in terms of semantic feelings, or the so-called "colour emotion" in the co-authors' previous studies, has focused on colour patches or colour images as the stimuli, presented either in a viewing cabinet or on a calibrated computer display. Psychophysical findings have shown that such a relationship was consistent and predictable, and was culture-independent for some semantic scales. For instance, observer response for "active/passive" can be well predicted by a modified version of CIELAB difference between the colour stimulus and a medium grey. Little is known, however, as to whether these findings can also apply to interior lighting. LEDs have become a dominant light source and can easily manipulate light colours to create an atmosphere. Can a room lit by a coloured light create a specific feeling that is shared by individuals in the room? Can the relationship between light colour and the observer's response be also consistent and predictable, just like what has been discovered in the conventional colour emotion studies?

Methods

To answer these questions, the present study used four Philips Colour Blast RGB LED lamps to light an entire experimental room, 3.5m (width) by 2.5m (depth) by 2.3m (height) in size, decorated like a fashion store to provide a context. Observers were asked to stay individually and rate the room in terms of 4 scales "liking", "brightness", "tension" and "dizziness". This was followed by rating of the observer's own facial skin using a mirror in the room in terms of 5 semantic scales "like/dislike", "smooth/rough", "natural/unnatural", "young/old" and "feminine/masculine".

There were 40 light colours used in this study, consisting of 25 white lights and 15 coloured lights. Note that all the 40 light colours had the same luminance value, 300 cd/m^2. The 25 white lights were selected to cover 5 Duv levels, -0.02, -0.01, 0, 0.01 and 0.02, and 5 CCTs, 3000K, 3500K, 4000K, 5000K and 6500K. The 15 coloured lights included 5 hue regions, red, yellow, green, blue and purple, and 3 levels of purity based on Illuminant E.Twelve observers, 6 females and 6 males, all Taiwanese university students, participated in the experiment. More observers will take part in this study and the results will be reported in more detail in the full paper. All observers had normal colour vision. During the experiment, each observer was seated at the centre of the room and was asked to wear a grey coat in order to avoid any influence of their clothes colour on the experimental results. For each light colour, the observer was asked to rate the room as well as his/her facial skin using the 9 scales described above after the eyes fully adapted to the lighting condition. The observer was asked to focus on the wall right before him/her when rating the room but could look around to better appreciate the appearance of the room. The sequence of the 40 light colours was randomised for each observer.

Results

The experimental results for white lights show that the Duv level had a strong impact on "brightness". The white lights at negative Duv, i.e. those located below the Planckian locus, tended to feel brighter than those at positive Duv. Regarding "liking", observers tended to like the room when Duv $\leq$ 0 more than when Duv > 0. The findings for "liking" were found to correlate well with "brightness". The experimental results also show that facial skin tended to look young, smooth and feminine for negative Duv more than for positive Duv. Nevertheless, the "natural" response for facial skin was found highest for Duv = 0.

The results also show strong influences of CCT on the observer response. The observers tended to feel less dizzy and feel the room was brighter when CCT = 5000K or 6500K, and they also found their facial skin more natural, younger and more masculine for high CCT. Nevertheless, the highest rating for "smoothness" of facial skin was found to be at 4000K.

The above findings regarding white lights indicate that the room tended to feel brighter, more liked, less tense and less dizzy for Duv < 0 than for Duv > 0. This tendency was found more significant for high CCTs, i.e. observers tended to prefer white lights having negative Duv and high CCT (5000K and 6500K).

For coloured lights, the experimental results show that blue and purple lights had the highest rating for “brightness”, while green and yellow lights had the lowest rating. Red and green lights were not preferred because they tended to create greater tension and dizziness. Among the 5 hue regions, yellow light was found to have the highest rating for “naturalness” for facial skin. Blue and green lights tended to make the facial skin feel old, rough and masculine, while red and purple lights tended to make it feel smooth and feminine.

The purity of light colour had a strong influence on observer responses not only for feelings of the room but also for facial skin. The experimental results show that the higher the purity, the more tense and more dizzy the room tended to feel, and thus the room was less liked. The higher the purity, the less natural and less young the facial skin tended to appear, and thus was less liked.

According to these findings, it is fair to say that colour emotion has a systematic tendency when examined by CCT, Duv, hue region and purity. The findings will be able to help develop guidelines for interior lighting design based on either white lights or coloured lights.

PP48 (PO84)

HOW ACCENT LIGHTING AND AMBIENT LIGHTING AFFECT HUMAN VISUAL RESPONSE

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Abstract

Layering lighting plays an essential role in creating a comfortable and appealing atmosphere in an interior space. There is an increasing demand from the industry for understanding how the combination of accent and ambient lighting can affect the occupant's visual perception in terms of comfort and attractiveness.

Methods

To answer the research question, the present study used a small experimental room, 3.5m (width) by 2.5m (depth) by 2.3m (height) in size, where a 3D polyhedron object was displayed to serve as a visual task for the observers. The three walls were grey in colour. The wood veneer floor appeared dark brown. The grey 3D object was 10.63cm (width) by 10.63cm (height) in size, placed at a one-metre-high cabinet which was covered by a black fabric, situated in the middle of the room.

A panel of 12 observers, 6 males and 6 females, with normal colour vision took part in the study, individually conducting visual assessment in the room. More observers will participate in the study and the results will be reported in more detail in the full paper. During the experiment, each observer was asked to stand right in front of the 3D object, with a distance of 1m, to assess the 3D object in terms of "sense of depth" and "liking", followed by assessment of the entire room in terms of "brightness" and "comfort".

The room used two types of lighting, accent and ambient. The accent lighting was aimed to light up the 3D object. An LED ceiling track light (1080lm, 14.8W), with a beam angle of 60 degrees, was used for the accent lighting. The light was located at either of two positions under the ceiling. The first position was right on top of the observer, providing a horizontal incident light angle of 0 degree to the 3D object, as can be seen in the top view of the room. This is called T1 in the study. The second position of the ceiling track light was located to the left side of the observer, with a distance of 1m, providing a horizontal angle of 45 degrees to the 3D object. This is called T2.

The ambient lighting was provided by indirect lighting from the three walls, the background wall behind the 3D object and the two side walls. The background wall was lit by three liner LED light bars, called W1 in this study, recessed in the ceiling to down light the background wall. Each light bar (36.9W, 1360lm) was 1m in length. The side walls were each lit by two light bars, called W2 and W3, both installed on the floor, for up lighting the left and the right walls respectively. All lights used in this study had CCT = 3000K and were provided by TONS Lightology Inc.

There were two settings of ambient lighting in this study. The first setting was that W1, W2 and W3 were all switched on and were dimmed by changing the currency at the same rate, by 6 steps: 100%, 80%, 60%, 40%, 20% and 0%. The second setting was that only W1 was switched on and was also dimmed using the 6 steps described above. The sequence of the dimming settings was randomised in the experiment for each observer. Throughout the experiment, the light intensity of T1 and T2 was kept constant.

Results

Experimental results show that for W1, W2 and W3 all switched on and dimmed at the same rate, the observer responses were found to have different tendencies between T1 and T2. For T1, the darker the ambient lighting was, the more likely it was that the 3D object felt rich in sense of depth, the 3D object was more liked and the entire room felt more comfortable. This suggests that the most preferred lighting setup was when W1, W2 and W3 were all switched off. For T2, on the other hand,

the most preferred lighting setup was when W1, W2 and W3 were all dimmed at 60% in currency to provide medium ambient lighting to the room.

When only W1 was switched on for ambient lighting, the observer responses were not affected by the positions T1 and T2 for accent lighting. In this scenario, the most preferred setting for lighting was when W1 provided a medium luminance contrast for the 3D object, the ratio of vertical illuminance for the 3D object to the background wall being 2.5:1. This was when the 3D object felt most rich in sense of depth, the 3D object being liked most, and the room being rated the most comfortable.

The findings described above reveal interesting insight into how the effect of ambient lighting on the visual response can be influenced by the position of lamp providing the accent lighting. The findings can help develop useful guidelines of lighting design for related applications.

PP49 (PO85)

EXPLORING THE IMPACT OF LED LIGHTING ON DAILY ACTIVITIES FOR THE ELDERLY WITH AGE-RELATED VISUAL IMPAIRMENT

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Abstract

1. Introduction

Many countries are now facing the challenges brought by the upcoming ageing society. The prevalence of age-related visual impairments among aged population requires careful planning of public space and environment. The design of lighting, as critical part of public facilities, should thus consider the visual needs of ageing people with different type and severity of visual impairments. Since CIE published Technical Report "196-2011: Guide to Increasing Accessibility in Light and Lighting", much research work has been done on lighting and basic visual performance. However, more empirical evidence regarding daily activities of the elderly is still in need to provide basis for further lighting guidelines and standards. This study aims to investigate the impact of LED lighting on the performance of daily activity for the elderly with age-related visual impairment.

2. Methods

Laboratory experiments were performed to test the abilities of unlocking and small object identification under six lighting conditions. Two spectral power distribution (SPD) equivalent to white LED and orange high pressure sodium (HPS) and three lighting levels (3.3, 10.0 and 33.3 lux) were used. The SPD was modulated using a multi-channel and full-spectrum LED cube. Safety goggles were deliberately modified to simulate blurred vision, central and peripheral blindness. An extra untreated goggle was also used as control group. Two tasks were performed by 10 young participants (five male and five female; mean age of 25). In Task I, participants were asked to open a lock with swastika shaped keyhole; whilst in Task II, participants were asked to pick out all five small objects out of 70 slightly different LEGO bricks close in shape and colour. Task duration with successful finishing were recorded by the experimenter as data. Each test participant carried out all 48 possible trials (4 goggles, 3 illuminances, 2 SPDs and 2 tasks). The order of the trials was counterbalanced to avoid order effect. Each test started with ten-minute adaptation to the mesopic lighting condition. In both tasks, practice trials were used to confirm understanding and familiarity on the task.

3. Results

For Task I, the initial results show that when illuminance was 33.3 lux, unlocking task took 6.11s on average under HPS SPD and slightly shorter time under white LED (5.85s). When illuminance was 3.3 lux, it took 7.25s under HPS SPD and 8.05s under white LED on average. These suggest that higher illuminance can shortens the task duration of unlocking within mesopic range, but no effect of SPD was revealed. For Task II, the initial results show that when illuminance was 33.3 lux, small object identification task took 38.58s on average under HPS SPD and slightly shorter time under white LED (23.32s). When illuminance was 3.3 lux, it took 113.27s under HPS SPD and 86.36s under white LED on average. These suggest that both higher illuminance and broader spectrum can shorten the task duration of small object identification within mesopic range. More results with statistical analyses will be included in full paper.

4. Conclusions

This work reported an experiment carried out to explore the impact of illuminance and SPD on the performance of unlocking and small object identification for the elderly with age-related visual impairment. It was found that age-related visual impairments deteriorate the performance of the two tasks, which can be off-traded by higher illuminance. There is a clear benefit when using white LED comparing with HPS SPD, for that performance of small object identification task is heavily relying on

colour rendering ability of light source. Further quantitative work with more data points under finely adjusted lighting condition is expected.

POSTERS

PO01

VALIDATION OF A COLOUR DISCRIMINATION INDEX

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Abstract

1. Motivation, specific objective

In 1972, WA Thornton introduced the concept of colour discrimination as an important aspect of colour quality and defined it as "the extent to which the illumination allows the observer to discriminate among a large variety of object colours simultaneously viewed". To quantify this ability, Thornton proposed the Colour Discrimination Index (CDI), computed as the area enclosed by the eight test colour samples in the CIE Ra calculation in the CIE 1960 UCS. Thornton proposed using this gamut area as a way to predict colour discrimination and suggested that as gamut area increases, so does colour discrimination ability. Several recent studies show that this is not necessarily true for highly structured spectra, which is important due to the prevalence of the large peaks and valleys often present in the spectra of LED sources.

A recent study explored the colour discrimination ability—measured with the Farnsworth-Munsell 100 Hue Test—of 24 LED light sources with strategically varied average fidelity, average gamut, and gamut shape. This study was the first to evaluate colour discrimination using a large number of light sources; light sources systematically varied over a wide range of average fidelity and average gamut values; and spectra with opposing (orthogonal) gamut shapes. Results showed that average gamut indices—*CDI*, *FM-100 Gamut Area (FMG)*, $FMG_{CIECAM02}$, *Gamut Area Index (GAI)*, Colour Quality Scale (CQS) Q_g, and IES TM-30-15 R_g—all fail to reliably predict colour discrimination. Pairing each gamut index with a fidelity index increased model prediction, but models were still notably weak. The results of this study provide conclusive evidence that gamut area is not predictive of colour discrimination ability. The authors proposed a colour discrimination metric (R_d), calculated as a Farnsworth-type error score of FM-100 chips transposed by the test light source. R_d was a strong predictor of total error scores (r^2 = 0.860) and could correctly rank 5 of the 6 best light sources and 6 of the 8 worst light sources.

A primary objective of the current study is to validate R_d as a predictive colour discrimination metric. Additionally, specific hypothesis testing will determine if light sources with the same value of R_d, but transposing caps in different areas of colour space, can produce statistically different error scores. Testing for different age groups will determine if the predictive ability of R_d is consistent across age groups.

2. Methods

To validate R_d, 11 light sources with strategically optimized R_d values are tested using participants under the age of 30 with an approximate mean age of 26 years (similar to the previous study using R_d). R_d values to be tested include 0, 4, 8, 12, 16, 20, 40, and 60. An R_d of 0 means no transpositions caused by the light source, a value of 4 is one transposition, a value of 8 is two, a value of 12 is three, and so on. If the resulting predictive power is strong and the trend is consistent with the previous research work, we will have strong evidence that R_d is a valid metric for predicting colour discrimination.

An R_d of 4 indicates that the test light sources causes 1 cap transposition in colour space but gives no indication where in colour space the transposition occurs. To test if the location of the transposition can produce statistically different error scores, 4 light sources will be optimized with an R_d of 4, but with transpositions located at four distinct locations around the hue circle (a'b' plane of CIE CAM02 UCS).

Lastly, repeat testing of the experimental light sources over three age groups will determine the metric's predictive power for a larger population. The considered age ranges, consistent with previous research studies, are: 1). under the age of 30, 2). 30 to 50 years of age and, 3). above 50 years old.

All experiments are performed with the Farnsworth-Munsell 100 Hue Test in a 71 x 71 x 45 cm viewing booth. Spectra are designed using an 11-channel spectrally tuneable LED source (Thouslite LEDcube) which rests in a 30 x 30 cm cutout in the top of the booth.

3. Results

The experiment is in-progress and the results are to be determined.

4. Conclusions

Insufficient results to make conclusions at this time.

PO02

COLOUR PREFERENCE OF HUMAN SKIN TONES UNDER DIFFERENT CORRELATED COLOUR TEMPERATURES OF A MULTICHANNEL HYBRID LED-LUMINAIRE

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Abstract

The beauty of human skin tones is a very important requirement for the luminaires in the lighting of cinemas, hospitals, cosmetics, shops, museums, galleries as well as in other human activities. Independent of the different demands of relaxation, entertainment, communication, business, cultural and art activities, human skin tones should be illuminated best according to their colour properties under both natural and artificial light sources. The research questions are whether the highest colour fidelity property of a light source for human skin tones can satisfy the light source users or is there another aspect of colour quality that should be added? What is the role of correlated colour temperature concerning this aspect of artificial light sources? In this work these issues will be investigated by means of visual experiments under a programmable hybrid LED luminaire. Subjects had to scale the colour preference of their own skin tones visually. Analysing the visual results, the compromise between colour fidelity and colour saturation enhancement will be discussed.

1. Motivation

Since the beginning, human activities have taken place under daylight. It is understandable that daylight has been considered as the best light source to experience the beauty of human skin tones. Then, industrial revolution introduced traditional artificial light sources (candles, oil lamps) or electric conventional artificial light sources (incandescent, fluorescent or gas-discharge lamps) which brought several benefits but there was no chance to change and adapt their spectra dynamically and optimise them. As a result, visual experiments on human skin tone perception and preference could not work with very different illuminating spectra representing a multitude of different colour fidelity and colour saturation properties.

Nowadays, semiconductor based light sources have been applied worldwide in almost all applications in lighting industry achieving dramatic innovations on both aspects, energy saving and colour quality. Today, by means of the available combinations of LED types in multichannel hybrid LED-luminaires and an appropriate optimization algorithm, the colour quality of semiconductor light sources can be adjusted to best satisfy the different demands of the users in different lighting applications.

If the colour objects to be assessed visually are only limited to human skin tones and the above mentioned multichannel hybrid LED-luminaire is ready to be programmed, what criteria should be set for the optimization algorithm to achieve the most preferred skin tones? How can these criteria be verified and quantified? These issues will be discussed in this paper.

2. Description of the applied system and its experimental implementation

The appropriate number and region of origin of test subjects was first considered for the experimental implementation: Asian, European and African subjects were included. They were sorted into different skin tone groups according to the measured spectral reflectance of their skin.

For the visual assessment to be carried out by the subjects, the question "*how do you feel the about the preference of your own skin tone under the current illumination*" was asked. Observers had to answer on an interval scale between 0 and 100 labelled by categories (so-called semantics): "*very bad*", "*bad*", "*poor*", "*moderate*", "*good*", "*very good*", "*excellent*".

The LED-luminaire was programmed to yield ten different spectra with ten different saturation levels for warm white (3200 K) and ten different spectra for cool white (5600 K). The illuminance level under the LED luminaire was held constant, 2400 lux in all settings.

3. Calibration, evaluation and results

In case of the warm white light sources (3200 K), the following results were obtained:

- Maximal visual preference of the skin tone groups 1, 2, 3 and 4 were achieved with the chroma differences ΔC^* =0; 2; -1; and 0 in the four groups, respectively (chroma differences characterise desaturation (<0) or oversaturation (>0) of object colours compared to the reference light source).

In case of the cold white light sources (5600 K), the following results were obtained:

- Maximal visual preference of the skin tone groups 1, 2, 3 and 4 were achieved with the chroma differences ΔC^* =1; 2; 4; and 2, respectively.

4. Conclusions

The individuality of the skin tone preference tendencies in the different human skin tone groups could be seen clearly from the results of the experiments. The chroma difference values (object desaturation or oversaturation caused by the light source's spectrum) corresponding to maximal colour preference were different in case of the different skin tone groups. Therefore, a common spectral optimisation criterion for all types of human skin tones is not a correct approach for developing and/or evaluating luminaires of high colour quality in high-end lighting applications, especially in relaxation, hospital, entertainment and art activities.

The maximal colour fidelity is generally not a correct criterion for the optimization algorithm of human skin tones. Additionally, there is also an influence of correlated colour temperature factor on the colour preference of the test subjects. The warm white light source needs a smaller amount of colour saturation enhancement than the cold white light source.

PO03

OPTIMAL COMBINATIONS OF LIGHT COLOUR AND TYPE OF MAKE-UP ON APPEARANCE OF WOMAN'S FACIAL SKIN

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Abstract

1. Introduction

Women wear make-up for their own fashion, the manner and self-expression in their daily lives depending on occasion. However, the appearance of the facial skin changes with the lighting colour as well as the cosmetics, such as lip colour and cheek colour. To clarify which combinations of the light colour and the type of make-up are preferred on the appearance of woman's facial skin, we conducted an experiment on the appearance of woman's face with some types of make-up under some lighting conditions.

2. Methods

First, we prepared a female model who was 22 years old and wore four types of make-up, "Natural", "Cute", "Elegant" and "Cool". She wore orange colour lipstick and orange brusher as "Natural" make-up, pink colour as "Cute", rose colour as "Elegant" and wore beige colour as "Cool" make-up. Secondly, we set 20 kinds of lighting conditions with four levels of CCT (3000K, 4000K, 5000K, 6700K) and 5 kinds of duv (-0.010, -0.005, 0, +0.005, +0.010) in each CCT condition, using 24 RGB LED lamps [iColor Cove MX Powercore, Philips Color Kinetics] and 10 white LED lamps [iW CoveMX Powercore, Philips Color Kinetics] with three kinds of LED in different correlated colour temperature. In addition, we prepared the standard illuminant D65 condition.

We measured the chromaticity values of her face using a 2D colorimeter [UA-1000, Topcon Co. Ltd.] under the 21 lighting conditions above mentioned in the type of "natural" make-up, and under 5 lighting conditions (duv=0) in the type of "Cute", "Elegant" and "Cool" make-up. Measured chromaticity values of the face were transformed into their respective RGB values using the calibration data of an LC-display [CG245W, EIZO] used in the present experiment. In total, we generated 40 images of the woman's face with make-up, and each image was presented on the display. Participants observed the lower half of the woman's face, especially the lower cheeks, and evaluated "naturalness," "activity", "sophistication" and "preference" with a numerical scale from -10 (bad) to +10 (good) in each visual image. The 17 participants were all female in their twenties, and all had normal colour vision.

3. Results

According to the results in "Natural" make-up condition, the evaluations of "naturalness" and "sophistication" were higher under 5000K lighting conditions than that under other CCT conditions, whereas "activity" was higher under 4000K. Also, the evaluation values of "naturalness" and "sophistication" were more than +5, when duv was 0, -0.005 or -0.0010. The evaluation value of "preference" was more than +5, under the lighting conditions of 5000K in duv=0 and duv=-0.005, and low under 3000K and 6700K in positive values of duv.

In the comparison of the types of make-up, the evaluation of "naturalness" was relatively high under 4000-6700K and relatively low under 3000K in all types of make-up. The evaluation value of "sophistication" was more than +5 under 5000K and 6700K in "Natural", "Cute" and "Elegant" make-up conditions whereas 4000K lighting was the best (evaluation value was around +3) for "Cool" make-up. The evaluation of "activity" was relatively low under 6700K in "Natural" and "Cute" make-up, whereas the 3000K lighting was not so good for "Elegant" make-up. Also, the "activity" of the face with "Cool" make-up under the 5000K and 6700K lighting were very low, negative values.

Moreover, we analysed these evaluation data by using a multiple regression; "preference" was used as the response variable, and "naturalness", "activity" and "sophistication" were used as the

explanatory variables. As a result, it was derived that the standardized partial regression coefficient of “sophistication” was 0.557, that of “naturalness” was 0.296, and that of “activity” was 0.295, suggesting that the contribution of “sophistication” is much higher than that of “naturalness” or “activity” in “preference” evaluation.

4. Conclusions

In conclusion, the face with “Natural” make-up (in orange colour) looks good under 5000K in positive duv. Also, the face with “Cute” (in pink colour) and “Elegant” (in rose colour) make-up looks good under 5000K. On the other hand, the face with “Cool” (in beige colour) make-up looks better under 4000K. Therefore, the preferred light colour depends on the type of make-up.

*This study was supported by JSPS KAKENHI Grant Number 25282006.

PO04

AN ILLUMINANT LOCUS BASED ON NEUTRAL WHITES

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Abstract

1. Objective

White lights are typically specified by the CIE as chromaticities in the Planckian and Daylight loci. Until recently, Rea and Freyssinier investigated the white perception in an enclosed viewing cabinet. They found that white perception occurs above and below the Planckian locus at 4000K respectively from the 6 CCTs studied. However, Smet et al found neutral whites are below the Planckian locus and the most neutral white is located at about 6000K having a Duv of -0.0085. Ohno and Fein investigated 'natural' whites along four iso-CCT lines at 2700K, 3500K, 4500K and 6500K with Duv ranged from -0.025 to -0.02.

From the above studies, all the findings revealed that the neutral or natural whites are not located on Planckian locus. Also, there are obvious difference on neutral whites above CCT of 4000K between different studies. The goal of the present study is to verify 'neutral locus'.

2. Methods

A double viewing cabinet was used in this study. It was equipped with a spectrum tunable LED lighting system. Nine LED channels were used in this study. The interior of each cabinet was painted using a grey matte paint having an L* of 80. Sixty-one light stimuli having a luminance of 300 cd/m^2 were used including 7 iso-CCT lines (6500K, 6000K,5000K, 4500K, 4000K, 3500K, 3000K) at 7-9 Duv levels (-0.025, -0.02, -0.015, -0.01, -0.005, 0, 0.005, 0.01, 0.015). All stimuli were strictly controlled at CCT of ±50K, Duv at ±0.0005 and CIE-Ra>90 and at 5% of 300 cd/m^2. The chromaticity between the two neighbouring stimuli was also produced to be used as the adaptation point.

Pair comparison method was used for visual assessment. Observers compared neighbouring pair stimuli to judge which one appeared to be more 'neutral', which is defined as no trace of hue. For each iso-CCT line, observers performed from one end to the other and also the reverse direction. The iso-CCT and direction for each observer were randomized. In total, 54 pairs of stimuli were assessed. Note that the experiment of iso-CCT of 6500K was repeated to determine the intra-observer variability.

Two experiments were conducted according to the adaptation source used between two consecutive neighbouring light stimuli. The first adaptation source had the chromaticity between the pair of the sources to be compared as used by Ohno. The other adaptation source was fixed at 6000K at the Planckian locus as the most neutral CCT found by Smet.

Seventeen normal colour vision observers attended the experiment. Their ages had a mean of 24 with a standard deviation of 3.4. At the beginning of an iso-CCT series, the adaptation time was 1 min. They were then adapted at an 'adaptation source' for 30s, and made the judgement, i.e. which side in a pair of lights to appear more 'neutral'. The whole procedure was repeated until the completion of the work. Overall, each observer assessed 6 or 8 pairs for 7 iso-CCT (6500K was repeated). Each CCT was done four times, i.e. two directions (forward and reverse) and two adaptation methods (6500K and middle points). In total, 3672 estimations were made.

3. Results

The 50% threshold method was used to find the white locus. Firstly, for each pair, the percentage of the 'neutral' judgements for each pair was calculated. These and Duv for each iso-CCT were used to determine the threshold, i.e. 50% of the observers judged as neutral and the other half judged as not neutral. The results were used to derive four neutral loci from two directions for each adaptation method.

The results showed that the forward direction (from positive to negative Duv) locus is always closer to the Planckian locus than that from the backward direction (from negative to positive Duv) regardless which adaptation method used. There was a statistically significant difference between the forward and reverse directions (P=0.000).

Secondly, the results from the two directions for each adaptation method were averaged and compared. It showed that the results from the 6000K adaptation method is consistently larger than the middle point adaptation method by about 0.003 Duv units until reach about 6000K. However, this difference is small comparing with the inter-observer variability (from 0.003 to 0.004) found in the present study. The cross point between two loci is at about 6000K. This seems to indicate a neutral white unaffected by the adaptation background used. Also, ANOVA test showed that there is no significant difference between the two adaptation methods (P=0.36) when CCT is larger than 6000K.

At each CCT level, the most neutral Duv values are ranged from -0.015 to -0.01 from low to high CCTs. This agrees with Ohno's results that the white lighting locus is located below the Planckian locus from -0.020 to -0.025). The present neutral white locus is closer to Planckian locus than the natural locus found by Ohno's.

The above method was also used to find the most neutral white point. The same 17 observers participated this experiment. At this time, all the white points along the locus from the middle point adaptation method were used. All the experimental stimuli and their adaptation points were prepared from the neutral locus with middle point adaptation method. It was found the neutral white to be at 5900K with a Duv of -0.011. This agrees well with those found by Smet et al (2015), having a CCT about 6000K at Duv of -0.0085.

4. Conclusions

This study was aimed to establish a neutral white locus and the most neutral colour. The conclusions are:

- The results are very consistent that the neutral whites of different iso-CCTs are located below Planckian at a Duv from -0.01 to -0.015 .
- As for the most neutral white point, the present is 5900K at -0.011 Duv which closely agrees with that found by Smet.

PO05

COLOUR RENDERING, SPECTRAL DISPERSION AND WAVELENGTH RESOLUTION

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Abstract

1. Motivation, specific objective

Several recent studies have summarised the research into colour rendering metrics. Much of the effort in this field has been stimulated by the increasing use of LEDs for lighting, as the spectral characteristics of LED lighting solutions have highlighted deficiencies in existing evaluations.

In 2015, the IES published TM-30-15 as a potential replacement for the Colour Rendering Index (CRI) and Colour Quality Scale (CQS). TM-30-15 provides fidelity index R_f and relative-gamut index R_g, based on 99 spectral reflectances which are claimed to have uniform coverage in both the colour and wavelength spaces.

The uniform coverage claims highlight two basic requirements for successful colour rendering metrics. However, it is not wholly clear why (or whether) 99 spectral reflectances were sufficient.

It seems clear that uniform coverage in multidimensional wavelength space requires finer effective wavelength resolution than uniform coverage in the two dimensional colour space. This would explain the substantial increase in the number of reflectances from CRI and CQS. Accordingly, this study investigates the wavelength space requirement, and provides insight into the sample spaces of a number of current metrics.

2. Methods

Spectral dispersion metrics reveal useful information for colour rendering. Indeed, measuring spectral dispersion is fundamental in colour rendering assessment. Mathematical dispersion relates to the variability, scatter or spread of a distribution, as opposed to central tendency (e.g. mean, mode or median). Spectral dispersion relates to the variability, scatter or spread in a spectral distribution ignoring the wavelength order. Due to their simplicity, spectral dispersion metrics are also a helpful tool for investigating possible changes to the wavelength resolution, or the number of spectral reflectances of other colour rendering metrics.

The spectral entropy H_{Sp} and Gini Lamp index L_G are colour rendering metrics based on evaluating spectral dispersion. Respectively, these metrics are equivalent to the Shannon Entropy of communication theory and the Gini Index of economics. In their original form the metrics' formulae are applied to the 81 five-nanometre-wide wavelength bins of relative spectral measurements across the wavelength range 380 nm to 780 nm inclusive. The modified H_{Sp} and L_G metrics that have been used here to investigate the effects of wavelength resolution simply divide the same wavelength range into different size wavelength bins.

These spectral dispersion measures were applied with a range of wavelength bins to a measurement set of lighting solutions (n=48, <1 nm resolution), including LED, tungsten-halogen (TH), incandescent (INC) and compact fluorescent lamps (CFLs), to examine how the sample space of a metric meets the resolution requirements for uniform coverage of wavelength spaces. The bin widths used were 1, 5, 10, 20, 25, 36 (396 nm range), 40, 50, 57 (399 nm range), 67 (402 nm range), 80, 100, 133 (399 nm range) and 200 nm, with a 400 nm range where not stated.

3. Results

It was shown that as bin width is gradually reduced, the spectral dispersion metrics become predictable. The relative scores of different lamps become "frozen-in" below a certain threshold. Above this resolution, the metrics were observed to be too unpredictable, or volatile, to provide information about the illuminant performance:

- Using individual LED, TH and CFL lamp spectra, the spectral dispersion metrics suffered from volatility at coarse resolutions of approximately 25 nm or more
- Also below 25 nm the results for the sample correlated well to the 1 nm resolution values
- The ranking of spectral dispersion between different light sources begins to change for resolutions over 5 nm
- The modified range of H_{Sp} exhibited non-linearities from approximately 10 nm

The sample spaces for CRI, CQS and TM-30-15 cannot preserve the information equivalent to wavelength resolutions lower than 50 nm, 25 nm and 4 nm respectively.

As has been previously described, CRI R_a and CQS Q_a showed a high degree of correlation ($R^2 \approx$ 97%). However, this may not in itself imply a compromised effective wavelength resolution in CQS Q_a as the ranking was much less well matched ($r_s \approx 73\%$).

4. Conclusions

An effective bin width no wider than 5 nm to 20 nm (possibly narrower) is required to support an unbiased and general metric. Consequently a sample space of approximately 20 to 80 independent samples (possibly more) is needed, i.e. counted after reduction for sample degeneracy. The original 81-bin spectral dispersion metrics H_{Sp} and L_G already achieved this.

CRI and CQS were found to have an inadequate sample space to support the required wavelength space coverage. Due to the way the 99 samples were conceived TM-30-15 is likely to have an adequate sample space.

This study did not in itself provide sufficient evidence to say when wavelength resolution in a metric becomes too fine; TM-30-15, H_{Sp} and L_G may turn out to be over-specified, i.e. with too many samples and/or too fine a resolution.

Future investigations relating to spectral reflectances of everyday natural and artificial objects and their interaction with common illuminants, employing measurements with finer wavelength resolution, would provide additional valuable information for specifying the wavelength resolution for colour rendering metrics relating to everyday lighting conditions. Arguably, these investigations should precede further subjective preference evaluations studies on low resolution metrics.

The contrast between r_s and R^2 is mirrored in the emergence of metric failures in ranking at lower wavelength resolutions (> 5 nm) than for non-linearities (> 10 nm) and volatility (> 25 nm). The correlation, R^2, should be high between a colour rendering metric and an ideal perfect solution, but this criterion is not sufficient for lamp comparison metrics if the rank correlation r_s remains low.

Statistical dispersion is an integral, unavoidable part of evaluating colour rendering. However, statistical dispersion theory and colour rendering have developed largely independently, and their similarities appear to have gone unnoticed. H_{Sp} and L_G were both knowingly based on widely quoted dimensionless statistical dispersion measures. The coefficient of variation, generalised entropies and quartile dispersion are amongst other dispersion measures that could also be used.

PO06 (PP31)

BLH, LEDs AND CCT EQUIVALENT MELANOPIC ILLUMINANCES

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Abstract

1. Motivation, specific objective

It has been suggested that LED lighting provides more blue light than other lighting technologies. This perception persists despite the range of available correlated colour temperatures (CCTs), and needs to be regularly debunked. Nevertheless, increased efficiency, reduced sizes and the ability to produce affordable display screens with LEDs is likely to have increased exposure to artificial light, and changed typical circadian exposure profiles.

CCT is a widely recognised and established metric to describe the appearance of a light due to its relative spectrum. Different spectra can share the same CCT, but other human responses to lights with the same CCT may vary according to other aspects of the spectrum. The aim was to investigate the use of CCT as a guide to certain human responses.

2. Methods

This study builds on two previous studies, one concerning the potential blue light hazard (BLH) for both a range of screens, and another on human responses to LEDs and other lighting technologies. For each of the sources in these studies, the spectral irradiance was measured.

From this data the CCT and illuminance were calculated. A reference illuminant was defined as the blackbody that matched the source CCT and illuminance.

The ratio of the equivalent melanopic illuminances was then calculated (as $E_{z,source}/E_{z,ref}$). Finally, an adjusted colour temperature was determined in order to set this ratio to 1. This is referred to as the correlated melanopic temperature (CMT).

This was repeated to find the BLH ratio ($E_{B,source}/E_{B,ref}$). The adjusted colour temperature required to set this ratio to 1 is referred to as the correlated blue light temperature (CBLT).

More correlated equivalence temperatures (CETs) were found in the same way for other short-wavelength weighting functions related to the human eye.

3. Results

The CBLT values for these white light sources were generally lower than but reasonably close to CCT, although the accuracy reduced for high CCTs over 6000 K (CBLT/CCT = 0.92 ± 0.07).

The CMT values were also generally lower but less correlated with CCT (CMT/CCT = 0.83 ± 0.11). For CBLT and CMT, where the CET exceeded CCT, this was by no more than 12%.

CCT was not an entirely reliable proxy for either CET (CBLT or CMT), but CCT appeared to give a reasonably prudent prediction of the CIE's proposed blue light hazard factor of luminous radiation, $a_{B,v}$, which is closely linked to CBLT.

CCT uses a colour space to determine the correlated temperature whereas CET effectively uses the weighted efficacy of luminous radiation. To investigate why CCT did not predict CET, the CET using the 1931 2-degree standard observer colour matching function z was calculated (CET/CCT = 0.99 ± 0.05).

This shows the difference in approach immediately adds small unpredictable discrepancies. This level of variation was even present within a fairly homogeneous sample of blue LED plus phosphor lighting LEDs.

The non-visual cyanopic weighting function relates to the short wavelength cones in the peripheral retina. Cyanopic CET might be expected to be similar to those using the colour matching function z. However, the cyanopic CET values were more variable than expected, and the CCT values needed moderate adjustments (CET/CCT 0.98 ± 0.06). The change from colour space to hazard ratio correlation and the change of weighting function both contribute similar amounts towards this 6% variability.

The CBLT/CCT and particularly CMT/CCT ratios were quite varied for the LEDs. The change from colour space to hazard ratio correlation accounts for less of the variability than the changes in the weighting function. Similar results apply to the rods, regardless of whether the scotopic function V'(λ) or the rhodopic weighting function is used.

As well as exactly describing the melanopic content, the CMT values provided a useful rule-of-thumb description for predicting the rhodopic content of the light sources.

4. Conclusions

No evidence was found to support the hypothesis that LED technology is generally leading to potentially harmful lighting spectra when compared with other familiar lighting types. Based on these results, CCT might provide a useful rule-of-thumb description of a range of white light sources for cyanopic and BLH purposes. However, this should first be tested with a wider variety of illuminants.

For blue-LED driven phosphor LED lighting, the spectral dip between the peak of the blue LED and the longer wavelength peak(s) leads to a deficit in both melanopsin and rhodopsin stimulus when compared to a daylight or incandescent reference spectrum with the same colour appearance. There was, however, a similar result for the fluorescent sources tested. This is reflected in lower CET values for melanopsin (CMT) and rhodopsin.

The data demonstrate the power and limitations of describing white light spectra other than blackbody radiation in terms of colour temperatures.

Further discussion

As previously shown, the display screens are between 2.4 and 3.4 orders below the blue light hazard safety threshold for any exposure duration, and the threshold itself includes a substantial safety margin.

As also previously shown, none of the lighting sources presented a blue light hazard in normal use. Although LED street and panel lighting had moderately high CCTs, low CCTs are widely available for LED domestic lighting, and tended to predominate. The domestic lamps available suggests people prefer warmer CCTs and low radiance lamps.

There is a mismatch between the BLH function and the colour matching function z used in the CCT. This means CCT can theoretically understate the BLH-weighted radiance for some spectra. For white LED lights that would only be the case if there were a significant component around 420 nm. However, using LEDs below around 440 nm for these lights would be inefficient, which explains why CCT actually overstated the BLH-weighted radiance for all the LEDs measured.

PO07

PROPOSAL OF THE METHODS TO CONTROL ILLUMINANCE AND CHROMATICITY AT THE SAME TIME IN THE FULL COLOUR ILLUMINATON LABORATORY

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Abstract

1. Motivation, specific objective

With the development of full-colour LED lighting, it is easy to introduce lights with various colours in offices and general households, and the introduction of colour light environment according to personal work and preference is being carried out in part. It is known that people are variously influenced by the colour of light. Experiments to investigate the influence of specific illuminance and chromaticity on people are necessary, however the experimental environment was hard to construct. Therefore, a method to realize the target illuminance / chromaticity environment should be considered.

Since the range of the chromaticity at a specific illuminance of the full colour LED is unclear, the problem is that it is not easy to examine feasibility of the target illuminance and chromaticity. Therefore, we consider that the range of chromaticity at a specific illuminance is shown on the chromaticity diagram. The experiment consists in a room with full-colour LED illumination that combines four-colours (RGBY) dimmable LED with many different lighting patterns. We measure the illuminance and chromaticity while new patterns appear. From this result, we obtain a feasible chromaticity range at a specific illuminance.

We consider a method to realize arbitrary illuminance and chromaticity by stochastic hill climbing method in the laboratory (about 50 m^2) using 29 full-colour LED lamps. However, since the number of trials of calculation increases, it is expected that it will take time to create the target illuminance and chromaticity environment. For this reason, we will consider a method to speed up the target illuminance / chromaticity realization using the database created from the illuminance and chromaticity data of the numerous lighting patterns mentioned above. It lights up with a lighting pattern close to the target value in the database, and then creates the target light environment in a short time by using stochastic hill climbing method.

The digital signal value of each RGBY of the full colour LED illumination can be selected is between 0 and 1000. The total number combination is 10^{12}. So, it is impossible to register all lighting patterns in the database. As a result, in order to create the target light environment at high speed from as few lighting patterns as possible, the number of lighting patterns to be stored in the database has to be examined.

2. Methods

Illuminance and chromaticity of the RGBY signal values are obtained beforehand, and a database is created to store those informations. By inputting arbitrary illuminance and chromaticity, we choose automatically the closest pattern to the input value from the information registered in the database. After that, by searching the lighting pattern with the stochastic hill climbing method, an optimum lighting pattern for realizing the target illuminance and chromaticity is calculated.

3. Results

With full **colour** LED we were able to measure the range of chromaticity. In addition, we found that for each **colour** there is a specific range of illuminance. We use a full **colour** LED with a lots of dimming patterns. We searched lighting patterns by inputted new illuminance and chromaticity values. It was possible to calculate the light control signal value that lights within a illuminance difference of ± 50 lx and within the **colour** difference of 0.02 with respect to the target value. By using the database to light up the initial signal value around the target value, it was possible to shorten the time to calculate the optimum lighting pattern and obtain the target illuminance and chromaticity. We were also able to reduce the number of lighting patterns registered in the database.

4. Conclusion

In a room with multiple lighting colours patterns available, we proposed a method to obtain relatively uniform measurement points on the chromaticity diagram. By using this method, we obtained 100,000 measurement points on the chromaticity diagram, and the range of the chromaticity at each specific illuminance was found. This makes it easier to examine feasibility regarding the target illuminance and chromaticity. Moreover, by lighting with a lighting pattern close to the target value from the database, then using the stochastic hill climbing method, it was possible to create the target illuminance / chromaticity environment at high speed. When we use only the stochastic hill climbing method, it takes about 10 minutes to build the target light environment, but with the database based method, the target light environment can be constructed within 1 minute.

It was possible to reduce the number of measurement points required for examining feasibility regarding target illuminance and chromaticity. We succeeded in extracting 30,000 measurement effective points from a total of 10^{12} points. The time required to create 30,000 databases was about 8 hours, and when you install the system, you need to create the database only one time.

PO08

STUDY ON SPECTRAL COMPOSITION OF WHITE LIGHT-EMITTING-DIODE FOR CHINESE TRADITIONAL PAINTING

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Abstract

Chinese traditional painting with the characteristics of large stock, high value, extremely sensitive to light and so on is emphatically studied in museum illumination research. The generation of solid-state light sources white light-emitting-diode(WLED) is widely used in museum illumination for advantages of free from infrared and ultraviolet radiation which traditional light sources lack of, high luminous efficiency, long-lived, small size, easy regulation and so on. In addition, spectral power distribution (SPD) of WLED can be adjusted according to specific requirements. Red, yellow, blue, green four kinds of monochromatic lights are the main components in WLED. The relative damage coefficients of monochromatic lights on Chinese traditional painting were obtained by the research group. Culture relics illumination should not only consider the lowest level of damage to the painting caused by the light source, but also meet viewing requirement. So monochromatic light combination's impact on colour effect is researched based on the obtained relative damage coefficients, and then WLED spectral which meet the requirements can be proposed.

2700K is the limit colour temperature of light source in museum illumination environment of painting, so CIE standard illuminant A was selected as reference light source in the research, CIE standard colour samples were chosen as the objects for colour recognition, TOPCON BM-5A colour brightness meter was used to examine CIE 1964 U*, V*, W* values of standard colour samples under the illumination of standard illuminant A. Meanwhile, the lowest damage SPD of WLED was fit according to the obtained relative damage coefficients of WLED monochromatic lights. Then CIE spectral tristimulus X, Y, Z values of the standard samples under testing light source were calculated. X, Y, Z values were transformed into u,v coordinates in CIE 1960 uniform colour space. Since the colour adaptation conditions are different in two kinds of illumination conditions, the colour samples under illumination of texting light source should be subject to colour shift correction. The u, v, Y values were converted into U*, V* and W* values in CIE 1964 uniform colour space for the lack of lightness coordinate in CIE 1960 UCS. Based on the U*, V* and W* values under standard illuminant A and texting light source, special colour rendering index(CRI) and general CRI could be calculated.

The lowest damage SPD of WLED was optimized and corrected based on the calculation results, then CRI was recalculated, finally WLED spectral which not only meet the lowest lighting damage to painting, but also meet viewing requirement was obtained.

The results can provide data base for related research and support for research and development of new WLED to reduce the illumination damage to culture relics and better preserve the authenticity of Chinese traditional painting in history, art and culture.

PO09

TRADE-OFF BETWEEN COLOUR FIDELITY AND COLOUR GAMUT: A CASE STUDY

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Abstract

With the IES method, including a colour fidelity index (R_f) and a colour gamut index (R_g), for evaluating the colour rendition properties of light sources, the trade-off relationships between colour fidelity and colour gamut were investigated theoretically by optimizing the peak wavelengths, the spectral widths, and the relative intensities of four-channel LEDs at the correlated colour temperatures (CCTs) ranging from 2800 to 6500 K. The results indicate that the highest levels of R_g (all over 100) indeed decrease with the increasing R_f, and that the pattern of the trade-off between R_f and R_g is almost independent on the CCT. Furthermore, it is feasible to seek out a set of four peak wavelengths for relatively high colour fidelity as well as large colour gamut at different CCTs.

1. Motivation

The Illuminating Engineering Society of North America (IES) published a two-measure system recently, including a colour fidelity index (R_f) and a colour gamut index (R_g), for evaluating the colour rendition properties of light sources, which has improvements over the CIE colour rendering index (CRI). In particular, the two indexes cannot be maximized simultaneously. By definition, R_f is a more accurate version of the CIE general CRI (R_a), and R_g can be applied to estimating the average variation in the saturation of object colours. Considering that the light sources with increased saturation, as long as not excessive, are usually preferred by observers, it is therefore essential to understand to what extent R_g can increase while maintaining a certain level of R_f.

2. Methods

The new-type lighting technology based on LEDs, especially its spectral tunability, can provide considerable convenience to customize the colour rendition properties of light sources for some lighting applications. For simplicity, four LED channels, including red, amber, green, and blue channels, each with an assumed Gaussian spectrum, were employed to investigate the competitive relationships between IES R_f and R_g. These relationships were established through adjusting the peak wavelengths, the spectral widths, and the relative intensities of individual channels utilizing a two-objective optimization algorithm based on differential evolution at the nine chosen white-light chromaticities ranging from 2800 to 6500 K, covering the usual white-light range for general lighting.

3. Results

1) The highest level of R_g (all over 100) at different CCTs decreases with the increasing R_f. The highest levels of R_f and R_g achieved with four-channel LEDs are about 94 and 133, respectively, and their corresponding R_g and R_f are about 103 and 35, respectively.

2) The trade-off relationships between R_f and R_g are almost the same for different CCTs.

3) The CIE R_a scores of those optimized spectral power distributions (SPDs) with respect to R_f and R_g are generally lower than the corresponding R_f, especially at the low levels of R_f. However, the CIE R_a scores of those SPDs corresponding to around the highest level of R_f are somewhat larger than R_f.

4) The optimized peak wavelengths of four LED channels are grouped into four small wavelength regions with the increasing R_f. Therefore, it is feasible to find a set of four peak wavelengths for relatively high colour fidelity as well as large colour gamut at different CCTs.

4. Conclusions

The competitive relationships between colour fidelity and colour gamut of light sources in terms of IES R_f and R_g were discussed at a series of white-light chromaticities ranging from 2800 to 6500 K. The resulting relationships scarcely vary with the CCT, which are conducive to weighting the colour fidelity

and the colour gamut of light sources for a specific lighting requirement. Moreover, a set of four peak wavelengths for different CCTs could yield relatively high colour fidelity and large colour gamut.

PO10

COLOUR RENDERING INDEX VARIATIONS ACCORDING TO SPECTRAL CHANGES OF MULTI-CHIP LEDS

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Abstract

Recently, various methods for improving colour rendering property of multi-chip LEDs have been developed, due to their variety of colours and colour temperatures. In this paper, CRI variations were simulated by changing peak wavelengths and full widths at half maximum (FWHMs) of a commercially available RGB or RGBY LED. For an RGB LED, CRI higher than 90 was accomplished in the correlated colour temperature (CCT) ranging from 2000K to 6000K as in the previous researches. For an RGBY LED, a CRI higher than 98 at 2500 K to 6000 K was simulated by changing the peak wavelength. The possibility of a CRI higher than 95 and 98 with RGB and RGBY LED, respectively, was proposed by controlling the spectral characteristics.

1. Motivation

Recent studies have been made to develop various methods for improving colour rendering property of multi-chip LEDs, e.g. 3-chip and 4-chip LEDs. It is well known that RGB 3-chip LEDs have different CRI according to the CCTs and barely have a CRI above 90 as in the previous researches. In the case of RGBY multi-chip LEDs they have somewhat higher CRI. As the knowledge of the authors, there is no research on optical characteristics variations of LEDs according to the shifts of the peak wavelength, the peak power and the bandwidth. Therefore, in this study, spectra of commercially available RGB and RGBY LEDs were approximated to Gaussian spectral power distributions (SPDs), and by changing the Gaussian SPDs CRI fluctuations according to the CCTs were investigated.

2. Methods

2.1 Simulation program configuration

For this simulation a program was composed using the Matlab program based on the calculation formulae for the colour coordinates, CCT and CRI as presented in the CIE and Korea Standards (KS). Input data of the simulation is SPD of LED. The SPD was derived from a commercially available RGB or RGBY LED and approximated to the Gaussian model. The SPD was calculated to yield CIE 1931 *xy* colour coordinates, fitted to a CCT on the Plank's block body radiation curve in the coordinates. Then CRI was obtained.

2.2 CRI calculation method

Once a Gaussian SPD was derived, CCT was fixed to a certain value and a confined range by controlling the power ratios of the red, green, blue and yellow peaks. And by shifting the peak wavelengths of the SPDs in the order of red, yellow, green and blue, CRI values were generated. Then by controlling the power ratios, CCTs were scanned from 3000K to 6000K. After this procedure was completed, FWHM was modulated and did the procedure again to give CRI fluctuations according to the bandwidth variations.

3. Results

3.1 RGB 3-chip LEDs

The original maximum R_a for an RGB 3-chip LED package from a company N was 41 at the CCT 5500K. However, it was calculated to be R_a of 86~90 after the peak wavelength shift processes. In the case of an RGB LED from a producer S, R_a was 45~70 before the wavelength shifts, but increased to be 87 or more after the processes. The difference between the N and S companies was from the spectral mismatch of the two.

3.2 RGBY 4-chip LEDs

For an RGBY 4-chip LED from the company N, R_a increased to 85~92 by the shifts, which was increased by 3 to 7 from the first RGBY SPD in the CCT ranging from 2500 K to 6000 K. In the case of an RGBY from the S, R_a grew from 45~70 to 87 or more after the shift processes.

3.3 CRI changes by FWHM variances for RGB and RGBY LEDs

In the case of an RGB 3-chip LED from a manufacturer C, R_a value increased by 3 or more after broadening each RGB FWHM by 20%. When the spectrum was increased up to 140%, R_a was improved by 6 or more. At this time, the wavelength regions for RGB for the highest CRI were 620~630 nm, 550~560 nm, and 450~460 nm, respectively.

In the case of an RGBY 4-chip from the manufacturer C, if the RGBY FWHM was constantly increased by 10%, 20% and 30%, CRI decreased at 2500K but increased at 3000K, 4000K, 5000K and 6000K. Therefore, changing the FWHM of each RGBY could increase the CRI value. The CRI values also were calculated by increasing the FWHM by 100%, 150%, and 200%. As a result, the maximum R_a with 100% was 98 at 4000K and at 4500K at 150%, and 97~99 with 200% at 2500K and at 6000K. At this time, the wavelength ranges of RGBY for the maxima were 620~630nm, 500~510nm, 450~460nm and 560~570 nm, respectively.

4. Conclusions

In this study, we constructed a CRI simulation program according to the CCTs for the peak wavelength shifts and the FWHM changes of multi-chip LEDs. We also confirmed the maximum CRI variations in the CCT ranges of 2500K~6000K caused by the changes of the spectral characteristics. First, it was investigated that the CRI increased through the peak wavelength shift of the spectrum. After that, the FWHM and the peak wavelength shift of the spectrum were simultaneously performed. For RGB 3-chip LEDs, a 20% increment in FWHM resulted in more than 90 of R_a in all CCT ranges. For RGBY 4-chip LEDs, a 200% increase in FWHM resulted in more than 97 of R_a in all CCT ranges. When FWHM was increased by 400%, it was obtained that above 98 of R_a.

PO11

CHROMATIC FACTORS OF BRIGHTNESS MATCHING BETWEEN COMPUTER DISPLAY AND AMBIENT ILLUMINATION

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Abstract

1. Motivation, specific objective

The aim of the current study was to analyse the effect of the spectral distribution of the ambient illumination on brightness matching of colours on a computer display.

2. Methods

A human size light booth was constructed to create uniform ambient illumination for visual psychophysical tests. The booth was equipped with LED and fluorescent light sources. For the current test the luminance of these were adjusted to L = 90.4 ± 9.7 cd/m^2 for the LED and L = 89.3 ± 13.7 cd/m^2 for the FL illumination. The correlated colour temperature was also similar for both illumination conditions (2702K for the LED and 2653K for the FL). Fifteen healthy participants with no colour vision problems (verified with the Cambridge Colour Test) took part in the study. Their task was to immerse in the illumination ambient and, after 10 minutes adaptation, adjust the luminance of a uniform chromatic stimulus presented on a calibrated computer display, within 3° and 6° of field of view, to be equal to that of the ambient. The display was placed outside the light booth to avoid screen reflections, and the colour stimuli applied were yellow (u',v'=0.202,0.542) and white (u'v'=0.192,0.441). The recorded values were those of the adjusted display luminances matching the ambient illumination. The participants were instructed to fixate on the centre of the display when matching the luminance with the ambient. Further test (red-green HFP – Heterochromatic Flicker Photometry) was done to estimate the long and medium cone ratio of the observers in order to see if it correlates with the matching brightness between the illumination ambients.

3. Results

Matching results on the display with the ambient illumination had large variability among the test participants, with the larger (6° FOV) having higher adjusted values than the smaller FOV (3°). However, we have found differences between the two illumination ambients depending on the stimulus used. In case of the white stimulus, the matched brightness values in the two illumination ambients were similar (seven participants out of fifteen gave higher luminance adjustments for the LED ambient). On the other hand, in the case of the yellow stimulus the LED ambient appeared brighter for the majority of the participants. Beside these findings, the variability of the adjusted luminances were lower for the yellow stimulus than for the white. The HFP results showed correlation with the brightness matches for the yellow stimulus, while no correlation in case of the white stimulus.

4. Conclusions

One conclusion is that when matching a display to its ambient in terms of chromaticity, observers may demonstrate less variability when the ambient colour is closer to the display colour. The correlation found between the L/M cone ratio for the yellow stimulation indicates, that while matching colours with a similar ambient, the role of the cone ratio might be more effective than in the case of larger chromatic differences.

PO12 (PP01)

COLOUR APPEARANCE OF OBJECTS UNDER OPTIMIZED SPECTRA

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Abstract

1. Introduction

The colour appearances of objects are determined by the human visual system, the spectral power distribution (SPD) of a light source, and the reflectance characteristics of objects. Objects reflect only some of the incident light on their surface, while the absorbed light turns into heat and does not contribute to visibility. This absorbed energy can be considered loss for illumination purposes.

