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CIE RESEARCH: Application of CIE 2015 Cone-Fundamental-Based CIE Colorimetry

Special Excerpt

Application of CIE 2015 Cone-Fundamental-Based CIE Colorimetry

CIE Division 1, Vision and Color, is responsible for studying visual responses to light and establishing standards of response functions, models and procedures for specifications relevant to photometry, colorimetry, color rendering, visual performance and visual assessment of light and