Emerging technologies, such as light emitting diodes (LEDs), offer unprecedented control over the SPD of light sources. Since the spectral output of the new technologies can be controlled, it is possible to minimize the energy absorption, by optimizing the spectrum of a light source to the object reflectance, without altering colour appearance. In this study, the potential energy savings from optimized spectra and colour appearance of commonly found objects was investigated computationally and experimentally.

2. Methods

The colour appearance of 10 real object of different hues (a cola can and a tomato for the red hue, a mandarin and a carrot for the orange hue, a post-it note and a lemon for the yellow hue, a Granny Smith apple and a lime for the green hue, and a container of creme moisturizer and a blueberry for the blue hue) was calculated in CIE 1976 $L^*a^*b^*$ colour space. Two reference white light sources were considered: a phosphor coated LED (pcLED) and a phosphor-coated LED with an additional red peak (pcLED+red). Iteratively simulated test SPDs were generated by mixing nine narrowband LEDs of different magnitudes. Test SPDs that maintained the object colour appearance and resulted in the greatest reduction in energy consumption were selected to be tested in laboratory settings.

Two experiments were conducted to investigate the colour appearance of five of the ten real objects under optimized spectra selected from the computational study. Twenty-one naïve subjects, aged 18 to 40 years, were asked to judge the naturalness and attractiveness of the stimuli (i.e. tomato for red, mandarin for orange, lemon for yellow, Granny Smith apple for green, blueberry for blue) in two separate experiments. In a two-alternative forced choice task, objects were placed in two side-to-side black booths 1.5 m from the observers. One of the stimuli was lit by the reference light source (pcLED or pcLED+red), and the other was lit by one of the six test SPDs. The different test SPDs induced differences in the colour appearance of the illuminated objects, ΔE^*_{ab}<1.0, ΔE^*_{ab}=1-3, ΔE^*_{ab}=3-5, ΔE^*_{ab}=5-7, ΔE^*_{ab}=7-9 and ΔE^*_{ab}=9-15. These colour differences were primarily increases in chroma; hue and lightness differences were limited. Each test SPD was presented 10 times in a random order, resulting in 60 trials for each object and each reference light source. Each participant completed a total of 600 trials. Test and reference light sources alternated between the booths to reduce bias, and the luminance was constant to avoid impact from the Hunt effect and the Bezold-Brucke hue shift.

3. Results

The computational analysis showed that energy savings up to 15% are possible without shifting object colour appearance. When a slight colour difference was permitted, energy savings could increase up to 19%. Red objects resulted in the lowest energy savings, especially when the reference light source was pcLED+red, due to its spectral peak at the longer wavelengths.

The data from the experiments further suggested that spectrally optimized lighting systems could reduce energy consumption without negatively impacting object appearance. The coloured objects appeared equally natural and attractive under optimized test SPDs and reference light sources, especially when the colour differences between the objects illuminated by the test and reference

sources were low. Some increases in object chroma did reduce the perceived naturalness of the objects.

When illuminated by the chroma-enhancing test SPDs, the objects were reported to appear more attractive than natural. This is consistent with other research that suggests a distinction between naturalness and attractiveness of object colours, as well observer preference for saturated colours.

Overall, the test SPDs did not negatively impact object appearance, except for the tomato stimulus. The translucency of the tomato resulted in colour appearances that deviated from colorimetric predictions. The strongly directional light used in the experiments induced a perceived border of light between the top and bottom half of the tomato, which made judgments difficult for observers.

4. Conclusions

The computational and experimental data show that reducing energy consumption by optimizing light source spectrum to real object reflectance is possible with a caveat (i.e., translucent nature of objects). Most of the optimized spectra rendered object colours to be equally natural and attractive to their appearance when illuminated by a reference source. The results show that colour differences as high as ΔE^*_{ab}=15 can be induced in object colour appearance without reducing perceived attractiveness, which indicates that higher energy savings could be achieved without causing user dissatisfaction. However, the translucent nature of some objects may alter their colour appearance under optimized spectra. The effect of optical surface properties on the perceived colour appearance of objects by optimized spectra should be investigated.

PO13 (PP02)

CHROMATIC DISCRIMINATION UNDER DIFFERENT STATES OF CHROMATIC ADAPTATION

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Abstract

1. Motivation, specific objective

The objective of our study was to examine the effect of different states of chromatic adaptation on the adapted white point based on chromatic discrimination measurements.

2. Methods

In the study 26 normal colour observers performed the trivector test of the Cambridge Colour Test in order to measure the just-noticeable stimuli on the three confusion lines under different states of chromatic adaptation. Two states of chromatic adaptation were achieved applying colour filters. The tests were accomplished without filter as a reference.

The chromaticity of the background was shifted from the neutral point of the display towards the chromaticity points of the filters in the CIE (1976) u'v' diagram, calculated based on their transmission spectra. The test directions were set to the confusion axes towards the Protan, Deutan and Tritan points. The minimum and maximum luminance values of the pseudoisochromatic plates were set considering the spectral transmission of the applied filters in order to reach equi-luminance among the filters.

The factors (and their levels) of the statistical analysis were the followings: state of adaptation (no filter and the two different filters), analysed confusion line (Protan, Deutan and Tritan), and background chromaticity (distance from the neutral point towards the chromaticity point of the filter and in the opposite direction).

3. Results

The analysis shows that adapting to the filters affects colour discrimination depending on the background chromaticity compared to the results with the reference test. In our results we estimate the change in chromaticity of the background for best colour discrimination.

4. Conclusions

Our work may contribute to the understanding of colour discrimination issues when chromatic adaptation is involved and to the design of chromatic stimulation when the background of the adaptation differs from the neutral point.

PO14 (PP03)

HOW CHROMATICITY ALONE AFFECTS SOURCE PREFERENCE?

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Abstract

1. Motivation, specific objective

Recent studies suggested that sources with chromaticities slightly below the blackbody locus were preferred by human observers. The preferred light settings identified in these studies, however, had high values in colour fidelity and colour gamut measures. The preference was speculated to be caused by colour rendition, rather than chromaticity. This study was specifically designed to test whether chromaticity alone affects source preference by keeping the colour rendition of sources (i.e., the IES TM-30-15 R_f, R_g, and the Colour Vector Graphic) similar.

2. Methods

The light settings in this study were carefully designed using a genetic algorithm and produced using an 11-channel spectrally tuneable LED lighting device, comprising two levels of nominal CCT. Five light settings were created for 3000 K, with Duv from + 0.01 to - 0.03, Rf of 65 ± 1, and Rg of 109 ± 2. Seven light settings were created for 6500 K, with Duv from + 0.03 to -0.03, Rf of 83 ± 2, and Rg of 101 ± 1. The gamut shapes of the light settings were also maintained as similar as possible. All the light settings were calibrated to provide a uniform illumination at 300 ± 10 lux to the scene, which included an oil painting, flowers, soda cans, fruits, and snack boxes. A black felt was used as the background, trying to minimize the effect of back wall on observers' evaluations.

Twenty-three colour normal observers within the range of 20 and 24 years of age were recruited for the experiment. The pairs of light settings were presented in a rapid-sequential mode and were alternated every four seconds. Only the settings that had a same CCT level and adjacent Duv levels were compared. The observers were asked to compare the pairs of light settings and to evaluate whether there was a noticeable colour difference under the two light settings. If s/he perceived a noticeable colour difference, they were then asked to judge which light setting was preferred and which colour affected their judgement. In order to counter a possible interval bias (or order bias), each pair of the light settings were presented in two orders (e.g., AB and BA).

3. Results

For nine of the ten pairs of light settings, the colour appearances of the objects were perceived different under the two light settings, and the observers had a preference between the two light settings for eight pairs, as tested using a Chi-Square Goodness-of-Fit Test with the $\alpha = 0.05$ level. For the 3000 K pairs, the setting with a lower Duv value was generally preferred, except no preference was rated between Duv values of -0.02 and -0.03. For the 6500 K pairs, the light settings with Duv values of 0 and -0.01 were the most preferred and no preference was found between these two light settings. White was the most frequently selected colour which affected the observers' evaluations.

CIECAM02 was used to verify the similar colour appearance of the objects under the light settings, as there was a mismatch between the observed objects and the test colour samples used in the colour rendition calculation.

4. Conclusions

The result of this study suggested that sources with chromaticities below the blackbody locus were generally preferred under the investigated viewing condition and adaptation condition. Coupled with past studies, such an effect was especially strong for sources with a lower CCT level (e.g., 3000 K in this study, 2200 K and 2700 K in a past study). Further study is necessary to investigate the effect of

chromaticity on source preference under longer exposure viewing conditions and against different backgrounds.

PO15 (PP04)

A PHYSICALLY-BASED INTERPRETATION OF THE HUE OF SURFACES

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Abstract

1. Introduction

The perception of surface colour includes attributes of hue, saturation (chroma), and lightness. Among these, hue is especially useful, because unlike lightness and chroma, it correlates directly with the presence of specific colorants, and thus is diagnostic of the underlying chemical composition of a surface, indicating, for example, whether certain foods are fresh and healthy. However, hue is also the most difficult dimension of colour to define. Current definitions are merely circular (hue is defined by which hues are present) and moreover provide little insight into the physical correlates of hue. The goal in this project was to develop a physically-based interpretation of the hue of surfaces in order to explore the spectral properties encoded and represented by hue.

2. The current definition of hue and the need for improvement

The International Commission on Illumination (CIE) defines hue as the "attribute of a visual perception according to which an area appears to be similar to one of the colours red, yellow, green, and blue, or to a combination of adjacent pairs of these colours considered in a closed ring." Further, the terms red, yellow, green, or blue are described as the four "unique hues". Thus, hue is the attribute of visual perception that differs between areas that have different hues. A self-referencing definition such as this does not say what hue actually *is*. This suggests the need for a better interpretation that is simple, accurate and physically meaningful.

Ideally, this would help to explain how and why hue perception is so stable and accurate that it enables most people to discern roughly 40 different hues, largely independent of lighting conditions. Current colour appearance models, such as CIECAM02, are able to predict hue fairly accurately, but they do not explain what hue is, nor how our colour vision system is able to perceive it so well. Furthermore, such models are very complex. CIECAM02 requires the use of colour matching functions and the illuminant spectrum (at least 320 numerical values), and it comprises 14 equation groups involving 39 arbitrary numerical parameters that were adjusted to best fit experimental data. Within this context of complexity, little understanding can be gleaned as to the meaning of hue.

In contrast, the goal of this study was a physically-based interpretation of hue that is simple, accurate, and which clearly explains its meaning.

3. A simple mathematical interpretation of hue

A strong correlation is found between the perceived Munsell hue of a surface, θ_M, and a new mathematically-determined hue, θ_{math}, which is based on the ratio of the effective curvature and the effective slope of the surface spectral radiance factor $R(\lambda)$ within the visible band.

θ_{math} is calculated using just four parameters - three wavelength values, λ_c, λ_Δ, λ_m, which summarize the human visual response, and an angle θ_0 that adapts to the arbitrary zero point of the Munsell system. Notably, the calculation uses neither colour matching functions nor cone fundamentals nor an illuminant spectral power distribution.

θ_{math} is calculated in two simple steps:

(a) Over the wavelength range from λ_c-λ_Δ to λ_c+λ_Δ, a second order polynomial (i.e. a portion of a parabola) is fit to $R(\lambda)$, using the least square error method, yielding a curvature value, c, (in units of nm^{-2}) and an average slope value s (in units of nm^{-1}).

(b) θ_{math} is based on the polar angle in a dimensionless 2D plane: $\theta_{math} = \theta_0 + \text{atan2}(s\lambda_m, -c\lambda_m^2)$.

Note this approach is related to principal components analysis (PCA) in terms of representing variations in spectra by the variations in a small number of dimensions. However, our analysis differs from PCA in that the dimensions are defined theoretically rather than empirically, and because the goal is to model the perceptual correlate of the spectrum (hue) rather than to approximate the physical spectrum itself.

To evaluate its accuracy, θ_{math} was evaluated for 256 uniformly distributed Munsell colours. Over that set, the rms value of the difference (θ_M - θ_{math}) was minimized by varying λ_c, λ_Δ, λ_m, and θ_o. The optimum result was sharply defined and yielded an excellent correlation coefficient between θ_M and θ_{math} of R^2= 0.995, and an rms hue angle difference of 0.12 rad. As a comparison, the angular separation between adjacent hues in the Munsell system is $\pi/20$ (about 0.16 rad), which is barely discernible. Therefore the observed fit is about as good as could be expected for perception-based data. The four parameters were narrowly constrained by the optimization process, with the result being: λ_c = 520 nm, λ_Δ = 86 nm, λ_m = 42 nm, and θ_o = 1.41 rad.

As mentioned, θ_o has no physical meaning – it merely aligns to the arbitrary zero hue of the Munsell system. However the three wavelength parameters do have physical meaning – they arise from the centres of sensitivity of the three human cone cells: λ_L = 561 nm, λ_M = 536 nm, and λ_S = 450 nm. A recently introduced two-stage subtractive colour vision model predicts that λ_c, should be about ($\lambda_L/4+\lambda_M/2+\lambda_S/4$) and this match is found to be almost exact. The evaluation band should include most of the cone response sensitivity, and λ_m should be roughly λ_Δ /2, which is the case. Thus, θ_{math} makes sense both physically and physiologically.

4. Conclusion

A simple physically-based interpretation of hue has been developed. It accurately matches the perceptually-determined hues of the Munsell system. This is probably not a coincidence. More likely, the visual system evolved to assess the ratio of curvature to slope in a surface's spectral radiance factor, because this usefully correlates with the chemical colorants in the underlying material, largely independent of lighting intensity or colorant concentration.

PO16 (PP29)

POSSIBLE HEALTH IMPLICATIONS OF LOW INFRARED LEVELS IN INDOOR ILLUMINATION

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Abstract

1. Introduction

The spectral power distribution of indoor illumination can extend beyond the band of visible wavelengths, into both the near-ultraviolet (NUV) and near-infrared (NIR). By definition, radiation in the NUV and NIR bands provides no direct visual benefit to building occupants, but it does have the potential to influence health, since radiation in these bands can interact with human tissue in ways that can be beneficial, harmful, or both.

In the case of the near-ultra-violet (NUV) band of radiation, the associated photons have enough energy to break molecular bonds, thus potentially damaging cells, and this can have negative health consequences. However, NUV radiation can also be beneficial – for example by killing potentially harmful bacteria and enabling the body to produce vitamin D. There is an important trade-off between these aspects, and therefore, not surprisingly, this topic has garnered considerable attention.

With the visible band, there is also considerable interest in non-visual effects of light which depend on how the spectral power distribution of the light varies throughout the day, involving, at least in part, absorption of light by intrinsically photosensitive Retinal Ganglion Cells.

The situation is very different for the near-infra-red band (NIR), roughly from 700 nm to 900 nm. Unlike NUV and visible radiation, there has been little, if any, discussion about possible health effects of NIR radiation in ambient illumination. In general, manufacturers of electrical light sources try to minimize the emission of NIR radiation, not because it is harmful, but because it does not contribute significantly to visual perception and is therefore viewed, to some extent, as a waste of energy.

2. Evidence from the medical field of photobiomodulation

NIR radiation is however of growing interest in medical treatment – especially in the field now known as photobiomodulation. Medical Subject Headings defines photobiomodulation as "*a form of light therapy that utilizes non-ionizing forms of light sources, including lasers, LEDs, and broadband light, in the visible and infrared spectrum. It is a nonthermal process involving endogenous chromophores eliciting photophysical (i.e., linear and nonlinear) and photochemical events at various biological scales. This process results in beneficial therapeutic outcomes including but not limited to the alleviation of pain or inflammation, immunomodulation, and promotion of wound healing and tissue regeneration*." In particular, it is believed that NIR radiation is absorbed by the enzyme cytochrome c oxidase (often abbreviated COX) which plays a key role in energy production within cell mitochondria. Since NIR wavelengths readily penetrate several cm into human tissue, NIR in ambient radiation can reach many parts of the body. In particular, it easily reaches the retina, since it passes through both the pupil and the sclera. The effect of NIR radiation on cells is generally beneficial – improving the ability of tissue to withstand and recover from oxidative stress.

These observations have given rise to a number of well-established treatment techniques for various medical conditions, as established in numerous randomized double-blind placebo-controlled clinical trials. Particularly intriguing are animal models in which retinal harm from exposure to blue light can be reversed by concurrent exposure to NIR light.

Since NIR radiation is abundant in natural daylight and typical natural cumulative daily doses of NIR are comparable to those that have had therapeutic benefits, it seems reasonable to consider whether these ideas may be related. It would not be particularly surprising for organisms to have evolved

biochemical uses for naturally occurring NIR photons, and for the known therapeutic effects of NIR to operate via those same mechanisms.

This raises a question that appears not to have been broadly asked: Is it possible that a significant health factor could be a person's daily NIR exposure, or the ratio of their NIR exposure to that of blue light? For example, perhaps the retina can benefit from absorption of a certain number of NIR photons for each absorbed blue light photon, in order to help counteract, to some extent, blue light damage.

3. Estimating NIR content in common illumination settings

From this perspective it is interesting to consider the ratio of NIR radiance to luminance in various settings. A fairly high ratio is found in three common settings - viewing a fire (about 20 mW/lm), viewing sun-lit leaves, which reflect mainly in the NIR band (about 8 mW/lm), and reading paper under an incandescent lamp (about 8 mW/lm). In comparison, two settings have a much lower ratio – sun-lit barren ground (2 mW/lm) and reading under a typical LED lamp (0.3 mW/lm).

An interesting possibility is that even though people cannot see NIR radiation they may nevertheless sense its presence unconsciously, and perhaps this could explain why people often choose NIR-rich settings such as sun-lit vegetation, fire-light, and incandescent light. If NIR light in ambient illumination is indeed healthful, such a preference could have naturally evolved.

Certainly there are other possible explanations for a correlation between fractional NIR content and the appeal of an illumination setting; clinical trials will be essential to better understand this. Fortunately, because NIR radiation is invisible, it is straightforward to carry out truly double-blind experimental protocols. For these reasons, new research along these lines is highly recommended.

4. Conclusion

It is proposed that the possibility of health benefits arising from NIR radiation in illumination (and conversely the possibility of harm in its absence) warrants careful investigation. This seems especially appropriate considering two worldwide trends: First, a growing fraction of people are spending a greater portion of their time indoors under electrical illumination, and second, lamps that emit very little NIR radiation are rapidly displacing NIR-rich incandescent lamps and high efficiency windows are removing much of the NIR radiation from the daylight entering buildings. Thus, overall NIR exposure is being greatly reduced for many people. Fortunately, if NIR is found to be needed for healthful lighting, it can readily be provided by incorporating inexpensive, highly efficient NIR LEDs into the design of electrical light fixtures.

PO17 (PP05)

DEVELOPMENT OF WHITENESS FORMULA BASED ON CIECAM02

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Abstract

1. Motivation, specific objective

The aim of the study was to develop a new whiteness index which correlates to perception of whiteness on textile samples. Former TC 1-77 recommend modifications of the existing CIE Whiteness and Tint Equations to extend their application to illuminants other than D65 and review the restrictions imposed on the validity of the equations to samples that are measured on the same instrument at nearly the same time, and review the colorimetric limits hitherto set. New TC 1-95 follows these recommendations, validity of CIE Whiteness formula mainly. Nevertheless, CIE Whiteness formula similarly as Ganz-Griesser linear whiteness formula are in principle two-dimensional what complicate understanding of resulting values in industry. Since CIECAM02 colour appearance model begins to be used widely, it is urgent to establish a whiteness formula in CIECAM02 that has well correlations with observers' evaluations.

2. Methods

Psychophysical experiments were conducted by a panel of 10 observers under a standard viewing condition at viewing box equipped by D65 daylight simulator (classified into category D as D65 simulator) as well as under alternative light sources such as white LEDs based on blue and violet chip. Relative spectral power distribution of the light source was obtained from spectral radiance of the plaque containing pressed certified Barium Sulphate white standard produced by Merck. Plaque was placed in the center of the bottom surface of the lighting cabinet and spectral radiance was measured by Photo Research PR-740 spectroradiometer as well as spectroradiometer OceanOptics STS-UV-L-25-400. light source is.

In the experiment was used set of 60 white textile samples, which were divided into six randomly fulfilled group each containing 10 samples. CIE Whiteness of tested samples varies from 60 till 170 and tint values were in range of -8 to +7 units.

Total radiance factor and computed luminescence factor of each sample was derived from CIBA White Plastic Scale, which was used during calibration of Datacolor SF600+ spectrophotometer in de:8° mode. For comparison and correction was measured the same sample set by using bispectral method on spectrofluorimeters JASCO FP-8600. All samples were measured also by using of X-RITE spectrophotometer ERX30 with 45°a:0° geometry and numerical method of UV adjustment. For a measurement, the sample is illuminated by white light (Xenon flash lamp, daylight) and light without UV component. Measured area is 12 mm diameter. Measured results are reported with true 1 nm spectral measurement resolution from 330 nm to 730 nm. As UV checker was used UV standard plastic plaque GM27006980, sn STD35 with CIE Whiteness SCE = 125.1, expiration date 9/2016. The recommended ultraviolet calibration routine by the manufacture was applied before measuring sequence. Every sample was measured four times.

All of the visual evaluations were conducted in completely darkened room by 10 colour normal discriminating observers with 5 replications. Method of assessment was ordering of evaluated samples from highest to lowest visually assessed whiteness and pair comparison method; when observers compare, which sample appears whiter. Together was made 45 pair comparison per each replication by one observer. On the end was used matching method, when observer choose nearest white standard from newly prepared CIBA cotton white scale. Obvious delay between replication was 1 day and ordering of samples was randomized.

Various existing whiteness indices were compared with regard to their ability to measure the perceived whiteness of whitened textile samples. The Spearmen rank coefficient, wrong decision criterion method (WDC) and STRESS was used to determine the best index for whiteness measurement.

Based on projection of measured data into CAM02 was derived new one dimensional whiteness formula allowing comparison of assessed whiteness of green and red tinted white samples.

3. Results

Analysis of the visual estimations was conducted by using of Spearman's rank correlation coefficient, which is defined as the Pearson correlation coefficient between the ranked variables. It is important to assume that Pearson's correlation assesses linear relationships; Spearman's correlation assesses monotonic relationships (whether linear or not). If there are no repeated data values, a perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other. Intuitively, the Spearman correlation between two variables will be high when observations have a similar (or identical for a correlation of 1) rank (i.e. relative position label of the observations within the variable: 1st, 2nd, 3rd, etc.) between the two variables, and low when observations have a dissimilar (or fully opposed for a correlation of -1) rank between the two variables. In order to study the limitations factor of CIE whiteness formula on the results, where highly tinted samples appear as more reddish (T<-2) and greenish (T>4) in comparison to others as 30% of all set. All observers attending in panel of observers were having tendency to separate these samples from ranked set if was used ranking method, where observers ordered samples from highest to lowest visually assessed whiteness. This is interesting result because some of red tinted samples aren't highly tinted in point of view of CIE tint. This problem was partially reduced by pair comparison method, where observers evaluate only if sample is whiter or darker. Computed Spearman's rank correlation of both assessing methods shows high consistency of panel of observers and rS = 0.93 confirms legitimacy of both methods. Last matching method was by observers most preferred method, which allows evaluation of assessed tint by grey scale method. As important result, it is necessary to point out also, that measured variability of this method was approximately twice time lower in comparison to previously mentioned assessments.

A new whiteness formula (WI CAM02) was developed by optimizing of projection the original CIE whiteness formula into CAM02 colour appearance model and it was found that WI CAM02 gave the best performance for predicting whiteness based on the colour matching and ranking visual results.

4. Conclusions

In this paper, the performance of the selected whiteness formulae was compared on set of white textile fabrics visually assessed under three different light sources. Any known tested whiteness formula correlates strongly these tinted samples. Samples slightly greener than the white scale were preferred contrary to redder tinted samples.

From experimental study, it is revealed that new CIE CAM02 based whiteness index WI CAM02 is appropriate for the prediction of whiteness of tinted textile fabric under different light sources.

PO18 (PP06)

PERCEPTION OF CORRELATED COLOUR TEMPERATURE

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Abstract

1. Motivation, specific objective

The Correlated Colour Temperature (CCT) is an important quantity for specifying the tone of white light (warm to cool) in lighting applications and others (display and photography). CCT is defined, by International Commission on Illlumination (CIE), as the temperature of the Planckian radiator having the chromaticity nearest the chromaticity associated with the given spectral distribution on a diagram where the (CIE 1931 standard observer based) u', 2/3 v' coordinates of the Planckian locus and the test stimulus are depicted. This means that the CCT is calculated using the (now obsolete) CIE 1960 u,v diagram, though the current CIE recommendation for uniform colour space is 1976 u',v' diagram. Questions are raised on why the obsolete u,v diagram is still used to determine the CCT. The distance to the Planckian locus (Duv defined in ANSI C78.377) is also calculated from u,v coodinates following the definition of CCT, which causes confusion with delta u'v' used to specify colour tolerances of light sources. Available literature does not justify the use of u,v coorinates over u'v' for CCT.

This research investigates which coordinates, (u,v), or (u', v'), agree more closely with visual perception to calculate CCT when the illumination source chromaticity is deviated from the Planckian locus.

2. Methods

A double-lighting booth with spectrally tuneable light sources was used for the experiment. The source has 16 channels of light emitting diode (LED) spectra controlled with a computer control program that allows colour settings by entering CCT and Duv values. The experiments were conducted at two CCTs, 3000 K and 5500 K, and at two Duv levels -0.015 and +0.015, therefore, four chromaticity points of test light. The inner wall surface of the booth is painted with neutral grey. A white target sheet (~28 cm x 28 cm) made of high reflectance diffuse material at the bottom of the booth so that subjects could compare the colours of the white sheet on both sides, while the surrounding area of the booth was used for subject's adaptation. The right side of the booth was set to a test light, which was 3000K with Duv +0.015 or -0.015. The left side of the booth was set for nine points on the Planckian locus, where point No.1 has the highest CCT (3384 K) and No. 9 has the lowest CCT (2773 K). The point No.5 (mid point) is at exactly the same CCT (3000 K) as the test lights based on the current definition of CCT (calculated based on the 1960 (u,v) coordinate), point No. 3 (3179 K in the current CCT definition) is at the same CCT of the test light at D_{uv} = -0.015 calculated based on the CIE 1976 (u',v') coordinate, and No. 7 (2882 K in the current CCT definition) is at the same CCT of the test light at D_{uv} = 0.015 calculated based on the (u',v') coordinate. 12 subjects having normal colour vision participated in the experiment; 8 males and 4 females, from 20 to 71 years old, 7 white and 5 Asians.

To handle chromatic adaption appropriately, two methods were used in our experiment. The first method is the *non-haploscopic method*, in which a subject directly compared different Planckian lights (left side of booth) against the Test light (right side) using both eyes. The second method is the haploscopic method, where the subject's left eye and right eye are adapted separately to the light at each side of the booth. With this method, the colours of the two lights will appear closer colours due to chromatic adaptation of each eye.

In non-haploscopic method, first, one of the Planckian point, *m* (between No. 2 to No. 8 of the 9 points), was selected. Then a subject's eyes were adapted under the adapting light at mid-point between a test light and Planckian point, m). After adaptation, the right booth was changed to the test light and the left booth was changed to the Planckian point *m*-1 or *m*+1 in random order. Each subject was asked to select which point (*m*-1 or *m*+1) looked closer to the test light. In total, there were 6

adapting points and 6 pairs of Planckian points to compare with each test light. In haploscopic method, first, the subject's left eye was adapted to Planckian point m and right eye to test light (Duv -0.015 or +0.015), then Planckian point *m*-1 and *m*+1 were presented sequentially an repeatedly. Subjects answered which point (*m*-1 or *m*+1) on left side looked closer to the test light (right side).

3. Results

The subjects' responses on which light he or she chose were sorted in the order from Planckian adaptation point No. 2 to No. 8. The percentage that subject chose higher CCT light in the pair would ideally change from zero (No.2) to 100 % (No. 8). The 50% crossover point is considered to be the point where the Planckian light was perceived closest to the CCT of test light. The experimental results followed such a trend in many cases, from the crossover CCT points were estimated, and judged whether these crossover points were closer to the CCTs from (u,v) or (u', v') coordinates. All results for 3000 K (Duv -0.015, +0.015, non-haploscopic, haploscopic) showed that crossover points were closer to those from the (u',v') coordinates. 5500 K results had some variations and the average result was considered to be between (u,v) and (u',v'). There were no clear distinctions in results between non-haploscopic method and haploscopic method, some subjects reported that judgement was easier with haploscopic method.

4. Conclusions

With limited experimental conditions (range of CCT and Duv) and number of subjects used in this experiment, the overall results show that perceived CCT agrees better with the CCT calculated from the 1976 (u',v') coordinates. Further experiments with more number of subjects and more CCT points are desired to verify the results of this experiment.

PO19 (PP07)

VISION EXPERIMENT ON CHROMA SATURATION PREFERENCE IN DIFFERENT HUES

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Abstract

1. Motivation, specific objective

It has been identified by CIE that, for accurate evaluation of overall colour quality of light sources for lighting, not only colour fidelity but also the aspect of colour quality related to preference is also critical. It is well known from previous studies that increase of chroma is a major factor for colour quality preference, and a certain level of oversaturation of chroma of objects seems to be generally preferred. To measure the level of chroma increase by a light source, gamut area measures are often used to evaluate colour preference aspects. However, the gamut area accounts for chroma increase or decrease regardless of direction of hue. Experiences in lighting indicate that the effect of chroma increase on colour preference varies significantly with hue, and one gamut area number would not indicate colour preference accurately for all cases. In particular, red is considered to be most dominant in colour quality preference, but such scientific data have not been available. This work aims to obtain such experimental data on colour preference of lighting depending on chroma increase in different hue directions, toward developing more accurate preference measures than simple gamut area.

2. Methods

Vision experiments were conducted to evaluate colour quality preference with chroma increase of illuminated objects in different hues, using a 25-channel spectrally tunable lighting facility (STLF) simulating an interior room. A coffee table was placed in the center, on which two plates of various fresh fruits and vegetables (strawberries, red apple, tomato, orange, bananas, green apple, green grapes, green pepper, lime, lettuce, purple grapes, red cabbage) and a blue package of popular snack. 19 subjects participated in the experiments. Each subject evaluated their preference on colour appearance of the target objects under illumination of 11 different spectra of different gamut shapes compared as pairs in all combinations (55 pairs total), which formed an experimental session. The experiments with fruits and vegetables were conducted at four correlated colour temperature (CCT) conditions; 2700 K, 3500 K, 5000 K (on Planckian locus) and 3500 K below Planckian locus (D_{uv}= -0.015). In addition, experiments on their skin tones (hands and face in a mirror) were conducted separately at 3500 K. The experimental session at 3500 K for fruits and vegetables was repeated to check reproducibility. Thus, six experimental sessions were conducted for each subject, requiring approximately two and half hours in total for each subject.

The 11 spectra for each CCT were set for different chroma shifts of red, green, yellow, and yellow-green Munsell samples, with -5 to 15 ΔC^*ab differences from the neutral saturation (reference illuminant used in the Colour Rendering Index). A reference light was set to be as close as possible to the reference illuminant. The CRI Ra values of all lights ranged from 63 to 98. Illuminance was set at 250 lx for all conditions. The spectra of STLF lights were tuned so that, when setting chroma shifts of one sample (e.g., green), chroma of other colours (e.g., red) was kept constant (in most cases) so that the saturation effect of only one colour could be evaluated.

The 55 pairs were presented in random order. Each pair of light was presented sequentially and repeatedly as “A” and “B”, for several seconds each, and subjects answered which light, A or B, he or she preferred (forced choice), when viewing targets in the room.

3. Results

From the raw results of 55 pair comparisons for 19 subjects, first the percentage that “A” was chosen for each of 55 pairs were calculated. For example, in a pair of ΔC^*ab = 5 (“A”) and ΔC^*ab = 0 (“B”) of a red sample at 3500 K, 89% (17 out of 19) of subjects preferred A. These data were then converted to z-scores, which provide a score in the relative scale of preference for each of 11 lights based on

statistical analysis of results of all pair comparisons – a method known in psychophysics. In this case, z-score = 0 is the mid point of the scale; positive numbers mean preferred, and negative numbers mean disliked, proportional to the magnitude of value. Then, all the z-score values were normalized to the reference light (neutral) so that preference values are shown with respect to the reference light.

The grand average of all results (fruits and vegetables at all CCTs and skin tone at 3500 K) show that normalized z-scores for red samples for ΔC^*ab = -5, 5, 10, 15 were -0.63, 0.59, 0.71, 0.54, respectively. For green samples, z-scores were -0.15, 0.07, 046, for ΔC^*ab = –5, 10, 15, respectively. For yellow samples z-scores were 0.05, 0.04 for ΔC^*ab = -5 and 5. For the yellow-green sample, z-scores were 0.00 for ΔC^*ab = 8. The results for skin tone and fruits and vegetables were similar. There were small variations among different CCTs but not significant.

4. Conclusions

The results verified that the chroma increase of red colour has the dominant effect on colour preference among all colours. The results for chroma increase and decrease of red colours agreed well with the results of previous studies. The effect of green saturation is the second, but it is much less sensitive than red, requiring a large chroma increase (ΔC^*ab=15) to be effective on colour preference. The effects of yellow and yellow-green are found insignificant.

In this experiment, it was hoped to test all hues, but chroma control was limited to only red, green, yellow, and yellow-green, partially due to the performance of STLF and possibly due to theoretical reasons. Yellow shifts were made only in small ranges, as there were significant hue shifts. Chroma control of blue (only) was not possible. Further experiments are desired to examine preference in more hue colours possibly with some other experimental techniques.

PO20 (PP08)

OPTIMAL LED SPECTRA

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Abstract

1. Motivation, specific objective

Light-emitting diodes (LEDs) have become one of the most important light sources. More and more applications of LEDs are including indoor lighting, outdoor lighting, transportation lighting, etc. Besides, the standard light sources for the measurement and the calibration of the radiometry and the photometry are also of great necessity to apply for the LED light sources. Therefore, the optic properties of the LEDs are very essential subject for the applications. Especially, how to standardize the spectrum of the LEDs must be the most urgent subject for the time being.

However, the composition of the LED spectra is complicated and not well clarified yet so far. For the most common LED light sources, it consists of a blue GaN LED die and the yellow YAG phosphor. In principle, there are at least two different kinds of mechanism for forming the emission spectra. One mechanism is the generation-recombination of the electron-hole pairs in the band structure of the blue GaN LED die. According to the basic semiconductor theory, the emission spectrum of the blue GaN LED should be able to be completely determined. Unfortunately, there might be some other unknown or some complicated hidden effects working such that the theoretical emission spectrum based on the band theory is still seriously deviated away from the practical measured spectrum. The other mechanism is the excitation-emission effect in the phosphors. The quantum single configurational coordinate model (QSCCM) proposes the Gaussian spectral function for the emission spectrum. Meanwhile, it still happens the re-absorption and the re-emission phenomena. Under such a circumstance, it is believed that the phosphor emission spectrum should be much more complicated than the one as QSCCM suggesting. Moreover, the phosphors in the applications are not limited to YAG. How to have general way to describe the emission spectra of the LED light sources becomes a practical and urgent subject to explore with. Then, the optimal LED spectra can be obtained.

2. Methods

To find the optimal LED spectra, we take two steps of analysis to approach the goal. The first step is to find an empirical function to lineate the LED emission spectrum with few characteristic parameters. As compared with a large amount of real LED spectra, the empirical spectra function is then confirmed. According to the previous reports, the candidates of the spectral functions for the blue LED dies are the sum of two Gaussian functions with 6 characteristic parameters and the asymmetric Gaussian function with 4 characteristic parameters. For the sake of the convenience and the accuracy both, we prefer to the latter one with lesser parameters but still providing with enough accuracy.

Besides, the phosphor emission spectrum follows the QSCCM suggestion. Furthermore, the suggested Gaussian spectral function for the phosphors is in term of the frequency rather than the wavelength of the light. We convert the QSCCM Gaussian spectral function into the alternative function in term of the wavelength instead. Fortunately, it is found that the re-absorption and the re-emission phenomena obey the behaviour of the alternative spectral function predicting.

In such a way, we now have a general spectral function with 10 characteristic parameters to precisely describe the full emission spectrum of a LED light source. Among them, there are 3 characteristic parameters for the center wavelengths, 4 characteristic parameters for the spectral bandwidths, and 3 characteristic parameters for the relative radiometric strengths. By appropriate tuning the 10 characteristic parameters, any one practically measured LED spectrum can be approached with high accuracy.

The second step is the optimization process. With the pre-determined CCT and the normalization to the light power, the 3 characteristic parameters for the relative radiometric strengths are thus determined, too. The rest 7 characteristic parameters are further approached by an optimization

algorithm calculation such that the merit function reach its extremes. Then, the optimal LED spectrum can be obtained. The details of the merit function can be depend on the applications. For example, the maximal CRI, the highest optic efficiency and so on.

3. Results

After the comparison with more than 1,000 various LED spectra from different manufacturers, our spectral function for the LED light sources works very well. Furthermore, it does not only work very well for the blue LED with yellow phosphor, but also even for the RGB LED combo, the UV LED with RGB phosphors, the B/R LEDs with green phosphor, etc.

For simplicity, we optimize the case of the blue LED die with yellow phosphors only. By the optimization evaluation, the corresponding characteristic parameters are found and the optimal LED spectra for the highest CRI of warm white and cool white are thus obtained.

4. Conclusions

In this work, we have successfully obtained the optimal LED spectra for the highest CRI of warm white and cool white. By developing an empirical spectral function to describe the LED spectra with high accuracy and optimizing the empirical spectral function with a specified merit function, the optimal LED spectrum can be easily evaluated. Actually, a series of the optimal LED spectra for the highest CRI of various CCTs can also be concluded. Besides, the obtained optimal LED spectra can apply for the standard light sources for the measurement and the calibration of the radiometry and the photometry.

PO21

INFLUENCE OF A GLARE SOURCES SPECTRUM ON DISCOMFORT GLARE – A PHYSIOLOGICAL EXPLANATION FOR A PSYCHOLOGICAL PHENOMENON

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Abstract

1. Motivation, specific objective

It´s well known that the illuminance at the eye strongly influences glare perception. At the same time an influence of a glare sources spectrum (SPD) on discomfort glare is known and often discussed in the literature. Concerning this the short wavelength component in the SPD is said to increase glare perception.

To determine physiological mechanism for that psychological phenomenon many studies were conducted. But to this day the results are inconclusive and a determination of physiological mechanism is not possible.

2. Methods

To that a study was initiated to find an explanation for this inconsistency. This investigation focuses on the influence of the stimulation of the retinal receptors rods, blue cones and the opponent canal L-M on glare perception. Due to that selective synthetic spectra were generated with a spectral free adjustable light source. Based on the different sensitivity curves, visual stimuli were generated to stimulate primarily one of theses visual paths. To verify the applicability of the results on broadband spectra, different real existing SPDs with a large range of the short wavelength component were presented. Stimuli were adjusted to the same illuminance at the eye to eliminate that parameter. In a preliminary study it could be shown, that the results are equal for the illuminance levels of 0.5 and 1.5 lx. In the main study the illuminance at the eye was set to 1 lx. The glare source was shown at an angle of 4° to the line of sight. The adaptation background was realized with a sphere and the adaptation level was set on 0.05 cd/sqm (mesopic condition). Stimuli were shown twice and in a randomized order. To investigate a possible influence of pupil diameter on glare perception, the pupil diameter was measured with an IR eye-tracking camera mounted in the half sphere. Subjects had to rate discomfort glare on a nine-point scale. 30 subjects took part in the examination.

3. Results

The results indicate that the stimulation of the blue cone increases glare perception. A mismatch was found for the rods. No influence of the glare sources SPD on pupil diameter could be detected.

4. Conclusions

The approach gives important information about the relation of spectrum and glare perception and subsequently the design of light sources, to reduce discomfort glare.

PO22

RED ON RED

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Abstract

This research project is based on a garden proposal for Les Jardins de Métis in Grand-Métis, Québec, Canada. The garden borrows its idea from Josef Albers' Interaction of Colour and serves as framework to experience perception and sensation, colour and light. The objective of this study is to demonstrate: The Interaction of Colour is valuable architecturally and aesthetically and in terms of performance. The effect of colour can be increased without changing people's perceptions of the colour in the space, by applying the interaction of colour with the larger built environment in nature or within larger fields.

Given the qualities of colour interaction, why are spaces not typically designed with a set of these? To test the hypothesis, the perception of colour interaction will be assessed empirically. Stepping outside the white cube, and outside of Albers' colour experiments, how does colour interact? Future research will focus of the development of physical models that testing the interaction of colour within larger spaces and environments. The models will explore colour interaction by using a range of graphic techniques to maximize the relative appearance of a colour in relation to adjacent colours when these fields are interspersed (Bezold effect). Guiding research questions are:

- Can we achieve the perception of intense colours while also providing little colour?
- How can space be colourful without using too much colour? Moreover what is the minimum required?
- What is a strategy for colour interaction in nature - with the plants, the sky, the seasons? How to apply the Interaction of Colour to conditions that are in a constant state of flux?
- Building on El Lssitzky and Theo van Doesberg, are there other ways to challenge the primacy spatial form? In what ways can the use of colour alter or deny three dimensional space?
- Can spatial composition and colour be at once independent and dependent systems? How to minimize and maximize the optical destruction of volumes and forms in space? What are the fundamental techniques?
- What are the potentials of the Liebermann effect- where two colours that are of equal brightness but differing in hue assume the same spatial plane? Or of colour vibration?
- What are the ways that built forms can generate the atmospheric effects of a Seurat painting? How can the viewer assimilate coloured elements?

Investigation of these effects will be looked at in a larger context of variables, including daylight, shadow, background conditions and colours, and the position of the viewer. The following issues will serve as key points of investigation:

- The outline and definition of space through colour. And conversely the undermining of architectural space through colour application.
- Spatial effects of colour including compression, extension and resolution of volumes.
- Connection and disconnection of spatial elements by colour.
- Contrast effect of colour especially in outdoor and/or daylit spaces.

Although these are preliminary experiments and results, the implications were of sufficient interest to continue the work. Multiple tests are being conducted. These results will be evaluated to find a rule for the perception of colour, which will lead to design applications for the use of colour in spaces and will be pursued further in a larger experiment.

PO23

VISUAL EVALUATION RESULTS OF PERCEIVED WHITENESS UNDER THE ILLUMINANT D50 CONDITION AND THEIR PREDICTIONS

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Abstract

1. Objective

The TC1-95 is currently considering the applicability of the CIE whiteness formula and the CIE tint formula to lighting conditions other than the standard illuminant D65. In this study, we conducted visual evaluation experiments of perceived whiteness under the illuminant D50 condition, which are normally used in graphics arts, and investigated the relationship between the visual evaluation results and the predicted values by the whiteness formulas of CIE, Uchida, and Grum to provide useful information to the TC1-95.

2. Methods

We used a colour liquid crystal display (Eizo CG223W) and presented 11 types of near-white stimuli to the observers. The chromaticity coordinates for the near-white stimuli were set at equal intervals along a baseline that connected the chromaticity coordinates for the illuminant D50 (0.3457, 0.3585) to the chromaticity coordinates for a 466 nm spectral light (0.1335, 0.0427). We conducted measurements using a luminance colorimeter and obtained the following actual values. The chromaticity coordinates of a stimulus closest to the illuminant D50 were (0.3318, 0.3374) and those of the most bluish stimulus were (0.3290, 0.3331). The average luminance of the presented stimuli was 66.7 cd/m², with a standard deviation of 0.77 cd/m², and the maximum luminance of the white point that corresponds to the illuminant D50 on the liquid crystal display was 73.0 cd/m². Thus, when converted into a luminous reflectance, the average was 91.3%, with a standard deviation of 1.06%. The stimulus was a 5 × 5 cm square, which constituted a stimulus pair where different stimuli were juxtaposed with a 1 mm distance. The observer viewed them from a distance of about 60 cm by binocular vision. The viewing angle for the stimulus was 4.8° × 4.8°.

After the observers were adapted to the N7 equivalent achromatic background, which was adjusted to match the chromaticity of the illuminant D50, displayed on the colour liquid crystal display for 1 min, they were asked to select the stimulus that they thought to be more whitish from the pair of the near-white stimuli displayed on the N7 background. Fifty-five stimulus pairs of 11 types of near-white stimuli were displayed in random order. The above procedure was considered as one session, which was repeated twice.

3. Results and Discussion

A total of 50 male and female observers who were confirmed to have normal colour vision using the Ishihara plate participated in the experiment. Forty-seven of the observers had significant consistency in the evaluation results of each session and had significant rank correlation in the evaluation results between the two sessions (31 males and 16 females, with an average age of 21.2 years and a standard deviation of 3.9 years). We assumed that the remaining three observers did not have a one-dimensional internal criterion on the evaluation of perceived whiteness or did not have the ability to properly evaluate, so they were excluded from the analysis.

We composed an interval scale of perceived whiteness based on the visual evaluation results of the 47 observers and found that perceived whiteness was evaluated to be higher when the bluish purity of the stimulus was higher. We obtained simple correlation coefficients between the interval scale values of the perceived whiteness and each of the predicted values by the whiteness formulas of CIE, Uchida, and Grum and then compared the predicting performances. It became clear that the CIE whiteness formula and the Grum whiteness formula showed very high predictive performances, but the Uchida whiteness formula did not predict the visual evaluation results well. Although the predicted

values in the CIE whiteness formula agreed well with the visual evaluation results, many of the presented stimuli that the observers evaluated to have higher perceived whiteness were out of the applicable limit of the CIE whiteness formula, so relaxing the limits of the application might be needed. Furthermore, the slope of the baseline becomes slightly smaller in the illuminant D50 condition compared to the standard illuminant D65 condition, so modifications of the tint formula might be needed. As a result, modifications of the coefficients that determine the equiwhiteness lines will also be needed. However, the Grum whiteness formula does not need to change its coefficients under the illuminant D50 condition. In addition, regarding diverse visual evaluation data sets on perceived whiteness under the standard illuminant D65 condition, the Grum whiteness formula showed significantly superior predictive performances than the CIE whiteness formula did.

4. Conclusions

When near-white stimuli with the same luminance along the baseline of the CIE whiteness formula were presented under the illuminant D50 condition, even in regions with higher bluish purity that exceeded the applicable limit of the CIE whiteness formula, the perceived whiteness was evaluated to be higher when the bluish purity of the stimulus became higher. The predicted whiteness of both formulas of CIE and Grum correlated well with these visual evaluation results. However, all things considered, we believe that the Grum whiteness formula is better than the current CIE whiteness formula.

PO24

RESEARCH ON PROTECTIVE ILLUMINATION OF CHINESE TRADITIONAL PAINTING BASED ON RAMAN SPECTROSCOPY

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Abstract

Chinese traditional painting is not only an art treasure of China, but also an important part of the world cultural heritage. At present, there are more than 640,000 pieces of traditional painting collections in museum, and the stock is huge. Meanwhile, during more than 1300 years from the Sui Dynasty (DC581) to the late Qing Dynasty (DC1911), a large number of national treasures of painting with high artistic and cultural value had been preserved. However, due to existing problems of preservation, there are different degrees of damage to traditional painting collections, which is irreversible permanent damage. In classification of the CIE, according to photochemical stability of material, Chinese traditional painting belongs to the highest level of light sensitivity, which is more vulnerable to light damage than other cultural relics. Light, temperature, humidity and air quality are the influencing factors of cultural relics. However, in museum environment, temperature, humidity and air quality can be adjusted to the best state of painting preservation through relevant technical means, but a little bit of light will have an impact on painting. At the same time, owing to the lack of natural illumination and environmental illumination in traditional painting exhibition hall, optical radiation is the most important factor in damage to painting, leading to substrate blacking, crisping, cracking, as well as pigment fading, discoloration, even the loss of colour and other serious damage. The fundamental cause of the above-mentioned damage is that protein molecules in painting undergo photochemical reactions, such as molecular bond breakage under illumination. Therefore, for accurate protection of Chinese traditional painting, it is necessary to study quantitative influence of the typical light source of museum illumination on the microscopic morphology of painting.

Choosing the typical light sources as experimental light sources, such as halogen tungsten lamp, metal halide lamp and white LED (WLED), Chinese traditional heavy colour painting specimens were carried out illumination experiment. The experiment was carried out in dark optical laboratory with consistent surface illumination on each specimen, and indoor temperature, humidity and air quality were kept constant according to the corresponding standard. The experiment was carried out by periodic illumination, twelve hours per day and six months for one measurement cycle. The whole experiment was carried out for two cycles. With extension of illumination time, total light exposure of the illuminated objects was accumulated, and the parameters were measured after each illumination period. Raman spectra of the specimens was measured after each illumination cycle using the American Thermal Power Company DXR Microscope Confocal Microscopy Raman Spectrometer. The Raman characteristic peaks and representative molecular structure of various specimens were obtained by looking up the Raman spectrum database. Then the peak shift and peak intensity of Raman spectrum characteristic peaks were analysed, and the spectra between peak shift and peak intensity were plotted. Through analysis of quantitative effects of three kinds of typical light sources on the microscopic morphology of painting based on the spectra analysis, damage degree of the typical light source to Chinese traditional painting, such as molecular bond breaking, material decomposition and crystal shape change, was evaluated. And relative influence coefficients of the typical light source on the microscopic morphology of painting were also put forward.

The results can provide not only theoretical basis and data base for relevant research, but also support for revision of the museum illumination standards and a reference for selection of light sources for display illumination, so as to better protect the authenticity of Chinese traditional painting relics.

PO25

STUDY ON VISIBILITY THRESHOLD CURVE OF CIRCULAR OBJECTS AND VISIBILITY ESTIMATION METHOD USING C-A GRAPH

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Abstract

1. Motivation, specific objective

It is vitally important to estimate the visibility of all visual targets in real environments in order to maintain a visual safety especially for low-vision people. As luminance images of real lit environments are relatively easily obtained, it is reasonable to attempt to establish a method to estimate visibility of objects using luminance images. Authors have proposed C-A graph based on contrast profile method. In contrast profile method, luminance contrast is obtained by convolution of 9 by 9 matrix called n-filter into a logarithmic luminance image. This n-filter is a kind of the Mexican hat filter. A luminance contrast profile of the object is obtained by changing detection size of the filter. A logarithmic average of the object and the immediate background is obtained by the same size averaging filter as the n-filter in the logarithmic image of luminance. C-A graph presents luminance contrast and logarithmic average as vertical and horizontal axes for varying object sizes respectively. It expresses the three factors necessary for visibility estimation. Previous study, where Landolt rings and circular objects were used as visual targets, indicate that estimation of visibility using luminance image and C-A graph is possible. In the previous study, threshold visibility luminance contrast for circular objects of 0.67 to 20 minutes sizes were obtained. The objective of this study is obtaining visibility threshold conditions of a wider range of objects size, and examine the relationship between visibility threshold values and visibility evaluation.

2. Methods

In this study, two experiments were conducted. The first experiment was done to obtain visibility threshold conditions of a wider range of objects size. The second experiment was done to examine the relationship between visibility threshold values and visibility evaluation. Visibility estimation model using C-A graph was considered using the results of these experiments. In both experiments, circular objects with varying luminance contrast, background luminance and size, were displayed on 27inch digital display screen. Subjects observed the targets from 0.625m and 2.5m distance and their answers were analysed using C-A graph.

3. Results

EXPERIMENT 1: VISIBILITY THRESHOLD CURVE OF CIRCULAR OBJECTS ANALYSED USING C-A GRAPH.

The parameters adopted in this experiment were background luminance varying from 2.5 to 160 cd/m^2, varying luminance contrast between the circular object and the background and object size. The range of object size used in this experiment, 3.3 to 600 minutes, is relatively larger than that of previous experiment, 0.67 to 20 minutes. 10 subjects with an average age 25 participated in the experiment. The median visual acuity of these subjects was 20/11.8. Subjects observed circular targets displayed on uniform-luminance background with both eyes. The targets were shown on digital display screen and subjects answered whether the targets was visible or invisible. Luminance images of visual targets used in the experiment were analysed using contrast profile method and presented on C-A graph. By plotting visible and invisible contrast values of for each target size and finding out contrast values that half of the subjects evaluated as visible, visibility threshold curve can be drawn between visible and invisible conditions on C-A graph. As object size became smaller, visibility threshold curve opened outward on C-A graph and both positive and negative visibility threshold contrast becomes greater. Using results of previous and this experiment, model estimation equation applicable for greater range of object size, 1.25 to 600, minutes was obtained. As median visual acuity

of the 10 subjects in the previous experiment was 20/14.8 and is different from this experiment, the variable obtained by multiplying object size and the visual acuity was used to concatenate the results.

EXPERIMENT 2: ANALYSIS OF VISIBILITY ESTIMATION METHOD USING C-A GRAPH.

The parameters adopted in this experiment were background luminance varying from 2.5 to 160 cd/m^2, luminance contrast between circular object and background and the object size. The objects size ranged from 1.25 to 600 minutes. 14 subjects with average age of 24 participated in the experiment. The median visual acuity of 14 subjects was 20/11.8. The subjects evaluated visibility of circular objects shown on digital display screen using scale of '0' to '4'. '0' is invisible, '1' is visible effortlessly, '2' is visible with effort, '3' is visible effortlessly, and '4' is easily visible. As in the case with Experiment 1, these experiment results were analysed using contrast profile and presented on C-A graph. When visibility threshold curve obtained from Experiment 1 was shown in the same C-A graph, the visibility threshold curve fit between evaluation '0' and evaluation '1'. Referring to the Blackwell's Visibility Level, the magnification of threshold luminance contrast between evaluation '0'-'1' and '1'-'2', and '2'-'3' respectively were obtained. A correlation between visual target size and these magnification values were seen. As the size of the visual targets became smaller, the magnification necessary for improvement for visibility became greater. This tendency was seen strongly in negative luminance contrast. Visibility of visual objects can be estimated using visual threshold curve and magnification between threshold luminance contrast values.

4. Conclusions

In this study, threshold visibility estimation model adoptable to greater range of object size using C-A graph was established and visibility estimation method using threshold visibility and the magnification was proposed. Whether these models are applicable to people with other visual ability, such as low-vision and average but weak vision, must further be examined.

PO26

LIGHTING RECOMMENDATIONS OF TYPICAL LIGHT SOURCES ON CHINESE TRADITIONAL HEAVY COLOUR PAINTINGS

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Abstract

1. Motivation, specific objective

The Chinese traditional painting is a treasured art form, an invaluable part of China's history, and an important element of the world's cultural heritage. At present, China has 3993 art museums that preserve paintings, and more than 640,000 pieces in traditional painting collections. Chinese traditional heavy colour paintings from Sui Dynasty (DC581) to the end of Qing Dynasty (DC1911) encompassed more than 1300 years, resulting in a wealth of ancient art with high aesthetic and cultural value that has been preserved for centuries. Moreover, they are all "high responsivity" in terms of chemical stability – in other words, the paintings are highly prone to colour change, colour fading, and ultimately colour vanishing. At present, 50.66 percent of the paintings have different degrees of damage, in which that caused by the change of temperature, humidity, air quality, etc. can be avoided by adjusting the environment in the display cabinet, but the light is a must, which will cause irreversible damage to the paintings.

The substrate and pigment of Chinese traditional heavy colour paintings are different from western paintings and therefore using the same standard for different light sources cannot provide precise recommendation for them, especially for the easily damaged Chinese traditional heavy colour paintings. Moreover, all the standards now are based on the traditional light sources, which do not involve white light emitting diodes (WLEDs). The purpose of this paper is to put forward quantitative influence rules of typical light sources and provide recommendations for the light source choice in Chinese traditional heavy colour painting illuminations.

2. Methods

Light sources for painting illumination, according to the standards, must meet the following three requirements simultaneously: It shouldn't contain infrared and ultraviolet rays, CCT must be lower than 3300K, and the CRI must be larger than 90. The experiment utilized a tungsten halogen lamp (CCT=2700K, CRI Ra=97, 50W, with an infrared filter to remove the infrared spectrum), a metal halide lamp (CCT=2700K, CRI Ra=95, 35W) and an RYGB-type WLED (CCT=2700K, CRI Ra=92, 13.3W), that commonly used in museum, as light sources. The painting specimens were crafted by the Chinese Traditional Fine Brushwork Heavy Colour Painting Institute of Tianjin University using traditional techniques and technology. All the experiment was conducted in an all-dark optical laboratory with the indoor temperature, humidity and air quality remaining constant according to the standard. Irradiation of the specimens was for 12 hours every day and 6 days as a cycle, the whole experiment being 16 cycles giving a total exposure duration of 1152 hours. CIEXYL parameters were measured after each cycle of irradiation.

3. Results

The measured parameters were applied to draw the decay curves of dominant wavelength, illuminance and excitation purity over exposure. Thus, the quantitative influence rules of typical light sources on different pigments could be obtained by analysing the change rules of the decay curves. Then the influence relative ratios of the three parameters for different light sources could be obtained by calculating the average values over the 16 cycles, providing recommendations for the choice of minimum-damage light sources.

4. Conclusions

These results provide data support and reference for the research and preservation of Chinese traditional heavy colour paintings. Moreover, they provide a basis for the revision of the museum illumination standards, guiding the exhibition lighting design. Therefore, the historical, artistic and cultural authenticity of Chinese traditional heavy colour painting can be better preserved.

PO27 (PP41)

LUMINANCE EFFECT ON LEGIBILITY OF LETTERS PRESENTED BY A LIGHT-PROJECTION SYSTEM

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Abstract

1. Motivation, specific objective

Recently, a light-projection image technology like projection signing on buildings and roads or augmented reality devices, is rapidly progressed. Projected letters are often used in this technology and legibility of those letters is very important for safety and efficiency usage, for example. But it is difficult to define the adequate luminance of letters with regard to better legibility because background of those projected letters varies depending on the environments which affects the legibility..

The other interest of this study is to see the effect of age on the legibility for those projected letters. The projected letters are basically seen in the luminous mode and a higher luminance level than that in the reflected mode may occur. This might cause a glare sensation for which older people are more sensitive than younger people.

The purpose of this study is to investigate the effect of luminance of a projected single letter on legibility with variable background luminance. Legibility scaling of young and older adults will be measured and in addition, glare evaluation for the letter will also be investigated.

2. Methods

A Head-Up Display (HUD) system including its dedicated glass plate and a projector was used for the projection of letters in this experiment. The letter was presented as a virtual image on a real background generated by a LED Light box with a translucence diffuser the luminance of which was controlable.

Thirty five letters of a sans-serif font type (26 alphabets and 9 numerals) were used. Letter height was 0.121m, and the viewing distance was 2.5m. Five background conditions of different luminances (1.5cd/m^2, 10 cd/m^2, 100 cd/m^2, 1000 cd/m^2, 10000 cd/m^2) were employed. In each background condition, letters of nine different luminances (RGB: 255, 152, 116, 89, 68, 52, 40, 30) were projected on the virtual image plane, one at each time selected randomly. For each viewing condition, three trials with different letters were conducted. Totally, 135 letters (9x5x3) were presented to each subject.

A total of 30 older persons (mean age 70 years old) and 28 younger persons (mean age, 23 year old) were participated in the experiment. The subject was asked to try to read a letter presented and to evaluate the legibility by using a 5 point scale from 1 (very poor legibility) to 5 (very good legibility) without any restriction of time. In case the subject could not see the letter, he/she gave a 0 point. After the evaluation of legibility, the subject were also asked to judge whether he/she felt glare or not. The subject's visual acuity was corrected so as to get the best acuity at 5m distance.

3. Results

With increasing the luminance of the letter, the legibility evaluation score gradually increased from nearly 0 to up to 5 for each background condition. Comparing the legibility based on same Michelson contrast of a letter and background luminance, it is not the same but vary depending on the background luminance. When the background luminance is low, letters are less legible than the letters with high background luminance. For example, at the Michelson contrast 0.5, the score of legibility of older and young subjects is 2.5 (between moderate and bad legibility) in 1.5cd/m^2 background condition, but 4.0 (good legibility) in 10000cd/m^2. Therefore, it is assumed that the legibility of projected letters are affected not only by the Michelson contrast, but also absolute level of the letter luminance. This fact is quite different from the findings of previous studies.

Another interesting finding is the ageing effect for legibility of projected letters. In case of younger people, legibility score for high luminance letters were saturated except for the lowest background conditions (1.5 cd/m^2). In some cases, legibility of the highest luminances were worse than the moderate or lower one. Such situations were not seen in older subjects. If this reduction of legibility at very high luminance level is due to a glare of the letter, it might be more pronounced for older people. It is not the case, however.

The age-related difference is only clearly observed in the moderate luminance levels where significant difference between young and older subjects exists (legibility of young people were always better than, the older), but this difference is not seen in high and low luminance levels. ,

There were also age-related difference in the percentage of glare. Percentage of young subjects who feel glare are higher than those of older subjects at high luminance letters. Though older adults used to be considered that they feel more glare than young people, this result was considered to lead a different idea of cause of glare for older adults.

4. Conclusions

Following two points were concluded from the present study.

3) Legibility of projected letters is not simply Michelson contrast dependent. Luminance of good legibility for projected letters should be defined for different background conditions taking into account the age-related differences.
4) Two age-related differences were found in the legibility of projected letters. One is the appropriate luminance level for good visibility at moderate luminance level and the other is the percentage of feeling glare at higher luminance level of letters where young people felt more glaring effect than older people.

These findings could be applied for the design of letters which are generated by projected image technologies.

PO28 (PP42)

DISPLAY BASED METHODS FOR INTER-CULTURAL IMAGE QUALITY EVALUATION

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Abstract

1. Motivation

Image quality enhancement based on one- and two-dimensional colour attributes (e.g., chroma, lightness contrast, vividness,…) plays a crucial role for the post-productional workflow in motion picture and photographic applications. Usually, a lot of effort and money is put into the attempt to increase the image quality for a target audience or spectators group by film and photo studios all over the world without actually knowing the underlying psychophysical mechanisms leading to improved image preference. The aim of this study, therefore, is to approach the topic of image quality enhancement with respect to the observers' preference from a more scientific point of view and, as a long-term goal, to contribute to the establishment of a well-founded theory being able to describe the experimental results of image quality assessments.

2. Methods

In order to investigate the effect of one- and two-dimensional colour attributes on the perceived image quality and the observers' preference, two different but yet related display based experiments have been conducted.

For the first experiment, eight carefully chosen test images, providing a representative variety of image content, were rendered using five different one- and two-dimensional colour attributes. The one-dimensional attributes include chroma, hue, and lightness contrast, whereas the two-dimensional attributes are given by depth and clarity. For each colour attribute four distinct levels were applied leading to 21 different versions of each test image (5 attributes x 4 levels + 1 original). A paired comparison experiment was eventually performed in order to determine the corresponding z-scores of the observers' average preference ratings assuming Case V of Thurstone's Law on comparative judgements. For each test image the resulting 210 different pairs were shown to the observers in randomized order leading to a total number of 1680 comparisons, which were split into two sessions on subsequent days. Each session lasted approximately 45 minutes.

This first experiment was performed in both countries China and Germany using exactly the same experimental setup (the complete hard- and software was shipped to China and vice versa) and environmental conditions (fully darkened room with the experimental display being the only light source). In China only native Chinese observers and in Germany only native German observers were considered for participation in order to account for the cultural differences between these two observer groups and to avoid unwanted bias which could potentially be induced when mixing these two observer groups with participants having a different cultural or ethnical background. In total, assessments of 25 Chinese and 44 German observers could be gathered.

The second experiment that should be presented here can be considered as a supplement to the first one. Again, eight different test images were chosen. However, in contrast to the first experiment, no single attribute based transformations but so-called functional transformations based on colour attributes were applied to the test images including white point transformation in terms of correlated colour temperature, local and global contrast enhancement, and hue-dependent chroma transformation. In the second experiment, each transformation was considered separately, i.e., paired comparison to determine preference z-score values was only performed among images rendered with the same kind of functional transformation. Furthermore, for each test image and transformation eleven distinct levels should be applied. However, it turned out that not all four transformations were suitable for every test image and, therefore, we ended up with a total number of 1570 comparisons

instead of 1760 possible ones. Nevertheless, observers were again asked to complete the pair comparison task in two different sessions on subsequent days. Here, each session lasted approximately 40 minutes.

In order to also consider cultural differences and to compare the results from both experiments, 20 native Chinese and 20 native German observers were invited to participate in the second experiment. However, since the second experiment took entirely place in Germany one has to be careful when analysing and interpreting the experimental results, because it cannot be ruled out that the results of Chinese observers that have been living in Germany for quite a long time (>1 years) might differ significantly from those who have never left China due to cultural adaptation and bias effects.

3. Results

First results indicate that both Chinese and German observers are in favour of slightly more colourful images being in accordance with our common knowledge. For all eight test images of the first experiment and both observer groups the relation between mean preference ratings in terms of z-scores and colour attribute variation can be described by an inverted U-shaped function giving point to the conclusion that too large attribute variations – regardless of their direction – will not improve image preference. The same holds true for the transformations of the second experiment.

In both experiments it could be further confirmed that preference ratings as a function of colour attribute variations are largely influenced by the image content and, therefore, no generic image enhancement method could be derived from the results. Nevertheless, a strategy of image enhancement for a certain image content (e.g., blue sky, green grass, face skin,…) is considered to be feasible and should be presented in the final conference paper.

Regarding the cultural effects on the image preference ratings, the overall difference between the two observer groups is smaller than expected. The average correlation coefficient of Chinese and German observers reaches 0.82. Only for some specific images and transformations significant differences could be observed. The details will be reported in the full paper.

4. Conclusions

In order to investigate the cultural influences on image preference ratings two different display based experiments were performed comparing Chinese and German observers. Several different one- and two-dimensional colour attribute variations as well as more complex functional transformations were applied to the test images, which were eventually presented to the observers using the method of paired comparison. Results indicate that the preference ratings of both observer groups are mainly influenced by the image content. Therefore, a strategy of content-dependent image enhancement, where cultural differences will also be taken into account, should be presented in the final conference paper.

PO29 (PP43)

ANALYSIS OF THE LIGHTING INFLUENCE IN THE SPARKLE DETECTION BY APPLYING STATISTICAL DESIGN OF EXPERIMENTS

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Abstract

1. Motivation, specific objective

The objective of this work is to determine the light source influence in the visual perception of the sparkle texture effect on gonio-apparent materials. Sparkle texture effect is defined by ASTM E-284 as "the aspect of the appearance of a material that seems to emit or reveal tiny bright points of light that are strikingly brighter than their immediate surround and are made more apparent when a minimum of one of the contributors (observer, specimen, light source) is moved". Therefore, the influence of different lamps (with different SPD, CCT and CRI) in this appearance will be studied. In addition, three geometries mainly used in the automotive sector, 15ºx:0º, 45ºx:0º and 75ºx:0º following the CIE nomenclature, will be included in this study to evaluate its relevance on the sparkle detection distance. The motivation that has led to the development of this experiment is that there is no a previous similar work that addresses the influence of lighting in the sparkle detection.

2. Methods

A specific lighting booth for sparkle evaluation was designed and manufactured at the University of Alicante. This cabinet allow to evaluate the sparkle texture effect for any illumination angle and it is flexible to change the lamp and adapt it according to specific needs (daylight, warm light, CCT and CRI), as well as changes on the illuminance level (E in lx).

Three types of samples with different features were selected for this experiment. Firstly, a sample was chosen with a silverdollar pigment type and a large particle size (D50 = 34µm) to ensure that for any configuration we are sure that the observer is able to detect the sparkle effect. The remaining two samples (composed of Luxan® and Xirallic® effect-pigments) were selected based on the results obtained from a previous work. The behaviour of both samples was different regarding the sparkle detection for this reason it is considered interesting to see how they can be influenced by environmental conditions.

In this experiment, two light sources were selected: a warm LED lamp with a 3200K colour temperature and a daylight LED lamp with a 6500K colour temperature. For each lamp, different illuminance levels were considered: 800, 2400 and 5000 lx. Regarding the measurement geometry, the evaluation was performed in three different measurement conditions following those conventionally used in the automotive sector and available at instrumental level by the BYK-mac-i gonio-spectrophotometer: 15ºas15º, 45ºas45º and 75ºas75º.

The design of the visual experiment was based on the adjustment psychophysical method. It was consist of determining the maximum sparkle detection distance. The procedure was to adjust the maximum distance in which is perceived the sparkle texture by get closer or away from the sample. The samples were presented in a random way for each observer session. A total of 12 observers (7 men and 5 women) participated in the visual experiment with a visual acuity equal to 1. Three repetitions were performed for each lamp, illuminance level and measurement geometry. In total, each observer performed 972 evaluations for a total number of 11,664 visual assessments.

When the entire experimental phase was completed, all data related to the two lamps, three illuminance levels and measurement geometries were collected. With all these data the inter-variability and intra-variability were analysed by applying the STRESS parameter.

The analysis of the results was conducted by using the statistical design of experiments (DoE). A 3221 multilevel factorial design was selected taking into account the involved factors (CCT, illuminance level and measurement geometry) and the number of levels for each factor. It has to be in mind three levels

were considered for measurement geometry (15º, 45º and 75º) and illuminance level (800, 2400 and 5000 lx) and two levels for the lamp (3200k and 6500k). The design of experiments allows to evaluate the influence in the sparkle detection of the three factors independently as well as to analyse if there is linear or non-linear interaction among them.

3. Results

The STRESS analysis results were very good; the results of the average inter-observer variability were of 21.24 STRESS units, and an intra-observer variability of 11.05 units.

From the visual experiment it is obtained that the observer detects more sparkle for low illuminance levels and for the 45ºas45º geometry. Regarding the influence of the lamp, although the differences are not significant, the sparkle texture effect is best detected for a lamp with warm temperature.

Thanks to the statistical design of experiments (DoE) we obtain that the measurement geometry and illuminance level variables are significant (p-value < 0.05) since have been obtained p-values equal to 0.0001 and 0.0010 respectively for the sparkle detection, therefore the most relevant variable is the measurement geometry, instead the effect of the lamp type is not significant. The only significant interaction between variables is that related to geometry and the lamp type.

In resume, the statistical design of experiments has corroborated the results obtained visually in which the sparkle texture effect is detected at a greater distance for low illuminance levels and for the 45as45 geometry.

4. Conclusions

This study has shown that there are still many doubts about the sparkle perception, since as it has been verified that any slight variation in any of the variables studied, in this case environmental, causes a variation in the way in which we detect the sparkle.

In the absence of similar studies, thanks to this work and to the application of the design of experiments, some clarifications have been made on a topic, as is the sparkle visual appearance in which much work still remains. It has been concluded that the sparkle texture effect is detected at a greater distance for low illumination levels and for the 45ºas45º geometry, besides the colour temperature does not influence significantly.

It was possible to highlight the influence of the geometry variation and the illumination level when evaluating the sparkle detection distance, which extrapolated at the industrial level generates some uncertainty, since for instance it may be the case that samples that are accepted under specific illumination and observation conditions can be rejected with other measurement configurations. It should also be remembered that BYK-mac-i only performs measurements (by monochrome imaging methods and algorithms) with a fixed illuminance level and colour temperature / colour rendering general index (spectral power distribution).

PO30 (PP44)

CHROMATICITY AND EYE-MOVEMENT SPEED DEPENDENCE OF THE PHANTOM ARRAY

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Abstract

1. Motivation

The phantom array is one of the temporal light artefacts (TLA) that perform saccadic eye movement. We would like to develop a model to describe the phantom array and its threshold frequency. As a step to develop the model to explain the phantom array, we investigate the chromatic dependence of the phantom array; flicker and stroboscopic effect, which have no eye movement, shows importance of luminance variations and limited influence of the chromaticity in the TLAs.

We also examine the relationship between the threshold frequency of the phantom array and the eye-movement speed of each individual. The threshold frequency for detecting the phantom array has a large individual difference. The difference of eye-movement speed may account for individual variation of the threshold frequency of the phantom array.

2. Methods

We have developed an apparatus for the experiment of the phantom array with varying chromatic light stimulus. Red, green, and blue RGB LED bars are used in flat panel light sources in experiments. One of the light bars is controlled by DC power and the other is controlled by pulse-width modulation (PWM) with the same luminance level. The chromaticity (red, green, or blue) and the control methods (PWM vs DC power) of the illumination bars are randomly switched to remove the ordering effect from the experiment. An eye tracker with a headrest was placed in front of the participant to track the speed of eye movement during the experiment. Calibration of the eye tracker was performed in each individual at the start of each subject's the experiment.

Three luminance levels, 25 lx, 200 lx, and 400 lx, are used for the experiment. Nine college students with two females participate in the experiment. Experiments were performed in the dark chamber after dark adaptation. Each subject participated sessions: 3 chromaticity sessions x 3 luminance levels.

3. Results

The experiment results show that the threshold frequency of the phantom array is dependent on the logarithmic luminance level and linear relationship. In chromaticity, a blue LED indicates a threshold frequency lower than the green or red LED in the same luminance level. The chromatic different of the threshold frequency of the phantom array may come from the difference of L, M, S cone response time; L and M cone cell have similar shape and response time, and S cone has longer response time than L or M cone.

For the eye movement speed, each individual shows different eye movement speed. Even in the same subject, there are variations in the eye movement speed. To find out the relationship between eye movement speed and threshold frequency of the phantom array, we used average frequency of each subject and find relationship of their threshold frequency of the phantom array. The correlation between the threshold frequency of the phantom array and the eye movement speed is very high. When a subject has faster eye movement than other subjects, the subject is more likely to show higher threshold frequency of the phantom array.

4. Conclusions

Our experiments show that chromaticity and eye-movement speed are important variables for the development of the phantom array model. The temporal contrast sensitivity of the eye may also be very important factor for modelling the phantom array and other TLAs. Therefore, we further investigate the temporal contrast sensitivity during eye movement in the future.

PO31 (PP45)

VISUAL CLARITY AND BRIGHTNESS IN INDOOR AND OUTDOOR LIGHTING: EXPERIMENTS AND MODELLING

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Abstract

1. Motivation, specific objective

In indoor lighting, a wide range of illuminance levels (from the high mesopic range up to high photopic illuminances in brilliant environments) and correlated colour temperatures (from warm white to cool white) can be found. This results in very different levels of perceived visual clarity and spatial brightness impressions. Latter visual attributes are important to assure the acceptance and comfort of the built interior and also for good visual performance in relevant lighting applications (e.g. shopping, office or industrial production).

The objective of the present contribution is to define new descriptor quantities for visual clarity (*C*) and brightness (*B*) that combine the signals of multiple retinal mechanisms including chromatic components and rod and ipRGC signals by re-analysing the results of two psychophysical experiments (one on visual clarity and one on mesopic brightness) published earlier. What is meant by "visual clarity" here is defined by the psychophysical method, see Section 2.

2. Method

In the psychophysical experiment on visual clarity (published earlier), several achromatic and coloured objects were assessed according to the clear visibility of their achromatic and chromatic texture and spatial structure under different light sources (CCT=2200 K to 5000 K) at different illuminance levels (40 lx to 1000 lx). The dataset of the visual clarity scale values of the observers was considered to be re-analysed in the present paper in terms of the new descriptor *C*.

In the experiment on mesopic brightness (published earlier), one half of a >20° bipartite field was matched in brightness visually to its other half (the reference field) at three mesopic light levels between 0.1 and 1.5 cd/m^2. The test and reference field was illuminated by two different light sources of different chromaticity. Seven different light sources (including halogen, Xenon, LED, mercury vapour, sodium and metal halide lamps) were used altogether. The dataset of the resulting visually matching luminance values (together with the relative spectral power distributions of the light sources) was considered to be re-analysed in the present paper in terms of the new descriptor *B*.

The new descriptor of visual clarity (*C*) was defined from the logarithm of the prevailing illuminance plus the logarithm of a weighted sum of normalised S-cone, ipRGC, rod and L-cone minus M-cone signals of the white tone predominating in the experimental room. Signals were normalised by dividing by an integral quantity which considers every wavelength as equally important across the whole visible spectral range according to a recent idea found in literature.

The new descriptor of brightness (*B*) was defined as a product of the luminance of the stimulus and the weighted sum of normalised (in the above sense) S-cone, ipRGC, rod and L-cone minus M-cone signals of the stimulus.

3. Results

The z-scores of the visual clarity dataset of the observers correlated well (r^2=0.98) with the new descriptor of visual clarity (*C*). According to the higher illuminance levels, the weight of the rods equalled zero. The weight of the S-cones equalled 82% while the weight of the ipRGC channel equalled 12%.

The new descriptor of brightness (*B*) was used to predict the visually matching mesopic stimuli. The ratios of the B values of the matching stimuli (B_{test}/B_{ref}) were closer to unity (goodness criterion of predicting of a visual brightness match) than the ratios of the luminance values of the matching stimuli.

At the lowest mesopic luminance level (0.1 cd/m^2), (B_{test}/B_{ref}) ratios ranged between 0.93 and 1.06 instead of the broader range of the luminance ratios between 0.82 and 1.51. The ratio of the brightness predictor should equal unity for a perfect model. The 95% confidence intervals of the luminance ratios ranged between 0.05 and 0.10 at this luminance level.

At the intermediate mesopic luminance level (0.5 cd/m^2), (B_{test}/B_{ref}) ratios ranged between 0.90 and 1.05 instead of the broader range of the luminance ratios between 0.85 and 1.19. The 95% confidence intervals of the luminance ratios ranged between 0.04 and 0.10 at this luminance level.

At the highest investigated mesopic luminance level (1.5 cd/m^2), (B_{test}/B_{ref}) ratios ranged between 0.81 and 1.04 instead of the somewhat broader range of the luminance ratios between 0.79 and 1.06. The 95% confidence intervals of the luminance ratios ranged between 0.05 and 0.08 at this luminance level.

4. Conclusions

Previously obtained visual clarity and mesopic brightness datasets were re-analysed by the use of two new descriptor quantities based on the luminance, S-cone, ipRGC, rod and L-cone minus M-cone signals of the stimuli. For visual clarity, a good fit of the model to the visual data was obtained. For mesopic brightness, the model provided a better prediction than the (photopic) luminance ratios and other brightness models from literature. Further brightness matching experiments with highly variable LED spectra are currently underway.

PO32 (PP46)

PUPILLARY LIGHT REFLEX AND RECEPTIVE FIELD CALCULATION OF VISUAL DISCOMFORT FOR DIFFERENT SPATIAL FREQUENCIES AND LUMINANCE STEPS

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Abstract

1. Motivation, specific objective

Discomfort glare is defined as glare that causes discomfort without necessarily impairing the vision of objects. Researchers have been attempting to quantify the amount of visual discomfort ever since the beginning of the previous century. Some of the physiological mechanisms like the receptive field mechanism and the pupillary light reflex are known for decades. The spatial frequency and luminance distribution within the luminaire affects the perceived visual comfort. Traditional glare metrics are under discussion since they lack physiological or psychological justification and often ignore any non-uniformities in the luminance distribution.

The extended receptive field model links the luminance distribution to the neural response. In a previous study, a receptive field model was proposed as a possible alternative for traditional glare metrics. The model is extended with the pupillary light reflex. By taking the pupil area into account, a high resolution luminance map is converted to a retinal illuminance. Visual discomfort is calculated by applying the extended model on the retinal illuminance distribution. A forced choice paired comparison experiment involving non-uniform stimuli with different spatial frequencies and luminance steps illustrates the performance of the receptive field model.

2. Methods

The eye images an object plane characterized by a luminance distribution on the retina. The retinal illuminance is proportional to the pupil area and is regulated by the pupillary light reflex. In lit environments, a constriction of the iris reduces the pupil area and limits the incident light. In dimmed settings, an iris dilation increases the pupil area maximizing the retinal illuminance. An eye photoreceptor converts light into an electrical signal. In the centre-surround receptive field mechanism, the signal of one or more central photoreceptors is directly transmitted to a bipolar cell. A horizontal cell parallel to the retina connects several surround photoreceptors and relays an indirect signal to the bipolar cell. A ganglion cell combines the direct and indirect bipolar signals and relays a pulsed signal train to the brain. In an ON-centre OFF-surround receptive field, the ganglion cell is excited by the centre but inhibited by the surround signal and vice versa for an OFF-centre ON-surround. At a sharp dark-light edge, the surround (or centre) is not entirely illuminated resulting in a net signal. Receptive fields consequently act as an edge filter. The convolution of a retinal illuminance map and a centre-surround receptive field kernel produces a brain signal map representing the luminaire's visual neural response.

In a paired comparison experiment, 9 non-uniform stimuli were rear projected on a diffusor screen creating a Lambertian light source. The stimuli were composed of light emitting squares on a background. DALI controlled wall washers generated a fixed room background luminance level of 45 cd/m². In two tests, a constant stimulus surface of 33.5 cm by 34 cm observed from 3 m with an average luminance level of 200 cd/m² was maintained. In a first frequency test, if the number of squares was increased, the luminous surface per square and the spatial separation between squares was decreased. In a second test for luminance differences, the stimulus background was increased while the luminance level of the light emitting patches was decreased. 20 observers were asked to indicate the most visual discomforting stimulus in a full paired comparison forced choice experiment. Luminance maps were measured with an LMK luminance camera. A generalised linear model produced a z-score on an interval scale and a standard error for visual discomfort for each stimulus.

3. Results

A coefficient of determination of 0.90 between the observed paired comparison assessment and the extended receptive field value is obtained. For the first test, if the number of light patches is increased, the total amount of edges increases and the spatial separation decreases. The increase in the amount of edges initially results in an increase in visual discomfort. When the spatial separation of the light patches reaches the spatial eye resolving power, the light-dark edges become less clear. The human eye will not resolve any edges and the visual discomfort saturates. If the spatial separation of the light patches is further decreased, the stimuli will appear more uniform and the observed visual discomfort starts to decrease. The receptive field model also returns an initial increase when the amount of edges increases. As the spatial separation of the stimuli reaches the spatial centre-surround receptive field retinal dimension, the calculated value saturates. The model is less sensitive to the high frequency edges resulting in lower calculated values. For the second test, by decreasing the light-dark luminance step, the luminaire will appear as more uniform. In agreement with the extended receptive field model, the observer visual discomfort assessment decreases for increasing stimulus uniformity.

4. Conclusions

The pupillary light reflex is included in the extended receptive field model. Starting from the retinal illuminance distribution, the receptive field model successfully calculates visual discomfort for non-uniform stimuli varying in spatial frequency and luminance step. With a coefficient of determination of 0.90, the model is a promising candidate to replace current failing traditional discomfort glare indices.

PO33

INFLUENCE OF CROSSTALK ON SPECTRAL RESPONSIVITY OF COLOUR IMAGE SENSORS

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Abstract

1. Motivation, specific objective

Image quality of pictures taken by a digital camera is greatly affected by the performance of the image sensor inside the camera. The image sensor is a photoelectric transducer converting the optical image produced by the lens optics into the two-dimensional data, which are digitized from the photocurrent signals of the pixel array.

Crosstalk of image sensors is referred to as the phenomenon that the photocurrent signals from each pixel are interfered by the adjacent pixels. The crosstalk can reduce the separation rate by location, and hence deteriorate the resolution or sharpness of the image. For colour image sensors, the crosstalk affects not only the spatial resolution but also the colour characteristics, because the pixels are covered with different colour transmission filters depending on their location. The signal for each colour channel can be blended with other channels by crosstalk so that the colour purity is diluted.

Several methods are suggested to measure the crosstalk of image sensors, but the influence of crosstalk on the colour characteristics of the image could not be directly evaluated. In this work, we demonstrate that the crosstalk of a colour image sensor can be tested by measuring its spectral responsivity at different beam incidence conditions.

2. Methods

For measurement of spectral responsivity of an image sensor, the monochromatic beam is delivered on the sensor under test and its image is recorded as a function of wavelength. In the case of a colour image sensor consisting of three or four different types of pixels, the measured spectral responsivity shows the dependence on the incidence angle of the beam. By measuring the spectral responsivity with various beam incidence conditions, the magnitude and influence of crosstalk on the colour characteristics can be analysed. In the experiment, we used a collimated beam at different incidence angle as well as a diffuse illumination from an integrating sphere. The wavelength is varied from 350 nm to 950 nm by using a grating monochromator with a tungsten-halogen lamp.

We tested two types of Si-based CMOS image sensor: one type has the array of 712 × 512 (RGB) pixels with a pixel size of 5.6 μm × 5.6 μm, and another has the array of 1296 × 736 pixels with a pixel size of 3 μm × 3 μm.

3. Results

We first take a look at the difference between the collimated beam and the diffuse illumination, which immediately shows the magnitude of the crosstalk for the image sensor under test. Then, we measured the sensor with the collimated beam at several different incidence angles to verify the proportionality of the change of the spectral responsivity to the incidence angle. From these results and from the geometric arrangement of the pixels, we can explain that the dependence of spectral responsivity is related to the crosstalk. We also confirm that the dependence of spectral responsivity on the beam incidence condition becomes smaller when we measure an image sensor designed for lower crosstalk.

4. Conclusions

The experimental results present that the spectral responsivity measurement provides a practical and effective method to test the crosstalk property of colour image sensors and to directly evaluate the influence of the crosstalk on the colour characteristics of the sensor.

PO34

AN EVALUATION OF THE CHARACTERISTICS OF CONNECTED LED LAMPS

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Abstract

1. Motivation, specific objective

After incandescent lamp invention, lighting has been part of our lives. Lighting is celebrating a new paradigm with the introduction of LED technology. Now, LED lighting is beyond the scope of classical category and creates a variety of value-added situation such as motional lighting and connected lighting. Eco-friendly policy and implementation of energy saving and environmental regulatory system, such as reducing greenhouse gas emissions around the world became one of the most important issues. Thus the potential for energy saving of lighting systems get more attentions.

Moreover, connected LED lighting based on human centric lighting is being actively developed by freely adjusting the colour temperature and coordinates according to the time or the surrounding environment. Thus we can expect new level of lighting to interact with the human senses. After 2010, various types of connected LED lamps have been on the lighting market. But due to lack of related contents, connected LED lamps started getting great interests only in recent years. And these interests are led to the standardization activities naturally. However, there is no international standard for such connected lighting for the time being. IEC (International Electro-technical Commission) recognized the importance and need for such connected lighting and established a new working group to deal such a standard in last years. Now, advisory group 4 of IEC TC34 acts very actively to find consensus about standards for lighting systems.

In In this paper, we have investigated the characteristics of various types connected LED lamps then propose some kinds of performance requirements based on the testing results.

2. Methods

Five kinds of connected LED lamps were tested to find their electrical and optical characteristics. For example, we changed the colour temperature, colour coordinates and the lighting outputs by controlling application software which installed on android system based cell phone. Then the electrical and optical characteristics such as luminous efficacy, power factor, SDCM(standard deviation colour matching) and standby mode power were measured according to each operating conditions.

3. Results

Some kinds of connected LED lamps still have good luminous efficacy, power factor, SDCM indices with various dimming and CCT settings. However, electrical and optical characteristics of certain connected LED lamps degraded rapidly with different dimming and CCT settings.

4. Conclusions

We proposed performance requirements for connected LED lamps based on the testing results based on our experiments.

PO35

HIGH DYNAMIC RANGE IMAGING LUMINANCE MEASURING DEVICE (HDR-ILMD) AND APPLICATIONS IN MOTION

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Abstract

Performance requirements of road and tunnel lighting are well defined in CIE or CEN documents. These documents specify a set of photometric requirements aiming at the visual needs of road users. The main lighting criteria are based on the road surface luminance of the carriageway (average luminance, overall uniformity and longitudinal uniformity) and on the potentially glare sources luminance (Threshold Increment calculation).

The metrology to verify that the actual installation fits the requirements is relied essentially on static measurements with a spot-luminancemeter. These are mainly established for the reception of new installations, but cannot be applied for the diagnostic of a whole network. Dynamic measurements have thus been developed and CIE has published a document on these devices. They are adapted to the diagnostic on carriageways over a large territory or the whole length of a tunnel.

In order to cover the large range of luminance perceived by a driver's eye and to obtain an imaging system able to measure in motion, we developed a High Dynamic Range (HDR) imaging Luminance measuring device (ILMD) based on four synchronous cameras. A calibration step is needed to obtain a photometric calibration as well as a geometric calibration. The photometric calibration leads to a reachable luminance range from 0.1 cd/m² to 100 000 cd/m² and let suppose measurements on the road and in the sources at the same time in the same image. The geometric calibration is derived from the stereoscopic one and permits to retrieve intrinsec parameters of each camera as well as extrinsec parameters. Thus images can be rectified to facilitate the HDR construction because the major default of such a system is the algorithm's complexity to retrieve the same pixel (imaging the same object) in the four cameras. Indeed it is impossible to superpose exactly (pixel by pixel) the four images produced with different point of view.

This system is used to diagnose road and tunnel lighting performance in accordance with CIE recommendations, EN 13201 standard requirements for road lighting and FD CEN/CR 14380 standard requirements for tunnel lighting. Moreover threshold increment calculations can be carried out from HDR luminance images along a tunnel or a roadway.

PO36

UNIFORMITY MEASUREMENT METHOD FOR CURVED DISPLAY USING IMAGE LUMINANCE MEASURING DEVICE

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Abstract

Due to display market diversification, conventional flat panel displays are being developed in curved and flexible. The performance of the display evaluation is evaluated not only by the design elements but also by the functional elements (luminance uniformity, resolution, contrast ratio and chromaticity)

In FPD, typically use the point-type 9-point measurement as an international standard. Also in Curved display, IEC-TS-62715 proposes a method of optical axis is fixed and divided into 9-spots to evaluate the luminance and uniformity.

A curved display is designed to allow the same distance between the viewer and every part of the screen, unlike the conventional flat panel display, the distance from the eyes of the viewer to the center of the screen is the same with that to the sides of the screen. However, the edge of the display is a critical area not only the front surface. It is not a good fit to evaluate this area with spot-type device.

In this paper, we propose a method of evaluating curved display uniformity using each pixel luminance value measured by ILMD (image luminance measuring device) which Benchmarked from flat panel display evaluation method from DFF (German Flat panel display forum).

PO37

PHOSPHOR CONVERTED LASER DIODE LIGHT SOURCE FOR ENDOSCOPIC DIAGNOSTICS

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Abstract

1. Motivation

With the technological development minimally-invasive surgery (MIS) allows obtaining qualitative diagnostics offering also small incisions, less pain, low risk of infection, short hospital stay, quick recovery time, less scarring and reduced blood loss. However, during MIS the surgeon does not have a direct access to the area under investigation and is highly dependent on the quality of the imaging system. Together with the optical system the light source of the endoscope, as a standard for MIS, is the key to successful diagnostics. The light is generated by xenon, halogen or nowadays also by LED-lamps or supercontinuum laser in an external device located close to the surgical field. A fiber-optic cable transmits the light to the endoscope through which further fibers transfer it to the surgical site. Because of the highly attenuative nature of visible light in biological tissue and low light coupling efficiency in endoscopes, enhancement of the light delivery system is a crucial factor to improve diagnostics itself. The most common method is using xenon lamp as a light source, however, this method has a number of limitations, including inefficiency. Arc-lamps are very inefficient at converting electrical power into light and must be remotely mounted to allow excess heat to be dissipated safely. This also means that the light must be coupled from the source to the operative field by combination of liquid light guides and fiber optics, resulting in high light loss. A relatively new approach in endoscope illumination is white phosphor converted light emitting diode (PC-LED) mounted at the distal end of a steel rod. This light source offers the advantages of a more compact and ergonomic design, lower cost, and more uniform illumination in comparison with current technological standard, as well as providing the possibility of shadow formation within the operative field. Among the main disadvantages is “efficiency droop” at high input current densities, poor coupling efficiency to optical fibers and phosphors material at the distal end of the endoscope, that will produce additional heat generation and could also be toxic.

2. Methods

The alternative light delivery system we are demonstrating is aiming to solve the above described drawbacks. The technology is comparable to white PC-LED constructed using a blue LED and phosphor material, which absorbs part of the blue light and emits light with a lower frequency, resulting in white light being emitted from the phosphor. Instead of using LED we replace it with an InGaN blue laser diode together with Ce:LuAG and Eu-doped nitride phosphors, so the problem with droop in efficiency can be solved. One of the main advantages of the phosphor converted laser diode (PC-LD) illuminating source we are showing is phosphor material placement in a way that the white light is obtained at the proximal end of the endoscope and only after this light is coupled directly into the optical fiber by means of off-axis parabolic mirrors. When delivering light in this way we can give a solution to high temperature of the endoscope tip, so there is no overheating, and moreover, we can avoid having toxic element inside of the patient’s body. Another great advantage is the opportunity to couple light from the PC-LD into 200 μm optical fibers that will allow reduction of the overall size of the endoscope that will eventually make the diagnostics less invasive.

3. Results

In order to provide light sources for endoscopy and on-site testing of the light source, we are developing a portable endoscope prototype. The development also involves designing optics for optimizing the light extraction efficiency and guiding of light to the area of interest. Highly focused white light beam spot from the PC-LD (80×80 μm) have already been achieved and 60% coupling efficiency to a 200 μm fiber of the generated white light has been obtained proving that the described

above light source is suitable for endoscopy illumination. Limiting factors are also investigated through the detailed spectral analysis, among which saturation effects in ceramic phosphors are the key factor to the high-luminance PC-LD. When focusing a laser diode beam into the phosphors plate in order to achieve the smallest possible spot size for the further efficient white light coupling into the optical fiber (ø 200 µm), saturation level of phosphor is achieved at relatively low input power. This limits obtaining both high-luminance illumination and correlated colour temperature that doesn't exceed range where light can be perceived by the human eye as white.

4. Conclusions

Light sources like xenon and halogen are contemporary architecture of endoscopy systems for MIS, though they have plenty of disadvantages including low efficiency and non-uniform illumination. In recent times, another approach for endoscopic illumination, based on white LED technology has been developed, but it also have several limitations like "efficiency droop" with increasing input current densities, high temperature on the tip of the endoscope, and toxic material used at the distal end of the endoscope. Recently, supercontinuum lasers are also being under investigation for MIS, but due to the very high price, they are not widely used. With the phosphor converted laser diode light source we are aiming to provide a solution to many of the abovementioned disadvantages. Saturation in ceramic phosphors becomes a major limiting factor when light with high intensity hits the phosphor plate, but when varying intensity of the laser beam and thickness of the downconverting material this problem can be solved. In this connection, a novel endoscopic illumination source, based on blue laser diode and Ce:LuAG and Eu-doped nitride phosphor, that can offer higher efficiency, much higher coupling efficiency, better temperature control and no toxicity for the patient will be presented.

PO38

HOW WOULD A CIE L STANDARD ILLUMINANT AFFECT MEASUREMENT UNCERTAINTY OF FIELD MEASUREMENTS

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Abstract

Motivation for the research

Recent very rapid and successful development of solid state light sources especially light emitted diodes (LEDs) brought LEDs in the leading position in road lighting as well as in indoor lighting applications. Growing share of LEDs between used light sources made also CIE to start thinking about introducing a new standard illuminant L, which would be based on selected LED or LEDs and could be used for calibration of illuminance and luminance meters.

The aim of this new calibration source is to reduce the measurement uncertainty for the measurements where illuminance (luminance) meters, calibrated with CIE standard illuminant A are used to measure the lighting conditions where LEDs are used.

Of course the measurement uncertainty can always be reduced by calculating and applying spectral mismatch correction factor but for this the relative spectral responsivity of the photometer and the relative spectral power distributions (SPDs) of the light source to be measured need to be known.

In field measurements of illuminance or luminance, which are perform e.g. to check the compliance of lighting installation with standards like EN 12464 for lighting of workplaces or EN 13201 for road lighting installations, both relative spectral responsivity of the photometer and the relative SPD of the light source are not know so the spectral mismatch correction factor cannot be applied. Beside that the technician who carries out measurement in most cases does not have enough knowledge to perform this mismatch correction. So the idea behind the CIE standard illuminant L is to reduce the measurement uncertainty in such cases with calibration of instruments with a standard illuminant which SPD would be much closer to the one of the measured light source.

Unfortunately there is not only one LED light source but there are many with different SPDs so the one used for calibration will not necessary be the same as the one of the measured source. To find out the influence of SPDs of calibration and measured light source on measurement uncertainty at field measurements, a research was performed in our laboratory and the results will be presented in scope of this paper.

Used methods

At the beginning two sets of data were collected: spectral responses of different illuminance and luminance meters used for field measurements and SPDs of different solid state (LED) and other light sources as incandescent lamps, tubular and compact fluorescent lamps and HID lamps.

Set of considered meters (spectral responses) contained some class L devices from our laboratory with well known spectral responsivity very close to the V(λ) but also some more commonly used meters of class A and B and even class C for field measurements with different spectral responses. We included also some intentionally degraded spectral responses as well as spectral responses of different photo diodes to find out how much spectral response of the instrument, which is not so close to the V(λ), actually influences final measurement uncertainty. All used spectral responses were obtained from the literature of the producers.

We were pursuing the same objective when we were choosing light sources and their SPDs to be included into this study. Not only SPDs of different white and monochromatic LEDs were used but also SPDs of different "classical" light sources used in indoor and outdoor lighting including incandescent lamp. Some of them were used as calibration light sources and all of them were used as measured light sources. Most of the used SPDs were obtained with measurements in our laboratory and some of them were taken from literature.

With the obtained data spectral mismatch correction factors were calculated for a large number of combinations of relative spectral responsivity functions, relative spectral power distribution of calibration light source and relative spectral power distribution of source to be measured.

Results

Results show that as expected most of the calculated spectral mismatch correction factors are very close to the value 1. The differences are in most cases smaller than 5 % and lay around 2 % or 3 %. This is valid for the class L instruments as well as for instruments from lower classes which usually means also larger difference between their spectral responsivity and the V(λ) function.

But in some cases spectral mismatch correction factors may significantly different from 1. This might happened if spectral power distributions of used calibration source and measured source are very different or if relative spectral responsivity function of the instrument significantly differ from V(λ) function at a specific region. The worst results were obtained when a "naked" silicon photo diode was used as a measurement instrument. In such a case the spectral mismatch correction factors might be lower than 0,6 when measuring e.g. a low pressure sodium lamp after the calibration with cold white LED.

Conclusions

Results show that when taking into consideration other sources of measurement uncertainty at field measurements the influence of used calibration light source might not be so significant. Of course it is possible to decrease measurement uncertainty with selection of proper calibration light source based on measured light source but illuminance and luminance meters used for field measurements are calibrated only once every few years and only with one calibration source.

Taking into consideration also many different light sources used in indoor and outdoor lighting today (and in next years) the question arises if the calibration of measurement instruments with the CIE L standard illuminant is really the best choice. And if so, which LED should be used for its realization: cold white one, warm white one or something in-between. The question is also how much would pre-calculate tables with spectral mismatch correction factors help obtain more accurate results of field measurements.

As this is still ongoing research we will also try to answer these and some other open question in our final paper.

PO39

AUTOMATED MEASUREMENT OF LED DIMMING CHARACTERISTICS

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Abstract

1. Motivation

LED dimming characteristics differ significantly from conventional light sources. Especially in the context of light management systems and a higher degree of digitalization, an accurate description of energy consumption and efficacy at different levels of dimming is necessary. Dimming characteristics are so far not provided by luminaire manufacturers but represent an important factor in the product documentation process.

2. Setting and materials

An automated approach was used to accurately measure the dimming characteristics of more than 40 different LED-luminaires by various manufacturers.

The measurements took place in the Ulbricht-sphere at TU Berlin (diameter:3m) with a stabilized power supply system; A photometer was used to determine the luminous flux at different dimming levels; power consumption was recorded.

To achieve an automated measurement, a control algorithm “dimCurve” was developed. Using 5% steps (DALI), the luminaire was started at 100% connected power. To account for thermal effects on flux output, one measurement was taken every minute as recommended in EN 13032-4:2015 Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 4: LED lamps, modules and luminaires.

The measurement was continued until the following condition was fulfilled: if during 15 minutes the flux read-out did not change by more than 0.5%, the measurement was recorded and the next dimming step was triggered.

The resulting pairs (power and resulting flux) were then shown as spreadsheet and graph for further analysis.

3. Results

Dimming characteristics varied extensively throughout the measurements, highly depending on the type of luminaire used. Compared to a standardized T8 dimming curve, all LED-luminaires achieved a dimming characteristics, that showed significant advantages in relative luminous efficacy at all regarded levels of dimming. Interestingly, some luminaires showed a dimming curve, where relative efficacy increased throughout the first 20%-30% of the gradual dimming.

4. Conclusions

In contrast to fluorescent luminaires, LED fixtures showed no consistent dimming characteristics. Results highly depended on the shape, type and thermal management solution of the measured fixture. The obtained differences to conventional luminaires supports the hypothesis, that LED with light management systems contribute to energy savings in buildings even when absolute luminous efficacies are not taken into account. To ensure meaningful building energy calculations and to accurately describe luminaire properties as an important decision support, dimming characteristics should be included in data sheets or technical documentations as well as standards regarding lighting energy efficiency.

PO40

CALIBRATION OF LUMINANCE METERS

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Abstract

1. Motivation, specific objective

Luminance (unit in candela per meter square, cd m^{-2}) is a fundamental photometric quantity which measures the radiation emitted in a given direction from a given area of a source. In layman's term, luminance describes the visual attribute of 'brightness'. It is commonly used to characterize the emission or reflection from a flat diffused surface and have many applications in the field of testing and certification, which in turn provides calibration services to the aerospace industry, construction industry, digital filming industry, display and lighting industry, etc.

To support the calibration demands from the local testing and certification industry, the Standards and Calibration Laboratory (SCL) of Hong Kong has recently developed the calibration service of luminance meters. A detector based calibration system is developed which is simpler than a traditional source based calibration system that used a standard light source as the reference standard. The detector based reference standard is portable and can be easily transported to other laboratories for comparison and proficiency testing.

2. Methods

At the SCL, the luminance of a light source is determined from the area of the source aperture, the illuminance measured by the reference photometer and the effective distance between the aperture of the source and the reference photometer. The effective distance between the aperture planes of the source and the reference photometer includes the radius of the photometer aperture, the radius of the source and the physical distance between the two apertures. The luminance meter under test is placed along the optical path, and its readings are calibrated against the reference luminance value. The details of the test setup are described below:

The uniform light source is operated at 2856 K with a large integrating sphere and several satellite spheres. The large 12-inch sphere is being irradiated by two quartz halogen lamps and by two 3-inch satellite spheres with quartz halogen lamp. Each satellite sphere has a shutter with electronic adjustable iris to control the output irradiation level. During measurement, the directly connected quartz lamps are used to control the coarse luminance level, while the satellite spheres with electronic adjustable iris can be used to fine tune the luminance level. The large sphere is equipped with a monitor detector and a precision exit port aperture of 40 mm. The reference photometer with $V(\lambda)$ mismatch error of less than 0.8 % is placed on a movable carrier. The distance between the light source and the photometer is measured by a laser distance meter with uncertainty of 0.55 mm for distance up to 3 m. The entire 2 meter photometric bench is under light shield enclosure and screens are placed along the optical path to minimise stray light effect. The sphere source is allowed to stabilize for 45 minutes before calibration to minimize the drift of the monitor detector. A colorimeter is used to monitor the colour temperature of the optical signal.

3. Results

The developed calibration range for luminance is from 50 cd m^{-2} to 3000 cd m^{-2}. The measurement model was validated by GUM framework in accordance with the JCGM 100:2008 "Evaluation of measurement data – "Guide to the expression of uncertainty in measurement" and JCGM 101:2008 "Supplement 1 – Propagation of distributions using a Monte Carlo method". The measurement uncertainty components are extensively evaluated, which included the calibration uncertainty, drift, resolution and alignment error of the reference photometer, accuracy of the distance measurement, stability of the light source, stray light effect and accuracy of the source aperture area. The best measurement uncertainty is estimated as 1.5%. This measurement uncertainty and the range of measurements are considered adequate for most measurement applications.

4. Conclusions

The calibration system of luminance is setup at the SCL. The calibration range for luminance is from 50 cd m^{-2} to 3000 cd m^{-2}. The best measurement uncertainty is estimated as 1.5%, which could support the demands in luminance meter calibration from the testing and certification industry in Hong Kong.

PO41

MEASUREMENT OF REGULAR SPECTRAL TRANSMITTANCE OF OPTICAL FILTERS

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Abstract

1. Motivation, specific objective

In radiometric measurements, optical filters are used to attenuate the intensity of light over a specified range of wavelengths. An optical beam will be partially absorbed, reflected and transmitted when it reaches an optical filter composed of materials with different properties. In practice, optical filters are widely used as reference standards to calibrate chemical analysis instruments, such as spectrophotometers which measure the amount of light at particular wavelength that is absorbed by a specimen solution. The transmittance at a particular wavelength of the specimen solution in general varies directly with its content concentration. The term “regular spectral transmittance” is defined as the intensity ratio of the transmitted optical beam to the incident optical beam across a range of spectral wavelength.

Traceable calibration of regular spectral transmittance of optical filters is particularly important for the testing and certification industry. To support the calibration demands from the local industries, the Standards and Calibration Laboratory (SCL) of Hong Kong has recently developed this calibration service. Instead of using a reference transmittance spectrophotometer (RTS) as the reference instrument, the laboratory’s reference 3-element trap detector and a double monochromator are used as the reference system to measure the ratio of the transmitted optical signal to the incident optical signal. The use of trap detector could effectively minimise the error due to multiple reflection than using a regular detector, as the reflected signal from the detector is significantly weaker after multiple internal reflection inside the trap detector.

2. Methods

At the SCL, the calibration is performed at (23±1) °C with the collimated monochromatic beam incident perpendicularly to the front surface and at the centre of the optical filter under test. The regular spectral transmittance is calibrated by comparing the transmitted monochromatic beam from the optical filter under test to the direct monochromatic beam without passing through the optical filter. The details of the test setup are described below:

A quartz-tungsten-halogen lamp is used as the light source, and the light beam is focused to the entrance of the double monochromator using parabolic mirrors. The required wavelength of the light beam is selected by a double monochromator with grating of 600 lines/mm blazed at 500 nm and with bandwidth estimated to be 5 nm. Stray light effect is eliminated by comparing the light and dark signals by controlling the opening of a shutter at the entrance of the double monochromator. The output optical beam from the double monochromator is then collimated by a parabolic mirror to a square flat mirror. The reflected beam from the flat mirror then illuminates a variable aperture which is used to control the size of the beam. This collimated light beam then perpendicularly illuminates the surface of the optical filter under test. The transmitted beam from the filter is then focused to a 3-element trap detector by a parabolic mirror. As the optical filter under test is set up on an X-Y translation stage, the optical filter under test can be removed from the collimated light beam path for the trap detector to measure the incident flux.

3. Results

The spectral range of this calibration service is from 400 nm to 1000 nm with transmittance range from 0.01 to 1. The measurement model was validated by GUM framework in accordance with the JCGM 100:2008 “Evaluation of measurement data – “Guide to the expression of uncertainty in measurement” and JCGM 101:2008 “Supplement 1 – Propagation of distributions using a Monte Carlo method”.

The measurement uncertainty components are extensively evaluated, which include the digital voltmeter (DVM) measurement uncertainty of the detector's amplifier output, the wavelength scale error of the double monochromator, the non-linearity of the current-to-voltage amplifier of the DVM, the non-linearity of trap detector by using double-aperture technique, the stray light effect of the monochromator and the polarization effect. The best expanded measurement uncertainty for the spectral regular transmittance is estimated as 0.5 %. For filters with high rate of change of transmittance per wavelength (i.e. not a spectral flat material), the uncertainty due to wavelength scale error in the double monochromator will be dominated.

4. Conclusions

The calibration system of regular spectral transmittance of optical filters is setup at the SCL. The calibration range for transmittance is from 0.01 to 1 for optical spectral range from 400 nm to 1000 nm. The best measurement uncertainty is estimated as 0.5%, which could support the demands in optical filter calibration from the testing and certification industry in Hong Kong.

PO42

ON-SITE EVALUATION OF PHOTOBIOLOGICAL SAFETY AND LIGHTING HEALTHY

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Abstract

There is a growing need for better lighting environment nowadays. The traditional indicators, e.g. Correlated Colour Temperature (CCT) and illuminance distribution, are not enough to evaluate lighting quality comprehensively, and people now are paying more attention to lighting safety and health. The photobiological safety of lighting products, especially levels of blue light hazard and UV hazard have been specified in IEC 60598.1. Besides, CIE D1, D2, D3 and D6 have established a new JTC9 to define action spectra and metrics to quantify the ocular radiation input from those photoreceptors involved in non-visual effects. Furthermore, CIE built a JTC7 focusing on building a new glare index for the popular LED lightings to ensure a comfortable and safe environment.

The above mentioned lighting safety and health evaluations raise higher requirements for measurement device. Illuminance meter can hardly meet the challenge and luminance camera and spectroradiometer should be applied. The former is mainly involved in glare evaluation and the latter is for various indicators by integrating spectral weighting functions for different non-visual effects with Spectral Power Distribution (SPD). Considering portability and convenience of instruments for on-site measurement, the present paper proposed a speed measurement solution for the related parameters. The solution integrated spectral radiance and luminance distribution measurements at one time, and the measured luminance distribution can be automatically corrected to further improve the accuracy. The details of the solution and the measurement process, especially for the blue light hazard and glare evaluation, will be described in the full paper. Note that the traditional glare measurement using an imaging camera equipped with eye-fish lens suffers from non-uniformity and distortion, and this solution can solve the problem effectively.

PO43

REFERENCE UV LED SOURCES

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Abstract

Nowadays, ultraviolet (UV) sources are widely used in a numerous applications: chemical identification, polygraphy and photopolymerization, medicine and defectoscopy, etc. Safety, efficiency and quality of work with using of UV sources depend considerably on quality of UV metrology. Therefore, development and improvement of reference, measuring and methodical base for UV spectral region is one of the most important tasks of optical radiometry. UV measurement assurance has a number of substantial problems. Lamp-based UV sources (deuterium, mercury or xenon) used at now as secondary standard cannot provide sufficiently high accuracy of measure UV sources optical characteristics and calibration of measurement tools. The greatest accuracy of measurements can be ensured by using radiation sources having similar characteristics (spectral, energetic, spatial). In this connection, development of light emitting diode (LED)-based reference UV sources is one of the possible ways of increasing of UV measurements accuracy.

In B.I. Stepanov Institute of Physics of the NAS of Belarus two types of reference UV LED sources based on hemispherical and cylindrical diffuser were developed. Reference hemispherical LED's source (RHLEDS) includes three series-connected LED Nichia NC4U133A emitting at wavelength of ~ 364-367 nm. Reference cylindrical LED's (RCLEDS) source includes one LED Nichia NCB133A or NCB134. The interior surface of RHLEDS and RHLEDS sources are coated by barium sulfate and Spectralon respectively. A temperature controller, Peltier and thermistor sensor were used to stabilize temperature of the RHLEDS and RCLEDS sources.

In the paper, optical characteristics of the RHLEDS and RCLEDS sources are presented. The measurement of optical characteristics of the UV Reference LED sources were carried out using setup which was developed and constructed in B.I. Stepanov Institute of Physics of the NAS of Belarus.

The main metrological characteristics of the measurement setup were determined: the spectral range of the measurement of the radiation power is from 200 to 1100 nm; the deviation angles in two perpendicular planes are ± 110° and 360°; the relative expanded uncertainty of the reproduction range of the rotation angle is 0.08 %; the relative combined uncertainty of measurement of the spatial distribution of luminous intensity is less than 1.04 %; the relative combined uncertainty of LED spectral irradiance measurement in the spectral range from 250 to 900 nm is less than 2.8 %; the range of measurement of the LED spectral irradiance is from 10^2 to 10^{10} $W \cdot m^3$; the relative combined uncertainty of the LED spectral radiance measurement in spectral range from 250 to 500 nm is less than 3.5 %; the range of measurement of the LED spectral radiance is from 10^2 to 10^{12} $W \cdot m^3 sr^{-1}$.

Advantages and disadvantages of different types of references LED's UV sources are discussed. It should be noted that there is no spectral shift in the emission spectra of the RHLEDS at any radiation angles, which is an advantage of this source. It is shown that RCLEDS source can be used as a reference in the A, B, C UV and visible spectral ranges depending on LED used. Errors of measurements of radiometric characteristics of UV reference LED sources caused by alignment, working time, temperature instability and injection current were considered.

PO44

DEVELOPMENT OF AN INTEGRATING SPHERE LIGHT SOURCE OF MULTIPLE LIGHTING ELEMENTS FOR GENERATION OF WIDE DYNAMIC RANGE OF LUMINANCE

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Abstract

1. Motivation, specific objective

At KRISS, one of the major services (having many customers) provided in the field of photometry is of luminance meters. We currently provide the luminance calibration service at the range of (1 ~ 3000) cd/m^2 (or nt) using a QTH (quartz-tungsten-halogen) lamp-based integrating sphere light source whose correlated colour temperature is about 2860 K. The integrating sphere light source has a computer controlled variable iris aperture to control output luminance level and a monitor photometer whose signal is scaled to actual luminance value. Recently, customers have asked for extension of the calibration range down to 0.001 nt and up to 100 000 nt. By this motivation, we have decided to make a new integrating sphere light source which is capable of generating a wide dynamic range of luminance (0.001 ~ 100 000) nt in order to extend our calibration service.

2. Methods

We have drawn up 3 performance requirements for the new integrating light source. First, It should be capable of generating the luminance level of (0.001 ~ 100 000) nt. Secondly, it should be capable of generating multiple colour of light using multiple LEDs of different colours and multiple QTH lamps of different correlated colour temperatures, which enable us to apply it to colorimeter calibration, spectral radiance meter calibration as well. Thirdly, it should have a monitor photometer of matched FOV (field of view) to DUT luminance meter's whose output has to be scale to output luminance level of (0.001 ~ 100 000) nt.

Based on the requirements, we have designed the integrating sphere light source: an integrating sphere of 500 mm, having an output window port of 100 mm, 8 light source ports of 40 mm, 2 detector ports of 25 mm (every dimension is in diameter). Note that its luminance throughput is estimated to 10.35 nt/lm from this sphere configuration. For lighting elements, 4 kinds of coloured LEDs (R: 270 lm, G: 440 lm, B: 100 lm, Y: 305 lm), 3 kinds of white LEDs (6500 K: 9600 lm, 3000 K: 8500 lm, 2700 K: 6430 lm), and 2 QTH lamps (2860 K: 800 lm, 3100 K: 1500 lm) are installed on the integrating sphere. To monitor output luminance, a 3.6 mm × 3.6 mm photometer is used, of which luminance responsivity and NEP (noise equivalent optical power) amount to 66 pA/nt and 4 fW (13 μnt), respectively.

3. Results

One QTH lamp is operated in a fixed DC current corresponding to 2860 K of correlated colour temperature which is the standard condition for luminance meter calibration. The other QTH lamp is also operated in another fixed DC current corresponding to 3100 K of correlated colour temperature, which is more favourable condition for spectro-radiometer calibration since it gives more intense spectral radiance at less than 400 nm compared to the QTH of 2860 K. All the LEDs can be dimmable in principle. For example, the two white LED of 6500 K can generate nearly zero nt to 2× 9600 lm × 10.35 nt/lm ~ 200 000 nt by simply adjusting feeding electrical current. Furthermore, the LED pair can be used to test linearity of a DUT luminance meter since they can easily form the flux addition method. As it has many kinds of coloured LEDs, it can be used as a chromaticity standard source.

4. Conclusions

Based on the designed configuration and operation scheme, we have made the multi-purpose integrating sphere light source. All the LEDs are thermo-electrically temperature-controlled at 35°C. We will characterise its optical performance such as luminance, chromaticity, their uniformity, dynamic range, etc. for various operation condition including calibration and linearity test of the monitor photometer. The detailed results will be reported in the conference.

PO45

SIMULATION OF TOTAL LUMINOUS FLUX MEASUREMENT FOR PANEL LIGHT SOURCE USING INTEGRATING SPHERE

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Abstract

1. Motivation

There is a great expectation for the organic light emitting diode (OLED) as a next-generation lighting technology following incandescent light bulbs, fluorescent lights and light emitting diode (LED). It is well-known that LEDs that have been rapidly spreading in recent years have a lot of advantages such as long life and high energy efficacy compared with existing illumination light sources. Currently, OLED is achieving the long life and the energy efficiency comparable to LED. Furthermore, OLED has many unique features: a panel light source, and a flexible or bendable light source. Hence, it is expected to be used as a new application light source which could not be realized by existing illumination light sources.

Total luminous flux is one of the most fundamental optical indexes to evaluate the quality of the light source. The total luminous flux is typically measured by integration of the luminous flux passing through the spherical surface centered on the light source. An integrating sphere (IS) can easily measure the data that corresponds to the total luminous flux from a test source, and is often used to measure the total luminous flux. International standards concerning optical measurement of LED lighting are summarized in CIE S 025 and IES LM-79, but it has not been clarified whether these standards can be applied for the panel source. One of the major error factors related to the measurement of OLED panels using the IS is the shadowing effect inside the IS, where the panel source itself would cast a shadow on the sphere wall that prevents the radiation of the light source from reflecting evenly across the inner-walls. Regarding the rule of test source size in the measurement using IS, it is limited to be less than 10% of the diameter of IS in CIE S 025, and to be less than 2% of the surface area of IS in IES LM-79. However, these rules assume a point light source such as LED, and do not assume a panel source such as OLED.

In this study, we simulate the effects of the configurations and specifications of the IS on total luminous flux measurement for the panel light source such as OLED.

2. Methods

For the simulation of the total luminous flux measurement by the IS, we used hybrid light simulation software using bidirectional Monte Carlo ray tracing method (Lumicept, Integra Inc.).

In order to investigate the shadowing effect of panel source for total luminous flux measurements using IS, we assume the following conditions. Experiment 1 focused on the effect of the luminous distribution of the reference standard lamp. The geometry of IS was similar to the general one, whose diameter was 1 m. We set the reference standard lamp to be a point light source whose luminous distributions to be either 2π sr Lambertian or 4π sr. The sizes of the panel source were: 1, 3, 7, 10, 14, 20, 25, 30, and 40 cm. Experiment 2 examined the influence of the diameter of IS. The geometry of IS was same to the experiment 1, but we changed the diameter of IS were 1 m or 3 m. The sizes of panel source were: 10, 20, 30, and 40 cm in IS with the diameter of 1 m, and 10, 20, 40, 80, 160 cm in IS with the diameter of 3 m. The luminous distribution of the standard lamp used was 2π sr Lambertian. Experiment 3 addressed the effects of the geometry of the panel source installation. In order to arranged the panel source on the wall of IS, we changed the configuration of the IS by reference to a hemispherical IS. The sizes of panel source were: 10, 20, 40 (and 60) cm, and the luminous distribution of the standard lamp was 2π sr Lambertian.

The calculations were continued until the difference between total luminous flux obtained from two successive rays became smaller than 0.1%. About 3 billion light rays are emitted depending on the conditions.

3. Results

The results of Experiment 1 showed that the estimated total luminous flux was decreased by about 2% when the luminous distribution of the reference standard source was changed from 4π to 2π sr Lambertian. Moreover, the larger the size of the panel source, the smaller the total luminous flux. The results of Experiment 2 were found the estimated total luminous flux for 1 m and 3 m of the diameter of IS were almost the same when comparing the size of the panel source as a ratio of the diameter of the IS. The results of Experiment 3 indicated that the estimated total luminous flux showed almost ideal value regardless of the size of panel source when the installation of the panel source was changed from the center to the wall of IS. This trend may have been derived because the shadowing effect is minimized.

4. Conclusions

We investigated the optimal condition of the IS on total luminous flux measurement for the panel light source. We found that by installing the light source panel on the wall of the IS, the shadowing effect can be minimized, enabling the permitted size of the light source larger.

PO46

VNISI TEST CENTER IN THE SYSTEM OF QUALITY ASSESSMENT OF MODERN LIGHTING EQUIPMENT IN RUSSIA

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Abstract

Starting from 2015, the Ministry of Energy in cooperation with the Ministry of Trade and Industry of the Russian Federation with the assistance of the UN Development Program in Russia in the framework of the Global Environment Facility project "Transforming the Market for Efficient Lighting", started a great job of an independent examination of the domestic lighting market. This activity is carried out and is currently running in the competition on the Eurasian Illuminating Engineering Award. To do this, the selection was made of certified test centers and laboratories in the country and the CIS countries who are involved in the measurement of light, colour and electrical characteristics of lighting devices, participating in the competition. Central to the group of laboratories devoted VNISI test center with advanced measuring systems, laboratory conditions corresponding to the international standards, with heat and cold chambers, and highly qualified personnel. Analysis work center allows you to highlight a number of important problems of metrological support of modern measuring systems used in photometry and colorimetry.

Keywords: goniophotometer, spectroradiometer, photometric head, spectral mismatch factor, international comparisons, and standard's sources of the spectral distribution of the radiation parameters, CIE S025 / E Standard: 2015

Competition for the Eurasian LIGHTING Prize was launched in 2015. To participate in the competition received applications from 30 companies to 89 models fixtures. Samples were purchased through a retail network by the Ministry of Energy. Tests to conform to the manufacturer's parameters and guidelines of standards performed five lighting accredited laboratories, including the Test Center VNISI by S.I. Vavilov, a stronghold of the light of science and technology, including the technology of measurements, since the fifties of the last century.

Test Center Institute is equipped with several measurement systems based on near-field goniophotometer, two spherical integrators, one of which has a thermal stabilization system, several types of spectroradiometries with differing levels of accuracy, photometric benches and test stands for climate, vibration, mechanical and moisture resistant test. As part of the test center has a mobile laboratory, demanded by designers and consumers of outdoor street and road lighting installations.

All settings of the test center put into the state register of measuring instruments and calibrated in VNIIOFI - National Laboratory and special state primary standards in the field of optical radiometry (spectroradiometry, photometry, colorimetry) with traceability to the SI base units.

Reference lamp spectral density of irradiance, spectral irradiance, luminous intensity and luminous flux during VNIIOFI verified annually. The spectral characteristics of the photometric head, spectral mismatch ratios and conversion factors are also subject to an annual verification and evaluation. The detector based and spectral approaches used in the laboratories of the center, taking into account all the complex components of the measurement uncertainty and correction factors.

VNISI Test Center takes an active part in international comparisons within the IEA 4E Project. Results of comparisons of 2013 renew the center of the measurement accuracy. The collation of measurement to be successful and beneficial for VNISI, they allowed to estimate the level of VNISI measurements regarding the level of the world's laboratories, to identify measures to further improve the accuracy and improve the quality of measurements. At the same time it should be noted some of the difficulties of the metrological plan that emerged in the course of the comparisons. In particular, a few more than expected, differences in chromaticity coordinates measurements of some samples due to the fact that it was not possible to apply the method of measuring the chromaticity coordinates, designed by NIST. In the future, under the auspices of the IEA 4E SSL Annex is planned to continue the practice of international comparisons and in the near future to carry out the next stage of comparisons of the

parameters of LED products based on goniometric measurement methods (in particular, it is planned to measure luminous intensity of source of light, used as models not only lamps but and LED luminaires). As before, in the comparisons will be open to all comers, including the Russian testing laboratories and centers.

Much attention is paid to the development of the Institute of measurement methods (mobile laboratory), the use of modern instruments - the image-luminance meter.

The activity of the center in national and international practice of light and colour measurement allows you to focus on the problem moments of metrological support of photometry and colorimetry. Primarily, that is the absence of widely available standard's LED light sources. Using them as a reference radiation source with spectral composition close to the spectral composition of the test luminaire, eliminates a number of correction factors and systematic components of measurement uncertainty.

PO47 (PP09)

LASER DRIVEN WHITE LIGHT SOURCE FOR BRDF MEASUREMENT

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Abstract

1. Objective

A bidirectional reflectance distribution function (BRDF) defines the reflectance properties of a surface by specifying the amount of radiance incident from one direction and the reflected into another direction, with respect to the surface normal. In computer graphics or other photorealistic studies BRDF measurement plays a very important role. Measurements were done to obtain the BRDF measurement of different kinds of samples based on our setup which consists of a new laser driven broadband light source (UV-VIS-NIR), spectroradiometer and sample holder stepper motor in a dark UV-protected environment. Here, we introduced BRDF measurements using a special kind of light source which has a bright, stable, broad spectral range and well collimated light output to give a very good angular resolution.

2. Method

The measurement of BRDF of a material is mainly dependent on a light source illumination and detector viewing direction. In our method, the light source used provides a bright illumination across the UV-VIS-NIR range with high spatial and power stability. In addition, the light source is well collimated by off-axis parabolic mirrors. Hence, the complete collimated light source used in our BRDF measurement consists of a laser driven light source with spectral emission between 190 and 2100 nm, collimating off-axis parabolic mirrors and a UV filter. The detector was spectroradiometer coupled with a high angular resolution collimating fibre coupler and was calibrated for visible wavelength region. We have used a stepper motor with two freedom of motion as a sample and detector mount. The whole measurement system was controlled by a LabVIEW controlled PC. The UV filter was positioned immediately after the light source in order to remove the UV-C part for safety. The measurement room was kept at a temperature of 21°C using an air conditioning system. In our measurement method, the light source is fixed during the measurement. The incoming and outgoing direction of the light is changed by the rotation of the sample and the detector. The samples we used are diffuse white sample, mirror and different anodized aluminium samples. Since the sample is mounted on a small rotating stage, its size is limited to 8cm in diameter. We have done in-plane measurements for four angles of incidences (15°, 30°, 45° and 75°).

3. Results

The complete light source consists of laser driven light source in combination with a collimating optics to give a very bright light with a broad spectral range. Results will show the properties of the light source in the BRDF setup. The spectral power distribution, spectral radiance and the stability over measurement time, and the obtainable degree of collimation using off-axis parabolic mirror will be shown. These properties of the light source give a very high signal to noise ratio and angular resolution for BRDF measurement. In addition to our light source, our detector used a collimating off-axis parabolic mirror fibre coupler with a very good angular resolution, and we managed to obtain a FWHM (Full Width-Half Maximum) as small as possible with a high signal to noise ratio. We have measured BRDFs for diffuse and non-diffuse samples.

4. Conclusions

The light source we used is optimized for high brightness, since it is radiated from a very small plasma spot and this provides a high spectral radiance. Furthermore, it is a broad-spectrum light with high spatial and power stability. This property makes it very effective for BRDF measurement especially where a very high signal to noise ratio and high angular resolution is needed. For our final paper, we will present some more measurements on different samples and present the result in relation to the light source we used.

PO48 (PP10)

CHARACTERIZING AN INTEGRATING SPHERE PHOTOMETER FOR MEASUREMENTS OF SOLID-STATE LIGHTING PANELS

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Abstract

1. Motivation, specific objective

During the recent years, solid-state lighting products (SSLs), often based on white light emitting diodes (LEDs), have replaced the majority of conventional incandescent and fluorescent lamps and luminaires used in general lighting. To accurately determine the luminous efficacy (lm/W) of new SSLs in product development, measurement of their total luminous flux (lm) is of high importance.

A common method to measure the luminous flux of SSLs is to use a 4π integrating sphere photometer, in which the lamp under test is attached in the centre of the sphere using a suitable sample holder. For accurate luminous flux measurements with integrating spheres, various spectral, spatial and geometrical correction factors are needed. Typical correction factors required in luminous flux measurements include spatial non-uniformity, spectral self-absorption and spectral mismatch corrections.

Commercial SSLs utilize LED components in various forms. Due to the small size of LEDs, building lamps and luminaires with various different geometrical properties is possible. Many new types of LEDs have appeared on the market, including large area chip-on-board, strips and filaments, as well as large-area panels built using arrays of LEDs with suitable diffusing elements or organic light emitting diodes (OLEDs). OLEDs typically have large light emitting surfaces, some of which can be transparent or even bent. As LED and OLED products have very distinctive spectral properties that often depend on the angle of observation as well, the spectral responsivity of the integrating sphere in different positions on the sphere surface may introduce additional errors in the measured luminous flux, especially in the case of directional light sources. Therefore, it is advantageous to measure the spatial responsivity distribution function (SRDF) of an integrating sphere spectrally to allow determining spectral and spatial correction factors and the related uncertainties of the measurements more accurately.

2. Methods

In this work, a 1.65-m integrating sphere with coating reflectance of 98 % was characterised for measurements of OLED panels of different sizes. Typical spectral and photometric errors, as well as uncertainties related to the measurements of large-area SSLs in different geometrical alignments were determined. In the characterisation of spectrally resolved spatial non-uniformity and spectral throughput of the integrating sphere, a commercially available integrating sphere scanner was used. The LED used in the scanner was changed to a one with higher luminous intensity and extended spectral range at longer wavelengths to reduce the noise in the calculation of correction factors for warm white LEDs and OLEDs typically found on the market. The output beam of the modified LED sphere scanner was characterised using a near-field goniospectrometer.

For the test measurements, a total of six different OLED panels, from four different manufacturers, with the areas of the emitting surfaces ranging from 37 to 81 cm^2 were measured for luminous flux by mounting them to a 2-axis OLED holder in the integrating sphere. Half of the panels had diffuse emitting surfaces, whereas the other half had more specular reflecting surfaces. To study the effect of the panel orientation on the luminous flux, the panels were measured at horizontal and vertical orientations. The relative spectrally resolved angular intensity distributions of the OLEDs were measured in a near-field goniospectrometer, and the spatial non-uniformity corrections for the panels were calculated using the measured SRDF of the integrating sphere. The uncertainties of the spatial correction factors for each operating orientation of the OLED were determined using a Monte Carlo

analysis where the horizontal and vertical rotations of the OLED in the 2-axis holder were offset up to ±10 degrees from the desired panel orientation.

3. Results

Based on the test measurements, the spatial correction factors for the OLEDs with specular reflecting surfaces varied between 1.0055 and 1.0058, when the OLED was facing either downwards or towards the auxiliary port of the sphere, located on the opposite side of the detector port of the sphere. For the OLEDs with diffuse surface the spatial correction factors varied between 1.0061 and 1.0063. For a virtual Lambertian panel, the correction factor was 1.0059 for both of the studied orientations. The uncertainty arising from the alignment of the OLED in the integrating sphere for the operating position towards the bottom of the sphere was 0.13 % (k = 2) and for the position towards the auxiliary port was 0.03 % (k = 2). The larger uncertainty for the position towards the sphere bottom is due to the higher non-uniformity on the sphere surface around that specific point.

The spatial correction factor for the SSL under measurement varies as a function of the wavelength. The largest values of the correction are located at the short wavelength range and the smallest at longer wavelengths, being in the range of 1.0035-1.0085 for all the tested panels.

The measured luminous flux values of the OLEDs after corrections differed by 0.2 % to 1.3 % depending on the operating orientation. The total uncertainty for the luminous flux measurements in the integrating sphere for a typical OLED panel was 0.9 % (k = 2).

4. Conclusions

An integrating sphere was characterized both photometrically and spectrally for the measurements of LED and OLED panels at different operating orientations. The luminous flux of six different OLED panels were measured. The relative angular intensity distributions for the OLEDs were measured using a goniospectrometer. The spectral throughput of the sphere was determined from the spectral spatial scan of the integrating sphere.

The study shows that SSL panels can be measured with integrating sphere photometers at different geometrical alignments with small uncertainties. The luminous flux values of the studied OLED panels had an expanded uncertainty of 0.9 %. The effect of the operating position of the panel on the luminous flux was up to 1.3 %.

PO49 (PP11)

DEFINITION AND DETERMINATION OF THE BEAM AXIS AND BEAM ANGLE OF COMPLEX LUMINOUS INTENSITY DISTRIBUTIONS

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Abstract

1. Motivation, specific objective

Legal regulations in many countries require the determination and indication of the beam angle of lamps and luminaires on their product. As an example, the European eco-design directive EC Regulation (EU) No. 1194/2012 defines the useful luminous flux of a lamp based on the beam angle. The value of the beam angle may therefore have a direct impact on whether a product can be put on the market or not. Therefore, a rigorous method of determining the beam angle is required that can be universally applied and which gives representative and reproducible results.

The International Standard CIE S 025:2015 *Test Method for LED Lamps, LED Luminaires and LED Modules* defines the beam angle as “angle between two lines in a plane through the optical beam axis, such that these lines pass through the centre of the front face of the device and through points at which the luminous intensity is 50 % of the centre beam intensity, where the centre beam intensity is the value of luminous intensity measured on the optical beam axis”. For ideal rotationally-symmetrical and convex luminous intensity distributions this definition can be directly applied: the measurement of the luminous intensity distribution in a single plane is sufficient to determine beam angle according to the definition. For complex luminous intensity distributions, however, the definition can’t be applied directly and more sophisticated methods are required.

This paper discusses and compares different approaches using one already-defined method and introducing three new techniques. In addition to the pure research interest, this work is also important in the context of CIE TC 2-78, which is tasked with evaluating methods of determining beam axis and beam angle and making a recommendation on the best method for the task.

2. Methods

IEC/TR 61341 *Method of measurement of center beam intensity and beam angle(s) of reflector lamps* proposes to first determine the position of the peak intensity Ip visually by titling the lamp in different directions and observing the photometer reading. In a second step, the directions where the intensity is half of the peak intensity is determined in at least 6 different measurement planes. The optical beam axis is considered to be the bisection of the direction of the peak intensity and half peak intensity. This direction defines the centre beam intensity Ic. The angle between the optical beam axis and the direction in which the luminous intensity is half of the centre beam intensity is considered to be the half beam-angle. The beam angle of symmetrical beam is then defined as twice the average of the half beam angles determined in the different measurement planes. For asymmetrical beams the individual beam angles shall be reported.

A second method is based on the determination of the optical beam axis by the centroid of the luminous intensity distribution. A coordinate transformation moves this centroid position to coincide with the reference point of the coordinate system and the half-maximum intensity positions in each of the half planes in the distribution is determined. Finally, an ellipse is fitted to these half-maximum positions using a least-squares fit and the lengths of the major and minor axes of the ellipse are considered to be the beam angles.

A third method is based on numerically fitting an ideal tiltable cos^*g* distribution to the measurement data using a non-linear least square algorithm in each C-plane. There are three fitting parameters to be optimized: the tilt angles, the centre beam intensity and the exponent g of the cos^g distribution. From this ideal distribution the beam angles in each C-plane are directly determined analytically and

the average is taken. Similar to the second method, an ellipse can be fitted in case of asymmetric beams.

A fourth method considers a direct fit of an ideal 3D tiltable cos^g distribution to the whole set of measurement data. By this the beam angle is directly obtained as a parameter of the fitting process.

3. Discussion

The first method has some limitations because it requires the photometrist to manually locate the beam maximum point and from there to move away from the maximum point within measurement planes. It doesn't provide guidance on how to make the planes "straight" and so this can only be done in a practical sense by aligning the source with the origin of the coordinate system and then using different C-planes. This may require tilting the source, which can result in errors for discharge sources whose output can change when tilted with respect to gravity.

All four methods can, in principle, be evaluated from a measured luminous intensity distribution, although in the case of the first method it doesn't provide the means for undertaking the coordinate transformation to rotate the data so that the maximum intensity point coincides with the origin of the coordinate system.

4. Results

Preliminary results indicate that for reasonably symmetrical distributions the all methods yield similar results. As the beam becomes more asymmetrical the minimum and maximum of beam widths calculated in the six planes of the first method matches reasonably well with the lengths of the long and short axes of the second and third methods, and so these methods provide a useful summary of the beam shape.

For asymmetrical beams that are poorly aimed or for complex beams with multiple peaks, a better fit to the beam can be found by performing a coordinate transformation to the centroid rather than the direction of maximum intensity.

5. Conclusion

There is no unique solution to the problem of determining the beam angle of complex luminous intensity distributions. The final paper will present more details regarding the mathematics behind the different techniques, the coordinate transformation, the centroid determination and experimental results.

PO50 (PP12)

INVESTIGATION AND ANALYSIS OF GONIOPHOTOMETER CALIBRATION

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Abstract

1. Motivation, specific objective

In goniophotometer measurement, the two important performance criteria are the spatial angle and the luminous intensity accuracies in tested direction. For spatial azimuth angle accuracy of goniophotometer, the accuracy of (C, γ) coordinate system and the rotational positioning accuracy of C and γ angle are important. But the accuracy of (C, γ) coordinate system is usually not given enough attention as the horizontal axis consistency of the C- rotation axis in the photometric plane, the vertical axis consistency of the γ- rotation axis, the verticality and the mutual deviation of the two rotation axes. Especially for the goniophotometer with large size mirror, the rigidity of the rotating arm that supports the mirror, the linearity of rotation axis, the bearing mechanism, the coaxality of drive mechanism and installation position error will all affect the accuracy of the rotation axis. Additionally, the flatness, refraction offset, etc. will also significantly affect the accuracy of spatial angle. The goniophotometer with two or more mirrors, the above deviations will become further apparent and so the multi-mirror combined system must be systematically calibrated.

For calibration of luminous intensity, using luminous intensity lamp the standard preferred method. The alternatives often used include illuminance photometer method and luminous flux lamp method. However, the latter calibration methods have some problems. And if the calibration light beam does not pass through the mirror or all mirrors in a multi-mirror combination system, it will result in significant errors in the system.

In this work, we study the calibration of goniophotometer in relevance to the spatial azimuth angle and luminous intensity distribution. Also, we analyse the applicability of the calibrated illuminance photometer method and discuss the problems of the total luminous flux calibration method. Finally, through several laboratory tests in different countries. Our results indicate that the spatial luminous intensity distributions and total luminous flux that are calibrated using the spatial angle and luminous intensity standard lamp can ensure consistent results.

2. Methods

At present, the accuracy of goniophotometer used in laboratory is better than 0.2 °. It is possible to check the axis deviation of the coaxial rotation by laser by the laser mounted on the rotation axis. In this way, we can confirm the deviation angle of the axis shake, the verticality of the two rotation axes, and the offset of the origin of the coordinate system. For the accuracy of the spatial rotation angle, we can use optical goniometer to detect it. The 14bit (or higher) optical goniometer have very small error, so the goniometer with direct coaxial installation will generate small error than others (such as gear, toothed belt, etc.). According to the EN13032-1, the intersection of two axes should be less than 10mm, the perpendicularity of axis less than 0.02 ° and the shake of axis less than 0.03 °.

The calibrated illuminance photometer method is also used sometimes as another method of goniophotometer calibration. In this method, the photometer head is calibrated on an optical rail, and the size of standard lamp is small. This results in some problems using a photometer head to test large-size luminaires in goniophotometer. We chose two luminaires with different sizes of luminous surface (a halogen lamp and an LED panel light) for the experiment and used a calibrated photometer head to measure the illuminance value at different distances. The results indicate that the deviation level of the two test were signally different at near field.

Some laboratories use the luminous flux standard lamp method to calibrate the goniophotometer. But because the uncertainty of luminous flux, measurement uncertainty of spatial light intensity distribution and stray light. The luminous flux lamp method will result in some factors of uncertainty on luminous

intensity measurement. In order to test this, we chose some flood lights for the experiment. The luminous flux of these samples are almost the same, but with different beam angles. We measured these samples on the calibrated goniophotometer that uses the luminous flux lamp and compared the results with the intensity distribution measured in goniophotometer that uses the luminous intensity lamp method. We found the deviation is changed as anticipated at the positions where the light gets weak.

3. Results

Through the careful, and precision installation and commissioning, of a high precision goniometer, by angular optical polygon and automatic collimation, the spatial azimuth angle of goniophotometer can be accurately calibrated.

For the calibrated illuminance photometer method, the results indicate that the deviation level of the two tests were different, mainly because the photometer head calibration is typically done at far field, and the lamp used for calibration usually has a small luminous surface. However, in the test goniophotometer system, the photometric distance and the size of testing luminaire are not the same, and these will lead to measurement errors.

For luminous flux lamp method, the uncertainty of the luminous flux standard lamp should be considered carefully during the calibration procedure. However, the measurement error caused by stray light is more important. Usually the luminous flux standard lamp is weaker than the luminous intensity standard lamp, so the flux calibrated goniophotometer may not be accurate enough for all types of luminaires test.

We analysed the test results of calibrated illuminance photometer method and luminous flux lamp method, and find that is possible to improve tha accuracy better than 2% uncertainty.

4. Conclusions

The azimuth angle calibration and luminous intensity calibration are critical for improving the goniophotometer accuracy. The calibrated illuminance photometer method can also be adopted when the photometric distance can be accuratly measured. For the mirror goniophotometer factors such as reflectivity and polarization of the mirror are more influential on the measurement accuracy. In the case of the luminous flux lamp method, the luminous intensity measurement error and stray light can seriously influence the measurement uncertainty, especially for the mirror goniophotometer. The mirror will change the light distribution in the space, therefore, luminous flux lamp method will result in a greater error on luminous intensity measurement.

PO51 (PP13)

HDR IMAGES FOR GLARE EVALUATION: COMPARISON BETWEEN SELF-CALIBRATED DSLR CAMERA AND AN ABSOLUTE CALIBRATED LUMINANCE CAMERA

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Abstract

1. Motivation and objectives

High dynamic range (HDR) images are being used as a simple way to measure the luminance of lighting scenes. HDR images can be made by merging several low dynamic range (LDR) images, usually taken with varying shutter speeds, into one image; sometimes also referred to as luminance maps. Each pixel in these HDR images holds information about the luminance value and can then be used for different evaluations of the lighting scene, such as luminance distribution, contrast evaluations and glare analysis.

Professionally calibrated cameras that have an absolute calibration, making good and precise HDR images, do exist, but these are generally expensive. These can resolve almost all light scenes including scenes with both high and low luminances, as well as scenes that could produce flare. These cameras are also calibrated for influences from the optical system.

It is possible to self-calibrate commercially available digital single-lens reflex (DSLR) cameras, so that they can be used to produce usable HDR images. Self-calibrated luminance cameras are being used, among others, for light research purposes, as they provide an affordable alternative to absolutely calibrated cameras. However, if care is not taken, both in the calibration process and when shooting the LDR images, the resulting luminance maps will be faulty. Self-calibrated cameras have trouble resolving light scenes with both very dark and very bright parts in them. This is emphasized if the series of LDR images are not correct or don't cover the luminance range, resulting in wrong luminance values in these parts. This happens, for example, when none of the LDRs are under or overexposed (nearly black/white) or if the shutter speed steps between the LDRs is too large. The same can happen if the wrong aperture size is used, although this usually only affect either the high or low end of the luminance range. Vignetting (light drop off at the edges of an image compared to the image center) varies from aperture size to aperture size and typically becomes more pronounced at high and low aperture sizes. It is important to have vignetting correction for each aperture, otherwise luminances at edges of the images will be too low. When there are very bright parts in relatively dark scenes, flare (light spillover between pixels) results in wrong luminance values around the pixels representing the light source. Wrong luminance values in HDR images, however they occur, results in a wrong vertical illuminance value if this is calculated from the HDR image. This in turn makes glare analysis, some of which rely on vertical illuminance, unreliable.

The objective of this study is to compare luminance maps from self-calibrated commercial DSLR cameras with luminance maps from an absolutely calibrated luminance camera and to identify the limits of the self-calibrating method when applied for glare analysis. Targets in the luminance maps will also be compared with spot measurements from a handheld luminance meter.

2. Method

Two identical commercial available DSLR cameras with identical fisheye lenses are calibrated by following the guidelines for self-calibrating luminance cameras. Briefly the method is based on four steps:

- A response curve is derived for each camera by capturing a scene containing patches of bright natural daylight and some relatively large white, grey and black surfaces.

- The HDR images are corrected for lens vignetting by applying a correction factor to each pixel value. The correction factor, a polynomial function, is obtained by measuring the light drop off that occurs when the camera is rotated around the lens nodal point.
- The images are then corrected for lens projection by applying another correction factor to the pixel values in order to account for the distortion caused by the projection method of the lens.
- Finally, a calibration factor is applied to each HDR image based on luminance values measured at points in the scene with a handheld luminance-meter.

To compare the three cameras, HDR images are made of several lighting scenes. The cameras are controlled with remote control software, so that they can make images simultaneously and without camera shake. The cameras, mounted on a tripod, cover almost identical parts of the scene. An illuminance meter is also mounted at the camera lenses for vertical illuminance measurements. The scenes consist of typical office-like environments during different sky conditions and with varying light levels in them. Luminance at specific targets located in fore-, middle-, and background of the scenes are compared across the images from the different cameras and with spot luminance measurements. Vertical illuminance is also calculated from the luminance maps and compared with the measured illuminance. Furthermore, calculation of common glare-metrics is carried out on the images and the resulting values are compared.

3. Results

The preliminary investigation and calibration process with the DSLR cameras have revealed that resolving the sun or very high luminance is problematic and can cause large differences for the glare evaluation. This study investigates the limits of the self-calibration method and aims to show its influence on daylight-glare evaluation. Improvements for the calibration of DSLR cameras are also identified.

PO52 (PP14)

STUDY ON THE POSSIBIALITY OF LED FILAMENT LAMP AS PHOTOMETRIC STANDARD

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Abstract

Incandescent lamps are phasing out by more energy efficient light source light emitting diodes (LEDs). As this trend, firstly, many types of incandescent lamp extensively used in the past as photometric standard are no longer available in the future; Secondly, the current photometric measurement system is based on CIE standard illuminant A (i.e. incandescent lamps), which is quite different from the spectral distribution of LED. Therefore, the uncertainties may increase when measuring LEDs instead of incandescent lamps. For a recent preliminary study two LED-based calibration illuminants: Lw (warm white ,2935K) and Lc (cool white,5716K) have been defined and used as calibration source instead of illuminate A for photometer that measuring LED lighting. It indicates that the measurement errors could be reduced by a factor of 3, provided that the type of calibration LED source be selected according to the type of LED source to be measured. Thus LED based photometry could reduce the spectral mismatch error in a direct way which may be the convenient methodologies to simplify the LED measurement procedure.

Standard lamps are used to maintain and transfer the unit of photometry, they should have reproducible and stable output for repeated and long-time use. LEDs have several unique properties compared to incandescent lamps, such as energy efficient, very short response time, narrow spectral bandwidth, good temporal stability, robustness, long lifetime. The four later features make LEDs prior to incandescent as photometric standard.

The developed LED standard lamps should meet the general requirements of standard lamp, but also be compatibility with general electrical connection and the existing calibration facilities, meanwhile, inexpensive and easy to be got. Based on extensive investigations of different types and different manufactures, a kind of LED filament lamp has been selected as the candidate. It have the great advantage of short warm up time 5～12 min compared to other types LED which the warm up time is as long as 30 min or even several hours.

The characteristic of a group of DC and a group of AC 4W LED filament lamp were been investigated during one year period. The reproducibility of the luminous flux was checked by measuring three reference lamps (bromine tungsten lamp) which were calibrated the luminous flux and spectral radiant flux. The reproducibility of the luminous flux is better than 0.15%, the reproducibility of colour temperature is within 2K. After burning about 7000 h, the decrease of luminous flux is 1.4%～3.5%,and the increase of colour temperature is within 14K.The storage stability of several filament lamps also have been investigated, the fluctuation of luminous flux is within 0.2% during 10 month. But this lamp is sensitive to temperature, during measurement the temperature inside the integrating sphere should be monitored, the possibility of correction the temperature dependency of luminous flux by voltage will be studied.

The studied LED filament lamp show good reproducibility and stability, as well as low ageing rate about 1/30 of incandescent lamp, robust to shock, the shortcoming of temperature dependency could be corrected by voltage. This kind of LED lamp may could be used as a kind of photometric standard , but the long time storage character should be studied in the future.

PO53 (PP15)

PERFORMANCE EVALUATION OF IMAGING SPECTROPHOTOMETER IN THE VISIBLE AND INFRA-RED REGION

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Abstract

1. Motivation, specific objective

Imaging spectrophotometer is referred to as an instrument that measures the spatial distribution of spectral reflectance and/or transmittance of a 2-dimentional sample based on the spectral imaging technique. In 2014, we reported a proto-type instrument of the imaging spectrophotometer and demonstrated its feasibility in the visible region in Metrologia. Recently, we developed an improved instrument that should provide better accuracy and higher dynamic range in the extended wavelength range. The main objective of this study is how to evaluate the key performances of the imaging spectrophotometer.

2. Methods

The instrument to be investigated is an imaging spectrophotometer based on an integrating sphere for measurement of spectral reflectance in the geometry of diffuse illumination and 0-degree detection (d/0). A monochromator-based spectral light source using a tungsten lamp is used to uniformly illuminate the test sample, which is attached to a 25-mm-diameter port of the integrating sphere. The image of the illuminated sample surface is recorded by alternatively using two digital cameras, a monochrome Si CCD camera for the wavelength range from 350 nm to 1000 nm and an InGaAs camera from the range from 1000 nm to 1600 nm. Both cameras contain the thermoelectrically cooled image sensors with a high digitizing resolution (16 bit for Si and 14 bit for InGaAs). A data acquisition software is developed to extract the spectral reflectance of a selected region of interest (ROI) from the recorded digital images.

The instrument is calibrated by using the white reflectance standard of KRISS. Once calibrated, the digital number at each pixel of the recorded image of a test sample is converted to the value of total diffuse reflectance from its ratio to the current reading of the monitoring photodiode attached to the integrating sphere. The operation conditions and parameters of the instrument such as the size of the ROI, the signal-to-noise ratio of the readings, the spectral bandwidth of the source, etc., are set in such a way that the minimum uncertainty of the spectral reflectance measurement is expected. After calibration, the performance of the instrument is evaluated by measuring a set of grey and coloured reference samples and comparing the data with the data measured by the reference spectrophotometer at KRISS. In particular, the wavelength-dependent differences between the measured data and the reference data are investigated as the reflectance level of the sample varies (dynamic range), as the position of the ROI varies (spatial non-uniformity), as the size of the ROI varies (spatial resolution), as the spectral bandwidth of the light source varies (spectral resolution), and as the surface property like BRDF of the sample varies (sample dependence).

3. Results

From the measurement data in various conditions, we first evaluate the expected uncertainty or systematic error with respect to each parameter. For example, from the measurement for the samples with different reflectance levels (grey samples), we evaluate the change of the random uncertainty and the deviation from the reference data with respect to the reflectance level. We set the target value of the relative uncertainty to be 2 % in the visible and 4 % in the infrared region, both expressed as the expanded uncertainty with k = 2. Then, we determine the dynamic range of the reflectance

measurement, in which the systematic error due to the reflectance level is less than the target uncertainty. Similarly, we determine the performance specifications of spatial non-uniformity, spatial resolution, spectral resolution, and sample dependence based on the pre-defined target uncertainty boundary. The experimental evaluation is still on-going, and the summarized results will be presented in the conference.

4. Conclusions

The results of the performance evaluation of the imaging spectrophotometer will be used to test and improve the usefulness as well as the limitation of the instrument in the application.

PO54 (PP16)

INTER LABORATORY COMPARISON OF LED MEASUREMENTS AIMED AS INPUT FOR MULTI-DOMAIN COMPACT MODEL DEVELOPMENT WITHIN A EUROPEAN-WIDE R&D PROJECT

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Abstract

The European project Delphi4LED (launched within the support of the H2020 research framework of the European Union and with the financial contribution also from the national governments of the participating consortium members) is aimed at the development of new LED compact models that can help better design LED based lighting products at all integration levels along the SSL supply chain. The compact thermal models of LED packages and the multi-domain models of the LED chips within these packages are foreseen to be identified from measured LED characteristics. When setting the targeted accuracy levels of these models one needs to be aware how accurately and with what uncertainty the required LED characteristics can be measured in an average academic and industrial testing laboratory by the application of the latest available LED testing standards. Therefore the Delphi4LED consortium decided to start an inter-laboratory testing of 5 different representative LED types. The outcome of the this round robin testing is expected to provide valuable input of the CIE TC2-84 technical committee and will be the first such testing of e.g. the most recent LED thermal testing standards and the new CIE test methods for optical measurements of high power LEDs.

1. Motivation, specific objective

There are a few bottlenecks hampering efficient design of LED based products on different integration levels of the SSL supply chain. One major issue is that data sheet information provided about packaged LEDs is usually insufficient and inconsistent among different LED vendors.

An international consortium of European SSL manufacturers including big and small companies, industrial and academic research labs and companies involved in LED test equipment manufacturing and suppliers simulation tools has recently set an R&D project with the ultimate goal of developing standardized methods to create accurate multi-domain LED compact models from testing data. Despite high accuracy expectations of end-users, model accuracy should not be defined higher than the uncertainty of LED measurement data achievable by typical test laboratories performing daily characterization of LEDs.

2. Methods

To assess the capabilities of their laboratories the consortium members with LED measurement facilities decided to carry out round robin testing of selected LED packages which have been defined as the most important ones from the point of view system level design by consortium member companies active in luminaire and lighting design.

In planning this round robin test, the outcome of earlier inter laboratory comparisons were carefully considered. The test protocol of the present round robin test is based on new measurement standards and recommendations published by JEDEC and recently developed by CIE. Our planned measurements will be the first international round robin test based on these measurement procedures.

The LED packages chosen for the round robin test are the most representative LED devices used by the consortium members include:

- a high-power phosphor converted white LED,
- a high-power blue LED package (with the same blue chip as the above white LED) ,
- a high-power red LED package,
- a mid-power green LED package,
- and white CoB LED.

The measurands to be identified at set T_J junction temperature and I_F forward current include thermal resistance, absolute spectral power distribution, total luminous flux, total radiant flux and a few further light output properties derived from the measured spectral power distributions. For a selected LED package a whole set of isothermal I-V-L characteristics will be also measured.

To reduce the possible variations of the LED samples during the whole process 500 h hours of initial ageing / seasoning of the test samples has been decided.

The huge amount of test data will be collected in a quasi-standard format and will be subject to a final statistical analysis. Regarding the data collected this round robin test is expected to provide significant input not only to the present European R&D project but also to the work of the CIE TC2-84 technical committee.

3. Results

The ageing process has been finished at the time this abstract submission and the completion of all the measurements by the seven participating laboratories is expected at the deadline of the submission of the final papers. By the time of the conference the first results of the statistical evaluation of the raw test data is also expected.

4. Conclusions

Since the work of 7 laboratories needs to be coordinated and further two research teams will be involved in measurement data post processing are involved, test data reporting is key to the success of this round robin test. So besides a better understanding of the practices and the capabilities of industrial and academic LED testing laboratories initial suggestion for LED test data reporting (with data aimed at further processing e.g. for automated LED model generation) aimed as input for the CIE TC2-84 technical committee is expected. On top of that we hope to learn how easily the latest recommendations for LED testing can be implemented in the everyday practice of average industrial and academic laboratories.

PO55 (PP33)

ANALYTICAL MODELS FOR PHOTO-EMISSION SPECTRA OF SINGLE COLOUR LEDS

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Abstract

1. Motivation, specific objective

LEDs are a rapidly developing key component in a wide range of modern lighting applications. Important tools for developing LEDs and assessing their properties are reliable simulations of their physical properties.

In this paper we present an *a priori* analytic model for the photo-emission spectrum of single colour LEDs. The model establishes a close connection between the spectral properties of LEDs and the underlying solid state physics and can in principle be used to predict the photo-emission spectrum of an LED from only a few of its semiconductor properties. The full model is compared to a more simple, empiric, model that turns out to be well suited for good quality fitting of real LED spectra.

2. Methods

The presented LED model is based on the Lasher-Stern-Würfel equation that allows calculation of the photo-emission spectrum of a direct bandgap semiconductor from its energy dependent absorption coefficient. The later is routinely measured for many semiconductors, but can also be calculated *a priori* if the band structure of the semiconductor is known. The model requires only five input parameters and includes in particular the effects of so called band tails in the density of states that are responsible for photoemission at energies below the band gap.

3. Results

The analytic model is verified by using it as a fit-model for various real LED spectra and good agreement is found. Previously, similar agreement with experimental data has been achieved by using an asymmetric gauss distribution as fit model. Based on the analytical model the connection of the empiric fit model to the underlying physics of the LED is explained and its general applicability as a fit model is confirmed.

4. Conclusions

An analytic physical model for the photo-emission spectra of single colour LEDs is presented and validated against experimental data. The model can be used either as a fit-model for experimental data or as a tool for predicting the photo-emission spectra of single colour LEDs *a priori*. The full model provides justification for using a more simple asymmetric gauss model for fitting experimental data. Because the analytic model provides a clear connection between the photo-emission spectra of LEDs and their semiconductor properties, the model can facilitate the simulation of more complex situations involving single colour LEDs like the properties of luminaires or of phosphor converted white LEDs.

PO56 (PP34)

NOVEL METHOD FOR ANGULAR CHARACTERISATION OF GONIOPHOTOMETERS WITH A PATTERN GENERATING ARTIFACT

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Abstract

1. Motivation, specific objective

A precise measurement of luminous flux and luminous intensity on a goniophotometer requires a precise characterisation of all angles set by the measurement system. According to the international standard CIE S 025 describing the test method for solid state lamps, luminaires and modules, several mandatory requirements addressing the angular resolution and adjustments of goniophotometers are listed. One specific requirement mentioned in the standard is the angular reading resolution of 0.1°. This parameter depends on the device hardware implementation and cannot be corrected for. Whereas the second angular criteria concerning the angular aiming of a device under test being adjusted and maintained during a measurement within ±0.5° can be addressed by applying a specific correction and should be disclosed in the uncertainty budget of the measurement device. Therefore a precise characterisation of the angular properties of a goniophotometer system is needed and can be performed with the here presented newly developed approach of using an illuminated sliced half sphere.

The different steps for a goniophotometer angular characterisation based on C-plane measurements are presented and described. The results might be used for an angular correction to comply with the angular requirements of the international standard.

2. Methods

For the investigations a commercially available luminous flux goniophotometer was used where a single warm white temperature controlled LED source is mounted in the optical centre of the system. The main emission direction of the point light source is heading to the side. The optical axis of the LED is oriented perpendicular if the measurement arm with the photometer head is at position 90°. Furthermore the light source is covered with a structured object which is made with additive manufacturing (3D-printing) and has the shape of a sliced half sphere centred on the LED source. Thus the illuminated seven incisions in the cap covering the LED are generating a periodical shadow/light pattern. The light distribution curve of this geometrical structure is measured by acquiring single C-planes at different measurement speeds and measuring/moving directions.

To analyse the angular precision of the different acquiring modes the edges of the periodical structure in the light distribution curve are analysed and fitted with linear slopes. A measure for the system angular precision can be found by comparing these linear slopes of the different acquiring modes. As a parameter of interest the angular shift between the linear slopes and a predefined reference mode is calculated. This reference mode is defined as a C-plane acquisition in the direction top/down in the slowest possible moving speed of the goniophotometer measurement arm.

As the stability of the light source might be an issue for this kind of analysis it can be tracked by assessing the light intensity levels of the centre part of this structured object. The stability criteria of the international standard CIE S 025 are applied.

3. Results

By comparing the reference mode to the specific angular shifts of the extracted linear slopes acquired with slow moving speeds it revealed that for the present system the moving direction (bottom up/top down) has no influence on the angular precision. For all analysed slopes the angular shift was negligible.

However a significant direction dependent angular shift can be found for fast moving speeds of the measurement arm close to the allowed limit of the device. Compared to the reference mode, the

top/down movement direction results in an underestimation of the angle as the calculated angular shifts are negative. On the other hand the angular shifts showed positive values for the bottom/up movement of the measurement arm with fast moving speeds resulting in an angular overestimation.

The analysis of stability of the chosen light source showed a good agreement with the specific requirement described in the standard.

4. Conclusion

In summary it can be concluded that this method allows for characterising the angular properties of a goniophotometer by analysing C-plane measurements of different operating modes. The standard measurement mode is defined by scanning the light source by moving the measurement arm top/down and after rotating the gamma-axis moving the arm bottom/up. The here presented method was able to detect an angular position mismatch between the two different arm movements. If the angular deviations are beyond the specified values defined in the standard a correction can be applied on the angular values. Furthermore this procedure allows to report the angular precision in the uncertainty budget of the measurement setup.

PO57 (PP35)

SPECTRAL NONLINEARITY MEASUREMENT OF ARRAY SPECTRORADIOMETERS FOR COLORIMETRY

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Abstract

1. Introduction

Array spectroradiometers constructed with a charge-coupled-device (CCD) or an arrayed photodetector have been widely used in the fields of photometry, radiometry, and colorimetry. Array spectroradiometers have several advantages for use in these fields, such as short-time spectral measurement, compact structure, and easy-to-use functionality. Taking these advantages, the measurement system with an array spectroradiometer, e.g. sphere-spectroradiometer systems and gonio-spectroradiometer systems, have been used for the accurate testing of total luminous flux and chromaticity of lighting products based on light emitting diodes (LEDs) and laser diodes (LDs) and displays.

To reliably evaluate the total luminous flux and chromaticity by using an array spectroradiometer, the operation stability, the wavelength accuracy, and its spectral responsivity are fundamental factors. The response of the array spectroradiometer needs to have a linear response over wide range of optical power level, because the optical power of a test lighting product is larger or smaller in several orders of magnitude than that of a reference standard used for calibration. In addition, spectral nonlinearity would distort the measured spectral power distribution that directly affects the error in the source colour measurement. However, almost all optical detectors have more or less nonlinear properties accompanied by wavelength dependence. Therefore, evaluating the spectral nonlinearity of the array spectroradiometer is important.

In this study, we report on the nonlinearity of array spectroradiometers and its wavelength dependence, and discuss the potential error attributed to them in the source colour measurement.

2. Methods

Nonlinearity of two types of array spectroradiometers in the visible region was measured based on the flux-addition method with several laser diodes. In this study, two commercial array spectroradiometers with CCD, the array spectroradiometer A and B, were selected. The measurement wavelength ranges of the array spectroradiometers A and B were 300 nm to1110 nm and 350 nm to700 nm, respectively.

Each laser beam was divided into two optical paths, Path-A and Path-B, by applying a polarization-beam-splitting (PBS) cube. Before irradiating to an irradiance head of the array spectroradiometer, the divided beams were aligned to the same spot by adjusting two plane mirrors and another PBS cube. The power balance between each beam was adjusted with an optical attenuator. By blocking the beam from one of the optical paths alternatively and opening both beams using two mechanical shutters, the output counts, CA, CAB, and CB, of the array spectroradiometer were measured in a time-symmetrical sequence. The linearity factor was calculated by CAB/(CA+CB). By increasing the laser power multiplicatively, the nonlinearity of the array spectroradiometer was obtained by summing up successive linearity factors.

As the light sources in the flux-addition method, three Fabry-Perot laser diodes (FPLDs) and a diode-pumped solid-state (DPSS) laser were used. To evaluate the wavelength dependence, the incident laser wavelengths were chosen as 405 nm, 460 nm, and 660 nm for the FPLDs and 530 nm for the DPSS laser, respectively. The spectral bandwidths of the lasers were 1 nm for the FPLDs and 2 nm for the DPSS. Laser intensity drift of approximately 0.03 % and wavelength drift of less than 0.01% were attained for all the lasers by the stabilization with thermoelectric coolers whose temperature variation was controlled within 0.01 K. These lasers were operated with a constant current source at

room temperature. Each beam was adjusted with a collimating lens to obtain a near-Gaussian spectral shape and a 1.0 mm beam in diameter.

3. Results

The spectral nonlinearities at four wavelengths—405 nm, 460 nm, 530 nm, and 660 nm—for the two array spectroradiometers were evaluated. For all the measurements, the exposure time was set to be 20 ms and the normalized output count was chosen to be the indicated output count of 1. For the two array spectroradiometers used in this study, the nonlinearity values decreased so that the output count was lower, and the nonlinearities did not show spectral dependence. The spectroradiometer A showed the nonlinearity of 4% in the output count range of three orders of magnitude, whereas of the spectroradiometer B showed that of 25% in the output count range of two orders of magnitude, respectively. This nonlinear behaviour can be explained by the difference of floating diffusion nonlinearity when detecting the charge at the CCD and a lowering of charge-transfer efficiency of the CCD with the increase of the output count. Additionally, Different nonlinear behaviour depends on the type of the CCDs in the spectrometers.

To investigate the influence of the nonlinearities observed for the array spectroradiometers when they are used for source colour measurement, the change of chromaticity coordinates (x, y) by spectral power distribution of light sources with and without correction with respect to the nonlinearity was compared for each spectroradiometer. Three light sources based one white LED (blue LED+ yellow phosphor), tricolor LEDs (blue, green, and red), and tricolor LDs (blue, green, and red), all of which were adjusted to have the correlated colour temperature of 3025 K, were selected for these comparison. The comparison between the corrected and uncorrected conditions showed that the nonlinearity of 25% in the spectroradiometer B gave the maximum differences of 0.2 and 0.1 in x and y values, respectively.

4. Conclusions

Spectral nonlinearity measurements of two commercial array spectroradiometers were performed in the visible region. Different nonlinear behaviour was observed depending on the performance of the CCDs in the spectroradiometers, whereas no clear wavelength dependence was observed for both spectroradiometers. Using the observed nonlinearities, their potential error for source colour measurement was evaluated by using ofthree types of common spectrum (a blue-YAG type white LED, R-G-B tricolor LEDs, and R-G-B tricolor LDs).

PO58 (PP36)

COMPARISON OF GONIPHOTOMETRIC METHODS FOR OLED

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Abstract

1. Motivation, specific objective

OLEDs are innovated light sources which are still undergoing major improvement. This new technology in the lighting technology promises wide usage in the practice owing to properties of these light sources. The necessity of their characterisation for electrical, colorimetric and photometric quantities is undoubtedly very actual. However, the requirements and test methods misses in the international standards. Therefore, recently in CIE was established new technical committee TC 2-83 to create standard on test methods for OLED light sources. Simultaneously, this standard should amend recently released international standard CIE S025:2015 with the requirements for measurements of important quantities which characterise OLEDs. One of the important parameter is luminous intensity distribution curve (LIDC) to describe spatial characteristics of OLEDs to provide this information for other process in combination with statement of luminous flux from this curve. This measurement is performed by means of goniophotometer is the fundamental measurement method for the measurement of spatial distribution of the light output of light sources. Although in the science community the measurement of LIDC by goniophotometers based on various methods is very well known and sufficiently defined for OLEDs, in some international standardisation committees, prevails hesitations about using of some goniophotometric methods based on near-field goniophotometry with imaging photometers. These hesitations block implementing of this method for measurement of LIDC into the other standards what is making difficult to work for testing laboratories using this types of goniophotometers. Furthermore, this fact not allow to use references of these standards into another documents or standards. To cancel doubts about goniophotometry of OLEDs it should be underpinned by real measurements using different goniophotometers on different OLED light sources samples to validate of using various types and methods to also follow present standards.

2. Methods

This paper deals with investigation of the measurement various methods in goniophotometric measurements using various OLEDs samples with different goniophotometers e.g. two light source rotating goniophotometers, two different types of mirror goniophotometers, near-field goniophotometer with imaging photometer, goniophotometer with rotating arm with photometer and rotating light source around of OLED's axis. Cooperation between three testing laboratories having these types of goniophotometers will be presented. Previous work already done in few years ago on LED luminaires was extended to test of OLED light sources.

3. Results

Based on the measurement of different OLEDs was identified reliability of used goniophotometers and methods to measure of LIDCs of samples of OLEDs. The presentation will show

- comparison two approaches used in practice for measurement of LIDCs e.g. far-field goniophotometry vs. near-field goniophotometry for OLEDs,
- comparison various types and technologically different goniophotometers used for OLEDs
- what correction methods (if applicable), shall be applied to reach best possible accuracy for some

4. Conclusions

Comparison of goniophotometer based on near-field method need to be performed to prove ability of the measurement of this system in goniophotometric measurements of OLED light sources. The reference method was considered for far-field goniophotometers without changing working position of OLED light source in the Earth gravitational field which are based on allowed methods in the international standards and widely accepted in the standardisation community to underpin acceptance of near-field goniophotometers into the test methods of OLEDs. Even more, meassurements by goniophotometer with changing position of the light source in the Earth gravitational field with rotating light source widely used by testing laboratories was done to prove also their ability to perform measurements of LIDCs of OLEDs.

PO59 (PP37)

PARAMETERS CONTRIBUTING INTO THE UNCERTAINTY OF FIELD MEASUREMENT IN THE VERIFICATION OF REALISATION OF LIGHTING SYSTEMS

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Abstract

1. Motivation, specific objective

To have good indoor lighting system of indoor workplaces is very important for health and well-being of the persons especially for workplaces with long-term staying of persons. After installation of lighting system based on lighting design according to international standards for designing of lighting systems shall be performed verification of the lighting design. It performs by means of field measurement in the practice with photometric devices to measure various parameters which are defined in the standards. Each result of measurement should have the non-negative assigned parameter evaluated according to guide developed in BIPM (GUM). However, field measurement is not performed under laboratory conditions and lot of parameters influence the result of measurement. Furthermore, nowadays still exist doubts about expression of uncertainties for field measurement and agreement in this problem among science community is not clear. The estimation of this important parameter is undoubtedly necessary to judge if result of measurement is in the frame of desired limits defined in the standards. Until now it was not precisely defined unified guideline or recommendation at CIE or ISO level how to perform evaluation of uncertainty of measurement in the field measurement for verification of lighting systems beside on road lighting where some ideas where changed into the local standards or recommendations. In some countries is verification of lighting design one of the condition to have building commissioning of lighting system and shall be performed when new building or reconstruction of lighting system was done. At the present CIE standard S008 for indoor lighting is under revision and in the near future will be released new updated version. Also for anothe lighting systems as sports lighting or outdoor lighting standards describe necessity of measurement. In these documents are also included notes about necessity of verification indoor systems by means of field measurement which are performed by lighting designers by means of lighting calculation tools. Some discrepancies between simulations and realisation of designs were described in some papers.

2. Methods

In the research work were performed field measurements of various lighting systems in the practice based on common methods using in the stage of verification using devices properly metrologically characterised e.g. illuminance meters, luminance meters etc. Parameters which significantly contribute to the uncertainty of measurement were investigated in these measurements using guide GUM. Even more new approache for evaluation of uncertainty as Monte Carlo method were investigated and they will be presented as method for estimation of some parameters contributing to the uncertainty of measurement. For photometric quantities were evaluated from the measurements according to standards define requirements of particular lighting system. Correlations between some photometric parameters should be assumed.

3. Results

Based on the field measurements of lighting systems were identified parameters which contributes to the uncertainty listed in the uncertainty budgets for various cases and lighting systems installations. The use value of this parameter in results to be able consider how to treat with uncertainty will be presented in the paper.

4. Conclusions

The non-positive parameter shall be assigned to the result. This parameter is uncertainty and obviously minimum of investigation about this parameter was performed in the practice for verification of lighting systems so far besides road lighting. Very often evaluation process of uncertainties in the

field measurements are avoided due to lack of knowledge about parameters which contributes in the measurement. Therefore identification of all parameters contributing into the uncertainties is very important for practice by means of list of uncertainty budges similarly to measurements under laboratory conditions in combination with new approaches which appear in the process of evaluation of uncertainty of field measurements.

PO60

PHOTOMETRIC MEASUREMENT OF ROAD LIGHTING LUMINAIRES

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Abstract

The results from goniophotometric measurements are very important for lighting engineers who are using these results in lighting calculation of photometric parameters of the various lighting systems. These results are in the form of an intensity table (I-table) which gives the distribution of luminous intensity emitted by the luminaire in all relevant directions. Luminous intensity is measured in defined angular intervals in the (C, γ) system of coordinates. Especially in road lighting calculation distance between angles should be measured as much as possible providing sufficient photometric data for the calculation purpose. The opinions about the right distance between angles are different also inside professional lighting communities although stated angular intervals present in the standards are so far. In CIE 140 is defined that angular interval in photometric azimuth (C) shall at most be 5° and angular interval in vertical photometric angle (γ) shall at most be 2,5°. Some new optical systems and some LED luminaires which as found by measurement may contain various local extremes in the luminous intensity distribution curve. Due to this fact is in the CIE note that the some types of luminaires, in particular those with LED light sources require smaller angular intervals.

The paper deals with the influence of the density of measurement angular intervals to the resulting light intensity distribution curve and performance parameters. On individual cases will be shown difference between the light intensity distribution curve measured by the angular intervals due to CIE 140 and the smaller angular intervals. The results of these comparison will be able to be a basis to determine an appropriate measurement angular intervals for road lighting luminaires.

PO61 (PP38)

ASSESSMENT OF FILAMENT LED BULBS WITH RESPECT TO TEMPORAL LIGHT ARTEFACTS

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Abstract

Temporal light artefacts, abbreviated TLAs (including flicker, stroboscopic effect and phantom arrays), i.e. undesired time modulation in luminance from a light source, has shown to be a threat to wider SSL adoption especially related to dimming functions and low-quality LED products. This is due to the effects that both noticeable and unperceivable TLAs have on human perception and wellbeing. In the summer of 2016 the CIE TC 1-83 published a technical note (Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models) in which methods which can be used to quantify TLAs are described, e.g. the visibility measure M_v. In the present work a number of filament LED bulbs, currently available on the market, are assessed with respect to TLAs.

1. Motivation, specific objective

The objective of this work is to establish a pre-study of an overview of the state of the current market of commercial available LED lamps and put the results in relation to the recommendations put forward in some recent publications, such as the Product Performance Tiers published by the IEA SSL Annex (http://ssl.iea-4e.org/product-performance) or the IEEE Std 1789-2015. The work presented investigates filament LED products, which are a relatively new category of products where the form factor sets very tight limitations on the size of driver electronics.

2. Methods

There are a number of measures to quantify TLAs, including Flicker Index and Percent Flicker (also called Modulation depth). Together with the frequency of the modulated light, these figures can give a sufficient judgment of the TLA, however that is not always the case. Addition information is in most cases needed in order to verify the impact of the TLA on human perception. The visibility measure, M_v, is a measure of the visibility of the stroboscopic effect proposed as a standard metric by the CIE.

In the present work, a number of commercial available filament LEDs are investigated and the TLAs are quantified using both Flicker Index, Percent Flicker, the frequency of the modulated light and the visibility measure M_v. Additionally, not only TLAs are measured, but electrical, photometric and colorimetric parameters as well, such as power consumption, luminous flux, radiant flux, correlated colour temperature and colour rendering index. Regarding colour rendering, this is assessed using both the current standard of CIE CRI Ra, and the fidelity index R_f and gamut index R_g proposed in TM-30 by IES in 2015.

Some of the investigated bulbs are dimmable, and furthermore some of those are equipped with so called colour tuning, i.e. the colour temperature is decreased as the lamps are dimmed. Here the dimming properties, such as dimming range, dead-travel and occurrence of dimming introduced TLA are investigated, and the TLAs, photometric and colorimetric properties are investigated as a function of dimming level.

Regarding TLAs in combination with photometry, the integration time needs to be taken into consideration. Otherwise this can led to inaccurate results especially in the luminous flux value. To effectively avoid this issue the integration time needs to be an even multiple of the repetition period of the modulated light.

3. Results

The expected result is a comprehensive table, showing the resulting values of visibility measure M_v, CCT, CRI, luminous efficacy etc. for each of the investigated lamps. This overview will serve as a pre-

screening of the state of the current market of filament LEDs. The results will also be viewed in the context of the resent suggested recommendations regarding TLAs in SSL products.

4. Conclusion

The presented work will investigate a limited amount of a specific SSL product (LED filament lamps) with respect to TLAs, and put the results in relation to recently published recommendations regarding the both noticeable and unperceivable effects TLAs have on human perception and wellbeing.

PO62 (PP39)

BROADBAND DEEP-ULTRAVIOLET TO BLUE LED MEASUREMENTS

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Abstract

Deep-UV LEDs have low output optical power. For radiometric applications, they need evaluations and selections. Also, traditional photometric measurements in the blue wavelength range have large uncertainties because of the poor realizations of the CIE standard V(□) function in the wings. Pyroelectric radiometers with low noise-equivalent-power (NEP) and flat spectral response have been developed with NIST coordination to solve these LED measurement problems. The relative detector-response was determined from spectral reflectance measurements of the black-coating between 250 nm and 800 nm. The new pyroelectric radiometers have NEP of less than 1 nW/Hz1/2 and can be used at the output of regular monochromators. They also can accurately measure the broadband irradiance from deep-UV LEDs where the manufacturer reported output optical power is only between 1 mW and 50 mW. These pyroelectric detectors are an order of magnitude more flat in the UV-VIS range than filtered silicon detectors. An irradiance responsivity tie point for the pyroelectric detector was derived from a silicon-trap-detector. This scale transfer, was performed in the collimated irradiance of a current and temperature controlled LED of 660 nm peak. Using the tie point, the relative response function of the pyroelectric detector was converted into an irradiance responsivity function. The deviation of the response function from a constant value was less than +/- 0.2 % between 250 nm and 780 nm. This spectral flatness was validated in DC mode against a Si photodiode standard down to 350 nm. To improve the stray light in the UV, the validation was performed using an LED collimator with 368-nm peak at the input of the monochromator as an alternate source of the originally used tungsten-halogen lamp. The flat pyroelectric detector measured the integrated irradiance from deep-UV LEDs with nominal wavelengths of 265 nm, 275 nm, and 285 nm and also from high power LEDs with 365 nm, 400 nm, and 405 nm peaks. Source standards were not used in these detector-based calibrations. The broadband irradiance measurements were performed at different distances. The low-end limit of the measurements for the pyroelectric detector was 2 □W/cm2 at a signal-to-noise ratio (S/N) of 100. The spectral irradiance responsivity uncertainty of this new pyroelectric radiometer standard was 0.25 % (k=1) between 250 nm and 780 nm.

PO63 (PP40)

WAVELENGTH CALIBRATION OF SPECTRORADIOMETERS WITH PICO-METER UNCERTAINTY

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Abstract

Accuracy wavelength calibration of an array spectroradiometer is critical to many applications. We developed a method for calibration of the wavelength scales of array spectroradiometers using a tuneable kHz optical parametric oscillator (OPO) laser and achieved a wavelength uncertainty on the level of picometers; a reduction of approximately two orders of magnitude compared to those using traditional methods. This high-accuracy wavelength calibration method can significantly reduce the overall measurement uncertainties in various applications.

1. Introduction

The accurate wavelength calibration of an array spectroradiometer is critical to many applications. For measurement of optical radiation of a light source using a spectroradiometer a small wavelength error can result in a large spectral measurement error in the spectral region where the spectrum of the light source (e.g., a colour LED source) rises or falls sharply or where the spectral responsivity of the spectroradiometer changes rapidly. An array spectroradiometer is typically calibrated for its wavelength scale by measuring a limited number (e.g., 10) of narrow spectral emission lines with known wavelengths and then determining the wavelengths for the corresponding pixels near the calibrated wavelengths. The wavelengths of the rest (majority) of the pixels are obtained through interpolations, extrapolations, or curving fitting based on the small number of calibrated pixels. Using this conventional calibration approach, the wavelength uncertainty across the entire spectral range is limited to a sub-nanometer (for metrology-grade spectroradiometers) to a few nanometers (for low cost spectroradiometers). In order to reduce the wavelength uncertainty, a much larger number of spectral lines are required for the wavelength calibration. Therefore, Fabry–Perot etalons and Lyot filters were proposed to be used for wavelength calibrations, both of which produce multiple transmission maxima over the spectroradiometer's spectral range. However, such devices are not readily available, and also, their transmission maxima are typically broad which limits the wavelength calibration uncertainty.

2. Method of the wavelength calibration

In this paper, we describe a different approach for the calibration of wavelength scales of spectroradiometers that uses a fully automated, commercial kHz tuneable optical parametric oscillator (OPO) laser. A metrology-grade 1024 pixel CCD-array spectroradiometer was calibrated for its wavelength scale. The spectral range of the spectroradiometer is from 300 nm to 1100 nm with a bandpass of approximately 2.5 nm. The OPO laser was tuned across the entire spectral range of the spectroradiometer with a wavelength step of 5 nm. The wavelength of the OPO laser was measured by both the spectroradiometer and a high accuracy laser spectrum analyser with pico-meters wavelength uncertainty. The total number of measured laser lines is approximately 160. Because the wavelength calibration was fully automated, the total measurement time was within one hour.

3. Results of the wavelength calibration

The measured wavelength error of the metrology-grade spectroradiometer varies from approximately -0.2 nm to 1 nm across the spectral range and changes rapidly in some spectral regions, indicating a fine step wavelength calibration is required. Based on the large number of measured wavelength errors across the spectral range, the wavelength error of each pixel was obtained by interpolation between measured wavelengths, and a correction for wavelength error was applied to each pixel. As the result, the wavelength uncertainty of the spectroradiometer is reduced to a level of a few pico-meters.

4. Summary

High accuracy wavelength calibration of an array spectroradiometer is critical to many applications. A fast method for calibration of the wavelength scale of an array spectroradiometer is developed using a fully automated kHz OPO laser. A calibration uncertainty of wavelength on the level of pico-meters was achieved across the entire spectral range of the spectroradiometer, which is an improvement of approximately two orders of magnitude compared to those using conventional approaches.

PO64

STUDY ON THE EFFECT OF COLOUR TEMPERATURE ON LEARNING

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Abstract

Recently, along with numerous other developments in lighting technology, there have been significant advancements in the field of light emitting diode (LED) technology. For example, LED lighting has been decreased in price, in addition, straight tube type LEDs have been developed and such systems are now being introduced into offices and classrooms. Moreover, lighting systems that allow users to freely control colour temperature and illuminance are becoming commercially available, and it is now possible to create various lighting environments using LEDs. Previous studies have found that low colour temperature environments have calming effects and that high colour temperature environments improve concentration. It is also suggested that mental stress is alleviated by changing colour temperature. However, there have been no reports of detailed investigations into the influence of colour temperature on various learning tasks. Therefore, in this study, we aimed to clarify the influence of colour temperature on learning. To that end, we conducted two experiments, the first of which investigated the influence of colour temperature on learning efficiency, and the second of which examined the effects of changing colour temperature during adaptation at lighting environments on subsequent learning. In both experiments, the experimental work surface illuminance was set to 500 lx. Experiment 1 was performed under three colour temperature conditions, and the learning tasks were calculation, memory, concentration, and sentence-related work. Experiment 2 was performed by Changing colour temperature change pattern to 8 conditions, and learning tasks were simple tasks. From the electrocardiogram (ECG) data recorded throughout the experiments, we extracted the low-frequency/high-frequency (LF/HF) values that act as sympathetic nervous function indicators. The results of our experiments also suggest that 4000 K is suitable for memory and sentence-related tasks, and that changing the colour temperature from 3000 to 5000 K by the start of the tasks increased alertness. Especially, it is noted that the change may be even more effective if it occurs one minute before the start of the tasks.

PO65

RESEARCH ON THE RANGE OF PLEASANT DARKNESS AND BRIGHTNESS IN RESTAURANTS

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Abstract

1. Motivation, specific objective

In various studies on spatial brightness, many predictive equations and methods are examined. Luminance (distribution) is used in most cases, instead of illuminance, to examine the relation with the sense of brightness. As measurements of luminance distribution became simpler, and with the technical development of lighting simulation, discussion is held to include luminance as one of the lighting standards. The Environmental Standards “AIJES-L0002-2016” published by Architectural Institute of Japan included average luminance in the standard as its first attempt. It is important to confirm that goals listed in the standard are attainable before including it into the standard. This includes being able to confirm using measurable means, and that it is a realistically achievable value. In order to find out luminance distribution that is generally achievable, previous research clarified the relationship between the average illuminance and luminance using lighting simulation in common settings with several lighting methods. However, since the relationship between the range of pleasant lighting situation and its luminance distribution is not clarified, this research aims to determine a pleasant lighting environment using an adjustment method in a simple full scale experimental situation.

2. Methods

Previous researches point out that necessary brightness differs among activities; therefore restaurant was chosen as it is a generally used space, and ranging from bars to family-friendly casual restaurants, “eating” behaviour takes place under various lighting environments and level of brightness. In order to examine various main visual targets, ranging from horizontal plane to vertical plane, four behaviours, namely “eating”, “drinking”, “relaxing”, and “chatting”, were selected. Lighting methods were selected through a bibliographic survey, and three lighting methods used in dark environments were selected; local lighting method using spot lights to light tables, general lighting method using down lights with wide lighting distribution, and indirect lighting method using cornice lighting.

Two experiments were conducted in the same apparatus. As a basic experimental setting, a white interior room with no windows was used. To increase reality of the setting, mannequin and food replicas were placed as necessary associated with the above behaviour. For the first experiment, using adjustment method, subjects were asked to adjust lighting power to the threshold value between “dark” and “not dark,” and “unpleasant” and “pleasant” (in upward and downward adjustment directions, 48 adjustments in total) for each lighting method (3 methods) and behaviour (4 behaviours). 20 students in their 20s and 30s were the subjects, and darkening filter sheet was placed on the lighting equipment in order to adjust precisely.

Lighting environment was measured, and the following illuminance values were measured; vertical plane of the subject’s face, vertical plane of the mannequin’s face, table surface (average of five points including the centre), and the wall (average of six points). Luminance distribution was measured at the subject’s eye level, and the following values were calculated using distribution; average luminance of the whole viewing field (180 degrees from right to left and top to bottom, using fisheye lens with an equisolid angle), the table surface, the wall and the mannequin’s face.

For the second experiment, darkening filter sheets were removed from the lighting equipment to adjust lighting in a brighter range. This time, subjects were asked to adjust threshold between “not bright” and “bright”, “unpleasant” and “pleasant”, and “bright” and “too bright”, in addition to “pleasant” and

“unpleasant”, which was adjusted under high illuminance levels (96 adjustments in total). 20 students in their 20s and 30s were subjects, and lighting environment was measured similarly to experiment 1.

3. Results

Using the results of experiment 1, t-test was being done, and there were significant difference in 9 out of 12 conditions between the “darkness” threshold value and “pleasantness” threshold value, and “pleasantness” threshold value were darker in all cases. Therefore, it shows that, under a certain condition, “pleasantness” exists even in a dark environment.

Logistic analysis was conducted, setting physical quantities such as luminance and illuminance values on x-axis, and responses of the subjects for each lighting power level on y-axis. A point with a positive response rate of 50% was calculated (in other words, a point that 50% of the subjects would respond “yes”). Overall, the point was within the range of 5-17 cd/m2, and it tended to get brighter in the following order; local lighting, indirect lighting and general lighting, as the brightest. Although brightness associated with each behaviour differs slightly by the lighting method, overall, it gets brighter in the following order; drinking, eating, relaxing and chatting.

As a result of t-test of experiment 2, there were significant differences between “not bright” threshold value and “pleasant” threshold value in all 12 conditions. On the other hand, statistical differences between “too bright” threshold value and “unpleasant” threshold value were not observed. Although it might be due to lighting power limitations, conditions evaluated as “too bright” and “unpleasant” at the same time did not exist in this experiment. As a result of logistic analysis, the threshold value of “pleasantness” was always lower than the threshold value of “brightness”, which indicates that “pleasantness” also exists within a range that is “not bright”, which confirms the result of experiment 1.

4. Conclusions

As a result of the experiment, range of “darkness”, “brightness” and “pleasantness” were clarified under 4 behaviours and 3 lighting methods. For discussion, the experimental results were compared with standard values. Further study will be carried out under a more realistic space using various wallpapers, and another experiment will be conducted, which includes elderly people in the subjects.

PO66

WHITE LED FOR ILLUMINATION OF CHINESE TRADITIONAL LIGHT COLOUR PAINTING

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Abstract

Chinese traditional paintings are one of the important elements of the world's cultural heritage, most museums have special traditional painting exhibition hall, additionally, many of the famous foreign museums also hold a large number of precious Chinese paintings. Traditional painting extended for more than 1300 years, resulting in a wealth of ancient art with high aesthetic and cultural value that has been preserved for centuries. According to the ICOM (International Council of Museums) and the CIE (Commission Internationale de L'Eclairage), the standard of museum illumination design is "highly responsive" in terms of chemical stability. Optical radiation from any light source causes permanent damage to Chinese traditional paintings. Chinese traditional painting has the characteristics of abundant stock, high-value and vulnerability, and is an important type in the research of exhibition illumination.

The paintings can be divided into heavy colour painting and light colour painting categories. Heavy colour paintings are those created with the use of inorganic pigments, which are made from natural mineral material, while light colour paintings are those created with organic pigments. The most commonly used organic pigments are carmine (red), cambogia (yellow), indigo (cyan), and pine-ink (black). Compared to inorganic pigments, organic pigments are more likely to be affected by the illuminant. Consequently, for this study, we selected Chinese traditional light colour paintings rendered by organic pigments as the research object. At present, the research for illumination protection on paintings mainly focuses on Western paintings, such as oil paintings; and very few studies focus on Chinese traditional paintings. At the same time, the current researches are mostly about traditional light sources such as metal halide lamp and halogen tungsten lamp. The WLED is currently a hot topic in the field of exhibition illumination due to its advantages, the luminous principle and spectral irradiance distribution of WLED is different from the traditional light source. The practical of WLED applicability lacks scientific basis and the damage degree to painting are unknown up to now.

A solution to the above problems is derived by constructing the experiment in optical laboratory. The experiment utilized a WLED (CCT =2700K, Ra=92, 13.3W) as experimental light source, and a tungsten halogen lamp (CCT=2700K, Ra=97, 50W, with an infrared filter to remove the infrared spectrum), a metal halide lamp (CCT =2700K, Ra=95, 35W) as contrast light sources. Three groups of painting specimens was manufactured using typical organic pigments (carmine, cambogia, indigo, and pine-ink) to paint red, yellow, cyan, and black colours with traditional techniques and materials. Three experiment groups were used according to light sources: First, we set three illumination experimental boxes and adjusted temperature, humidity, and air quality in each according to standard requirements, which remained constant throughout the experiment; next, we separated the three boxes into independent spaces with blackout cloth to ensure that they did not interfere each other; and finally, we set the painting specimens under the three light sources and adjusted the distances between light sources and specimens to control consistency of the irradiance for each group of specimens.

The illumination was provided for 12 h each day during 6-day cycles, and the entire experiment included 20 cycles (a total of 1440 h). With prolonged illumination time, the total exposure accumulated, and the chromaticity coordinate was measured at the end of each illumination cycle: First, a Topcon BM-5 illuminance meter was utilized to measure the CIELAB chromaticity coordinates (a, b) and L* under the D65 standard light source after each illumination cycle. Then, the colour difference was calculated and the plot of colour difference against exposure was drawn. Finally, the fitting curves of colour difference against exposure for four pigments were drawn, and relative influence coefficient of different light sources on four organic pigments were obtained by analysing the regression equation.

These results provide a data base for the related research and also provide a reference for choosing light sources in the design of museum lighting. The conclusions can guide the museum staffs to better protect the cultural relics and reduce the damage caused by artificial lighting.

PO67

EFFECTS OF LIGHTING ON APPAREL FOR VISUAL MERCHANDISING

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Abstract

Lighting may affect product sales by enhancing visual merchandising in a fashion store. A good lighting design may help enable customers to better appreciate the style and the texture of a fashion product, and thus eventually increase sales. The interaction between lighting and fabric texture plays a significant role in creating attractive appearance of the apparel. To better understand how lighting can affect visual merchandising, the present study used apparel as an example presented in an indoor environment where various lighting setups and various fabric textures were used as the main factors that might affect the observer's preference, perceptual clarity and visual attention to each apparel sample presented.

To do this, a psychophysical experiment was carried out, in which 6 pieces of clothes, serving as the apparel samples, having the same slim line silhouette and the same colour (i.e. black) but different textures were presented individually using a mannequin under various lighting setups in an experimental room. The 6 textures included (a) polar fleece made from 100% polyester with knitted structure, (b) plain weave made from 100% cotton, (c) mesh fabric made from 100% nylon, (d) sateen made from 100% cotton, (e) double jersey knitted made from 88% cotton and 12% polyester and (f) non-woven fabric made from 100% polyester.

A panel of 20 observers with normal colour vision took part in the experiment. Prior to the experiment, each observer was asked to assess each of the 6 apparel samples in terms of tactile smoothness (without watching the clothes samples). Each observer then conducted a questionnaire to determine their fashion involvement and whether they were an opinion leader.

The experiment was divided into 2 stages. In Stage 1, a 7-channel ETC Source Four LED lamp was used as the light source, set up at the height of 1.5 meters, positioned at a 45-degree horizontal angle and 1.5 meters away from the 1.6-meters-high mannequin, with the light projected horizontally towards the mannequin's left shoulder. The lamp had a beam angle of 36 degrees. A total of 12 light colours were used in random order to light the apparel samples, including cool white (CCT=6500K), warm white (4000K), medium white (5750K), red, orange, amber, yellow, pink, cyan, blue, purple and magenta. During the experiment, each observer stood in front of the mannequin, with a viewing distance of 2.4 meters. For each of the 12 light colours, the observer was asked to visually assess each apparel sample presented on the mannequin in random order, in terms of 4 semantic scales "value of apparel", "richness in colour", "liking" and "visual smoothness".

In Stage 2, the apparel samples were lit by two lamps at the same time. The two lamps were situated on the left and the right sides of the mannequin, with a horizontal distance of 1.5 meters each. The light was projected horizontally towards the mannequin's two shoulders. During the experiment, 10 pairs of light colours were used for the two lamps: red-red, yellow-yellow, green-green, blue-blue, red-yellow, red-green, red-blue, yellow-green, yellow-blue and green-blue. The observers' tasks were the same as those in Stage 1.

The experimental results of Stage 1 show that for the "value of apparel" scale, white and blue lights tended to result in high-value response, while light colours in the other hue regions tended to make the apparel sample feel low-value.

For the "richness in colour" scale, the observer responses were found to be somewhat opposite to those for the "value of apparel" scale. When the lighting's colour was in the hue region of red, orange and yellow, the apparel sample tended to appear rich in colour, while light colours in the other hue regions tended to make the apparel sample feel weak in colour.

For the “liking” scale, the experimental results show that the observers tended to like apparel samples when the light colour was white or magenta, while light colours in the other hue regions tended to make the apparel sample feel less likable.

For the “smoothness” scale, when the light colour was white or was in the hue regions of red, orange, yellow and green, the visual smoothness and the tactile smoothless were closely correlated. For light colours of the other hue regions, i.e. blue and purple, low correlation was found between the visual smoothness and the tactile smoothless.

The experimental results of Stage 2 show that the scale values, i.e. the observer responses, for “smoothness”, “value of apparel” and “richness in colour” for the two-colour lighting can be well predicted by the arithmetic mean of scale values for the single-colour lighting. For example, the scale value for “smoothness” of apparel sample lit by a red lamp and a yellow lamp can be well predicted by the arithmetic mean of scale values for apparel sample lit by a red lamp and for that lit by a yellow lamp. This finding suggests an additivity relationship between the effect of single colour lighting and colour-combination lighting.

The results also show that only the scale “richness in colour” has high correlation between high fashion involver and low fashion involver. For the other scales, there was medium correlation between these two observer groups.

Findings of this study can help develop guidelines of lighting design for fashion retailers in order to provide more appealing display of products.

PO68

SPATIALLY RESOLVED SPECTRAL SKY DAYLIGHT MEASUREMENT DATA: METHODS OF COLLECTION, EVALUATION AND REPRESENTATION

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Abstract

Spatially resolved spectral power distribution measurements of daylight are carried out in Beijing (China), Berlin (Germany), Bratislava (Slovakia), Hannover (Germany) and Kyoto (Japan). The measurements are used to develop spectral sky models on the basis of CIE General Standard Skies and the Perez All-Weather Sky Model.

Information about the spectral distribution of daylight is relevant in the evaluation of the impact of daylight on human beings, materials, room appearance and energy conservation. It allows, for example, to assess performance of new technologies such as spectral selective fenestration materials or to determine the resulting non-visual effects of daylight in indoor and outdoor premises. Spectral data of daylight can also be used in the development of innovative lighting controls or artificial windows. To provide designers, researchers and engineers with validated spatially resolved spectral data, a cooperation between institutes is planned within IEA Task “Integrated solutions for daylight and electric lighting” and a Research Forum of CIE Division 3 “Interior Environment and Lighting Design”. The aim of this collaboration is an aligned approach of data collection, evaluation and representation of spatially resolved spectral sky data.

This paper describes a proposal for such an aligned approach. Both collection and processing are illustrated by using information from measuring sites in Berlin and Beijing. The paper includes the description and comparison of measuring equipment, incorporating applied calibration procedures and discrepancies, to confirm reliability of data collection from both sites. Additionally, the paper will present examples of spectral data sets for both Beijing and Berlin, being a result of alignment of data evaluation and representation.

With the collected data for different institutes, it will be possible to develop simplified measuring equipment, to set up a finer grid of measuring sites, to obtain more regional spatially resolved spectral information of daylight. The combined activity will also give insight into regional influences and the possibility to develop general spectral sky models.

PO69

STUDY ON THE EFFECT OF LED'S CORRELATED COLOUR TEMPERATURE AND ILLUMINANCE ON MUSEUM LIGHTING

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Abstract

1. Motivation, specific objective

In order to investigate suitable LED lighting conditions for viewing fine art paintings in a museum environment, in order to know the vision difference between easterners and westerners and to know the vision difference between male and female, the effect of correlated colour temperature(CCT)and illuminance to human vision was tested and studied in this paper.

2. Methods

The experiment was conducted in a room designed to simulate the exhibition of real paintings in museums. Simulated museum was established in a dark room. The background colour of wall was chosen according to the National Gallery of the United Kingdom. Fourty observers participate in the experiment to evaluate 6 paintings under 12 different lighting conditions. 12 lighting conditions were established on the base of 4 CCT values and 3 illuminance levels. On the base of the categorical judgement method, 13 word pairs were used to assess each painting under each lighting condition.

2.1 Lighting

LED sources were used in the experiment. They are named LEDCube. Four LEDCubes were used in the experiment in order to obtain enough illuminance level. LEDCube can accurately produce a range of sources from 2000K to 10000K. It is made of 11 different wavelength led lamps and includes 64 led lamp beads.

There are four CCTs(3000K、4000K、5000K、6000K) and four illuminance levels(50lx、200lx、600lx) under each CCT in the experiment. Different illuminance levels of the same CCT have extremely similarity in the shape of the SPD curve. Stable lighting conditions have been got in the experiment. Under the 12 lighting conditions, luminance uniforms were all larger than 60%. CRI values were all better than 94%. Duvs were all better than 0.005. Deviations between target CCT and real CCT were less than 35K. Deviations between target luminance and real luminance were less than 1%.

2.2 Obervers

Fourty observers included twenty easterners and twenty westerners, and included twenty men and twenty women.

2.3 Paintings

Six oil paintings included one fruit, one inside, two portraits and two outsides. The largest size is 1020 mm *720 mm（Width * Height）, the smallest size is 200 mm *260 mm（Width * Height）.

2.4 Scales

The method of categorical judgment was used in the experiment. Thirteen word pairs were used as scales to evaluate all the paintings under each lighting condition. They are comfortable /uncomfortable, pleasant/unpleasant, lively/boring, natural/unnatural, bright/dim, high contrast/low contrast, warm/cool, high vividness/low vividness, high gloss/low gloss, high texture detail/low texture detail, moist/dry, colourful/not colourful, clear/unclear. Each word pairs was evaluated using eight-point categorical scale from -4 to 4.

2.5 Procedure

For each lighting conditions, when observers were looking at the paint, they were asked to give one score to represent their feeling to each word pair. Before the experiment, observer's colour vision was tested by the Ishihara. The first step of the experiment procedure is to adapt one of lighting conditions for 1 minute. Then the observers used the 13 word pairs to access the paintings one by one. During this period, the experimenter read out questions and the observers answered orally to avoid the incomplete chromatic adaption likely to be caused by the observer staring at a questionnaire printed on white paper. Each observer participated in the experiment two times. Every time 6 lighting conditions were used. For each observer, the order of the paintings and the order of the lighting conditions were random.

3. Results

On the base of the experimental data, the mean rating curve on each word pair against CCT and illuminance was plotted. The results showed that the illuminance had a positive impact on visual perception and the impact of CCT on visual perception was different under different the illuminance level.

3.1 Impact of CCT and illuminance

Illuminance had a positive correlation to most scales except natural/unnatural, warm/cool, moist /dry but the effect weakened as the illuminance extended 200lux. To natural/unnatural, 200lux was the most suitable illuminance. To warm/cool and moist /dry, it was difficult to judge which illuminance was better between 200lux and 600lux, but 50lux was still the worst one.

Under 200lux and 600lux, CCT had no obvious impact on visual perception to most scales except warm/cool, moist /dry. To warm/cool, 4000K could brought obvious cool feeling. To moist /dry, 5000K could brought obvious dry feeling.

Under 50lux, a CCT around 3000K could brought obvious good visual comfort to most scales only except moist /dry. And 4000K,5000K and 6000K had a little impact on visual perception.

3.2 The vision difference between easterners and westerners

According to the experiment result, the visual perceptions of easterners and westerners have no obvious difference. The only difference is the impact of CCT to glossy under 50lx. under 50lux, CCT had a positive correlation to gloss for westerners while CCT had a negative correlation to gloss for easterners.

3.3 The vision difference between male and female

The visual perceptions of male and female have no obvious difference to most scales except comfortable /uncomfortable and pleasant/unpleasant. For westerners, Illuminance had a clear positive correlation to comfortable /uncomfortable and pleasant/unpleasant, but for easterners it was difficult to judge which illuminance was better between 200lux and 600lux. Under 50lux, for westerners, a CCT around 3000K could brought obvious good visual comfort, 4000K,5000K and 6000K had no difference. But for easterners CCT had a negative correlation to comfort.

4. Conclusions

High illuminance will be more suitable than low illuminance for viewing paintings. Under high illuminance lighting condition, CCT had a little impact on visual perception. But under low illuminance lighting condition, a CCT around 3000K could brought obvious good visual comfort. A comfort zone of illuminance and CCT for museum lighting has been proposed.

PO70

MUSEUM LIGHTING WITH LEDS: EVALUATION OF DAMAGE POTENTIAL FOR CONTEMPORARY PHOTOGRAPHIC MATERIALS

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Abstract

1. Motivation

In 1826, Joseph Nicéphore Niépce produced the world's first photograph "View from the window at Le Gras". The image products allow the photograph to record the general civilization widely of the world. Henceforward, there are more photographic materials be used in modern art. For example, there are more than 150,000 pieces of contemporary art collections in the Museum of Modern Art (MoMA), and 25,000 photographs furthermore.

In 1996, the CIE technical report 157:2004, "control of damage to museum objects by optical radiation", classified museum collection in 4 groups according to different light fastness. However, these studies were assessed in conventional light sources. Even LED technology was popular nowadays, there is no advanced evaluation about fading or colour change test for contemporary art works. In a recent study by the U.S. Department of Energy (DOE)-GATEWAY program supports evaluation and demonstration of high-performance solid-state lighting (SSL). The result realized that blue-pump LED is generally the least likely product type to cause material degradation at any given CCT. Even the violet-pump LED poses no more risk than a typical incandescent or halogen lamp. However, there has been no discussion about how the LED will degrade the modern art materials so far. Hence, the aim of this study is to modify the CIE157:2004 with LEDs and contemporary photographic materials, and to put into practice in the exhibition.

2. Methods

The art work damage was assessed by measuring different physical and chemical parameters. One of the most useful parameters is colour shift, which is symptomatic of chemical changes inside the material. When light sources with varying spectral irradiance distribution illuminate on the object, the extent of artifact damage due to radiant exposure can be represented by colour shift. The aim of this study is to verify the threshold of effective radiant exposures (Hs,dm) for the contemporary photographic materials, which is specified by the just noticeable different (JND) in $\Delta E^*ab=1$ under a given light exposure.

Accelerated ageing test was conducted for each primary colour colorant (cyan, magenta and yellow) of 3 types of photographic materials (9 pieces total) adopted in modern art frequently: Chromogenic print (denoted by C-print), Cibachrome print and inkjet print. They were illuminated by two types of 4000K white LEDs and a 4000K tungsten halogen lamp. For two white LEDs, one is blue-pump type with CIE Ra = 96 (termed white LED (blue-pump)), and the other is purple-pump type with CIE Ra = 88 (termed white LED (purple-pump)).

The samples are cut to 2 × 2 cm and located in the center of test chambers. The test light sources were installed on the top of chamber. Colour measurement is carried out in a stable environment set at 20±5°C with a relative humidity of 55±5%RH. The experimental data is assessed with an Elsec 765 environment monitor. A spectral irradiance meter ISM-Lux is used to measure the ambient illumeinence. Furthermore, the colour changes of test samples before and after the light exposures are measured at 150,000 lux-hour for each time. A total of light exposures are performed 13 times. The cumulative exposure is 1,950,000 lux-hours. Metric colour differences are evaluated based on CIELAB colour space.

3. Results

This study follows the criterion of "noticeable fade ΔE*ab=1" defined by CIE 157:2004. For the C Print, the ranking of Hs,dm was: tungsten-halogen lamp > white LED (blue-pump) > white LED (purple-pump). For the Cibachrome print, the Hs,dm was ranked as: white LED (purple-pump) > white LED (blue-pump) > tungsten halogen lamp. For inkjet print, the Hs,dm was ranked as: white LED (purple-pump) > tungsten-halogen lamp > white LED (blue-pump). As a whole, tungsten-halogen lamp tends to induce more colour change than the white LEDs, the LEDs had less radiant exposure (thus, safer) than tungsten-halogen lamp.

Both Cibachrome print and inkjet print have similar trend order (C Print＞Cibachrome print＞inkjet print) in the Hs,dm data. Even C print indicates the best ΔE*ab =1 radiant exposure score in comparison to the other two photographic materials, the cyan's colour shift value appears the maximum vale after 1,900,000 lx.hrs light dosage, no matter in white LEDs or tungsten-halogen lamp. Cibachrome print had a lower light-dosage than C-print in white LED (blue-pump) and tungsten-halogen lamp, but more stable in white LED (purple-pump). The yellow colorant of Cibachrome print presents the worst colour shift after 1,950,000 lx.hr exposure. Obviously, inkjet print is rather sensitive to all test illuminants, and yellow colorant shows the easiest to colour shift under the white LEDs.

4. Conclusions

From the above results, the limited light dosages for the photographic materials seem not to be in accord with CIE157:2004. This study identifies the Hs,dm model had a trend similar to the "1 unit of ΔE*ab" method, for which the ranking was white LED (purple-pump) > white LED (blue-pump) > tungsten-halogen lamp. This has confirmed to the earlier study by DOE, the purple-pump LED poses no more risk than a typical incandescent or halogen lamp, and tungsten-halogen lamp is easier to cause colorant fading in comparison with white LED (purple-pump). The phenomenon appears different damage potentials in their colour rendering properties, and that should be further investigated.

From the result of threshold effective radiant exposure corresponding to "1 unit of ΔE*ab", it is clear that different photographic materials present different fading degrees. The museum conservators should identify the types of photographic materials before they take action. This study provides a revised light dosage classification of modern photographic materials for museums. And this also offers the other art materials (i.e., oil painting and water colour) a reference to assess the damage potential under various illuminance levels.

PO71

THE ANALYSIS OF ARTIFICIAL ILLUMINATION PROBLEMS IN CHINESE COMMERCIAL BUILDINGS BASED ON VISUAL COMFORT

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Abstract

With the development of the economy and quality of life, the number of commercial buildings in China has dramatically increased, therefore the rise in energy consumption is becoming an increasingly serious problem. According to statistics, commercial buildings have the highest energy consumption of large-scale public buildings with 4–8 times more consumption than other public buildings. The proportion of total energy consumption on lighting in commercial buildings is 35% -40% compared to only 10%-20% for office buildings. Therefore, the reduction of energy used for lighting of commercial buildings has become an urgent problem for architects. Moreover, people's demand for particular materials and culture is increasing, so the role of commercial buildings has been transformed from pure "material consumption" to "material and spiritual dual consumption" in the society. Thus, people are becoming increasingly concerned about the physical environment in commercial buildings. Artificial lighting plays an important part in this physical environment, and the design of artificial illumination directly affects the visual comfort of consumers when they are shopping and seeking entertainment. Energy savings cannot be at the expense of visual comfort. Therefore, in order to reduce the energy consumption used for lighting in commercial buildings while maintaining high visual comfort, existing artificial illumination problems in Chinese commercial buildings urgently need to be summarized and analysed, and appropriate solution strategies and recommendations need to be presented.

In order to assist in solving this problem, this paper selected eight large-scale commercial buildings in Beijing and Tianjin, China to carry out a field investigation. This field investigation includes the measurement of the physical quantities of artificial lighting and the subjective evaluation of visual comfort. First, six physical quantities - space illumination, commodity illumination, general colour rendering index, colour temperature, light uniformity and glare – were measured for the selected areas of traffic areas, clothing stores and jewelry stores, etc. In addition, the illumination methods utilized in the selected areas were recorded. Second, for each area measured, questionnaires were sent to customers and sales clerks to subjectively evaluate visual comfort. The main questions in the questionnaires included "How do you feel about the level of brightness in the current light environment?" "Do you often feel the glare?" "How do you feel about the visual comfort in the current light environment?" The amount of lighting, glare, visual comfort were evaluated through the answers which were designed to provide a range of answering options. For example, the answer for visual comfort had five options from uncomfortable to comfortable.

By analysing the statistical data from this field investigation, the illumination situation in Chinese commercial buildings is described, as existing problems are summarized, and recommendations and solution strategies are presented. Commercial buildings blindly increase the amount of lighting to attract consumers. By comparing the measured data of the physical quantities of artificial illumination in commercial buildings and the specified values from Standard for Lighting Design of Buildings (GB 50034-2004), we find that the measured values are much higher than the current specified values, resulting in high illumination energy consumption in commercial buildings. However, this study find that high illumination did not bring high visual comfort, and the visual comfort in different areas of commercial buildings still need to be further improved. In view of the above problems, the following recommendations for improvement are put forward: A further experimental study should be implemented to obtain trends between visual comfort and the physical quantities of artificial lighting. Then, according to the trends, the numerical range of each physical quantity of artificial illumination will be determined, when the visual comfort requirements are met. On this basis, reasonable

illumination for commercial buildings can be designed, lighting energy consumption can be reduced, and the visual comfort in the lighting environment can be improved.

This study can provide guidance for the revision of standards for lighting design of Chinese commercial buildings. The conclusion can provide a reference for more rational commercial building illumination design to improve visual comfort and reduce lighting energy consumption.

PO72

VERBAL DEFINITION OF OBJECT COLOUR PERCEPTION IN ARTIFICIAL LIGHTING

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Abstract

1. Motivation, specific objective

Light is one of the most vital elements and enables people to perceive their environment and to continue their activities. The light necessary for visual perception is obtained by natural or artificial light sources. The colour appearance of objects depends on three components. The first component is a source visible electromagnetic energy necessary to initiate the sensory of vision. The second component is an object, whose chemical properties modulate the electromagnetic energy. The third component is human visual system. It is obvious that the perceived colour of an object varies according to the source type that it is illuminated by.

The colour quality of the light sources used in the lighting design has an important role in achieving the targeted and required effect for the impact of lighting. Nowadays the improvements in technology and the increase in the number of artificial light sources make it possible to select and use any source in any colour. Especially with the invention of gas-discharge lamps and LEDs (light emitting diodes) designers have begun to use coloured sources in lighting.

In the lighting applications, the colour qualities of the sources are generally determined by “colour temperature” and “colour rendering”. Indeed, the relevant standards include limitations / determinations on the colour properties of the sources to be used for lighting. In addition, various colour ordering systems have been developed for the identification of object colours. However, it is also a fact that in daily life the non-colour-educated people use verbal adjectives to describe the colour properties of objects. These adjectives are generally aimed at the hue and value of the object colour.

The purpose of this study is to investigate verbal definitions of colours experimentally, that are illuminated by light sources with different colour features (colour temperature and colour rendering), selected by a certain colour ordering system and perceived by non-colour-naming-educated persons. In other words it will sampled how far the variations of the colour perception can be expressed by non-colour-educated people due the change in colour characteristic of the light source. Thus, there will be a new knowledge about the effects of light source colour properties on object colours which create differences in verbal terms of users in daily life in lighting and colour design of spaces, forensic medicine etc.

2. Methods

The steps of research can be described as:

- Determining the light sources with various colour properties and surface colours which are both used frequently in daily life,
- Preparing the experimental environment,
- Measurement of inherent colours and spectral reflectance of the colour samples,
- Determining the responses of the subjects as verbal descriptions of perceived surface colours,
- Statistical evaluation of the responses obtained from the experiment.

3. Results

In the experiments, 12 colours were used which were determined according to Munsell Colour System with 5 light sources which are frequently used in practice. With light sources, a certain and similar illuminances are created on the surfaces. A total of 32 subjects, 22 female and 10 male, participated in

the study. Subjects used verbal adjectives for the colours they perceived for a total of 60 different conditions and their responses were recorded. The findings of the experiment were tested statistically by Student t test and SPSS.

Some of the statistic evaluation results of the findings of the experiment can be summarized as follows:

- There is no distinction between male and female subjects in terms of verbal description of colours.
- In terms of adjectives used in everyday speech, the perceived surface colours are much richer in terms of hue than the other colour components (value and chroma). The most undefined component is the chroma.
- Changes in colour-perceived colours for light sources similar in colour properties (colour temperature and colour rendering index) have been determined in the same way.

PO73

A STUDY ON QUANTITATIVE EFFECTS ON THE ENERGY SAVINGS OF DAYLIGHTING HARVESTING SYSTEMS IN NON-RESIDENTIAL BUILDINGS IN JAPAN

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Abstract

1. Backgrounds and Purposes

Improving the energy-efficiency of buildings is an important issue also in Japan, and until 2020 newly-built buildings will be gradually required to conform to energy saving standards under the Energy Saving Act (Act on the Rational Use of Energy) established in 2015 and enforced in 2017. Electricity consumption for lighting in non-residential buildings is not negligible even after high efficiency LED lightings have become widespread. Therefore, the Energy Saving Act places importance on daylight harvesting as an energy-saving method in non-residential buildings, of which openings are indispensable for a better working environment. In this research, annual daylight simulation was conducted to acquire basic data to examine the estimation method which makes it possible to evaluate the energy-saving effect of daylighting harvesting in simple and quantitative way.

2. Methods

A basic model for the simulation was 39.8m wide, 15m depth and 2.8m high, and it was supposed to be an office room with daylighting harvesting systems using sensors on the ceiling facing the floor. We changed several factors which will influence the effect of daylighting use: Window-to-Wall ratio (0.3, 0.5, 0.69), window orientation (East, South, West, North), the number of surface having the window (1,2,3), venetian blind position (fixed to 45 degrees, automatically controlled blinds to cut sun light) and depth of the space (7.8m, 15, 22,2m) and so on. Simulation programme Radiance was used for this simulation using standard annual daylight data (LESCOM) which include annual solar luminance and sky luminance distribution per 1 hour in Tokyo metropolitan area. Working hours in this office was set to be from 8:00 to 20:00 on weekdays. The calculation steps was as follows: 1) Calculate the annual daylighting illuminance per hour measured at the sensors on the ceiling facing the floor, 2) Calculate the dimming rate of luminaires when average desktop illuminance is kept to 750lx by using only LED luminaires, 3) Calculate the sensor illuminance when LEDs were turned on at the dimming rate for desktop illuminance 750lx, 4) When LEDs in one zone are fully turned on, the sensor illuminance in other zones are calculated, 5) Based on 1) – 4), calculate the annual dimming rate per hour in each dimming zone, by solving simultaneous equations. 6) Assuming the LEDs' dimming rate and its power consumption is in a linear relationship, annual electric power consumption of luminaires per unit floor area (kWh/m^2) is calculated. Energy-saving effects of daylighting harvesting were computed by calculating the reduction rate: lighting power densities in the daytime divided by those at night.

3. Results and conclusions

In the case of general daylighting harvesting in Tokyo, which has side windows, fixed venetian blinds and sensors on the ceiling facing the floor, there was a clear correlation between aperture ratio (Window-to-Floor ratio) and annual energy savings of artificial lightings, regardless of the room shapes or window orientation (East/South/West). When the aperture ratio is 10%, approximately 10% of the annual electric power consumption can be reduced, and in the case of 20% aperture ratio, we could have about 20% of energy-saving effects. In addition to that, when using the automatic control venetian blinds system, of which positions are changed to cut direct sunlight, the energy-saving effects of daylighting harvesting increases by more than 5%, compared with those of 45 degree fixed blinds. The results show that the aperture ratio (Window-to-Floor ratio) will become one of the valid indexes to evaluate the energy-saving effects of daylighting harvesting in simple and quantitative way.

PO74

A STUDY ON THE LEDS COMBINATION RATIO OF WINDOW LIGHTING FOR COLOUR TEMPERATURE AND CIRCADIAN ACTION FACTOR OF REAL SKY

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Abstract

1. Motivation, specific objective

Humans had lived in daylight (skylight) before artificial lightings were developed. Therefore, the human's circadian rhythm and life patterns naturally follow the sun (skylight). As the civilization developed, humans spend most of their time with artificial light in the building. Also, life in underground space where daylight does not enter has increased. The lack of exposure time to skylight negatively affect the human's circadian rhythm. To provide underground space, windowless space, submarine, spacecraft, etc. with luminous environment qualitatively similar to natural skylight, the advanced skylight lighting systems are needed to develop. Therefore, the goal of this study is to develop a window lighting system, which can create colour temperature and circadian action factor of real sky in real time.

2. Methods

For the development of a window lighting system, this study analysed the chromaticity coordinate, CCT, illuminance, and circadian action factor of natural skylight. This study also analysed the effective LED's mixing ratios of warm white, cool white, Red, Green, and Blue LED chips.

3. Results

CCTs of skylight were measured with a range from 4,000 K to 10,000 K over the day. The fluctuation of CCT was the largest during the sunrise. CCTs of skylight were measured at 5,000 K ~ 6,000 K after 7 a.m. The CIE 1931 x and y coordinates were measured at 0.2700 ~ 0.3730, and 0.2877 ~ 0.3825, respectively. CAF of skylight were measured with a range from 0.98 to 1.5

4. Conclusions

Since the high colour temperature of the white LED currently developed is about 6500K, it can not realize the maximum colour temperature of 10,000K of sky light and can not realize the CAF value. Therefore, it is suitable to configure the window lighting by combining the white LED device and the blue or green LED device.

PO75 (PP17)

RESEARCH ON THE INFLUENCE MECHANISM OF THE ARTIFICIAL LIGHT ENVIRONMENT EVALUATION INDEX ON OFFICE LIGHTING COMFORT

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Abstract

People learn about the world through hearing, sight, scent, taste, and touch, and 80 % of obtained information comes from light-induced vision. Therefore, the main research topic of architectural optics has been to create a comfortable light environment to improve overall visual performance. Artificial light environment is an important component of the indoor environment; its function is to meet the physical, physiological, psychological, ergonomic, and aesthetic requirements. A comfortable and healthy light environment can not only be pleasing both mentally and physically, but it also helps to improve efficiency, as well as to avoid the type of light that may cause discomfort or potential injury. With access to relevant research results from both at home and abroad, there are still some issues pertaining to the study of a comfortable artificial light environment. First, the evaluation method of a single parameter and discrete variable lacks the consideration of the coupling effect between variables. Secondly, the evaluation process using expert and non-expert field evaluation is not easy to operate. Therefore, the only way to further improve the research within the field of lighting is the rational use of mathematical methods, which are based on human subjective evaluation experiment built on the establishment of the multi-parameter comprehensive evaluation system. Taking into account the varying types of buildings, there are differing artificial light environment requirements, so the class of buildings that has been universally studied should be chosen. For the standard office building, the building space is relatively simple, people stay longer, and the artificial light environment has specific requirements; therefore, a small office space should be chosen for the study.

This paper mainly adopts the research method of subjective evaluation experiment, and explores the effects of artificial light environment based on the comfort of the lighting. First, a typical office space is built, the walls are light, brushed with white latex paint, and the window is shaded with a curtain cloth. Following the foundation of this area, the lamp is configured. Experimental straight fluorescent lamps were selected as experimental lamps, and configured with a dimmable ballast for the controlling the brightness of the lamp during the experiment. Furthermore, this experiment has developed a set of adjustable light control systems, and prepared a dimmable control program used to record the experimental conditions set in advance. The experimental conditions are then set. As an indicator of artificial light environment, the illumination (100l x, 200l x, 300l x, 400l x, 500l x), colour temperature (2700 K, 4000 K, 6500 K), colour rendering index (high colour group: 96, 91, 90; low colour group: 70, 61, 49), and illumination uniformity (0.4, 0.7) were selected. In ensuring the experimental method and procedure are reasonable, the combination of the index levels selected for each parameter should be arranged according to the above four lighting physical quantities, obtaining 36 kinds of artificial light environment conditions. Finally, the settings for the questionnaire and the experimental subjects. There are ten experiments in total, each questionnaire survey necessitates three subjects. The questionnaire provided two questions: “What do you think of the overall room ambient light comfort?” and “What do you think of the current light environment?” The questions were evaluated by scoring according to the degree of seven levels, respectively, from very uncomfortable to very comfortable and from too dark to too bright.

After the end of the experiment, the investigational questionnaire was entered and the results were statistically analysed. It is found that in the case of low illumination, the light environment created by the high colour light source is obviously more comfortable than compared with the low colour light source in the same situation. Colour temperature in the 2700 K low colour temperature light source to created a more comfortable light environment than using the same conditions but replacing it with a high colour temperature light source. In the case of high illumination, the colour temperature ranging between 4000 K and 6500 K or so in the high colour temperature light source created a higher degree of light comfort, where the 4000 K colour temperature of the light source had the highest comfort. In

the low colour temperature, the light environment is less comfortable. By using the results of the comfort questionnaire, the influence of illumination, colour temperature, colour rendering index, and illumination uniformity on the degree of comfort and brightness were found to further study the quantitative effects of individual physical environment on visual comfort. Combining the questionnaire statistics and experimental data correlation analysis, the correlation does not exist in interactions between independent variables; followed by a multivariate linear regression analysis by SPSS software, the mathematical model of artificial light environment is established. Further, a quantitative evaluation of the effects of various optical environment parameters on visual comfort in artificial light environment was conducted.

The model integrates a number of artificial light environmental evaluation indexes, taking into account the influence of parameter coupling. At the same time, the model is based on subjective evaluation, which eliminates the cumbersome evaluation of field scoring and has the reliability and convenience of optical environment comfort evaluation, as well as provides the basis for the establishment of the artificial light environment evaluation system. In addition, it also explores the relationship between the artificial light environment evaluation index by mathematical method.

PO76 (PP18)

MEASUREMENT OF ILLUMINANCE SATISFACTION REGARD TO DUTIES AND NEW CONTROL METHOD OF INTELLIGENT LIGHTING SYSTEM USING SATISFACTION LEVEL

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Abstract

1. Motivation, specific objective

In order to clarify the range of the preference illuminance that the office worker believes is easy to perform office, we examine the relation of satisfaction degree to the illuminance of the office worker. Next, in the conventional Intelligent Lighting System, there are cases where the target illuminance cannot be realized due to the physical characteristics of the illumination when the target illuminance of the adjacent office worker is greatly different. In this case, the illuminance determination is performed using a policy relating to illuminance determination such as giving priority to high illuminance, giving priority to low illuminance, providing average illuminance. Then, we decide the illuminance to provide to the officials based on physical indicators for both policies. However, in this method, problems such as extremely low satisfaction of a specific office worker occur. Therefore, based on the satisfaction level which is a psychological indicator of each user rather than a conventional physical indicator, all workers We propose a method that can obtain high satisfaction. Finally, since satisfaction with illuminance can be considered to change with season, physical condition, time, consider the learning function to estimate satisfaction level while doing daily work. We introduce this learning function to the Intelligent Lighting System, above mentioned, which maximizes satisfaction.

2. Methods

We propose a new intelligent lighting system that all officers can obtain high satisfaction. Then we propose a learning function to estimate satisfaction while doing daily work.

3. Results

When the illuminance close to the target illuminance was gained, a high level of satisfaction was obtained, and when the illuminance far from the target illuminance was gained, the satisfaction level decreased. Next, Intelligent Lighting System that introduced satisfaction compared to the standard Intelligent Lighting System could provide an illumination environment where all office workers can obtain high satisfaction. Finally, the Intelligent Lighting System that introduced satisfaction compared to standard intelligent lighting system has a small difference in satisfaction among each office worker, and it is said that all the officers have obtained similar satisfaction.

4. Conclusions

It was found that the degree of satisfaction got higher near the illuminance preferred by the office worker and the satisfaction level decreased when leaving the preference illuminance. In addition, we found that the relationship between illuminance and satisfaction level differs for each worker. Next, by measuring the degree of satisfaction of the office worker in advance, it is possible to calculate the degree of satisfaction for each office worker for the illuminance realized by the Intelligent Lighting System. Then, by performing control to maximize the total satisfaction level of the satisfaction of all office workers and dimming each lighting, the average satisfaction level of all office workers is higher than that of the conventional Intelligent Lighting System, and further We propose a new Intelligent Lighting System control method with less variability of satisfaction degree obtained by all office workers. Finally, while the office worker performs daily work, entering satisfaction with respect to the illuminance at that time enables learning the relationship between the illuminance to be provided to the office worker and the degree of satisfaction to the illuminance. Moreover, by inputting satisfaction degree every day, it is possible to learn appropriate degree of satisfaction for each office worker over

time, so that the proposed Intelligent Lighting System change to provide better illumination for each worker.

PO77 (PP19)

FIELD MEASUREMENT OF NET-ZERO ENERGY RENOVATION BUILDING

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Abstract

1. Motivation, specific objective

In Japan, buildings are responsible for more than 30% of primary energy usage and 32% of CO2 emissions to the atmosphere. One of the goals in the energy performance of buildings is achieving Net-Zero Energy Buildings (NZEB). In recent years, the renovation of office buildings to NZEB have proceeded. For NZEB renovation, photovoltaic panels, daylighting, natural ventilation, highly efficient HVAC, and replacement of conventional lamps by LED lighting are all recommended.

NZEBs should keep the comfort of their occupants as a priority. For the visual environment, well-controlled daylight and electric light are effective to reduce electric consumption and to keep occupants comfortable. An office building in an urban area near Tokyo was renovated to an NZEB. In this paper a field survey and subjective assessment of the visual environment of an NZEB renovation were carried out.

2. Methods

In the subject building LED task-ambient lighting and automated venetian blinds were used. The LED task-ambient lighting is controlled to keep the desktop illuminance around 300 lx. This electric light control requires input from the ceiling sensors. In addition, ceiling light fixtures protruding from the ceiling surface to provide ambient light to the ceiling surface. The automated venetian blinds in the northwest and southeast sides are controlled so that their slats cut direct sunlight (cut-off angle control).

The field survey and subjective assessment investigated (1) winding up the automated venetian blinds during periods of no direct sunlight, (2) the lighting environment produced by the protruding fixtures, and (3) the subjective assessment of brightness level.

The field survey was carried out in the subject NZEB renovation office for three days in sunny and cloudy conditions. The field survey conditions included two ambient lighting controls (dimming control based on desktop illuminance and without electric light) and three blind positions (horizontal angle of the slats, wound up, and closed). Desktop illuminance, luminance distribution, and brightness image (proposed by Nakamura) for each condition were measured from the 8 desk positions of the workers. Luminance of the ceiling surface and the glare index for daylighting (PGSV) for each condition were measured from the center of the office by HDR images.

A subjective assessment was carried out at the same time as the field survey. The subjective assessment conditions included the three blind controls with dimming light control on the assumption that subjects were working. After four subjects observed the room and the desktop, they assessed the brightness of each on a 5-point brightness scale. They repeated this for three different desk positions.

3. Results

The results of the field survey show that the illuminance of the desktop was kept at a minimum of 300lx, when the ambient lights were controlled automatically.

The comparison of blind positions (horizontal and wound-up) shows that wound-up blinds provided more daylight, while glare index value only increased slightly. The ceiling luminance with wound-up blinds on the southeast side was greater than that with wound-up blinds on the northwest side. The average spatial brightness values were higher than 6, which is the average recommended brightness level for work places.

The subjective assessment shows that subjects evaluation about room and desktop brightness were neutral (neither bright nor dark), when the northwest side blinds were both horizontal and wound-up. On the other hand, when blinds on both sides were closed, the brightness of the desktops on both window sides were assessed as dim. In addition, the southwest side of the room was assessed as dim in the same conditions.

4. Conclusions

In the absence of direct sunlight winding up the blinds increases the luminance of the ceiling, increases the brightness of the room, and saves energy while only slightly increasing glare. When light fixtures protrude from the ceiling surface the luminance of the ceiling is higher than before. of Brightness was considered to be comfortable in all cases except when the blinds were closed. Subjective assessment of brightness for desktops closer to the windows is more difficult to satisfy.

PO78 (PP20)

EVALUATION OF VISUAL ENVIRONMENT IN AN OFFICE WITH NOVEL LED LIGHT FIXTURES

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Abstract

1. Motivation and objective

LED lighting has become wide-spread in office spaces in Japan. First, LEDs have substituted fluorescent lamps in conventional light fixtures and LED light fixtures have gradually become more widespread. LED lighting is expected not only to reduce electricity consumption but also to improve lighting quality. Since LED lighting has high directionality, a small amount of light is emitted to the ceilings or walls. In order to avoid dark ceiling and wall, a point-source-type LED light fixture emitting direct and indirect light has been developed. The fixture is designed to use the direct light as task light and the indirect light reflecting on the ceiling as ambient light. Since the LED lighting is small in power and size, seven fixtures are required per 2 m^2 of floor area (one fixture per square 533 mm). It is expected that an office space with this LED lighting system increases workers' alertness and cognitive performance. On the other hand, there are concerns that this system may cause discomfort glare. Although UGR is an index to evaluate discomfort glare from electric lighting, recent research shows that UGR cannot accurately predict discomfort glare from LEDs.

The purpose of this study is to evaluate the visual environment in an office using the direct-indirect LED lighting system. Luminance distribution, subjective impression, workers' alertness, brightness and discomfort glare are measured and evaluated.

2. Methods

Field measurements and subject experiments were carried out in two office spaces; one used the point-source-type LED light fixtures and the other used conventional light fixtures with fluorescent tubes. The point-type LED light fixture which has a special lens to change the direction of light emitted from LEDs has direct light and indirect light. The desk illuminance in the office with the LED lighting system was set at 400, 750 and 1000 lx, while that in the office with the conventional light fixtures was 750 lx. The luminance distribution of the visual field was measured for each condition. Subjects assessed the visual environment using evaluation scales including brightness sensation, glare evaluation etc. Twenty-four university students participated as subjects. In addition, a subjective experiment was conducted using three 1/10 office scale models to cancel the effect of the interior of the office on evaluation. The scale models have conventional light fixtures for tube lamps, light fixtures for diffused point lighting and light fixtures for narrow-beam point lighting respectively. For the conventional tube lighting, thirty fixtures per 100 m^2 is necessary while 400 fixtures for the diffused point lighting and 350 fixtures for the narrow-beam point lighting. The horizontal illuminance in the models was set at 400 lx and 750 lx. Twenty university students participated as subjects in the scale model experiment.

3. Results

The luminance distribution of the visual field shows that the light fixtures positioned nearer to the subject show higher luminance in the office with the conventional light fixtures. However, in the office with the point-source-type LED lighting system, the light fixtures positioned farther away show higher luminance. In the field experiment, the subjects judged that desk surface illuminated by the LED lighting system was brighter than that illuminated by the conventional light fixtures, when the desk illuminance was 750 lx. The subjects judged that the visual field with the LED lighting system was brighter than that with the conventional light fixtures. The subjects felt that the office with the LED lighting system was vivid and the office with the conventional light fixtures was sombre. The subjects

could read the manuscript illuminated by the LED lighting more easily than that illuminated by the conventional light.

To calculate UGR, the threshold luminance between the glare source and the background should be determined. It was found that the effect of the threshold luminance on UGR was small when the threshold luminance was between 500 and 5000 cd/m^2. The UGR of the office with the LED lighting system was around 23 which was higher than that for the office with the conventional light fixtures. However, glare sensation evaluated by the subjects in the office with the point-source-type LED lighting system is “just acceptable” while that with the conventional light fixtures is “perceptible”.

In the 1/10 scale model experiment, the subjects judged that the space illuminated by the diffused point lighting was brighter than that illuminated by the conventional light fixtures for tube lamp in the case of 750 lx of desk illuminance.

The result obtained from the scale model experiment showed that UGR of the office with narrow-beam point lighting resulted in UGR higher than 23, however, glare sensation evaluated by the subjects was lower than “just acceptable”.

It was suggested that the UGR possibly overestimated glare from narrow-beam point-source light fixtures in high density arrangement.

4. Conclusions

In the office with the point-source-type LED lighting system, the light fixtures positioned farther away show higher luminance, while the light fixtures positioned nearer to the subject show higher luminance in the office with the conventional light fixtures. The subjects judged that the visual field and desk surface illuminated by the narrow-beam point-source LED lighting system was brighter than that illuminated by the conventional light fixtures. Also, the result of the typing test in the field experiment, the workers’ performance in the LED lighting system was higher than that in the conventional light fixtures. It was suggested that the UGR possibly overestimated glare from narrow-beam point-source light fixtures in high density arrangement.

PO79 (PP21)

DISTRIBUTION OF REFLECTANCE ON WALLS AND CEILINGS AND THEIR INFLUENCE ON LIGHTING PARAMETERS

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Abstract

1. Motivation, specific objective

Design of interior lighting systems is often made under simplified assumptions. Inputs for calculation of lighting parameters comprise data as such as room geometry, luminous flux distribution of luminaires, arrangement of luminaires and reflectance of ceiling, walls and floor. Depending on room geometry, reflectance of main surfaces may have very significant influence on resulting parameters of illumination. It is not only about the maintained illuminance but also background luminance created by large surfaces in field of view and also energy performance which benefits from better utilization of luminous flux. For energy efficient lighting it is, therefore, important to use bright colours of walls and ceilings and to maintain these surfaces clean enough to keep the high reflectance value. Influence of the floor is less important, although not neglectable as well.

In the stage of designing the lighting system it is seldom known how the furniture is arranged and what reflectances are to be taken for calculations. The room is usually calculated for the empty state where reflectances of walls are assumed as average values that take into account some average but uniform distribution of reflectances. Indicative values of main surfaces are proposed also in international standards like e.g. in the European standard for interior workplace EN 12464-1. In particular, 0,5 to 0,8 is recommended for walls while 0,7 to 0,9 is recommended for ceiling. Painting used for walls and ceiling are normally of the same kind. Therefore, drop in the value of walls reflectance is due to objects covering the walls. The standard requires usage of light colours for main surfaces and in this point of view low values of reflectances do not satisfy this approach.

It is obvious that distribution of reflectance on walls is significant. However, it depends on light distribution from luminaires, their arrangement in space and the shape factor of the room how much this distribution affects the luminance distribution on working area. For example, luminaires with double-parabolic louvres when placed on ceiling quite near the walls, will direct light on usually upper part of walls where normally no objects are covering the surface. Bottom parts of walls where darker furniture is placed are less affected. It can be supposed that taking into account the division of walls to zones with different reflectances may lead to better adjustment of lighting design, still keeping the situation simple enough (in comparison to 3D modelling, for instance), and having in result better energy performance. Aim of the investigation is to show that using simple zoning can be a better method of simple lighting design.

2. Methods

Following the objectives of this study, first, common reflectance distributions in typical rooms in administrative, educational buildings and in similar applications have been acquired and analysed. Selection of room types cover cell offices, classrooms, corridors and storage rooms. Reflectances of objects have been measured in real installations. For the installed lighting system also illuminance on the working area and on walls have been measured. Reflectance have been measured by the luminance/illuminance method assuming the lambertian nature of reflectance of diffuse surfaces. The focus was put on reflectance of the painting which was, where possible, checked for uniformity and depreciation. Based on measured data, typical reflectance distribution schemes have been composed.

In the second part of the study, room models have been created in the calcuation sofware. The combinations comprise: different room shape factors, different light distributions from luminaires and different reflectance distributions on surface of walls including the uniform wall reflectance. Discovered transparent windows transmitting the light outside the room have also been regarded.

3. Results

Results of the analyses showed that applying the proposed zoning of walls may bring 10 % to 15 % gain in illuminance on the working area in average and even more in places closer to the walls, if work places are specifically placed in such areas. Large window areas must be covered during night-time hours by light colour curtains to avoid light tresspass through windows what may cause significant losses. The paper will publish more detailed results for different situations, discussing the differences and concluding recommendations for practical lighting design and calculation.

4. Conclusions

It can be concluded that instead of using a single figure for wall reflectances it is more appropriate do divide the walls into zones, one being two thirds of the room height and the upper part being one third of the height. Then calculated values of illuminance on the workplane using simplified method match better the real values.

PO80 (PP22)

THE USE OF COLOUR-TUNEABLE LED LIGHTING FOR RESIDENTIAL APPLICATIONS

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Abstract

1. Motivation, specific objective

The development of solid-state lighting has brought a revolution to electrical lighting, changing LEDs from sources for indicators to those for general lighting. Especially, the development of control technologies makes it easier to adjust the intensity and colour of LED sources. Past studies have suggested the effectiveness of allowing individual adjustment of lighting system in enhancing productivities and satisfactions in commercial buildings. This study was purposely designed to investigate individual adjustments of LED lighting in a residential space.

2. Methods

A full-scaled space was built to mimic a typical bedroom setting in China. Thirty-one participants, between 18 and 26 years of age, were recruited to adjust the colour and intensity of a bedside lamp. The colour of the light is limited within the gamut enclosed by (0.1411,0.702), (0.6702, 0.3033), and (0.1334, 0.0715) in CIE 1931 chromaticity diagram.

Each participant was seated in a sofa which was around 0.5 m away from the table lamp, and was asked to adjust the colour and intensity of the table lamp for four different purposes—reading, waking up, relaxing, and atmosphere—through a smart phone. The order of the four purposes was randomized for the participant. Before the start of the adjustment, the participant experienced a wash-out (or adaptation) period for 5 minutes, during which the lamp was providing 32 lx at the calibration point on the desk with a chromaticity of (0.4527, 0.3943). When adjusting the lighting for the purpose of reading, the participant was given a book; for the other purposes, the participant was asked to make the adjustment based on the appearance of the entire space. After the participant adjusted the lighting for each purpose, the experimenter recorded the spectrum, the illuminance measured at a fixed point on the desk, and the luminance measured at a fixed point on the luminaire, as dependent variables.

After finishing the adjustments for all the purposes, the participant was asked to finish a questionnaire about his or her habit and preference for using the table lamp at home.

3. Results

Based on the analyses that have performed, reading mode had the highest light level, followed by waking up, atmosphere, and relaxing. The reading mode also had the highest variation among the participant, while the relaxing mode had the smallest variation. The adjustments made the participants also corroborated the results from the questionnaire. Interestingly, we found the females generally needed a higher light level than the males for reading and relaxing modes; but males needed a higher light level for the other two modes.

White light was generally needed for the reading mode, but most light settings adjusted by the participants had chromaticities above the blackbody locus. For the relaxing and atmosphere modes, wide variation in terms of chromaticity existed among the participants. For the waking-up mode, most participants needed a white light with a low CCT level.

4. Conclusions

This study provides valueable information for us to design a good lighting system for residential applications, especially with the popularity of spectrally-tuneable LED lighting and smart control. The results here suggested that a good scene control and fine-tuned light setting can provide high-quality

and comfortable luminous environment to human beings. Further studies are necessary to compare the results obtained from a laboratory experiment and from a field study.

PO81 (PP23)

RESEARCH ON PREDICTIVE EQUATION OF SPATIAL BRIGHTNESS CONSIDERING COLOUR EFFECT

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Abstract

1. Motivation, specific objective

There are many recent studies on the predictive equation of spatial brightness. Nevertheless, there are only a few that consider colour effect, which is a vital element in space. Previous studies have pointed out that colours have influence towards perception of brightness; for example, it is known that as purity of the colour stimulus increases, and as the colour is closer to blue, perception of brightness becomes stronger. Considering these results and its influence on spatial impression, colour effect must be considered when examining perception of brightness.

It has been reported that there is a neural mechanism that maintains the perceived colour balance when adapting to spectral distribution of the visual environment. Although no exclusive relationship is identified between a specific cone response and a specific hue, it is suspected that a relationship between XYZ distribution and cones exists. As XYZ colorimetric system is an improved version of RGB colorimetric system, it is clear that colour-related information is incorporated. Specifically, Y holds the information on brightness, and when combined with X and Z, the colour can be identified.

The predictive equation designed in the previous research only used Y distribution as luminance, which was derived by the imagery analysis of luminance camera, and the arithmetic average and standard deviation of the logarithm of luminance distribution were calculated. Based on this, the following hypothesis was formed; colour effect can be considered into perception of brightness by including X and Z distribution values into the predictive equation. This research aims to adjust the predictive equation of luminance and spatial brightness, and the previous experimental conditions were re-measured using CCD camera and software, which can output and analyse X, Y, and Z distribution from a measured image.

2. Methods

In the previous research, adjustment method was applied for an experiment using two boxes with the eyehole. The interior is covered by white paper, and the front surface is covered by white paper that is curved in semi-circular (cylindrical) form, so that the edge of the box is not seen. A stimulus box is lighted with a colour lighting system with the following 28 colours and purity levels; nine colours (blue, cyan, blue-green, green-blue, green, yellow, orange, red, and magenta) with respectively three colour purity levels (10%, 30%, and 50%), and white. An adjustment box is lighted with a white lighting system, and subjects were asked to adjust the power until the brightness of the two boxes are the same. There were minimum of 18 subjects for each set (Due to significant number of sets, the experiment was split into a couple of days. Number of subjects for each set may vary because some sets were measured several times, in order to maintain a stable benchmark.). Coefficients of X and Z were identified by measuring luminance distribution under a reproduced experimental condition. In order to preserve measuring conditions of the previous research, luminance distribution area was fixed to 104 degrees horizontally and 76 degrees vertically.

The following analysing steps were taken using the measured distribution of X, Y, and Z. As a hypothesis, synthetic distribution was formed with the following coefficients in order to adjust the predictive equation; alpha for X, 1 for Y, and beta for Z. Several combinations of alpha and beta were tested, and the predicted brightness of the stimulus and adjustment were calculated for each combination. The first four testing combinations of alpha and beta were selected to observe general tendency; (alpha, beta), (1, 1), (1, -1), (-1, 1), and (0, 0). The ratio of predicted brightness of the

stimulus (denominator) and predicted brightness of the adjustment (numerator) was calculated, and optimum values of alpha and beta were verified using the ratio for each combination of each colour.

3. Results

As a result, optimum values of alpha and beta varied by colour. Tendencies were divided into two groups; warm colours, namely orange, red and yellow as one, and other colours as the other. Generally, as values of alpha and beta were smaller than 1, (0.5, -0.5) were added to the testing combinations. The optimum values of alpha and beta were derived by regression analysis.

As a result of ANOVA, which set adjustment value as the objective variable, and “light colour” and “subject” as factors in order to identify personal differences of the subjects, statistical significance was evident in both factors. Previous research also suggested that differences are caused by light colour, and optimum coefficients may differ by colour. In order to clarify different tendencies among colours, the average of the ratio of the adjusted value was calculated for each colour, which was used in the regression analysis to output values for alpha and beta. Results of the regression analysis, which input all data, were compared to identify general tendencies. As a result, excluding warm colours, there was no statistical significance in the value of alpha. Statistical significance in the value of beta was observed in most colours, but the values varied by colour.

In addition, regression analysis was applied to each subject in order to identify personal differences among subjects. Contrary to differences among colours, statistical significance was identified for alpha, but not for beta. Although none of the subjects admitted to have a defective colour vision when the experiment took place, colour perception may vary by subjects. Therefore, subjects were divided into groups, and results of the analysis were compared with the general tendencies.

4. Conclusions

Using the data of re-measuring the experimental conditions of brightness experiment using light colours with a device that outputs X, Y, Z distribution, predictive equation that considers the effect of colour is being formed. For further consideration, similar experiments will be held to examine whether similar tendencies are observed when using surface colours, in order to adjust the predictive equation

PO82 (PP24)

LIGHTING ENVIRONMENT CONSIDERING THE COMBINATION OF Duv OF THE LIGHT SOURCE AND INTERIOR MATERIAL

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Abstract

1. Motivation, specific objective

In recent years, LED luminaires have becoming much popular to correspond for the demands of energy saving or the diversity of requests for lighting environment. LED can realize a variety of luminous colour by using multicolour LED. In JIS Z 8725: 1999, it can be expressed as the same correlated colour temperature in the cases with the chromaticity distance from Planckian locus (Duv) within about ±0.02. Chromaticity coordinates of the most present light sources, such as incandescent lamp, fluorescent lamp or non-dimming type LED bulbs, are almost on the Planckian locus. However, the chromaticity coordinates of toning controllable LED tends to be located on the negative side of the Planckian locus because the most of the current toning controllable LED is composed with 2 types of LEDs with different wavelength and the chromaticity coordinates changes linearly by toning control. It has been pointed out that LED sometimes causes unnatural colour appearance due to the chromaticity distance from the Planckian locus (Duv).

In this study, subjective experiment was conducted to identify the effects of Duv of the light source on the impression of the lighting environment with consideration of the difference of room inner surface. This paper reports the combined effects of Duv of the light source and inner surface material on brightness evaluation.

2. Methods

Subjective experiment was conducted by using scale model (W: 600×D: 600×H: 600). All 15 university age students participated in the experiment as the subjects (Male:10, Female: 5, 21.4 years old in average). The experiment was conducted in two ways. In the first way, the subjects compared the brightness of a pair of scale models with different condition (paired comparison experiment). In the other way, the subjects evaluated the lighting environment in the scale model using a subset of the 14 semantic differential ratings (SD evaluation experiment). The subjects adjusted their eyes to 150 lx during the experiment.

The scale model was illuminated by the luminaire set in the centre of the ceiling. The lighting condition was set with illuminance, correlated colour temperature (CCT) and Duv. LED bulbs with different CCT (3000 K and 5000 K) were used as the source. The illuminance was set at 2 levels for each CCT by using ND filter. Duv was set at 3 different levels ranging from -0.023 to +0.0096 with 3000 K of CCT and ranging from -0.013 to +0.019 with 5000 K of CCT by using colour filter. The inner surface of the model was finished with 7 different interior materials with the reflectance ranging from 0.14 to 0.82. All 84 conditions combined with 2 conditions of CCT, 2 levels of illuminance, 3 levels of Duv and 7 types of interior material were evaluated.

3. Results

In the paired comparison experiment, the subjects evaluated the brightness in the model with each condition comparing with the standard model finished with white vinyl wallpaper (78% of the reflectance) set at 300 lx with 5000 K at Duv=0. The results showed that the subjects sensed the model lit by luminaires with Duv=+0.019 much darker than Duv=0.0034 in the case with the same interior material, the same illuminance and the same CCT. From the results of SD evaluation experiment, it was certified that the lighting environment lit by the light source with negative Duv was brighter than positive Duv and Duv=0 for each CCT and each interior material. Wilcoxon signed-rank tests were conducted to identify the significant difference in brightness evaluation between Duv=0 and positive/negative Duv. The results showed significant difference between Duv=0 and negative Duv in

the case with the whitish interior material of rather higher reflectance, and between Duv=0 and positive Duv in the case with the brownish interior material of rather lower reflectance.

In addition, the percentage of the subjects who judged the lighting environment uncomfortable never fell below 20% in the cases with negative/positive Duv.

4. Conclusions

The effects of Duv of the light source on brightness evaluation and impression of the lighting environment were analysed. It was identified that brightness evaluation was significantly different when the chromaticity coordinates was off the Planckian locus even when the correlated colour temperature of the light source was classified as the same by JIS. It was also shown that the effects on brightness evaluation differs depending on the combination of interior material and which side the Duv shifts (Duv>0 or Duv<0).

PO83 (PP47)

COLOUR EMOTION FOR INTERIOR LIGHTING

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Abstract

The relationship between colour and observer response in terms of semantic feelings, or the so-called "colour emotion" in the co-authors' previous studies, has focused on colour patches or colour images as the stimuli, presented either in a viewing cabinet or on a calibrated computer display. Psychophysical findings have shown that such a relationship was consistent and predictable, and was culture-independent for some semantic scales. For instance, observer response for "active/passive" can be well predicted by a modified version of CIELAB difference between the colour stimulus and a medium grey. Little is known, however, as to whether these findings can also apply to interior lighting. LEDs have become a dominant light source and can easily manipulate light colours to create an atmosphere. Can a room lit by a coloured light create a specific feeling that is shared by individuals in the room? Can the relationship between light colour and the observer's response be also consistent and predictable, just like what has been discovered in the conventional colour emotion studies?

Methods

To answer these questions, the present study used four Philips Colour Blast RGB LED lamps to light an entire experimental room, 3.5m (width) by 2.5m (depth) by 2.3m (height) in size, decorated like a fashion store to provide a context. Observers were asked to stay individually and rate the room in terms of 4 scales "liking", "brightness", "tension" and "dizziness". This was followed by rating of the observer's own facial skin using a mirror in the room in terms of 5 semantic scales "like/dislike", "smooth/rough", "natural/unnatural", "young/old" and "feminine/masculine".

There were 40 light colours used in this study, consisting of 25 white lights and 15 coloured lights. Note that all the 40 light colours had the same luminance value, 300 cd/m^2. The 25 white lights were selected to cover 5 Duv levels, -0.02, -0.01, 0, 0.01 and 0.02, and 5 CCTs, 3000K, 3500K, 4000K, 5000K and 6500K. The 15 coloured lights included 5 hue regions, red, yellow, green, blue and purple, and 3 levels of purity based on Illuminant E.Twelve observers, 6 females and 6 males, all Taiwanese university students, participated in the experiment. More observers will take part in this study and the results will be reported in more detail in the full paper. All observers had normal colour vision. During the experiment, each observer was seated at the centre of the room and was asked to wear a grey coat in order to avoid any influence of their clothes colour on the experimental results. For each light colour, the observer was asked to rate the room as well as his/her facial skin using the 9 scales described above after the eyes fully adapted to the lighting condition. The observer was asked to focus on the wall right before him/her when rating the room but could look around to better appreciate the appearance of the room. The sequence of the 40 light colours was randomised for each observer.

Results

The experimental results for white lights show that the Duv level had a strong impact on "brightness". The white lights at negative Duv, i.e. those located below the Planckian locus, tended to feel brighter than those at positive Duv. Regarding "liking", observers tended to like the room when Duv $\leq$ 0 more than when Duv > 0. The findings for "liking" were found to correlate well with "brightness". The experimental results also show that facial skin tended to look young, smooth and feminine for negative Duv more than for positive Duv. Nevertheless, the "natural" response for facial skin was found highest for Duv = 0.

The results also show strong influences of CCT on the observer response. The observers tended to feel less dizzy and feel the room was brighter when CCT = 5000K or 6500K, and they also found their facial skin more natural, younger and more masculine for high CCT. Nevertheless, the highest rating for "smoothness" of facial skin was found to be at 4000K.

The above findings regarding white lights indicate that the room tended to feel brighter, more liked, less tense and less dizzy for Duv < 0 than for Duv > 0. This tendency was found more significant for high CCTs, i.e. observers tended to prefer white lights having negative Duv and high CCT (5000K and 6500K).

For coloured lights, the experimental results show that blue and purple lights had the highest rating for “brightness”, while green and yellow lights had the lowest rating. Red and green lights were not preferred because they tended to create greater tension and dizziness. Among the 5 hue regions, yellow light was found to have the highest rating for “naturalness” for facial skin. Blue and green lights tended to make the facial skin feel old, rough and masculine, while red and purple lights tended to make it feel smooth and feminine.

The purity of light colour had a strong influence on observer responses not only for feelings of the room but also for facial skin. The experimental results show that the higher the purity, the more tense and more dizzy the room tended to feel, and thus the room was less liked. The higher the purity, the less natural and less young the facial skin tended to appear, and thus was less liked.

According to these findings, it is fair to say that colour emotion has a systematic tendency when examined by CCT, Duv, hue region and purity. The findings will be able to help develop guidelines for interior lighting design based on either white lights or coloured lights.

PO84 (PP48)

HOW ACCENT LIGHTING AND AMBIENT LIGHTING AFFECT HUMAN VISUAL RESPONSE

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Abstract

Layering lighting plays an essential role in creating a comfortable and appealing atmosphere in an interior space. There is an increasing demand from the industry for understanding how the combination of accent and ambient lighting can affect the occupant's visual perception in terms of comfort and attractiveness.

Methods

To answer the research question, the present study used a small experimental room, 3.5m (width) by 2.5m (depth) by 2.3m (height) in size, where a 3D polyhedron object was displayed to serve as a visual task for the observers. The three walls were grey in colour. The wood veneer floor appeared dark brown. The grey 3D object was 10.63cm (width) by 10.63cm (height) in size, placed at a one-metre-high cabinet which was covered by a black fabric, situated in the middle of the room.

A panel of 12 observers, 6 males and 6 females, with normal colour vision took part in the study, individually conducting visual assessment in the room. More observers will participate in the study and the results will be reported in more detail in the full paper. During the experiment, each observer was asked to stand right in front of the 3D object, with a distance of 1m, to assess the 3D object in terms of "sense of depth" and "liking", followed by assessment of the entire room in terms of "brightness" and "comfort".

The room used two types of lighting, accent and ambient. The accent lighting was aimed to light up the 3D object. An LED ceiling track light (1080lm, 14.8W), with a beam angle of 60 degrees, was used for the accent lighting. The light was located at either of two positions under the ceiling. The first position was right on top of the observer, providing a horizontal incident light angle of 0 degree to the 3D object, as can be seen in the top view of the room. This is called T1 in the study. The second position of the ceiling track light was located to the left side of the observer, with a distance of 1m, providing a horizontal angle of 45 degrees to the 3D object. This is called T2.

The ambient lighting was provided by indirect lighting from the three walls, the background wall behind the 3D object and the two side walls. The background wall was lit by three liner LED light bars, called W1 in this study, recessed in the ceiling to down light the background wall. Each light bar (36.9W, 1360lm) was 1m in length. The side walls were each lit by two light bars, called W2 and W3, both installed on the floor, for up lighting the left and the right walls respectively. All lights used in this study had CCT = 3000K and were provided by TONS Lightology Inc.

There were two settings of ambient lighting in this study. The first setting was that W1, W2 and W3 were all switched on and were dimmed by changing the currency at the same rate, by 6 steps: 100%, 80%, 60%, 40%, 20% and 0%. The second setting was that only W1 was switched on and was also dimmed using the 6 steps described above. The sequence of the dimming settings was randomised in the experiment for each observer. Throughout the experiment, the light intensity of T1 and T2 was kept constant.

Results

Experimental results show that for W1, W2 and W3 all switched on and dimmed at the same rate, the observer responses were found to have different tendencies between T1 and T2. For T1, the darker the ambient lighting was, the more likely it was that the 3D object felt rich in sense of depth, the 3D object was more liked and the entire room felt more comfortable. This suggests that the most preferred lighting setup was when W1, W2 and W3 were all switched off. For T2, on the other hand,

the most preferred lighting setup was when W1, W2 and W3 were all dimmed at 60% in currency to provide medium ambient lighting to the room.

When only W1 was switched on for ambient lighting, the observer responses were not affected by the positions T1 and T2 for accent lighting. In this scenario, the most preferred setting for lighting was when W1 provided a medium luminance contrast for the 3D object, the ratio of vertical illuminance for the 3D object to the background wall being 2.5:1. This was when the 3D object felt most rich in sense of depth, the 3D object being liked most, and the room being rated the most comfortable.

The findings described above reveal interesting insight into how the effect of ambient lighting on the visual response can be influenced by the position of lamp providing the accent lighting. The findings can help develop useful guidelines of lighting design for related applications.

PO85 (PP49)

EXPLORING THE IMPACT OF LED LIGHTING ON DAILY ACTIVITIES FOR THE ELDERLY WITH AGE-RELATED VISUAL IMPAIRMENT

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Abstract

1. Introduction

Many countries are now facing the challenges brought by the upcoming ageing society. The prevalence of age-related visual impairments among aged population requires careful planning of public space and environment. The design of lighting, as critical part of public facilities, should thus consider the visual needs of ageing people with different type and severity of visual impairments. Since CIE published Technical Report "196-2011: Guide to Increasing Accessibility in Light and Lighting", much research work has been done on lighting and basic visual performance. However, more empirical evidence regarding daily activities of the elderly is still in need to provide basis for further lighting guidelines and standards. This study aims to investigate the impact of LED lighting on the performance of daily activity for the elderly with age-related visual impairment.

2. Methods

Laboratory experiments were performed to test the abilities of unlocking and small object identification under six lighting conditions. Two spectral power distribution (SPD) equivalent to white LED and orange high pressure sodium (HPS) and three lighting levels (3.3, 10.0 and 33.3 lux) were used. The SPD was modulated using a multi-channel and full-spectrum LED cube. Safety goggles were deliberately modified to simulate blurred vision, central and peripheral blindness. An extra untreated goggle was also used as control group. Two tasks were performed by 10 young participants (five male and five female; mean age of 25). In Task I, participants were asked to open a lock with swastika shaped keyhole; whilst in Task II, participants were asked to pick out all five small objects out of 70 slightly different LEGO bricks close in shape and colour. Task duration with successful finishing were recorded by the experimenter as data. Each test participant carried out all 48 possible trials (4 goggles, 3 illuminances, 2 SPDs and 2 tasks). The order of the trials was counterbalanced to avoid order effect. Each test started with ten-minute adaptation to the mesopic lighting condition. In both tasks, practice trials were used to confirm understanding and familiarity on the task.

3. Results

For Task I, the initial results show that when illuminance was 33.3 lux, unlocking task took 6.11s on average under HPS SPD and slightly shorter time under white LED (5.85s). When illuminance was 3.3 lux, it took 7.25s under HPS SPD and 8.05s under white LED on average. These suggest that higher illuminance can shortens the task duration of unlocking within mesopic range, but no effect of SPD was revealed. For Task II, the initial results show that when illuminance was 33.3 lux, small object identification task took 38.58s on average under HPS SPD and slightly shorter time under white LED (23.32s). When illuminance was 3.3 lux, it took 113.27s under HPS SPD and 86.36s under white LED on average. These suggest that both higher illuminance and broader spectrum can shorten the task duration of small object identification within mesopic range. More results with statistical analyses will be included in full paper.

4. Conclusions

This work reported an experiment carried out to explore the impact of illuminance and SPD on the performance of unlocking and small object identification for the elderly with age-related visual impairment. It was found that age-related visual impairments deteriorate the performance of the two tasks, which can be off-traded by higher illuminance. There is a clear benefit when using white LED comparing with HPS SPD, for that performance of small object identification task is heavily relying on

colour rendering ability of light source. Further quantitative work with more data points under finely adjusted lighting condition is expected.

PO86

PREDICTING THE DISCOMFORT GLARE EXPERIENCED BY PEDESTRIANS

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Abstract

1. Introduction

Urban lighting is designed for all road users, including pedestrians. Pedestrian comfort has become a research topic, especially with the increasing use of LED luminaires. Indeed, the small size of LED chips can lead to high luminances that may produce discomfort glare. Due to different visual tasks and gaze patterns, the discomfort glare experienced by pedestrians may differ from that experienced by drivers. This may explain why, research on discomfort glare is still in progress. The link between the visual scene, described with geometric and photometric data, and judgments of discomfort glare collected from observers has been investigated in order to develop discomfort glare models for interior and exterior lighting.

In this context, we have investigated the discomfort glare experienced by pedestrians under various urban LED luminaires through a psychovisual experiment conducted on a test track. We assessed the ability of state-of-the-art models to predict the level of discomfort glare for this application. Part of this work has already been published in LRT journal, focusing on models predicting De Boer ratings. In the present paper, we also tested others models: Unified Glare Ratio UGR (for small sources) and Cumulative Brightness Evaluation CBE.

2. Method

Thirty-three participants were asked to rate the discomfort glare of four different lanterns on the de Boer scale with one or two luminaires switched on, for four viewing positions and two gaze directions. Hence, sixty-four ratings were collected for each participant. The vertical illuminance at the eye of the observers, the source luminance, and the background luminance were also measured.

The implementation of the models is not straightforward because choices have to be made when estimating some of the variables such as the background luminance and the glare source area. The models have been evaluated with several variations in their input parameters. The background was either considered as the road surface, or as a 30° circular visual field. Predictions were computed with the source defined as the whole lantern, or as the LED Module inside the lantern.

Mean glare ratings have been compared to the model predictions in order to evaluate their relevance for a pedestrian application. This comparison was based on the Root Mean Square Error (RMSE) and on the Spearman correlation (R^2). R^2 quantifies the ability of the model to predict ordinal results (ranking). RMSE quantifies a global error between the participants' mean ratings and the model predictions. The rating scales being different between the experiment and the models, a correspondence between them was proposed based on the literature.

3. Results

A repeated measures ANOVA was first conducted. The lantern, the gaze direction, the number of switched on luminaires, and the position, have all statistically significant main effects on discomfort glare. The variation of discomfort glare with the pedestrian's position is significantly different depending on the lantern. No other significant interaction was found.

All models overestimate the mean subjective discomfort glare compared to the experimental data, but the rankings are correlated with the mean ratings (R^2>0.68). The strongest correlation is obtained for the log(CBE) model, based on Adrian's formula (R^2>0.81). It seems that this model could be employed to rank lighting installations based on discomfort glare for pedestrians. Based on the proposed scale correspondence, the log(CBE) model (either with Bennett's or Adrian's formula) makes better predictions of the glare ratings. This is consistent with the ranges of variable values for which UGR and CBE are valid. Especially, the background luminance and the source size of our case study are

included in the CBE range, but not all the eccentricities. In addition, predictions are not very sensitive to the implementation choices tested in this work. These findings are consistent with the one obtained with the other exterior lighting models in the previous article.

Moreover, neither UGR nor log(CBE) models succeeded in predicting the discomfort glare variations among those conditions which produced the strongest glare. As these conditions also provided the highest source luminance values, the poor performance may result from the underestimation of the source luminance due to measurement limitations. Therefore, efforts should be made to improve the measurement of high luminance and high contrast for a better understanding of these models.

4. Conclusions

In a previous paper, the relevance of several discomfort glare predictors has been challenged when considering pedestrian ratings. These results have now been extended to models which do not predict a de Boer rating, and the results are in line with the previous ones. Globally, it seems that the limited range of validity of these models leads to an overestimation of the glare experienced by pedestrians. In addition, it was confirmed that the choices made in defining the background and the source have only a small impact on the model predictions in such case study. However, measurement uncertainties (e.g. underestimation of the source luminance) may impact the accuracy of the models, especially for high glare levels. Such limitations deserve to be investigated in future work to ensure an accurate implementation of discomfort glare models in urban environments. Moreover, current models do not take into account the temporal changes in the pedestrian's glare experience. Hence, we plan to investigate the glare rating during a walk.

PO87

MEASUREMENTS OF REFLECTION PROPERTIES OF A WET LED-LIGHTED ROAD

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Abstract

Objective

There is a frequent comment that the reflection from the wet LED-lighted roads are more glaring than those lighted by traditional luminaires, especially at close observation distance to lighting pole, i.e., high observation angle (α). To improve this disadvantage, quantitatively study and comparison on reflections from the wet road lighted by LED and traditional luminaire are needed. This work performed the study by on-site measurements of reflected luminance images of a wet road at various observation distance. These luminance images were analysed and converted to luminance functions of deviation angle (β), incidence angle (ε), and observation angle to get relatively more physical properties.

Methods

The measurements were performed at an experimental 2-lane road at southern Taiwan. A set of LED road luminaires were mounted on the typical lighting poles at the road, which was sprinkled to have wet surface but have no standing water. The height of the luminaires, width of each lane, and distance between the luminaires are 10 m, 3.8 m, and 43.8 m, respectively. The luminance of road was measured with a calibrated image luminance measuring device (ILMD) with 10-22 mm focal length, which can be used for low luminance level (< 1 cd/m^2), far distance (> 60 m), and low acceptance angle (< 0.1°). The ILMD was placed at distance (D) of 2, 4, 6, 8, 10 and 12 m between the nearest pole, and the height of the ILMD is 1.5 m. The acceptance angles for analysation is between 0.3° and 0.8°. A set of HPS luminaires was also mounted with the same configuration as the LED luminaires for measurements and comparisons.

Results

The average illuminance, overall illuminance uniformity, and correlated colour temperature of the measured LED luminaire are 19.6 lx, 0.49, and 3080 K, respectively. The luminance images captured at all distances showed that the reflections have both diffuse and specular components, and luminance range of road are between 0.18 and 98.6 cd/m^2. The specular component in the luminance images appears as oblong oval with long axis approximately along the observation direction. The shape and orientation of the oblong oval are dependent on the relatively positions between ILMD, ground and luminaires. The illuminance distribution, reflection properties of pavement, and degree of wet of road are also important parameters to the reflection properties.

By analysing regions of interest (ROI) of the luminance images, the positional coordinate dependent on the reflected luminance can be obtained. Furthermore, to get more relative physical properties, these data were converted to the luminance functions of deviation angle, incidence angle, and observation angle (β, ε, and α). The obtained observation angle is between 1.5° and 33.8°, which covers the usual field of view of the driver. By plotting all normalized luminance (L/L_{max}) as a function of β and $\alpha+\varepsilon$, the distribution is near an oblong bell shape with peak at about $\beta = 0°$ and $\alpha+\varepsilon = 87°$, which is slightly deviated from pure specular reflection of $\alpha+\varepsilon = 90°$. The region of L/L_{max} > 10% is an oblong oval bounded between -3° < β < 2° and 78° < $\alpha+\varepsilon$ < 92°.

To be compared with the above results of LED lightings, a set of HPS lighting were mounted at same places, and similar experiments and analysations were repeated. The measured luminance images are analogous to those measured in LED lightings with more moderate appearance, and the reflected luminance range between 0.14 and 42.6 cd/m^2. The region of L/L_{max} > 10% is also an oblong oval bounded between -2° < β < 6° and 64° < $\alpha+\varepsilon$ < 95°, and peak is at about $\beta = 0°$ and $\alpha+\varepsilon = 88°$. These

analysed data show that in this wet road with high observation angle between 1.5° and 35°, the reflected luminance by LED lightings is more concentrated and has higher contrast than those by HPS. This provides a quantitative evidence for the comment that the reflected light from a wet road is more glare by LED than by traditional luminaires.

Conclusions

We have developed a method based on on-site measurement of luminance images to study the reflected properties of LED or HPS lighted wet road. The distance of ILMD can be very close to the measured region to have high observation angles. All the measured luminance images were analysed and summarized to a distribution of reflected luminance as a function of β, ε, and α. These comparison results show that the reflected light form wet road with LED luminaires is more glare than from HPS. These analysis processes as well as experimental data are expected to provide a contribution for the improvements of LED road lightings.

PO88

DISCOMFORT GLARE EVALUATION STUDY OF LED DYNAMIC ADVERTISING SIGNS

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Abstract

This study investigates the glare perception that is caused by the LED dynamic advertising signs. Dynamic changes include colour, blinking, brightness, pattern, etc. This study obtains the parameters of measuring the brightness that are suitable for evaluating the glare caused by different LED dynamic advertising signs through the results of psychophysics experiments, and uses the differences to further distinguish the LED dynamic advertising signs as two types: LED billboard and patterned LED sign. With respect to the patterned LED sign type, the luminance measurement has to be carried out based on the static areas that are divided by zones or colour units. With respect to the LED billboard type, it would be more representative to use the average illuminance or luminance of the dynamic light source as the criteria to evaluate the glare. This study also presents a model and method for evaluating and detecting glare.

Keywords: LED Dynamic Advertising Signs, Glare, Light Pollution

1. Motivation

As business activities develop and the technology of producing light source improves, Light-Emitting Diodes (LEDs) have been widely used in our daily life. It is used not only for general lighting, but also for commercial advertising signboards and the light system of the traffic light, for instance. The new type of LED dynamic advertising signs flash, are bright and fast in response, and have highly saturated colours and great variety of content. They will attract people's attention successfully, but at the same time cause harms with their glare. Moreover, the misuse of LED dynamic advertising signs may cause more serious light pollution to the environment. To reduce the damage and hard of glare and light pollution, this study analyses five LED dynamic advertising signs that are commonly seen in Asian area, and simulates the situation when the light source of the LED dynamic advertising signs is too bright. The study then evaluates the impact of the discomfort caused by the glare when people cannot avoid such light source when they are in an outdoor environment. It is hoped that a glare evaluation model and detection method of LED dynamic advertising signs can be put forward will be put forward for the summary and discussion of the results of the optical characteristics measurement and human factors experiments as a reference for setting up the governing standards of outdoor LED dynamic advertising signs in the future.

2. Method

The setup of the lab environment of this study uses the laboratory experimentation method. It simulates an outdoor environment at night and when people cannot avoid the LED dynamic signs (view angle at 15 degrees approximately). An evaluation on the light source of the LED dynamic signs is given based on the 9-score de Boer subjective evaluation table. The number of subjects of this experiment is 40 people, and they are divided into two groups (young adults, middle-aged/elderly) based on their ages. For each gender, there are 10 subjects respectively. The subjects are instructed to sit and look at the light source at a fixed distance of 5 meters from the light source.

Five types of light source of the LED dynamic advertising signs are used in this experiment, including LED peacock light, LED eight-trigrams light, LED font-type light, LED multimedia billboard, and LED scrolling message billboard. In addition, this experiment creates the dynamic depictions of each LED dynamic advertising signs by collecting the contents often shown by general dynamic signs or by LED advertising signs manufacturers.

The method to measure the luminosity in this study is to measure the pause screen and the dynamic screen while measuring the luminance and illuminance at the same time. The luminance is measured

with the TOPCON SR-UL1R. When measuring the luminance of different signs, the range of measurement is allocated based on concepts such as areas and colours of the pause screen. The TOPCON IM-600 is used to measure the illuminance of the dynamic depiction or the content of the video of the signs. The amount of change of the illuminance of the dynamic light source is recorded by using the same distance in the measurements.

3. Results

Based on the comparison of the results of the luminosity measurements and the data collected from the psychophysics experiments, these results can be categorized according to different methods of measuring the luminosity. The five types of LED dynamic advertising signs in this study are then divided into two categories. One is patterned LED sign. This would include the LED peacock light, LED font-type light and LED eight-trigrams light. The correlation coefficient value of the maximum brightness of their single LED package with respect to the glare evaluation average is R^2=0.89. The other type is the LED billboard, which includes the LED scrolling message billboard and LED multimedia billboard. The correlation coefficient value of the maximum illuminance of their static screen, the maximum illuminance of the dynamic screen and the average illuminance of the dynamic screen all can achieve to R^2=0.90.

4. Summary

This research covers five common types of LED dynamic advertising signs. They are then divided into two types, according to the type of their light sources. Different methods of evaluating the glare are applied to different types of signs. With respect to the patterned LED sign type light source, as the arrangement of its LED light source is relatively more disperse, the brightness on the surface of most of the signs is non-uniform. Such signs usually come with highly saturated colours and flickering effects from its LED light source. As a result, the brightness measurement has to be carried out based on the static areas that are divided by zones or colour units. With respect to the LED billboard type light source, the average brightness of the surface of the light source is more consistent because the LED arrangement is periodic and denser. Therefore, it would be more representative to use the average illuminance or luminance of the dynamic light source as the criteria to evaluate the glare.

PO89

IS LIGHTING THE PAVEMENT IMPORTANT?

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Abstract

1. Motivation

Technological advances mean that local authorities have unprecedented control over street lighting. Centrally managed control systems enable individual luminaires to be dimmed and switched off remotely using automated control systems. Therefore local governments consider using this flexibility to dim street lighting after dark as a means of reducing financial spending and conserving energy. However darker pavements may be hazardous by reducing the ability of pedestrians to detect obstacles. If pedestrians cannot see enough of their environment to navigate around objects which otherwise might be a danger, then subsequent trips may result in injury and in the worst cases, hospitalization. The objective of this paper is to examine the extent of tripping on pavements at night and the nature of perceived hazards on pavements, for different age groups. Once the problem is understood then the role of street lighting in alleviating the problem can be established. It is essential to understand the needs of all pedestrians to ensure inclusive and accessible lighting design.

2. Method

65 participants aged 15-65 attended a semi structured interview where they were questioned regarding their transport preferences, walking habits, perceptions of streets, whether they had ever tripped, conditions at the time of tripping, what they perceived to be hazards on pavements and what they thought about the street lighting of areas where they tripped. Sites at which participants remembered tripping were visited and horizontal illuminance conditions recorded. Interviewees answered the questions in their own words, and reasons for their answers were sorted into categories. These were summarised by counting the number of time a reason was given.

3. Results

81% of younger participants and 75% of older participants preferred walking to taking any other transport to a nearby destination. The most frequently mentioned reasons for this were speed, reduced cost compared to public transport, less traffic and health. Almost all participants thought the streets were safe to walk, giving a wide designated paving area, well maintained pavement surfaces, and good lighting as explanatory reasons.

58% of older participants had tripped and 71% of these trips occurred after dark. In one case this was due to self reported insufficient illumination. 69% of younger participants had tripped, mostly after dark, and four of these identified insufficient illumination as the reason for tripping. However, only one participant remembered the exact trip location. This location was a cobbled surface, located on a busy street with a horizontal illuminance of 14 lux.

73% of all participants identified uneven pavements as potential trip hazards. Also mentioned were slippery surfaces, stones, garbage including fruit peel, twigs and loose tiles. However this perception was not linked to the perceived safety of streets as 83% of participants thought that the streets were safe to walk. Of those who did not think the streets were safe to walk, five people gave pavement surface as a reason for concern. Other reasons given were spatial features such as narrow paths, darkness, poor reputation of an area, and quiet streets.

4. Conclusions

Whilst trips on streets at night happen, a self reported survey found that this is rarely due to perceived insufficient illumination. Amongst both young and older participants, the condition of the pavement was given by most as a potential cause of trips. However this was unrelated to perceived safety or trip occurrence. Further research is required to establish whether insufficient illumination could cause pedestrians to trip. If, as existing research suggests, very little illumination is required to see obstacles

on the pavement, then questioning and considering reducing the requirements for horizontal illuminance could aid lighting designers by permitting more creative solutions to the lighting of cities. For example, by allowing areas of low horizontal illuminance where this is compensated for by vertical illuminance as part of an overall lighting plan in which the appearance of the whole environment is considered. Further research should explore whether lighting vertical surfaces in the environment aids boundary perception and orientation after dark, and whether this is a more important task than obstacle detection after dark.

PO90

VISIBILITY OF LED ROAD SIGNS IN FOGGY CONDITION

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Abstract

Poor weather can lead to road traffic safety problems. When it rains or when there is heavy fog on a road, it becomes more difficult for the driver to see clearly on the road due to reduced visibility, including the route of the road and the traffic signs. There is an increasing need to address this issue as many governments are now considering to replace conventional street lamps with LED lights although it is still unclear how the new technology may influence road safety, especially under the poor weather scenario. Thus, in the present study we conducted two psychophysical experiments to investigate the influence of fog on the visibility on a road lit by LED street lamps.

Two psychophysical experiments were carried out in this study, an outdoor experiment and a computer simulated experiment. The first experiment was conducted in a real road where an LED road sign was set up under two types of street lamps, an LED street lamp with a CCT of 3100K and a high pressure sodium-vapour (HPS) lamp with a CCT of 2100K. The experimental site was at an internal road of the South Campus of the Industrial Technology Research Institute in Taiwan during late evening from 6:30 pm to 11:00 pm. In the experiment, 23 observers, including 16 males and 7 females, were asked to assess the visibility of an LED road direction sign placed on the road. The sign was placed at five possible positions in random order. The five positions were determined by equally dividing the distance between two street lamps on the road. A fog generating system was used at the experimental site to create the heavy fog condition. The categorical judgement method was used to scale the visibility of the LED road direction sign, with 10-point categories described by numbers from 1 (being invisible) to 10 (being very visible).

It was found difficult to control the fog conditions in an outdoor environment, and thus the second experiment was a computer simulation experiment, conducted using 130 simulated images as the stimuli presented on a calibrated LCD computer monitor situated in a darkened room. The simulated images were created on the basis of the scenes in the first experiment. The experimental settings such as the road sign positions and types of street lamps were the same as those in the first experiment. A panel of 28 observers, including 17 males and 11 females, participated in the second experiment.

The results of the first experiment (i.e. the outdoor experiment) show that as the position of the road direction sign gets closer and closer to the observers, the visibility of the sign increases. This effect appeared to be stronger under the LED street lamp than under the HPS lamp. The influence of fog on the visibility of the road direction sign was measured in terms of luminance contrast between the sign and its background, and was scaled psychophysically in the experiment by the observers in terms of visibility, as described in the methods section. The experimental result shows low correlation between luminance contrast and the visibility of the road direction sign. This surprising result may be due to the fact that the outdoor weather conditions were difficult to control. Fog, in particular, is heavily influenced by nearby topography and wind conditions. There were several weather factors that may have affected the experimental results in this outdoor experiment.

Results of the second experiment (i.e. the computer simulated experiment) show that the higher the luminance contrast was for the road direction sign, the more visible the sign tended to appear. This tendency did not seem to be affected by either type of the two street lamps, implying that the performance of LED street light is comparable to the conventional HPS lamp.

Two psychophysical experiments of visibility of a road direction sign placed at various positions on a road where two types of street lamps were used in a heavy fog condition during late evening. The experimental results show that the closer the sign was to the observers, the more visible the sign

tended to appear. In addition, the higher the luminance contrast was for the sign, the more visible the sign tended to appear. The findings are useful in designing sight distance under the poor weather scenario.

PO91

WAVELENGTH DEPENDENT SCATTERING & TRANSMITTANCE CHARACTERISTICS UNDER ADVERSE WEATHER CONDITIONS

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Abstract

1. Motivation

Large number of accidents occurs under adverse weather conditions. Fog and rain reduce the visibility to the driver. Reduced visibility occurs due to reduced light transmittance and increased light scattering, which reduces contrast. To estimate visibility in different colour temperature light sources under adverse weather condition, it is required to know wavelength dependent transmittance and scattering characteristics under adverse weather conditions.

2. Methods

To measure wavelength dependent transmittance and scattering characteristics of the light source under adverse weather condition, we developed adverse weather simulation chamber to generate different fog density condition and different rain conditions. The size was 12.5 m (L) x 3 m (W) x 3 m (H). It was made of aluminium profiles and black PVC foam boards. The chamber has two different water pipe and nozzle systems, one for artificial fog and the other for artificial rain. In addition, it has four electrical ventilating fans and shutter grilles with which experimenter can control the fog density with input voltage to the fans. Narrow band different wavelength light sources are generated by the combination of monochromator and collimator with Xenon illuminator.

A spectroradiometer (Konica-Minolta, CS-2000) and a 2D colour analyser (Konica-Minolta, CA-2000) are used to measure scattering characteristics and transmittance characteristics. Transmittance is estimated by the ratio of the luminance of the LED flat panel light source under clear weather condition and that of the light source under different fog density. The spectroradiometer is used for the measurement of the luminance. For the measurement of the scattering of the light source under different fog condition, we used collimator attached to a monochrometer (Betham, TMc300, IL7) which provide parallel illumination under clear weather condition.

For the measurement of transmittance and scattering in different fog density, we fill the chamber with very dense fog and reduced fog density continuously by circulating the chamber with dry air using fans attached to the chamber. We measured transmittance and scattering in a constant time interval with different narrow band wavelength. Scattering are estimated by the change of the area measured by 2D colour analyser.

3. Results

Longer wave length, such as red, have better transmittance compared to shorter wavelength with narrow band wavelength. In the case of scattering, we estimated illuminating area from the 2D analyser and found that the dependence of wavelength on the scattering characteristics.

4. Conclusions

Experiments show the transmission and scattering dependence of narrow band wavelengths. In particular, long wavelengths such as red and near infrared wavelengths exhibit better transmittance characteristics of the system. This result can be used for automotive lamp design for adverse weather conditions. For example, when developing spectral tunable or colour temperature tunable LED headlamp, we can adjust the spectral characteristics of the headlamps to improve visibility depending on weather conditions.

PO92

VARIATIONS OF S/P RATIOs AND CRIs IN CHANGING SPECTRAL CHARACTERISTICS OF MULTI-CHIP LEDS

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Abstract

Since LED lightings were suggested as a new lighting technology, researches have been fulfilled on photopic, scotopic and mesopic vision under LED lightings. In the IES-TM-12-12, the S/P ratios of the warm and the cool white LEDs are noted as 1.2 and 2.04, respectively, In this paper, variations of the S/P ratios and CRIs were simulated according to the spectral changes of RGB 3-chip and RGBY 4-chip LEDs. The peak wavelengths and the bandwidths, that is, full width at half maxima (FWHM) of the LEDs were varied in the CCT ranges from 3000K to 6000K. RGBY LEDs showed different trends from those of RGB LEDs.

1. Motivation

Studies on psychological effects and physiological effects according to the colours of lights have been continuously carried out. The human eyes change the received colourless wavelengths to the perceived colours and recognize things according to the surrounding brightness. Because the conversion of radiant energy to colour perceptions is exceedingly complex, there are so many models of human colour vision. One of the models is photopic vision, scotopic vision and mesopic vision, and an important parameter is S/P ratio. Commission Internationale de l'Eclairage (CIE) and Illuminating Engineering Society (IES) also provided standards for evaluating the visions and S/P ratio. But in Korea, this parameter, S/P ratio, is not sufficiently studied and also investigation for S/P ratios of multi-chip LEDs is not sufficient in world wide. Therefore, relationship between S/P ratio and CRI changes were investigated according to the shifts of wavelength and bandwidth.

2. Methods

2-1. Simulation program composition.

First of all, a simulation program calculating CCT, CRI and S/P ratio from spectral power distribution (SPD) of LED was composed based on the CIE standards. Secondly, SPD of LED was modelled as Gaussian envelope. Finally, by changing the peak wavelength and the bandwidth of the Gaussian envelope, variation of CCT, CRI and S/P ratio was simulated.

2-2. Simulation method.

In the case of the RGB LED, by fixing CCT at a certain value around the Plank blackbody locus, peak wavelengths of each red, green and blue SPD were scanned to cover all spectra. At this process highest value of S/P ratio and corresponding CRI were recorded according to the CCT value. Then, CCTs were varied from 3000K to 6000K by changing the ratios between powers of RGB LEDs. Finally, bandwidths of each RGB SPD were modulated at a certain ratio. During the simulation.

In the case of the RGBY LED, the procedures are the same as in RGB LED except Y LED. Also highest values of S/P ratio and corresponding CRI were derived according to the CCT values. The results were presented as the same fixture formats.

3. Results

3.1 S/P Ratio and CRI variations for RGB LED SPDs

Using an RGB spectrum, the S/P ratio and CRI variations according to the CCTs were investigated by wavelength shifts. At the CCT of 3000K, the S/P ratio was 2.4, while the CRI close to 0, the S/P ratio 2.0 while the CRI close to 25, and the S/P ratio 1.5 while the CRI close to 50. At the CCT of 4000K, the S/P ratio was 2.6 while the CRI was close to zero, the S/P ratio 2.1 while the CRI close to 25, and

the S/P ratio 1.8 while the CRI close to 50. And at the CCT of 6000K, the S/P ratio was 3.1, while the CRI close to 0, the S/P ratio 2.4 while the CRI close to 25, and the S/P ratio 2.0 while the CRI close to 50.

By modulating FWHM, there was no significant increment in the S/P ratio. As the FWHM increased, the S/P ratios were decreased reversely.

3.2 S/P Ratio and CRI variations for RGBY LED SPDs

Using an RGBY spectrum, the S/P ratio and CRI variations according to the CCTs were investigated by wavelength shifts. At the CCT of 3000K, the S/P ratio was 1.2 while the CRI was close to 70, the S/P ratio 1.7 while the CRI close to 80, and the S/P ratio 1.3 while the CRI close to 90. AT the CCT of 4000K, the S/P ratio was 1.4 while the CRI was close to 70, the S/P ratio 2.0 while the CRI close to 80, and the S/P ratio 1.9 while the CRI close to 90. At the CCT of 5000K, the S/P ratio was calculated as 1.7 while the CRI was close to 70, the S/P ratio 2.4 while the CRI close to 80, and the S/P ratio 2.1 while the CRI close to 90. And at the CCT 6000K, the S/P ratio was 2.0 while the CRI was close to 70, the S/P ratio 2.1 while the CRI close to 80, and the S/P ratio 2.5 while the CRI close to 90.

By modulating FWHM, there was no significant increment in the S/P ratio. As the FWHM increased, the S/P ratios were decreased reversely.

4. Conclusions

According to the IES-TM-12-12, the S/P ratio of RGB LED at 3500K is 1.39 and at 6000K 2.18. In this paper, S/P ratio and CRI variation trends were shown for RGB and RGBY LEDs. RGB LED showed relatively high S/P ratios while reversely low CRI values. At the CCT 3000K and 4000K, GRB LED spectral simulation resulted in 2.4 and 2.6, respectively, higher than 1.39 of the value in the TM-12-12, and at the CCT 5000K and 6000 K were 2.3 and 2.4, respectively, which were higher than 2.18 of that in the TM-12-12.

RGBY LED showed relatively high S / P ratio and high CRI value. At CCT 3000K and 4000K, RGBY LED spectrum simulations were 1.6 and 2.3 and 2.4 at CCT 5000K and 6000 K respectively.

There was no significant increase in the S / P ratio by adjusting the FWHM of the RGB and RGBY LEDs. And the FWHM increased, the S / P ratio decreased inversely.

PO93

LIGHTING EVALUATION TOOL FOR RAILWAY YARDS

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Abstract

1. Motivation, specific objective

Program an evaluation tool to assess the financial outcome of performing a lighting retrofit.

Achieve financial savings on electricity expenses, carbon offsetting, and maintenance costs.

The tool is designed to be easily used by a site-supervisor who will simply input the following key values to generate a high-level first-pass financial assessment.

- Select the Australian State where the Railway Yard is located.
- Identify the type and number of existing lights within the yard.
- Choose from a list of alternative types of lighting for comparison.

Recognise the most suitable lighting technology to install.

2. Methods

For improved accuracy, facilities management are able to edit default values, in accordance with the most accurate information available for a particular project.

- Investigate the condition of existing lighting, in terms of lightbulb configuration, technical specifications, operational hours, and electricity tariffs.
- Compare alternative lighting technology, with distinct regard to capital costs, energy efficiency and longevity.

3. Results

The tool exhibits the functionality to specify the financial assessment period, in which the following results will be reflected.

- Simple Payback Period
- Net Present Value of Return On Investment
- Internal Rate of Return
- Capital Expenditure
- Operation and Maintenance Expenses
- Total Cost of Ownership
- Business As Usual Comparison
- Sensitivity Analysis

Case Study:

In the Service Delivery Section of Willowburn Railway Yard, there exists one-hundred traditional high-intensity discharge lamps.

The financial outcome of replacing the existing lamps with an energy efficient lighting solution was evaluated.

Existing lighting technology: Mercury Vapour 400W

New lighting technology: LED 112W

The simple payback period is 2.69 years, for an initial investment of $42,400 in capital expenditure.

For a 15-year assessment, the internal rate of return is 61.21%, generating an investment profit of $135,864.

- The total cost of ownership in net present value for maintaining and operating existing lamps is $270,143.
- In comparison, the total cost of ownership in net present value would be reduced to $134,279 with the installation, operation and maintenance of new LED lighting technology.

Assumptions:

- Capital and operational expenditure is not financed by loans.
- Each existing lightbulb is replaced with a luminaire with equivalent lumens.
- The lighting installation is performed within a single year.
- The following assumptions are applicable to the first-pass assessment conducted by a site-supervisor, unless the default values are edited by management.
  - Each site in an Australian State incur the same electricity tariffs.
  - Lighting technologies have default technical specifications.
  - Lights are operational for an average of twelve hours a day.

4. Conclusions

Recommendations:

- Establish company standards for exterior lighting at railway yards, in accordance with international guidelines.
- Examine interior lighting requirements within locomotive and wagon workshops.
- Utilise the evaluation tool to assess the financial benefits of performing a lighting retrofit within railway yards nationwide.
- Identify and compare energy-efficient lighting technology that comply with established standards.
- Install new luminaries as part of preliminary trials. After successful trials, leverage upon discounted bulk purchasing of lighting technology.
- Conduct comprehensive energy audits of sites to minimise electricity expenses pertaining to demand above threshold network charges. It may be worthwhile to renegotiate electricity bill contracts to cater for the power demand on site, without incurring penalty fees.
- Explore the prospect of renewable power generation and storage, particularly solar technology.

PO94

INFLUENCE FACTORS FOR DISCOMFORT GLARE OF HEADLAMPS AND A NEW MODEL FOR ITS ESTIMATION

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Abstract

A large number of studies on discomfort glare evaluation of headlamps can be found in literature. Unfortunately, the majority of these studies with real headlamps did not control independent variables appropriately. For instance, the luminance of the headlamps and the illuminance on the eye of the oncoming driver is not separate adjustable. Therefore, these findings cannot be used to develop an accurate discomfort glare evaluation method.

The first part of this paper focuses on the analysis of influence factors. The analysis is based on a literature review and numerous studies by the author, which were carried out until 2006. The material of these studies and most of the results are unpublished. New findings will be included in this paper.

The analysis shows that the illuminance at the eye strongly influences glare perception. The luminance of the glare source has a high significant effect as well. Some more recent studies findings describe the impact of spectral power distribution. Additionally, the influence of lamp type, luminance distribution of glare source, age and experience of the driver, as well as used methods and test stimuli is considered.

After the review and analysis, a new model for the estimation of discomfort glare of headlamps is discussed. Which factors are included? It is obvious that discomfort glare is proportional to the illuminance at the eye and luminance of the glare source, invers proportional to the adaptation luminance and the angle between glare source and fixation point. The influence of spectral power distribution can be considered with an addend. A possible factor for homogeneity is under discussion.

In sum the new model is adapted to the known Unified Glare Rating (UGR) formula for indoor lighting. It is expected that the approach to asses discomfort glare for car lighting is also applicable for road lighting, as the visual and adaptation conditions are similar. Therefore, it seems to be possible to find a real ‘Unified Glare Rating’ for different applications. Data of the presented experiments by the author support this presumption.

Keywords: car lighting, headlamps, discomfort glare, glare model

PO95

THE POTENTIAL USAGE OF PUBLIC LIGHTNING IN THE SMART

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Abstract

1. Motivation, specific objective

Due to new technologies increase the public lighting gets currently into a ground-breaking phase. It is necessary to consider carefully how and where public lighting is heading forward and whether it is necessary to prepare for any changes right now so that we could use a potential of the public lighting, especially in connection with SMART CITIES. Two basic technologies influencing the public lighting are LED technology and its rapid development and progressive development of communication technologies, particularly the development of optical fibre networks and mobile networks 5G. By their combination we can achieve not only the visibility increase due to the influence of better primary colour properties of a luminous flux and significantly better possibilities of its directing to the roads, but in particular the usage of control options of each luminaire, which has already been proved to be crucial. The power system designed that way can be used throughout 24 hours as well as it can charge terminal active elements of technologies falling into the category of SMART CITY (free Wi-Fi for the population, IP camera systems, providing technologies that facilitate car2car2infrastructure communication WAVEp, environmental measurement and dynamic traffic management).

2. Methods

A very important characteristic of the LED is a simple adjustability of the luminous flux. The LED can be regulated in the entire range (0-100%) without loss of luminous efficacy and without reducing their median lifetime. This feature is primarily concerned with the energy balance of lighting systems, although the secondary may not concern only energy savings but also the luminous flux adapting to its surroundings, density and speed of traffic and drivers adaptation.

Another very important feature of the LED, which can be used with advantage in the public lighting, is their switching speed. While conventional light sources used in public lighting (e.g. high pressure sodium lamps) are started up to the nominal luminous flux after a few minutes and their re-inflammation is also possible after its cooling (also a few minutes), the LEDs do not have this problem. The LEDs react to a nominal luminous flux immediately and if we consider only the white LED provided with luminophore slowing down their response to changes into electrical parameters so the width of the band is in the order of MHz values (typically 3.5 MHz). By using a suitable modulation format of the luminous flux, ideally in combination with an OFDM transmission technology (Orthogonal Frequency Division Multiplexing) the parallel light can be achieved and the simultaneous data transmission in the luminous flux without causing the variation of the resulting luminous flux from the perspective of an observer so that it can reach transmission speed up to 1Gbps.

3. Results

The basic advantage of topology interconnection of the public lighting with modern communication systems can be seen in the fact that it de-facto provides data connectivity on all roads in the territorial areas of towns and villages. It is important to realize that the public lighting network have two major advantages from this point of view. The first advantage is the strategic position of public lighting networks. They cover almost completely the surface of all the towns and villages. The second advantage is the ownership of the public lighting networks. The dominant owners are the municipalities themselves. It means that the public lighting network can be used as a skeleton (bearer)

to transfer and retrieval the information from whole area of the municipalities. Although this infrastructure may seem outdated, it is existing and the ownership and the conditions allow graduating this public service to a higher level. It is not only the management and control of the actual public lighting, but the possibility of transmission of information (free Wi-Fi for the population, WAVEp car2car2infrastructure communication) into the public space (information about traffic density, availability of parking, etc.), but also gaining information from this area. From a security point of view there can be considered an important instalment of security or transport IP camera systems.

4. Conclusions

In order to provide plural data connectivity it is necessary to think about moving the switches of the public lighting from distribution board to individual luminaires during preparation for restoration and maintenance of the public lighting. This step ensures that the network of the public lighting will be powered during the whole day and not only during the absence of daylight. Although permanent voltage presence primarily does not provide the required connectivity, it will supply any technological device that needs a permanent supply. Data connectivity of the public lighting network can be provided by using three basic technologies. This is the signal transmission through the network of the public lighting, an installation of fibre optic cables in the implementation of new linear structures within the public lighting and the utilization of existing mobile providers (LTE, prospectively the technology 5G). Each of these options has certain advantages as well as shortcomings in the installation itself or in its own operation.

The paper will deal with the specification and analysis of the options available standardized technologies deployable on the existing public lighting network in the context of expanding their services towards the SMART CITY.

PO96

LIGHT POLLUTION IMPACTS ON SUBJECTIVE PERCEPTION OF FLICKER IN TAIWAN

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Abstract

This research is based on objective characteristics of our country to investigate and analyse the public light pollution. It would affect the degree of awareness and discomfort of public feeling. Reviews of the relevant light pollution regulations and analyses of the current petition cases, this research focuses on two major light pollution sources to investigate the subjective perception of glare and flicker for LED multimedia. The main tasks include: (1) perform subjective evaluation of glare and flicker at night condition to build up the borderline between comfort and discomfort (BCD) of human perception for LED billboard in outdoor environment; (2) conduct field experiment and field survey to propose the standard operation procedure; (3) propose predictive improvement and management programs for LED multimedia according to the international regulations and domestic situation. A total of 24 participants took part in this field experiment in the atrium of the Management School of Tunghai University, Taichung, Taiwan, and the total amount of subjective questionnaires were 1,561 trials.

Blocked repeated measures design with random assignments of one of three levels of the luminance percentage (Factor A) to participants and repeated measures on all the treatment combinations of flicker magnitude (Factor B) and observation distance (Factor C) were used since it is difficult to randomly change the factor levels of luminance percentage (Factor A). Each participant was randomly started at one of three levels of luminance percentage which are 25 %, 50 %, and 90 %, respectively. The factor levels of flicker magnitude (Factor B) are based on the 90th percentile flicker magnitude of 9 videos would be divided into low (less than PR33), medium (between PR33 and PR67), and high (larger than PR67) which are corresponding to [23.5, 32.5], [32.5, 38.5], and [38.5, 43.8]. The factor levels of observation distance (Factor C) consist of 10m, 20m, and 40m. The recruitment standards and notices for participants regarding the outdoor visual experiment were as follows: (1) Must be over the age of 20 years; (2) People who are diagnosed with colour vision deficiency or epilepsy are not recommended to participate in the experiment; (3) Must avoid or reduce the use of cell phones and computers two hours prior to the experiment. Experimental results revealed that:

1) The field study of the outdoor LED billboard via factorial experiment with blocking design was performed and the results of the analysis of variance (ANOVA) of the maximum glare evaluation showed that the maximum glare evaluation exhibited less comfort as the percentage of luminance level was increased or 90th percentile of flicker magnitude increased. In addition, the maximum glare evaluation also showed more serious discomfort as the observation distance is getting closer to the LED billboard. The interaction effect of gender and age-specific has shown significantly different for the mean maximum glare evaluation.

2) The results of ANOVA of the maximum flicker showed that the results were similar to the ones of maximum glare, except the difference was not significant between genders in the young group (20～30 years old). The discomfort of the males was higher than that of the females in the middle age (31~45 years old) group and the elderly (>46 years old) group. It has also shown a strong positive correlation between the maximum glare and maximum flicker subjective evaluation since the correlation coefficient r is equal to 0.803.

3) It is suggested to use 90th percentile flicker magnitude to evaluated the perceived flicker discomfort for LED billboard, where 90th percentile flicker magnitude can be obtained in terms of fast Fourier transformation (FFT) from the two-dimensional (2D) luminance distribution of LED billboard. Where the suggested maximum value of 90th percentile flicker frequency magnitude is under 31~33 for LED billboard with maximum luminance between 1,100 cd/m² and 4,299 cd/m².

4) The improvement methods for glare to be proposed consist of reducing the light source luminance, adjusting the direction of the light source, installing the shading devices. The improvement methods for flicker to be proposed consist of reducing the luminance of the light source and changing the

broadcast content of LED billboard to reduce the 90th percentile frequency magnitude of the light source.

PO97

LIGHTING REQUIREMENTS NEAR ASTRONOMICAL OBSERVATORIES

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Abstract

1. Motivation, specific objective

Nearly all astronomy at visible wavelengths involves the study of very faint objects in the night sky. Astronomy is therefore extremely vulnerable to the impact of artificial light, which can produce skyglow, making the night sky brighter. Artificial light can travel enormous distances in Earth's atmosphere, limited only by the curvature of the Earth. Astronomical observatories must therefore be carefully protected by strong lighting ordinances with lighting regulations that extend for distances up to 300 km from the observatory.

2. Methods

Hawaii has two major astronomical observatories: Maunakea Observatory on the Island of Hawaii, and Haleakala Observatory on the Island of Maui. Maunakea has been protected by a strong lighting ordinance since 1990. The ordinance has been recently adapted to allow use of LEDs. The lighting ordinance for the Island of Hawaii will be described in detail. Methods to control unwanted light at the observatory include a strict requirement of fully shielded light fixtures that emit no light above the horizontal plane, and strong limitations on blue light, which is efficiently scattered by air molecules (Rayleigh scattering). Upwards facing lights are prohibited; architectural features and vegetation can only be illuminated by fully shielded lights that point downwards. When LEDs are used, the blue light is filtered out in all high lumen usage. White LED light can be used in low lumen applications, but is limited to low CCT LED light with reduced blue emission. Mercury lighting, as well as most fluorescent lighting is prohibited. High energy costs on the Island of Hawaii have fortunately provided further motivation to limit light usage and to use light efficiently.

3. Results

The Island of Hawaii has a population of nearly 200,000. As a result of the strong lighting ordinance on the Island of Hawaii, the night sky over Maunakea observatory remains very dark, and is well suited to the demanding requirements of the deep sky astronomy performed by the large telescopes located there. In fact, the night sky over Maunakea is among the darkest night skies in the world. Astronomical observatories benefit from nearby communities, because these communities provide infrastructure such as schools, shops, and medical facilities for the staff that work at the observatories, as well as providing other logistical benefits such as transportation. However, very careful and strong lighting regulations are required for observatories to successfully coexist with urban development.

In contrast, the Island of Maui has a much weaker lighting ordinance, and as a consequence, the night sky over Haleakala observatory is less dark. Haleakala is also closer to the city of Honolulu and the Island of Oahu (population approximately 1 million), where the lighting is less well regulated. At a distance of approximately 200 km, Honolulu and Oahu have a significant impact on Haleakala's night sky, and make the northwestern sky brighter.

4. Conclusions

Strong lighting regulations are required to keep the night sky dark over astronomical observatories. The most important techniques that should be used include full shielding and strong limitations on blue light. These techniques are good lighting practices that can be widely applied in order to reduce light pollution. These same techniques are also important for protection of endangered species such as turtles and birds that are affected by light at night.

PO98

THE SHADING EFFECT CAUSED BY OPAQUE SOLAR PANEL INTEGRATED WITH AGRICULTURAL GREENHOUSE

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Abstract

1. Introduction

The capture and utilisation of solar energy in large scale usually requires great amount of land. Gobi Desert in China was once a preferred site for building photovoltaic (PV) plant. Recently it is found that much solar energy generated in Gobi Desert was eventually discarded. This is because that local consuming capacity is far lower than production capacity due to low population density. Making full use of the greenhouse space at the top of the greenhouse to set up photovoltaic power generation facilities will be able to save and make full use of land resources. The PV agricultural power station can reduce the power loss in the process of transmission as it is usually located in populated area. However, little is known on the shading effect caused by PV panel integrated with greenhouse. The aim of this study is to explore the pattern of shading brought by opaque solar panel with different layouts, such as checkerboard type and interlaced type. The design of such PV greenhouse should fully consider the need of sunlight for crop and plant.

2. Methods

Computational model of PV greenhouse at latitude 30° all covered by clear glass was built. The length of the greenhouse model is 32m, width is 8m and height 4m, the south roof has a width of 8m and 30° tilted roof. The fraction of coverage was fixed at 50%, i.e. half area of the roof was covered by opaque PV panels. Ten layouts of PV panel were used as independent variable: checkerboard and interlaced and each with five mesh sizes. Climate data of Shanghai were introduced for annual analysis. Average daily Photosynthetically Active Radiation (PAR) were selected to be the main indicator of shading effect. Insolation Analysis was performed to calculate the average daily PAR within a civil year. The grid of the model on ground were set into 1m × 1m, equivalent to 256 units on the roof. All simulations were performed in Autodesk Ecotect Analysis.

3. Results

For the given 256 gridded ground units, the number (cumulative frequency) of units with an average daily PAR lower than 40% was used as an indicator of sunlight gain, comparing with an arbitrary point under same condition without any shade. The initial results show that layout of PV Panel with denser grid has small number of units that have average daily PAR lower than 40%. When the minimum grid of PV panel layout was as small as 1m × 2m, more than 95% of the ground area has an average daily PAR higher than 40%. The total sunlight hours on the ground can be partly cut down to 20% due to the shading caused by PV panel. It should be noted that the fraction of coverage has already been fixed at 50%. More and detailed analysis will be presented in full paper.

4. Conclusions

This paper presented simulation results of shading effect caused by PV panel integrated on agriculture greenhouse. It was found that denser layout of PV panel on the roof will decrease the possibility of the presence of shaded spot. Results from simulation-based results is expected to be verified with data collected from physical modelling under controlled heliodon or artificial dome. More settings of fraction of coverage such as 20% and 80% need to be checked to get better understandings on the shading effect of opaque solar panel. Comparable PV panel with equivalent types of layout should be investigated in further work.

PO99 (PP25)

FLICKER EFFECTS IN TUNNEL LIGHTING

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Abstract

Flicker is when a light source varies its emission. CIE defines flicker as *"impression of unsteadiness of visual perception induced buy a light stimulus whose luminance or spectral distribution fluctuates with time",* [definition 17-443] in the International Lighting Vocabulary. Usually all traditional lighting sources flicker because of the AC voltage power input, but subjects are usually unaware of the flicker: sources flicker at 100 (120) times in a second, a frequency above the critical flicker frequency, i.e. *"the frequency of alternation stimuli above which flicker is not perceptible":* the human visual system is unable to detect it. Besides with old and not more sealable incandescent lamps the filament thermal mass was also able to smooth the flicker effect due to power supply and these lamps emit light with negligible flicker. With fluorescent lamps only power supply technologies working at high frequencies helped in reducing the flicker perception in the most sensitive subjects. SSL (Solid Light Source) can work with AC/DC drivers and AC/AC drivers. According to the driver type or power supply implementation flicker can be very low (i.e. it is due to the ripple in the output current for example 5 % in the low frequency range, i.e. 70 Hz – 1 kHz and 15 % in the high frequency range) or the LED can go dark every mains half-cycle when its voltage is at or near to 0 V.

Current a lot of researches and normative works are focused on the problem of how much flicker is acceptable, but in these researches the starting point is the flicker associated to power supply, as a direct consequence of power supply techniques or because of dimming conditions. In outdoor lighting, road and especially in tunnel lighting there is another situation in which flicker exists. It is when the observer drives *"through spatially periodic changes in luminance",* as CIE TR88-2004 said. CIE recognize that discomfort from flicker depends upon four main factors: the flicker frequency (i.e. the number of luminance change per second), the duration of the experience, the ratio between the two peaks (i.e. between light and dark condition) and the steepness of the increase. In CIE TR88-2004 is recognized that for flicker frequencies, i.e. the time between the passage under two different luminaires at the given speed, between 4 Hz and 11 Hz, subjects can experience discomfort if exposed to stimuli for more than 20 second; 20 seconds at 100 km/h is about 600 m.

CIE TR88-2004 suggests these conditions without providing a solid metrological background. By reason of this and the recognized problems in evaluating flicker effects (due to observer motion) the last revision of Italian National Standard UNI 10095 on tunnel lighting do not gives flicker requirements while they are suggested in its previous edition and in CIE TR88. In EU there is not a reference standard (only a Technical Report was published by CEN) and the Italian tunnel lighting standard has a great impact on lighting installation cost because in Italy we have a very high number of tunnels and more the 1500 km of the highway network are in tunnels.

New researches consider flicker due to source fluctuation because of several problems faced with electronic driven technology of some LED sources as well the applications on LED dimmer techniques and stroboscopic effects viewing moving vehicles but studies on flicker due to observer motion in road lighting are very limited. This paper presents the results of a research work carried out as a task of the European funded project EMRP ENG62 MESAIL, "Metrology for Save and Innovative Lighting". The effects of flicker in tunnel lighting due to passage of drivers trough different luminaires inside a tunnel lit by LED luminaires is investigate with subjective experiment on site (during driving in a road tunnel lit by LED technology) and on laboratory using an Eye tracker system to evaluate physiological eye parameters like pupil diameter and fixation times.

During subjective experiment in laboratory the visual acuity of several selected subjects has been tested using a Landolt ring table, and the physical parameters of pupil and the time for completing the test were measured too. During driving in tunnel lighting, fixation point and pupil parameters were measured too. In laboratory the Landolt ring table was lit using LED sources driven under DC voltage

(steady on) and at different frequency to simulate AC flickering (50 Hz) and different frequencies of 20 Hz, 5 Hz, 3 Hz, 2 Hz and 1 Hz the lowest values to simulate motion flickering due to the passage under different luminaires during driving in a tunnel. Considering the common distance of 10 m between consecutive luminaires in the internal zone of a tunnel the last tested frequencies correspond to an average speed of 100 km/h, 70 km/h and 36 km/h. Subjects had also to answer to a questionnaire regarding the discomfort they experienced at the different flickering frequencies. The results and influences of flicker will be discussed in the paper as well as future implementations in the UNI tunnel lighting standard and suggestion for future work in CEN and CIE working group.

PO100 (PP26)

VISUAL EXPERIENCES AND NEEDS OF AGEING DRIVERS

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Abstract

1. Motivation, specific objective

With advancing age, visual and motor performance tend to decrease. In higher age cohorts more people experience problems in driving and these problems also become more serious. This is often connected to the increase in crash risk for older drivers. But apart from crash risk, a perhaps even bigger issue is the economical, social and personal consequences of not being able to drive anymore. Research and surveys have shown that even among the healthy elderly, a large part refrains from driving, or at least adapts its driving behaviour. Due to its particular challenges, night driving is most often avoided, by up to 50 % of the 60+ population. Research also suggests that in the majority of these cases, problems with vision are the reason to stop driving at night.

The visual tasks related to (night) driving have been identified. There is also a lot of information on how these relate to visual functions and lighting conditions. If we want to explore what role road lighting could play to support ageing drivers, we first need to know which of these tasks and functions are related to the reported increase in visual problems, so that we can approach this in a focussed way.

In order to have a differentiated view on the experiences of drivers, they were categorized in four different subgroups. The normal driver still drives and does not change his driving behaviour even if he might experience problems while driving. Other drivers might still drive in daylight and at night, but self-regulate their driving behaviour when experiencing problems and are therefore called regulators. The subgroups of the restrictors are defined by two aspects, not driving at all (general) and not driving in the dark (night). In general, this project is focusing on the problems regulators experience and the reasons why restrictors stopped driving.

2. Methods

To achieve this, a literature review on the visual problems of ageing drivers and their reasons to refrain from driving at night was performed. Additionally, a survey was held under ageing drivers in three countries, the Netherlands, the United Kingdom and Germany. Recruitment of participants was done via social media and organizations for the elderly and relevant interest groups.The survey was conducted online using Vovici.

3. Results

Up to now, 301 people participated in the survey. 16 % from Germany, 25 % from the UK and 59 % from the Netherlands. As there were no significant differences between the answers from these different countries, we treated the results as one group in our further analysis.The mean age of the respondents was 71 years (ranging from 50 to 99 years), with 54 % females.

For more than 67 % of restrictors, the feeling not being able to see good enough is the reason to self regulate their driving.

Looking at the combined results from the night regulators and restrictors, we see six visual functions which are most cited as being the (main) reason to self regulate. These are related to contrast sensitivity (e.g. being able to discern a pedestrian who is wearing dark clothing, or low contrast obstacles on the road); glare from road lighting luminaires and from the headlights of oncoming cars; adapting to darkness coming from a brighter lighted road and noticing (sudden) differences in relative speed and detection of low contrast obstacles. Comparing the answers of the participants to the results of similar research, we get the impression that they are in general in better health and more active than the average elderly. There is very likely a bias towards the better performing elderly in our

recruiting largely via organizations which cater for the active seniors, such as third-age universities and motoring clubs.

The subjective results of our survey compare quite well with the conclusions from our literature survey. Also here, apart from glare sensitivity, deterioration in contrast sensitivity and dark adaptation are found as the major sources of problems. This causes a decline in visibility and conspicuity of other road users and obstacles, which in turns leads to longer perception-reaction-times, a smaller useful field of view, underestimations of relative speed and overestimation of distances and time-to-contact in potential collision situations.

4. Conclusions

From both scientific literature as from our own survey, dark adaptation, contrast sensitivity and glare sensitivity come forward as the three major factors causing issues for ageing drivers. Further research should now be directed at filling the gaps in the characterization of contrast sensitivity and dark adaptation for elderly under lighting conditions relevant for night driving. With this knowledge, it should be possible to suggest improvements in our road lighting recommendations to better meet the visual needs of the ageing driver. Special attention should be given to cyclists, as these have been almost completely neglected up to now, but are increasingly important in modern traffic.

We will discuss the latest overview of the survey, which is still running, as well as a more detailed overview of the relationships between the ageing visual functions and the driving performance of our ageing drivers.

PO101 (PP27)

CHANGES IN ROAD SURFACES AND WALLS INSIDE TUNNELS OVER TIME

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Abstract

The road surface and the walls of a tunnel are crucial elements that determine the luminance caused by the lighting inside a tunnel. The reflectivity of these surfaces undergo changes once the tunnel is opened to traffic and as cars are driven through the tunnel. Such change in reflectivity depends on tunnel's structure, surface material, and amount of traffic. Considering these changes during the designing stage of tunnel lighting to predetermine the appropriate reflectivity level, ensures that the design is accurate, while guaranteeing safety for drivers as well as economic feasibility of the tunnel lighting.

Our research team measured reflectivity of road surfaces and walls from 97 of 600 tunnels located throughout local highways in Korea. These measurements were then analysed with respect to the total number of automobiles that had driven through each tunnel since their openings, thus enabling us to predict the changes that take place. Further analysis were made to determine which value, among those changes, would be most economical as far as installation and operation of the tunnel lighting is concerned.

PO102 (PP28)

METHODS TO CONTROL OBSTRUSIVE LIGHT IN CONSIDERATION OF URBAN STRUCTURE AND OUTDOOR LIGHTING USAGE IN ASIA

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Abstract

Obtrusive light is a general term used for various problems such as light trespass, sky glow, and glare arising from outdoor lightings. Obtrusive light creates adverse living conditions for the residents and causes energy waste. In order to minimize these problems, CIE and IES have created standards applicable to outdoor lightings and are recommending that the designers as well as installers of outdoor lightings employ these standards in their works. In addition, matters to be considered in selection and installation processes of the outdoor lighting are also being suggested.

As economies grew sharply in the recent years, many Asian cities also expanded rapidly. And especially with the advancement of LED, various lighting equipment are being used all over the roads, public squares, and stores. The placement as well as the type of obtrusive light from the outdoor lighting in these Asian cities are very much different from those in the US or Europe, due to differences in shape and layout of the roads and residential buildings, and different ways of using advertisement lightings at retail stores, etc. Moreover, lightings that use new methods, which could not have been imagined when existing light sources were used, are continually being developed and applied.

It is therefore very difficult to control obtrusive light in these Asian cities just by applying existing regulation methods. In this report, different types of outdoor lightings in Asian cities are categorized and their problems associated with obtrusive light are identified. In resolving these problems, problems with existing standards are revealed, while new forms of standards to be proposed are presented.

PO103

THE EFFECT OF SPECTRUM TUNABLE LIGHTING ON THE ELDERLY PATIENTS' SLEEP QUALITY AND DAYTIME ALERTNESS

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Abstract

1. Motivation, specific objective

Human centric lighting or biologically effective illumination is attracting considerable attention from the people and is expected for many applications. We have developed a prototype of spectrum tunable lighting as a human centric lighting solution for the elderly and applied it to the elderly's ward in the hospital. And then, a comparative study using the lighting was carried out to know how much effective the lighting is to the improvement of their sleep pattern and quality.

2. Methods

For this study, elderly patients were divided to two groups; one for the experimental group and the other for the comparative one. The newly developed spectrum tunable lighting was applied to the experimental group and the conventional lighting, fluorescent lamps, was used for the comparative group. Each group consisted of 6 male and 6 female patients. They were randomly assigned to each group and their sleep pattern and quality were monitored for a week. Spectrum tunable lighting was controlled by the pre-programmed schedule in terms of brightness and colour temperature. To collect the sleep data, a smart band (Fitbit Charge HR) linked with smartphone application was given to every participants and their Saliva was sampled 3 times on 3 days (first, fourth, seventh) during the period to check up their melatonin levels. Additionally, we have collected the KSS (Karolinska Sleep Scale) questionnaire data from the participants and subjective evaluation data from the staff on the lighting environment.

3. Results

The results of sleep pattern and quality based on the data collected from the smart band were compared between two groups. The sleep pattern of the experimental group was more regular and the sleep quality was also better than the comparative group. Particularly in the experimental group, total sleep time was increased, whereas the frequency of wake-up during the sleep time was decreased in the experimental group. However, melatonin concentrations were not quite different between two groups, although the level was slightly higher under the spectrum tunable lighting. The result of KSS showed that the feeling of sleepiness was higher at the comparative group during the daytime. The overall satisfaction on the lighting environment by the staff was higher under the spectrum tunable lighting.

4. Conclusions

The results of this study suggest that the human centric lighting is an effective solution for the improvement of the sleep pattern and the quality of life of the elderly, particularly hospitalized elderly people. The elderly patients who spent a week under the spectrum tunable lighting and the proper lighting control scheme have slept longer time and shorter wake-up time during the sleep. Again, they spent more alerting time during the daytime. Consequently, human centric lighting is helpful for the regulation of circadian rhythm in the elderly patients' sleep in this study. It is expected that more human centric lightings will be applied for diverse areas including the elderly people.

PO104

REVISITING POTENTIAL HAZARD OF LED SOURCES TO CAUSE BLH IN SPECIFIC POPULATION

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Abstract

Following the strategy in a previous work, we have evaluated the potential Blue-Light Hazard (BLH) of high **colour** rendering index LED sources, on people whose crystalline lenses have been removed through a surgical procedure to implant intraocular lenses. Starting from the spectral transmittance of various models of commercial intraocular lenses (IOLs), modifications of the action spectrum for the BLH photo biological effect are proposed for each type of IOL. Then, using the corrected action spectra, the potential hazard of different types of white LED sources on subjects implanted with those IOLs, as compared to the potential hazard of the same sources for a person whose crystalline lens has not been removed, has been calculated.

1. Motivation, specific objective

The Blue-Light Hazard (BLH) is characterized by its action spectrum (CIE, 2000), which represents the relative weight of each wavelength in terms of the potential damage it can cause to the retina. This permits a direct comparison of different radiation sources to determine the relative effectiveness or the potential hazard that each one can cause. The global BLH for a given source depends, not only on the total radiant power emitted by the source, but also on its relative spectral distribution.

Currently, there are very few occurrences of aphakic eyes since usually during cataract surgery the removed crystalline lenses are replaced by intraocular lenses (IOLs). Although, in general, IOLs are provided with optical filtering (UV and blue blocking), they usually transmit much more violet and blue light (even occasionally part of UV) than crystalline lenses at any age, leading to an increased potential hazard for retinal photochemical injury.

In an earlier work on this subject, applied to conventional white LEDs (with blue LED and phosphor technology), which do not deliver short-wavelength radiation, it was concluded that the increase of the hazard factor with respect to a standard eye was non-significant for the studied IOLs.

However, in recent years, we have witnessed a growing use of high colour rendering index LED sources, especially in applications that require better light quality in terms of colour rendering. These types of white LEDs use primarily violet LEDs (and phosphor technology), significantly increasing the emission of radiation at short wavelengths.

This fact, together with the development of new types of intraocular lenses, has led us to evaluate the potential hazard to cause BLH of white LED sources (with violet LED + phosphor technology), on subjects whose crystalline lenses have been removed to implant intraocular lenses.

2. Methods and Results

The spectral transmittance (300 nm to 700 nm wavelength interval) on six new different models of intraocular lenses (IOLs) of similar power value, currently available in the market, has been measured. Significant differences among the various IOLs have been obtained. They all show a complete absorption of UVC (200 nm – 280 nm) and UVB (280 nm – 320 nm); however, their behaviour inside the UVA range (320 nm- 400 nm) differs considerably. Based on these data, adjustments to the action spectrum for the Blue-Light Hazard photo-biological effect are proposed for each type of IOL.

Based on the modified action spectra, the potential hazard of different high colour rendering index LED sources, whose spectral power distributions have been also experimentally determined, has been calculated. Conventional white LEDs (with blue LED and phosphor technology) have been also used.

As in the previous work, looking at the SSL devices with blue LED technology non-significant increase of the hazard factor with respect to a standard eye can be suggested. However, a hazard factor

increase as large as 40 % with respect to the standard one has been observed for the SSL devices with violet LED technology in some of the intraocular lenses studied.

PO105

RESEARCH ON BLUE LIGHT HAZARD MEASUREMENT METHOD BASED ON ACTUAL LIGHT ENVIRONMENT

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Abstract

1. Motivation, specific objective

"CIE S 009/E:2002 Photobiological Safety of Lamps and Lamp Systems" has recommended Blue Light Hazard (BLH) measurement systems and evaluation methods. We consider that the above methods are based on the evaluation of the lamps, which couldn't represent the BLH generated by the light sources when used in real scene.

We put forward that "Blue Light Hazard Measurement Method Based on Actual Light Environment", which is aimed on measuring and calculating the BLH generated by light at any position in space.

In this study, we expect to solve three key issues:

1) The variation law of blue light weighted radiance (LB) of light source at different measuring distances and different measuring angles;
2) Spatial distribution measurement method of BLH;
3) The variation law of LB when there exists background light.

2. Methods

First, some mathematical models are established to calculate and simulate the impact to BLH of measurement distance, measurement distance and background light.

Second, several experiments are designed to explore the variation law of LB in actual light environment. In these experiments, the spectrum is measured by Spectral Irradiance Meter, and the luminance (Lv) is measured by Imaging Luminance Meter, which shows three results respectively under the angles of field of view at 1.7mrad, 11mrad and 100mrad of one measurement. The Lv is measured under different measurement conditions and their combinations. The specific measurement conditions are:

Tested light source: 6600K LED, 3300K LED

Measuring distance: 200mm, 500mm, 1000mm, 2000mm, 3000mm;

Measuring angle: 0°, 15°, 30°, 45°, 60°, 75°;

Background light: Fluorescent Lamp, Sun Light.

The measuring distance is the distance from the center of the light source to the front of the lens of Imaging Luminance Meter. The measuring angle is the angle between the maximum light intensity direction of the light source and the normal direction of the lens surface of the Imaging Luminance Meter.

The spectrum and Lv are obtained directly by above experiments. The radiance (Le) is calculated with spectrum and Lv, and the LB is calculated with spectrum and Le. The blue light hazard efficiency of radiation (ηB) is calculated with spectrum.

3. Results

Analysing the results of simulations and experiments, there are some results as below:

1) The LB is strictly reduced when the field of view is enlarged, where the other conditions are same. But the degree of reduction of LB under different field of view is depended on different measurement conditions, such as different measuring distance and measuring angle.
2) In most cases, the LB is reduced when measuring distance is lengthened, where the other conditions are same. The simulation shows that the relationship between LB and measuring distance (s) is suitable for quadratic equation, but quadratic coefficient is varied with the field of view. When the angle of the field of view is 1.7mrad and 11mrad, the quadratic coefficient is 0.5-0.8. And when the angle of the field of view is 100mrad, the quadratic coefficient is 1.8-2.1, which is similar to square inverse law.
3) The relationship between LB and measuring angle is depended on the light distribution curve and emitting area of lighting source. On the one hand, enlarging the measuring angle usually means to reduce the Lv and that would reduce the LB. On the other hand, enlarging the measuring angle usually means to reduce the emitting area and that would increase the LB. So the relationship between LB and measuring angle should be analysed in specific conditions.
4) When there exists background light, the Le must be increased, and the ηB of mixed light must be between the ηB of light source and background light. Assuming that background light ηB > light source ηB, then it deduces to mixed light ηB > light source ηB , so LB must be increased with increasing Le and larger ηB. Assuming that background light ηB < light source ηB, then it deduces to mixed light ηB < light source ηB, so whether LB is increased or reduced is depend on specific conditions with increasing Le and smaller ηB. For example, the sun light would increase the LB of both 6600K LED and 3300K LED, as well as the fluorescent lamp light would reduce the LB of both 6600K LED but increase the LB of 3300K LED.

4. Conclusions

Blue light hazard measurement method based on actual light environment, is to use measuring equipment to simulate human eyes, and to obtain the actual received spectrum and radiance at any positon in space, then we could calculate and evaluate the BLH.

Using the above method, we could not only measure the LB at one positon in space but also calculate the spatial distribution of LB. First, measuring the LB at some typical positons. Second, considering the spectrum and correlated colour temperature (CCT) of light source and measurement field of view to choose suitable mathematical model parameters. Last, using the variation laws as the results of experiments to calculate the spatial distribution of LB, which means we could estimate the LB where is difficult to measure. The spatial distribution of LB could help to avoid BLH but not to waste usable space.

In addition, using the above method, we could also measure the LB of other luminous objects such as telephones and tablets. And the results of experiments prompt some methods to avoid the BLH, such as staying further from light source, reducing the CCT or using background light with low ηB.

PO106

CAN SHORT BREAK WITH A DYNAMIC LIGHT MAKE PEOPLE FULLY ENERGETIC?

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Abstract

The fiercely social competition and the hastening pace of life have resulted in long working hours in economic industry. Long working hours cause employees not having sufficient rest to therefore reduce the work efficiency and affect the psychological and physiological health. A short break during long working hours could effectively enhance employees' attention and work efficiency.

For the quality of short break, a dynamic lighting system suitable for a short break is proposed in this study, expecting to enhance users' spirit after a short break. Total 12 participants join in the experiment, in which a dynamic light system with the colour temperature 1900K and the light and dark transformation cycle 32sec is used. The participants stay 1m away from the lighting system with the measurement of illumination 10 Lux-0 Lux. The questionnaire survey is used in this experiment for the subjective evaluation, and the analyses of brainwave and heart rate variability are utilized for the non-subjective evaluation. The experiment lasts for 1hr, and the questionnaire survey is preceded before and after the experiment. The brainwave and heart rate are measured during the experiment.

The non-subjective analysis results reveal that the participants' parasympathetic activity is enhanced when using the dynamic light. The subjective analysis results, on the other hand, show that the participants feel the better spirit after taking a short break with such a light. The dynamic light will be actually applied to work field, expecting to enhance the work efficiency and attention of employees with long working hours.

PO107

CHEMOCHROMIC INDICATOR IN FORM OF SMART UNDERWEAR

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Abstract

1. Motivation, specific objective

The using of special protective clothes for dangerous environment expects the determination of limits their safety and reliability. One of possibility of evaluation of barrier properties these protective clothes are testing during acting model gas. Present method of evaluation is based on system local passive dosimeters. This method described above is very complicated and work-intensive (evaluation of the dosimeters by gas chromatography). Also, this method does not make possible accurate localization of the penetration place trough barrier textile. Therefore, was developed method at the National Authority for Nuclear, Biological and Chemical Protection Czech Republic, which makes possible the indication of penetration by the concrete place thanks the colour change of special underwear textile after reaction with acceptable indicator. This colour change allows quantitative evaluation of quantity of penetrated gas. Quantity is same as intensity of colour change as well as area of place where is colour change located. Penetrating gas has the most intensive reaction in area concrete penetration. Thanks, the diffusion and flow is his trace step by step feathered so that there are the new areas with progressive growing down of colour change intensity. The areas with growing down of colour change intensity are bigger than areas indicating concrete area of penetration. In past time the method of evaluation was based on the visual comparison colour changes by etalons done with the same material as underwear textile, which was exposed different gas dose (Dose is product cxt, that mean the influence of gas with concentration c during the time t on the etalon). This evaluation is relatively successful for approximate estimation of total penetration, but thanks the considerable incorrectness and subjectivity is non-acceptable for comparative determination and required correlations for extra dangerous substances. From these reasons was sought system of objective evaluation, which would safe advantages of single valued, prompt and area identification by the mean of colour change.

2. Methods

In our experiment was prepared set of gas doses so that was possible map dependence of colour change on concentration of dangerous substance and on the time of exposition – gas doses, according the experiences with visual judgement by means the etalons. Resulting colour change is from bright yellow colour into deep orange-red colour.

For measurement of colour changes of underwear textile was used two spectrophotometers, one of them was Microflash 200d (Datacolor International) under di:8° mode. Second spectrophotometer was MiniScanXE (HunterLab) equipped by 45°a:0° viewing geometry. Beside that was used capturing chamber LCAM Image Capturer equipped by CANON EOS 400D camera and F-type of D65 simulator and set of colour standards allowing calibration of captured images.

Every measurement was repeated by 10 times and was defined reproducibility of measurement 0.3 unit dE* in CIELAB colour space for spectrophotometric measurements and 1.4 units dE* in CIELAB colour space for image analysis.

Gas indicating chemochromic underwear was produced from knitted cotton fabric, which was dyed by fluorescent dye sensitive on presence of model gas by shift and decreasing of fluorescent maxima using exhaust method of dyeing. As second step was used protective coating of chemochromic indicator by glycerol containing supporting layer.

3. Results

Relation between reflectance and concentration of model gas, respectively **cxt** doses is non-linear and in our case, is situation complicated by the change of above mentioned drift of reflectance maximum to higher wavelengths. Therefore, was tested reflectance, Kubelka-Munk function as relation between

cxt dose and colour difference was measured in correlation to original colour of underwear textile before penetration by model gas. Reflectance itself and Kubelka-Munk function were not suitable for purpose of calibration. Reason is fluorescent character of remission curves of underwear textile and resulting nonlinear trend. Contrary to these findings was relationship between **cxt** dose and colour difference measured by CIE2000 colour difference formula, which was stepwise linear. Other advantage of this results is allowance to use image analysis system, which can follow not only evaluation of exact affected area of model gas contact, but mainly fuzzy images resulting from penetration of model gas through protective clothes.

4. Conclusions

New method for measurement of penetration of model gas allows quantitative evaluation of **cxt** dose of gas, characterize of distribution and critical areas of penetration. This method is new view on measurement of penetrated **cxt** dose of gas during dynamical stress of tested protective clothes. Advanced image analysis allows as supportive result measurement of size of affected area together with **cxt** dose of gas penetrating through protective clothes in both static and dynamic stress test.

PO108

IMPROVED SYSTEM AND METHOD FOR ILLUMINATION AND VENTILATION OF AN OPERATING ROOM

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Abstract

1. Motivation, specific objective

When a patient undergoes surgery in Europe, there is an average chance of 2.6% that the patient will develop a post-operative infection. Besides pain and discomfort, these infections can lead to hospital readmission, additional surgical procedures and even the decease of the patient. For the health care system, the yearly cost is estimated between 1.47 and 19 billion euro.

One of the measures to reduce the infection rate is the ventilation system which refreshes the air in the operating room. Such ventilation system provides clean, cooled air, that descends on the patient from the ceiling, and protects the patient from being infected by pathogens.

At the same time, the surgical lighting system provides adequate lighting to the wound, ensuring a high illuminance, even in challenging conditions as deep and narrow wounds. The light beam of such luminaires should promote shadow-free lighting and have a high colour rendition.

Currently, the protecting airflow is perturbed by the shape, position and heat of the surgical lighting system, thus causing turbulent air flows. Post-operative infections may originate as airborne pathogenic particles from outside the protective zone enter the surgical site by these turbulent air flows.

To reduce or even eliminate this disturbance of the laminar airflow by the surgical lighting, we have developed an integrated concept of an LED-based and automated light source, mounted above a transparent ventilation chamber. This paper outlines the optical design of the new surgical light source and its performance.

2. Methods

As the light must penetrate a transparent ventilation chamber, of which the bottom plate is perforated with holes of a specific dimension and arranged in a given density pattern, this paper starts by analyzing how light behaves when travelling through such plates. This is primarily studied analytically, after which these calculations are confirmed by simulations using ray tracing.

Using ray tracing, various performance metrics, indicating the quality of the surgical light source, are calculated: the central illuminance, the depth of illumination, the light field radius, its ability to provide shadow free lighting and the remaining central illuminance in the case of deep and narrow wounds, as defined in the European Standard for surgical lighting.

Also, the quality of the airflow is validated using simulations in Computed Fluid Dynamics (CFD) software and compared to experiments in a scaled test room.

3. Results

The proposed surgical luminaire system complies to the European Standard. It is possible to achieve a central illuminance of 160 klx. Moreover, based on simulations, all other optical performance indicators exceed state-of-the-art surgical luminaires. The light field diameter amounts to 46 cm, which is about 3 times larger than conventional luminaires. Shadow dilution is tested using masks and a tube: using two masks, an average reduction in central illuminance of 50% is observed; adding a tube has no influence on the central illuminance.

Based on particle measurements and simulations, the system is able to reduce the number of particles to the wound zone by 66%, thus reducing the risk of a post-operative infection.

4. Conclusions

In this paper an innovative and patent-pending system is presented to integrate surgical lighting and ventilation. The positions of the illumination and ventilation system are interchanged compared to the usual situation. By consequence, the ventilation chamber should be transparent, yet allow a flow of air through perforations.

The proposed system is equally performant or even better than conventional systems with respect to the lighting and air quality that is achieved. Moreover, patient safety is promoted by reducing the number of particles at patient level. Most importantly, patients will thus spend less time in hospital, resulting in a cost reduction for the health care system.

PO109 (PP30)

LIGHTING EFFECT HEALTH TEST AND EVALUATION METHOD BASED ON PHYSIOLOGICAL INDEX OF HUMAN VISUAL SYSTEM

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Abstract

1. Motivation, specific objective

Eyes are human organs of great importance, which play vital role in the living, learning, working and growing of human being. They function by dealing with visual activities, thus enabling people to obtain information from eyesight, and affect various physiological operations inside human body. Surrounding light transports image information outside to brain through eyes, and meantime more or less exerts an influence upon the visual system containing eyes and the brain. When exposed in poor lighting environment, visual functions of human eyes are inclined to be seriously harmed with an increasing level of visual fatigue. Moreover, undesirable lighting is likely to damage the rhythm of human body to some extent. In the last decades, studies on the health effect of lighting aroused wide attention of people. And a growing number of researchers devote to the study of health lighting recently. As far as lighting products are concerned, lighting effect on visual physiological as well as brain load function conditions display rather obvious distinctions with different optical parameters, such as luminance, illuminance, colour temperature, colour rendering index, peak spectral and flicker. It is found that there exists a certain relationship between physical parameters of lighting products and the condition of physiological functions of human body, thus providing guidance to lead the development direction of healthy production within lighting products field. This prompts lighting health study to be a key part in the future researches of international lighting industry. In the process of lighting, eyes are direct receptors of light. As a result, human eyes act as the main researching object in studies on visual health and visual comfort of lighting products. However, previous researchers tend to assess the visual comfort degree of products relying on subjective sensations of the product users. Few credible indices are provided for quantification, making their results controversial in stability and accuracy. Consequently, these researching results can hardly meet the “healthy and comfortable” aim of lighting products design. Several objective physiological indices related to human eyes are widely employed to reflect visual condition of human eyes, yet any single one of them without accompanied by other indices is far from competent to accurately and completely describe the visual fatigue degree of eyes after enduring lighting process from products. It is also inappropriate to select all these indices as a combined group to quantitatively describe visual fatigue degree of human eyes, since they are not independent of each other. Given a suitable parameter could be inferred based on all these physiological indices, it would be hopeful to achieve objective quantitative assessment of human eyes visual comfort.

2. Methods

Nonlinear Regression Analysis (NRA) is a widely used tool to transform multiple parameters into one by fitting curve model. However, this method is not ideal when it comes to the conversion aiming at obtaining a new index to assess the visual comfort of human eyes, as it requires quite complicated process for constructing nonlinear regression equations, which are full of uncertainty with the changing of tested samples and measurement scope. Artificial Neural Network (ANN) method brings a novel thought for constructing the quantitative assessment index model. This method simulates the neural network of human brain by making a large number of processing units connect with each other and constitute a large scale nonlinear self-adaption system. It analyses the potential regulation according to the input and output parameters provided by researchers. This potential regulation enables researchers to set multiple physiological indices as input parameters, and transform them into one index for assessing visual comfort. In the present study, target test people were given enough time to experience the lighting products after a rest in dark room and vision function test to ensure the sample availability. Then a total of six objective physiological indices were collected from the target people as

the input parameters for describing the visual condition of eyes: refractive status (RS), axial length (AL), keratometric refraction (KR), higher order aberrations (HOAs), modulation transfer function (MTF) and the ratio of accommodative convergence to accommodation ratio (AC/A).

3. Results

This study also designed the test on visual contrast standard based on the space frequency and time frequency of human eyes vision. Combined with subjective assessment, a psycho-physical scale was formed as the output parameter to reflect the visual fatigue degree of tested people. Back Propagation Neural Network Analysis (BPNNA), which is a convincing tool to analyse the potential regulation between input layers and output layers using error backpropagation algorithm, was carried out in the present study on the purpose of investigating the relationship between input parameters and the output parameter.

4. Conclusions

This method optimizes real output of network to be more close to the ideal output by continuously adjusting interlayer weight, thus successfully constructing the visual comfort algorithm model, and generating the VICO Index (Visual Comfort Index) which proves to be effective for visual comfort assessment of human eyes. Nearly ten thousands of physiological parameters of human eyes were collected in this study to construct the database of parameters characterizing visual function of human eyes. The VICO index inferred from our algorithm model is available for the quantitatively classified assessment of lighting and displaying products.

PO110 (PP32)

LIGHT EVALUATION IN HIGH AND LOW MOOD STATES

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Abstract

1. Motivation, specific objective

Experiments were conducted to elucidate the relation between a person's light environment evaluation and mood states. The lighting level was changed from dark to light, or from light to dark during experiments. Subjects were divided into high and low mood state score groups. Then lighting evaluation was compared between the groups. Subjects' mood states of tension–anxiety, depression–dejection, anger–hostility, vigor, fatigue and confusion during the preceding week were used to divide the subjects.

2. Methods

2.1 Experimental methods

Experiments of two types were conducted. In one experiment, a subject entered a chamber with a lower level of illuminance (1-DARK). Lighting was changed to a higher level (2-LIGHT) for the latter part of the experiment. In another experiment, the reverse order of the illuminance levels was used (1-LIGHT and 2-DARK). Lighting evaluations were reported before the change of the lighting level and at the end of the experiment. Each experiment continued for 25 min; the lighting level was changed at about 15 min from the time of entry into the chamber. Six subjects entered the experimental chamber, sat around a table, and filled in questionnaire sheets according to the instructions. The mean horizontal illuminance at the center of the table was 340 lx at the lower level and 2200 lx at the higher level. The experiments examined 471 high school student participants.

2.2 Items of evaluation

Evaluation items of the light environment were brightness, glare, comfort, preference, and performance. The mood state during the preceding week was asked during the time for adaptation to the test environments. Six Mood state factors were measured using several rating scales. Then scores were calculated for each factor. Basic personal attributes, living habits such as regularity of living time and turning off unneeded lighting, and consciousness of environmental issues such as preference for natural light, needs for 24-hr shops and needs for brighter streets at night were also asked.

3. Results

Lighting evaluation was compared between high score and low score groups of subjects for the mood state score. Limits of division were 25, 50, and 75 percentile scores.

3.1 Tension–Anxiety (TA) and glare evaluation

Results show that TA-75%-high evaluated 2-DARK as more glaring than TA-75%-low ($p<0.0001$), although both evaluated 2-DARK as less glaring than neutral. Also, TA-25%-low evaluated 2-DARK less glaring than TA-25%-high ($p<0.15$). We infer that 2-DARK was evaluated as more glaring for high tension–anxiety subjects and as less glaring for low tension–anxiety subjects.

Furthermore, TA-75%-high evaluated 1-DARK as more glaring than TA-75%-low ($p<0.05$), although no difference was reported between TA-25%-high and TA-25%-low in the evaluation of glare of 1-DARK. We infer that 1-DARK was evaluated as more glaring for high tension–anxiety subjects, although 1-DARK was not always less glaring for low tension–anxiety subjects.

3.2 Tension–Anxiety (TA) and comfort evaluation

TA-25%-low evaluated 2-DARK as more comfortable than TA-25%-high ($p<0.05$). However, no difference was reported in the evaluation of comfort of 1-DARK between TA-25%-low and TA-25%-

high. We infer that 2-DARK was evaluated as more comfortable for low tension–anxiety subjects, but that 1-DARK was not always more comfortable for low tension subjects.

3.3 Vigor (V) and evaluation of brightness, comfort and preference

Results show that V-75%-high evaluated 1-LIGHT as brighter ($p<0.05$) and more comfortable ($p<0.05$) than V-75%-low. However, no difference was reported in brightness or comfort of 2-DARK between V-75%-high and V-75%-low. No difference was found in brightness and comfort evaluations of 1-LIGHT and 2-DARK. We infer that 1-LIGHT was evaluated as brighter and more comfortable for high vigor subjects. No relation was found between vigor and the evaluation of brightness and comfort for 2-DARK. Low vigor subjects did not always evaluate 2-DARK or 1-LIGHT as less bright and less comfortable.

Also, V-25%-low evaluated 1-DARK as brighter than V-25%-high ($p<0.05$). However, no difference was reported between V-25%-high and V-25%-low in the evaluation of brightness of 2-LIGHT. V-25%-low evaluated 2-LIGHT as less comfortable ($p<0.05$), less preferable ($p<0.05$), and less performable ($p<0.01$). It can be said that low vigor subjects evaluated 1-DARK as brighter than high vigor subjects. However, no relation was reported between vigor and brightness evaluation for 2-LIGHT. Low vigor subjects evaluated 2-LIGHT as less comfortable and less performable. No difference was found in the evaluation of comfort, preference, or performance of 1-DARK between V-25%-high and V-25%-low.

3.4 Anger–Hostility (AH) and glare and performance evaluation

AH-25%-low evaluated 1-LIGHT as less bright ($p<0.01$) than AH-25%-high. AH-25%-low evaluated 2-DARK as less glaring ($p<0.05$) and more performable ($p<0.05$) than AH-25%-high. We infer that low anger–hostility subjects evaluated both 1-LIGHT and 2-DARK as less glaring than high anger–hostility subjects did. Low anger–hostility subjects evaluated 2-DARK as more performable than high anger–hostility subjects.

3.5 Depression-Dejection (D) and brightness and glare evaluation

Finally, D-75%-high evaluated 1-DARK as more bright ($p<0.05$) than D-75%-low did. No relation was reported between depression and brightness evaluation for 2-DARK. D-25%-low evaluated 1-LIGHT as less glaring ($p<0.05$) than D-25%-high did. Also, D-25%-low evaluated 2-DARK as less glaring ($p<0.01$) than D-25%-high did. Results show that high depression subjects evaluated 1-DARK as brighter but no relation was found between depression and the evaluation of brightness for 2-LIGHT. Low depression subjects evaluated 1-LIGHT and 2-DARK as less glaring than high depression subjects did.

4. Conclusions

Some mood states were found to be related to some lighting environment evaluations; tension–anxiety was related to the evaluation of glare and comfort; vigor was related to the brightness, comfort, preference and performance; anger-hostility was related to the glare and performance; depression was related to the brightness and glare. However, mood states of fatigue and confusion were apparently unrelated to the evaluation of light environment.

WORKSHOPS/SEMINARS

WS1

Workshop

COLOUR QUALITY

Conveners:
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Summary

Using an intelligent LED luminaire, all lighting quality aspects can be designed flexibly and individually according to the application and the user group. In addition to complying with standards, the aim is the users' high satisfaction. For this, an important factor is the colour quality provided by the light source that should illuminate the predominating coloured objects attractively and aesthetically for a positive emotional effect, e.g. in museum, shop, hotel, fair, office, home, cinema and TV studio lighting. In the last years, international efforts were taken to define new colour quality (so-called colour rendition) metrics as a mathematical optimisation target to realise light source spectra with excellent colour quality. Based on the results of recent visual experiments and new computational concepts, not only the colour rendering (so-called colour fidelity) index was re-defined but other new indices and calculation methods appeared to quantify the different colour quality aspects including colour preference, memory, naturalness, vividness, fidelity, saturation, gamut, harmony. The aim of the workshop is to gain insight into these issues with international experts working in the field. Topics include an overview of today's existing colour quality metrics (outcome of CIE TC 1-91); results of several international visual experiments on colour quality plus a round robin experiment; whiteness; the role of presented objects in colour preference studies; future research directions on colour quality; a proposal for a new CIE TC on colour quality; and the CIE's vision on colour quality research.

WS2

Workshop

ILLUMINANT L AND LED REFERENCE SPECTRA

Convener:
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Summary

The lighting market has significantly changed over the last decade toward solid–state lighting products. This change impacts greatly the activities of CIE: As an example the CIE technical committee TC 1-85 is presently updating the fundamental CIE publication 015:2004 Colorimetry, 3rd Edition. It is intended to include in the new revision a set of typical white light LED reference spectra of various types (phosphor based, hybrid, RGB, violet pumped). Division 2 presently discusses the replacement of incandescent calibration sources by LEDs. By this the measurement uncertainty due to the spectral mismatch of photometers could be reduced.

This workshop will present the selection methodology used to identify the typical reference spectra to be included in the next edition of CIE 015. In addition, the impact of the selection of one or several LED-based calibration spectra is discussed. This work is supported by the European research project EMPIR 15SIB07 PhotoLED (Future Photometry Based on Solid State Lighting Products, http://photoled.aalto.fi/) which had collected and analysed a large number of spectra of SSL products on the market.

WS3

Seminar

DISCOMFORT GLARE EVALUATION FOR DAYLIGHT AND ARTIFICIAL LIGHT

Conveners:
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Summary

The avoidance of glare is an important issue for the design of buildings in order to guarantee a comfortable visual environment for occupants. It is therefore necessary to have reliable metrics to predict glare situations within a building. In the last several years, façade and electric lighting installations have advanced dramatically, but these advances have also provided a challenge to glare metrics, since most of them were developed under different boundary conditions than what they are nowadays applied to. This workshop reviews the state of the art for glare research related to buildings and gives practical advice for measurements and experimental protocol.

The workshop is divided into three parts:

1. **State of the art and current issues** (~2,5 h). In this theoretical block of the workshop, the state of the art of glare metrics is reviewed – for both daylight and electric light. Latest developments, improvements and the reliability of the metrics will be discussed. The differences and similarities between glare from daylight and glare from electric light will be also be addressed. Within the discussions, the outcome of the research activities will be debated, with shortcomings and future research demand formulated.

2. **Measurement of luminance distributions in the field of view for glare evaluations** (~45 min). In this practical session, the methods of acquiring reliable HDR images will be explained, including the calibration and pitfalls.

3. **Requirements for user assessments and measurements of luminance distribution in the field of view** (~40 min). In this session, guidance for the assessment protocols for future research will be given. Topics are: Design of experiments, statistical methods, acquisition of reliable HDR images and metrics.

WS5

Workshop

ROAD SURFACE PHOTOMETRIC CHARACTERISTICS MEASUREMENT SYSTEMS AND RESULTS

Convener:
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Summary

The half day workshop has the aims to stimulate the International Lighting Community on the topic of road surface photometric characteristics and characterization and to provide large feedback for CIE TC 4-50 work and to the Project SURFACE "Road surface characterisation for efficient and smart lighting". This is a research programme funded by the European Metrology Programme for Innovation and Research (EMPIR) with the objective of assuring traceable data and new measurement methodologies as action to establish a safer and more energy efficient road lighting environment.

During the workshop the main topics highlighted and discussed will be:

- Measurement methods for laboratory characterization and on-site measurements,
- New solution and possibilities for portable and laboratory instruments for road surface characterization,
- Road surface characteristic challenges for 21st century road lighting,
- Measurement geometries,
- Visual optimization.

During the workshop the activity carried out in TC 4-50 and the SURFACE project will be presented and two invited speakers will illustrate some peculiar aspects about their last work on road surface characterization in the European Nordic Countries and in developing a new gonioreflectometer.

WS6

Seminar

TEMPORAL LIGHT ARTIFACTS IN AUTOMOTIVE AND GENERAL LIGHTING

Conveners:
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Summary

Lighting-emitting diodes (LEDs) are widely used in automotive lighting from rear lamp to headlamp. LEDs prevail in automotive exterior lighting and general interior lighting as well. Time-modulated light sources - especially LED light sources - can cause temporal light artifacts (TLA) such as flicker, stroboscopic effect, and phantom array effect. In this special session, we will overview recent advances in understanding temporal light artifacts in automotive and general lighting, potential risks, and their solutions.

The seminar will consist of:

1. Introduction to temporal light artifacts in automotive lighting and general lighting
2. Human spatial and temporal vision, saccadic suppression
3. Stroboscopic effect and methods to reduce the stroboscopic effect in general and automotive lighting
4. The phantom array effect in automotive lighting
5. Perspective of future advanced lighting systems

Invited Speakers

- Dragan Sekulovski (Philips Lighting, NL) – General Lighting/Stroboscopic effect
- Arnold Wilkins (University of Essex, UK) – General Lighting/Phantom Array Effect
- Peter Bodrogi (Darmstadt, DE) – Human Centric Lighting
- Alexander Herzog (Darmstadt, DE) – Investigation of spectral flicker and stroboscopic effects
- Chan-Su Lee (Yeungnam University, KR) – Automotive Lighting/Phantom Array Effect

WS7

Seminar

JUDGING THE SCIENTIFIC QUALITY OF APPLIED LIGHTING RESEARCH

Conveners:
Veitch, J.A.[1], **Houser, K.W.**[2], **Fotios, S.**[3]
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Summary

Applied lighting research is inherently interdisciplinary. Any one study in which investigators seek to understand the effects of light may involve expertise drawn from fields as varied as psychology, physiology, photobiology, vision science, engineering, physics, horticulture, and architecture. Despite differences in the specifics of research methods, data management, data analysis, and presentation, the logic of scientific thinking is a common thread. This is the basis on which the peer review system operates.

This seminar is a prelude to the 2018 Division 3 Expert Symposium on Lighting Research Methods. Led by journal editors and advisors, the seminar will lead participants through the criteria used to determine the acceptability of papers for publication in a peer-reviewed journal. This will be done by review of the 1941 paper by Kruithof: how one would review the original Kruithof paper today, and what we would expect to be told about this work in order to judge its strength.

The issues include:

- ethical issues associated with human participants
- specification of the lighting conditions
- description of the method
- sampling
- design of laboratory and field investigations for causal inference;
- operationalization, reliability, and validity of behavioural measurements;
- practical photometry and colorimetry;
- statistical analysis
- reporting standards

The convenors will introduce the paper for those who have not recently read it, and will extract from the paper the information relevant to each point. Through audience interaction, we will collectively consider the strengths and weaknesses of the report, leading to guidance concerning what we all should expect to find in a report submitted today.

Reference

Kruithof AA. 1941. Tubular luminescence lamps for general illumination. *Philips Technical Review, 6*(3):65–73.

ORAL PRESENTATIONS IN WORKSHOPS

WP01
(IN WS2: ILLUMINANT L AND LED REFERENCE SPECTRA)

DETERMINATION OF ILLUMINANTS REPRESENTING TYPICAL WHITE LIGHT EMITTING DIODES SOURCES

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Abstract

1. Motivation, specific objective

Solid-state lighting (SSL) products are already in use by consumers and are rapidly gaining the lighting market. Especially, white Light Emitting Diode (LED) sources are replacing banned incandescent lamps and other lighting technologies in most general lighting applications. Spectral power distributions (SPDs) of LEDs are quite different from those of conventional light sources which raise questions about applicability of colorimetry and photometry based on the standard illuminant A.

Currently, most lighting products measured in laboratories and in the field are LED sources while incandescent lamps and $V(\lambda)$-filtered photometers are still the standards used in photometric calibrations. However, in order to keep spectral errors of the measurement small, it is important to use a calibration source with a SPD close to the SPD of the tested light.

2. Methods

The new three-years European research project EMPIR 15SIB07 PhotoLED (Future Photometry Based on Solid State Lighting Products), aims to solve these issues by selecting new calibration spectra and developing standard lamps based on white LED sources in close connections with CIE Division 1 and Division 2.

The aim of this work is to develop LED-based illuminants that describe typical white LED products based on their SPDs. These new illuminants could complement the CIE illuminants for the update of the CIE publication 15:2004 on colorimetry and could be used to propose a substitute to CIE standard illuminant A for calibration use in photometry.

During autumn 2016, 1298 SPDs of white LED sources available on the market were collected from the partners and collaborators of the project PhotoLED. A database of traceable relative spectral measurements (relative radiant flux in sphere or irradiance with goniometer or bench) of typical white LED SPDs was established covering spectral range of 380 nm to 780 nm with 1 nm steps.

This study summarizes the sorting of the data according to different spectral shapes and correlated colour temperatures (CCTs) and the analysis proceeded to select representative illuminants for SSL products. The applicability of various statistical methods was explored to derive, from the database, typical LED spectra that could be used as new LED-based illuminants. Different approaches (AHC, kmeans, PCA…), distances (norms, Euclidean, Mahalanobis…), closeness or farness scores and methods of averaging were investigated to define these typical illuminants.

3. Results

The final process to determine the typical LED spectra was first to separate the SPDs into CCT bins. The specifications for the chromaticity of SSL products, provided by ANSI Standard, were applied to determine outliers (176) and to divide the SPDs into 8 CCT bins (2700K, 3000K, 3500K, 4000K, 4500K, 5000K, 5700K, 6500K).

Then typical spectral shapes of the remaining SPDs in the database were investigated. Within this database there were mainly phosphor-converted blue LEDs (BLED - 1071), 45 hybrid LEDs (mixing of phosphor-converted blue LED and red LED), four phosphor-converted violet LEDs (VLEDs) and two RGB LEDs composed of mixing of red, green and blue LEDs.

The final process to determine the eight typical BLEDs spectra corresponding to the ANSI bins was:

1. Normalization of each SPD at the same Y values.
2. Computation of a closeness score for each SPD within its bin.
3. Determination of the closest SPD for each bin (centroid).
4. Determination of a set of 10 SPDs, with the SPD centroid and its nine closest SPDs, for each bin.
5. Averaging those SPDs, for each bin.
6. Smoothing the averaged SPDs to avoid ripples due to measurement noise (particularly after 690 nm).
7. Interpolating the smoothed SPDs between 410 and 430 nm and extrapolating them below 410 nm to avoid measurement artefact due to some stray light in single grating spectrometers.

For the hybrid LEDs the same method was applied, regardless of the CCT, to obtain one typical hybrid LED spectrum.

VLEDs and RGB LEDs were not numerous enough to extract typical representative illuminants.

4. Conclusions

CIE TC1-85 plans to include in the new version of CIE Publication 15:2004 the spectral power distributions of the typical hybrid LED (CCT=2850K) and of five BLEDs. They will be published as illuminants representing typical LED lamps as it was done previously for fluorescent or HID lamps. The chosen corresponding CCTs bins for BLEDs are 2700K, 3000K, 4000K, 5000K, and 6500K as they are the most representative of the market.

Although not representative of the market, the two RGB LEDs and two violet LEDs will also be included in the publication to illustrate the spectral shape of these types of LED sources.

The new representative spectra proposed for colorimetry will form the basis of discussion to choose appropriate LED calibration spectra for the new LED-based system of photometry. It would be a great advantage for everyone working in the fields of photometry and colorimetry, if the LED illuminants recommended by Division 1 include the LED calibration spectra recommended by Division 2 for photometry.

5. Acknowledgments

The work leading to this study is partly funded by the European Metrology Programme for Innovation and Research (EMPIR) Project 15SIB07 PhotoLED “Future Photometry Based on Solid State Lighting Products”. The EMPIR initiative is co-funded by the European Union’s Horizon 2020 research and innovation programme and the EMPIR Participating States. The authors would like to thank all partners and collaborators of the project who provided spectral data of LED products for the analysis.

WP02
(IN WS2: ILLUMINANT L AND LED REFERENCE SPECTRA)

DEVELOPMENT OF NEW CALIBRATION SPECTRA AND TRANSFER STANDARD LAMPS FOR PHOTOMETRY BASED ON WHITE LIGHT EMITTING DIODES

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Abstract

1. Motivation, specific objective

Incandescent standard lamps and $V(\lambda)$-filtered photometers are commonly used as transfer standards in calibrations of luminous intensity, luminous flux and photometer illuminance responsivity. Methods used in classical photometry, including calibration of lamps with respect to Standard Illuminant A spectrum, were established long before light emitting diodes (LEDs) became popular in lighting. Increasing number of light sources measured with photometric instruments in testing of new products, as well as in the field, are based on white LEDs.

Due to the fact that relative spectral responsivities of photometers with optical $V(\lambda)$-filters differ from the defined CIE $V(\lambda)$ weighting curve, it is important to use a calibration source with spectral power distribution (SPD) close to the SPD of the light being measured to keep spectral errors of the measurement small. The global phasing out of incandescent lamps has changed the lighting market and products being tested for entering the market. Measurement tasks for photometric instruments no longer deal with incandescent lighting as often, but with light produced by LEDs. Despite this change, all typical photometers used for product testing and for measuring lighting are still calibrated with incandescent standard lamps with correlated colour temperature (CCT) adjusted close to 2856 K, corresponding to the Standard Illuminant A calibration spectrum. Another issue is that the availability of incandescent standard lamps has become poor, some standard lamp models already disappeared from the market. This introduces problems for calibration laboratories, especially for new test laboratories trying to establish measurement capabilities. International comparisons of photometric quantities are limited by the availability of some lamp types that were commonly available earlier.

2. Methods

European research project EMPIR 15SIB07 PhotoLED (Future Photometry Based on Solid State Lighting Products), started in September 2016, aims to solve the above issues by developing new calibration spectra and transfer standard lamps based on white LED sources that are urgently needed to complement and eventually to replace incandescent calibration lamp technology in photometry.

The project carries out three-year long scientific research to study the basis of new LED-based photometry with technical tasks covering selection of suitable calibration spectra, development of new transfer standard lamps and measurement methods for photometry. The methods will be validated in comparisons arranged as part of the project. The work is carried out by leading European National Metrology Instititutes (NMIs) and industrial partners working in the field of LED lighting and photometry, as well as with close connections to CIE Division 1 and Division 2 to involve experts working outside of the project to speed up the uptake of the methods by Technical Committees (TCs) of CIE. The advantages and issues arising from the change of indandescent calibration sources to LEDs are studied and published in various guideline documents, scientific papers and conferences.

New LED calibration spectra describing the SPDs of typical white LED products are used as the basis of the new LED-based photometric system to allow reducing typical spectral errors in measurements of LEDs. The impact of limited spectral range of typical white LED sources is studied by comparison with LED sources designed with extended spectral range to identify the underlying limitations and

possible compatibility issues related to performance of the new sources and measuring instruments. The new calibration spectra will be used in selection of physical calibration lamps based on LEDs.

The project aims to develop photometric transfer standard lamps for luminous intensity and luminous flux. Suitable LEDs and optical materials with spectral properties close to the analysed calibration spectra will be selected. The new LED standard lamps will be fully characterised and evaluated in two different comparisons to demonstrate their applicability in future international key comparisons as direct replacements for incandescent standard lamps.

3. Results

In the autumn of 2016, a total of 1298 relative spectra of white LED products were collected from the project partners and collaborators interested. Only spectral data measured with traceable and calibrated spectroradiometers used in combination with integrating spheres and goniophotometers was used. The spectral data were collected into a database and sorted into bins based on the different spectral shapes and correlated colour temperatures (CCTs) of the products measured. As a result, a total of 8 different bins with CCTs between 2700 K and 6500 K were obtained. A spectral shape that best represents each bin was then identified. This analysis process is described in more detail in the abstract of paper by S. Jost et al., submitted to the conference as well.

CIE Division 1 is about to publish a new revision of CIE15:2004 Colorimetry, including representative LED spectra. The first steps in discussions with CIE were carried out between the project PhotoLED and CIE Division 1. At the time of writing this abstract, information about Division 1 possibly adopting many of the analysed spectra was received. In order to make most out of the analysed spectra and ease the work of all in the field of photometry and colorimetry, the spectra published by Division 1 for colorimetry and Division 2 for calibration use in photometry should be the same. For practical reasons, mainly to limit the number of sources needed in calibration of photometers, Division 2 could adopt a subset of spectra chosen by Division 1, to be used as the basis for physical calibration sources. The next step is to open the discussion to Division 2 and choose suitable LED calibration spectra to be used in photometry.

4. Conclusions

The project PhotoLED is working towards new system of photometry based on white LED sources. A large database of traceable relative spectral data of white LED products collected was analysed to be used in applications of colorimetry and photometry. The new representative spectra proposed for colorimetry, as well as a subset of the spectra proposed to be used as LED calibration spectra in photometry will be presented and discussed at the conference. By that time, the applicability of the spectral data has been discussed with both CIE Division 1 and Division 2. Introducing the new LED spectra for colorimetry and photometry, as well as new LED calibration sources will ease the work of people working in the field of colorimetry and photometry, and help companies to build LED products with better quality and energy efficiency, also for the benefit of consumers and other end users.

Acknowledgements

The work leading to this study is partly funded by the European Metrology Programme for Innovation and Research (EMPIR) Project 15SIB07 PhotoLED “Future Photometry Based on Solid State Lighting Products”. The EMPIR initiative is co-funded by the European Union’s Horizon 2020 research and innovation programme and the EMPIR Participating States. The authors would like to thank all partners and collaborators of the project who provided spectral data of LED products for the analysis.

WP03
(IN WS5: ROAD SURFACE PHOTOMETRIC CHARACTERISTICS: MEASUREMENT SYSTEMS AND RESULTS)

CHARACTERISATION OF THE REFLECTION PROPERTIES OF ROAD SURFACES USING AN IN-LAB GONIOREFLECTOMETER

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Abstract

1. Introduction

Road lighting is intended to increase the visual perception of objects in the road scene and thus contributes to the comfort and safety of users at night. Ensuring adequate luminance levels on the pavement is therefore necessary. The luminance distribution depends, not only on the photometric properties of the lighting source, but also on those of the pavement. Hence, the reflection properties of the pavement have to be considered when designing a road lighting installation.

The complete reflection properties of a surface can be specified by means of a set of luminance coefficients. The luminance coefficient q is defined as the ratio between the luminance L of a point on a surface, and the horizontal illuminance E on this surface, at the same point, caused by a light source. This coefficient q varies both with the lighting and viewing directions, and is thus also referred as Bidirectional Reflectance Distribution Function (BRDF). It can be measured by means of a gonioreflectometer, with some limits such as difficulties to measure retroreflection direction and at grazing angles.

We present in this paper our in-house built gonioreflectometer for in-lab measurements, especially suited for public lighting applications.

2. Description of our gonioreflectometer and its specificities, methodologies of calibration and measurement

The functioning of our gonioreflectometer is summarized as follows. The incoming beam light from a 250 W still halogen lamp is projected onto the sample we want to measure, thanks to a system of mirrors placed on a 150 cm rotating arm called the lighting arm. The sample is laid on a rotating turntable which is solidary to a 150 cm rotating viewing arm, at the end of which is placed a photometer head. This sensor comprises a photopic spectral luminous efficiency function ($V(\lambda)$) filter and measures the illuminance reflected on it in a given direction from the lighted sample.

Independent motions of the lighting arm (whose motion defines lighting angles), the viewing arm (viewing angles), and the turntable (angles between the lighting and viewing planes), ensure that the gonioreflectometer measures the whole hemisphere above the sample, limited only by geometrical and optical constraints.

Motions of the various components of the gonioreflectometer, via monitored motors, as well as measurements are all performed automatically thanks to in-house developed software.

Usually, the horizontal illuminance E on the sample and the reflected luminance L in a given direction are measured to compute the luminance coefficient q. Instead, in our case, only illuminances on the photometer head are measured: after a prior calibration phase using the photometer head and a calibrated lambertian surface, we use the same detector during the measurement phase, to indirectly determine both the luminance L and the illuminance E, and thus q. The methodologies of calibration and measurement are detailed in the paper.

Our instrument was designed especially for measuring the BRDF of rough surface materials such as road pavement, thanks to a relatively wide circular measurement area of approximately 10 cm in diameter. The measurement principle of the instrument requires that this area be kept constant, whatever the movement of the arms or the turntable. And yet, the higher is the lighting angle (i.e. the higher is the grazing angle), the more elliptical becomes the lighted area. In order to correct this, a

circular diaphragm is placed in front of the source, which rotates concurrently with the lighting arm and corrects the elliptic nature of the lighted area so as to keep it circular and constant.

Our gonioreflectometer was equally designed for grazing lighting angles (up to 85° from the vertical) and even more grazing viewing angles (up to 89° from the vertical). It also closely approaches retroreflection (as near as 2.5°). Besides these geometrical and optical constraints, BRDF can be measured for any other combination of angles. Furthermore, in order to get a complete BRDF (i.e. in the whole hemisphere above the surface), a methodology was proposed in the literature, which uses extrapolations and interpolations from the available data to get the missing ones.

3. Applications and results

Our instrument which measures whole BRDF, may a fortiori measure r-tables. As it has been proved that standard r-tables seem no longer representative of current road surfaces, and the need for a large data base of measurements for updated classification is confirmed, our gonioreflectometer may be usefully utilized for these purposes.

Its utility could also arguably lie in its capabilities to measure at other viewing angles than the standard 1° which corresponds today to the motorist's view on the road. It may thus contribute to reflexions on the need of data or r-tables for other viewing angles and the specific requirements for certain applications in the fields of automotive and public lighting (adaptive lighting, observation from pedestrians, visually impaired people, truck drivers, aircraft, etc.).

The BRDF of some pavement samples measured by means of our gonioreflectometer are presented and commented in the paper.

4. Conclusions and future work

Our gonioreflectometer has been specifically designed keeping in mind various issues regarding road pavement and public lighting. More work is needed for metrological qualification of this instrument (e.g. inter comparisons, uncertainty calculations).

Adaptability of this instrument is also one of its assets. Indeed, on-going work includes adapting our instrument for measurement of wet surfaces. Defining and measuring in standard wet conditions as described by the CIE is a difficult task, especially when measurements are time-consuming. We have been working on solutions to address various issues arising out of wet conditions.

Future work also involves replacing the photometer head with a spectrometer head in order to be able to measure spectral luminance coefficients. This could be useful in computing other parameters such as scotopic or mesopic luminance coefficients, and even, non visible (e.g. near infrared) BRDF for ADAS sensors, for instance.

WP04
(IN WS5: ROAD SURFACE PHOTOMETRIC CHARACTERISTICS: MEASUREMENT SYSTEMS AND RESULTS)

PRINCIPLES FOR A PROTOTYPE INSTRUMENT FOR MEASUREMENT OF ROAD SURFACE PROPERTIES

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Abstract

1. Motivation

Road surface reflection data in the form of standard r-tables serve as input for design calculations of road lighting installations on traffic roads.

However, in several countries including the Nordic countries of Denmark, Finland, Norway and Sweden the use of the standard r-tables has not been verified by measurements in a long period of time, while the types of road surfaces in use have changed - for instance to road surface types with less noise from wheel passages.

Accordingly, a co-operation between the road administrations of the Nordic countries (abbreviated NMF) decided to construct a portable instrument to be used on selections of traffic roads within these countries in order to provide updated knowledge about the reflection properties.

The principle of this instrument was defined in an initial analysis of road surface reflection properties and a prototype instrument was available early 2017. The measurements in the Nordic countries are presently ongoing; results are accounted for.

It is believed that this principle is superior being both simple and quite accurate. The principle free for others to use and will be described in this article.

2. Methods

Road surface characteristics

The reflection properties of a road surface are fully accounted for by a table of the reduced luminance coefficient, called an r-table. Simultaneously, the level of reflection is described by either the average luminance coefficient Q0 or the luminance coefficient in diffuse illumination Qd, while the degree of specular reflection is described by the specular factor S1. These characteristics can be derived from the r-table.

This particular instrument measures the r-values at two positions in the r-table (r1 and r2, measured with illumination perpendicular and with an entrance angle of 63.4° to the road respectively). S1 is the ratio between the two, while Q0 and Qd values are obtained by linear expressions, which will be accounted for.

The instrument

The instrument has a cabinet with black interior surfaces, an illumination system for each of the two r-values, a 45° mirror at the bottom, a white surface at the bottom next to the measuring field and a luminance camera with a view through the mirror.

The illumination systems are arranged so that aperture angles of illumination stay within permissible limits. Further, the camera is placed at such an optical distance that aperture angles of measurement also stay within permissible limits

A field in the camera image defines the measuring field on the road surface on which the instrument is placed. The average value of this field is the average luminance of the road surface within the measuring field.

The measuring field is normally 4 cm times 20 cm, but can be reduced for the measurement of samples. The position of the camera defines the angle of measurement, which is normally 1,0°, but can be changed by movement of the camera.

An additional field of the camera image is used to measure the average luminance of the white surface. The measured value is taken as the ratio of the two average luminance values, which is not affected by variations of the illuminance of the road surface.

Calibration method

In order to avoid that drift in the illumination system influence the measurements a calibration of the instrument is needed. The calibration is based on a surface for which the two r-values are known. The ratio between one of the known r-values and the value measured on the surface with the relevant illumination system is the calibration constant for this r-value.

The surface with known values is actually a device made up of a plane white surface and an overlaying thin plate with diffuse transmittance placed so that they form a wedge with an opening towards the viewing direction of the camera. This brings advantages that will be accounted for.

The r-values of this device are measured in laboratory conditions.

Measurement method

The measurement method is straight forward, place the instrument at the desired location on a road surface, turn on the illumination system for the first r-value, expose a camera image, turn off the illumination system, turn on the other illumination system, expose another camera image and turn off the illumination system.

The two r-values are determined from the two camera images as indicated above. Special software is available for this.

3. Preliminary results

Intercomparisons with other parties by means of road surface samples are ongoing and will be accounted for.

As an example of results, two samples that have been measured by the Danish lighting laboratory have been measured and showed good agreement between the new measurements and the old results.

4. Conclusions

The prototype instrument is based on a simple principle, to measure only two r-values of a road surface, but to do it in a correct manner, and then to derive the characteristics of the road surface reflection properties from those two r-values. Further, sound methods for compensation for variations in illuminance and for calibration have been introduced.

The principle needs to be verified by intercomparisons, which are ongoing. Actual measurements are also ongoing.

WP05
(IN WS6: TEMPORAL LIGHT ARTEFACTS IN AUTOMOTIVE AND GENERAL LIGHTING)

ACCEPTABILITY CRITERIA FOR THE STROBOSCOPIC EFFECT VISIBILITY MEASURE

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Abstract

1. Motivation, specific objective

In 2016 the Technical Committee 1-83 of CIE published a Technical Note (TN), entitled Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models. The TN defines the perceptual effects that modulated light can produce, (flicker, stroboscopic effect and the phantom array effect), which are called Temporal Light Artefacts (TLAs). Stroboscopic effect is defined as a "change in motion perception induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a non-static environment". To quantify the visibility of the stroboscopic effect, CIE recommends to use the Stroboscopic Effect Visibility Measure (SVM). It is calculated in the frequency domain, by performing a discrete Fourier transform of the input periodic waveform, sensitivity normalization and summation of the amplitudes of the resulting frequency components using a Minkowski norm parameter of 3.7. The limit of SVM = 1 defines the visibility threshold. It means that in critical conditions, i.e. with an observer focused on a high contrast stimulus, moving with a speed of 4 m/s, she will on average detect the stroboscopic effect with the probability of 0.5. However, in realistic applications, like in home or in retail, the conditions are usually not so critical and setting SVM limit to be 1 might lead to over-specifications. This in turn can lead to increased price of LED light sources. Therefore, next to the visibility limit, the acceptability limits for different applications need be defined. Understanding acceptability of the stroboscopic effect is essential for establishing criteria for performance standards of lighting equipment.

In this article we present experiments that resulted in development of acceptability limit for the SVM in a typical office application. The limit can be used in other applications with comparable lighting characteristics and speeds of observed moving objects. Based on the results, a general method to assess the acceptability of the stroboscopic effect in any lighting conditions was developed.

2. Methods

Conditions, similar to ones used in a typical office were simulated. Two luminaires, equipped with LEDs, were mounted in a frame at a height of 2.5 m. Under the luminaires an office desk was placed. Four experiments were conducted and during each experiment participants were sitting at the desk, below the luminaires. The LED lighting system was used to generate a number of different light waveforms, including squared waveforms (experiment 1) and more practical waveforms that can be expected from use of different driver topologies, being single - stage drivers (experiment 2) and Tapped Linear Drivers (experiment 3 and 4). The light waveforms were normalized to produce 500 lux on the task surface. During each experiment, each of the lighting conditions was shown for a few minutes. Participants were instructed to perform a number of typical office activities during each of the conditions, such as reading an article, or writing an essay. After performing the activities, participants were instructed to evaluate the quality of light by filling in a questionnaire. To ensure that they were naïve to the purpose of the study, the temporal light qualities, including "flickering of the light" and "motion artefacts" were evaluated together with other attributes, e.g. "glare from the luminaires". To appraise these attributes, the questionnaire consisted of a 5-point categorical scale of (1) imperceptible, (2) perceptible but not annoying, (3) somewhat annoying, (4) annoying, (5) very annoying. After each lighting condition, a constant lighting stimulus (DC) was evaluated in the same way, as a reference condition.

3. Results

The results of the four experiments were aggregated and analysed together. SVM was calculated for the light waveforms of all lighting conditions, resulting in 13 points. Then, the percentage of observers that were annoyed due to the stroboscopic effect were calculated for each of the light waveforms. The observers were considered annoyed if they have chosen answers (3), (4) or (5). The percentage of annoyed observers was plotted as a function of SVM, and a maximum likelihood fitting procedure was used to derive the parameter values of the psychometric curve that best describes the annoyance percentage values.

It was found that 20% of the people are annoyed due to the stroboscopic effect at SVM = 1.5. At SVM = 0 (DC), about 5% of the people found the effect annoying. This might seem counterintuitive, but in realistic situations there are always people who complain, irrespective of the conditions. If corrected for this group of people, SVM = 1.5 means that less than 10% find the effect annoying, and this value was considered acceptable.

It has been established that the acceptability of the stroboscopic effect depends on the speed of the moving objects and the time people are exposed to the light waveform. These two variables, and the results of the four perception experiments in the office application were considered to develop a general method, which can be used to assess the acceptability of the stroboscopic effect in any application.

4. Discussion and conclusions

Four experiments were performed in conditions typical for an office application. Based on the results an acceptability limit of SVM = 1.5 was proposed. The experiments were designed for an application in an office environment, but the limit can be applied in a broader context, with comparable illumination level and speed of movement.

CIE recommends usage of SVM to objectively quantify visibility of the stroboscopic effect. To apply the measure in performance or application standards, we need to know more on how the acceptability varies in different applications. The current study shows a methodology and first results on SVM acceptability limits in a specific application. It will undoubtedly be beneficial to lighting community if more studies are done on the acceptability of the stroboscopic effect and other TLA effects performed for different applications and conditions, including exposure time, speed of movements, contrast, and daylight.

WP06
(IN WS6: TEMPORAL LIGHT ARTEFACTS IN AUTOMOTIVE AND GENERAL LIGHTING)

THE LINK BETWEEN PERCENT FLICKER AND THE FLICKER INDEX PROVIDES A SIMPLE AND POWERFUL TOOL FOR CLASSIFYING RESPONSES TO VARIABLE LIGHT SOURCES

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Abstract

1. Motivation, specific objective

The growth in LED lighting has prompted the international community to rethink the flicker problem. There is already a general understanding that lighting should not flicker below twice the existing mains frequencies, i.e. 120 Hz in the Americas, the pacific basin, Liberia and Saudi Arabia and 100 Hz elsewhere, but there is good evidence to suggest that this may not go far enough. Specialists now hope to prevent adverse health and safety effects due to modulation or flickering of light sources (see IEEE SA-P1789: 2015).

Visible flicker can cause health effects including epileptic seizures, headaches and eye strain. Some people are particularly susceptible. Even the frequency region above the critical fusion frequency (CFF) can cause headaches, eye strain and reduced visual performance, i.e. between approximately 80 Hz and 333 Hz. Combined with moving objects or eye saccades, these and higher frequencies can create both safety and visual performance concerns due to stroboscopic illusions and image trails.

The main methods for classifying the severity of flicker with a single figure are percent flicker F_P and flicker index F_I. Both have limitations, most notably that neither takes account of the all-important frequency of flicker. As a result neither can claim to predict the response to a general flickering source with mixed frequencies (i.e. waveforms with different shapes).

Physiological Percent Flicker F'_P is a proposal that takes account of frequency whilst remaining applicable for a general flickering source. F'_P also provides a mathematical connection between F_P and F_I.

2. Methods

F_P is based on the relative values of the extreme intensities, whereas F_I is based on the relative areas above and below the mean.

Although it does not directly take account of frequency, the area approach of F_I offers advantages when applied to the flicker frequency range of approximately 80 Hz to 333 Hz, as the physiological response time-horizon is similar to the flicker frequency.

Physiological Percent Flicker F'_P is the percent flicker of the smoothed waveform. Therefore, F'_P is still based on relative values, but the waveform is exponentially smoothed, with a “half-life” time horizon based on the cone IRF. This parameter determines the sensitivity to different frequencies. The shortest IRF published suggests the cones act as an early low-pass filter, matched by a half-life of approximately 10 ms. It is hypothesised that in a stationary system the cones cannot pass on information at frequencies much above this time horizon.

However, a cautious allowance for the possibility of periodic contributions from regular small eye movements known as ocular microtremor (OMT) is advisable. This physiological mechanism may even be used by the eye to leverage a faster response from the basic IRF. As OMT periods (1/frequencies) are similar to 10 ms these implications of OMT can be managed by using a slightly shorter time-horizon to allow for potential worst-case interference between OMT frequencies and the

modulating light. Accordingly, a half-life of 3 ms is used, which also provides a margin for uncertainty about the most rapid IRF in the human eye.

As the IRF of the cones act as an early low-pass filter with which light is initially transduced into internal physiological activity, and as the CFF is the result of one or more later low-pass filters acting on the internal activity, this directly implies physiological effects from flicker must exist above the CFF. This logic holds independently of any potential effects from OMT to increase the frequency threshold of the early filter.

3. Results

An existing library of LED and other lighting waveforms, incorporating new samples from up to 2017, and other lighting technologies, has been collected by acquiring waveforms at sampling frequencies in excess of 10 kHz. It was shown that the flicker waveforms from LED lighting solutions are heterogeneous, although none of the LEDs studied flickered at frequencies below 100 Hz.

This library also provides sufficient data for calculations down to 1 ms smoothing, and a selection of alternative time horizons is illustrated, and F'_P is compared to F_P and F_I.

4. Conclusions

If adopted for flicker frequencies above CFF, F'_P would greatly simplify regulating the flicker performance of general service lighting. F'_P can be used to predict which waveforms with frequencies over the CFF may still cause adverse health effects.

F'_P is a generalisation of F_P and, for flicker of a given frequency, F'_P closely correlates to F_I. Broadly speaking, F_P and F_I can be considered as instances of F'_P, although they are both sub-optimal instances for predicting responses to flicker. F_P is the extreme example of F'_P applicable only when flicker frequency >> IRF time-horizon. In addition, F_P is only proportionate to F'_P for a fixed waveform shape. F_I only approximates F'_P for a particular flicker frequency, and can, therefore, only be interpreted when the flicker frequency is given. In general, the transduction of time-varying light signals by the human eye doesn't correspond to either F_P or F_I predictions.

The F'_P approach also has limitations. Like F_P and F_I, it does not deal with the spatial distribution of light, saccades or stroboscopic effects. Where effects of this type are expected from flicker frequencies above approximately 333 Hz, an application-specific approach would be recommended.

Finally, consideration must be given to the threshold for F'_P values that are considered acceptable. In order that new lighting technologies are at least as good as existing ones, the F'_P threshold should perhaps be no higher than 3%, defined as the F'_P of a conventional incandescent light bulb driven by main electricity with a sinusoidal 60 Hz waveform with F_P = 10%. The potential for long-term effects of flickering light on eye health and other health outcomes should be the subject of further study within epidemiology, as there is little such data despite the existence of degenerative diseases with uncertain aetiology.

WP07
(IN WS6: TEMPORAL LIGHT ARTEFACTS IN AUTOMOTIVE AND GENERAL LIGHTING)

EFFECTS OF NON-VISUAL OPTICAL FLICKER IN AN OFFICE WITH TWO DIFFERENT LIGHT SOURCES

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Abstract

The negative effects of optical flicker have been known for a long time. Many people report problems like headache, eyestrain and nausea when working under flickering lights. For frequencies above the threshold for direct perceivable flicker, typically 60-90 Hz depending on the type of flicker and the individual's sensitivity, flicker may still be noticed through stroboscopic effects which can be very disturbing. With pulse width modulated LED lighting optical flicker has become a growing problem and it is not yet clear what frequencies, modulation depths, waveforms etc. that safely can be used to avoid negative health effects. With an abundance of different LED-products and drivers on the market there may also be situations in which different light sources in a room flicker with different frequencies, and by that increasing the risk of disturbing effects due to frequency mixing.

We report on an investigation on how people experience lighting in an office where the light from the ceiling and the light from the desk lamp are modulated separately with different frequencies. For this study an office with no influence of daylight was equipped with two commercially available light sources, one 60×60 cm LED-panel in the ceiling and one LED desk lamp. The lamps were slightly modified in order to be able to individually control the intensity and modulation (frequency, depth, waveform etc.) of each lamp, using a four channel LED-controller. In order to keep the number of influencing parameters reasonably small throughout the test, the type and depth of modulation were kept constant (square wave, 100% flicker) with a duty cycle of 30%. The position of the desk lamp was fixed and the lamp currents were set so that the illumination on the working area of the desk had equal contributions from the two lamps. The total illumination on the desk was about 850 lux.

The LED-controller was programmed with six different scenarios. Five scenarios had selected flicker frequencies in the range 100–800 Hz and one scenario was completely without flicker. The following scenarios with flicker were used:

- 400 Hz (ceiling) / 357 Hz (desk)
- 357 Hz (ceiling) / 100 Hz (desk)
- 100 Hz (ceiling) / 357 Hz (desk)
- 100 Hz (ceiling) / 100 Hz (desk)
- 833 Hz (ceiling) / 357 Hz (desk)

Note that the exact frequencies were selected so that they matched the time base of the LED-controller (20 µs). Also, as the channels were synchronized using a trigger signal, the waveform for each lamp had to overlap perfectly after a certain number of periods in order not to induce noticeable regular imperfections in the flicker.

A total of 30 test subjects (men and women in the ages between 24 and 61) were included in the study. Each test subject spent approximately 50 minutes in the office while performing different tasks. The same tasks were performed for each lighting scenario, each scenario was applied once and the order of the scenarios was randomized. The time spent on each scenario was approximately six minutes. The tasks included:

- General perception of the room. Looking at the patterned curtains, shifting some papers, turning the head, etc.
- Waving of the hand over the working area (lit task area) of the desk.
- Drawing a square on a piece of paper and hatching it with a pen.

- Counting words in a text and underlining the selected words.
- Modified d2 test of attention (three lines of the regular d2 test).
- Reaction time test.

For each task the test subject was asked to assess if he or she noticed any stroboscopic effects while performing the task, and if so, whether the effects were disturbing. Also, in the beginning of the test, the subjects were asked some reference questions about their need for visual aids, how well rested and incaffeinated they were and other general questions about their experienced alertness at the time.

Most test persons found the double 100 Hz modulated scenario the most disturbing, and many also experienced some discomfort with the other modulated scenarios. Only a few did not notice any stroboscopic effects or other discomfort in any of the scenarios. Before starting the test, it was anticipated that the tasks where stroboscopic effects would be more consciously discernable were the first 3 tasks. However, this assumption was at least partly rebutted as some subjects did not notice any stroboscopic effects during the initial tasks but instead experienced disturbing effects in the last three tasks.

All test subjects but one reported that they did not notice any stroboscopic effects in the flicker free scenario. The person reporting stroboscopic effects even in this scenario found all settings more or less disturbing, and it could be that the effects of the flickering in the scenarios preceding the flicker-free one is affecting the brain for a longer time in sensitive individuals.

The study confirms what other studies have shown, that the experience of optical flicker is very individual, however more perceived at lower frequencies but noticeable up to at least 400 Hz. The paper will report on the statistical analysis of the self-reported data in relation to the results of the attention test and reaction time test for all the scenarios also taking into account the order of the scenarios.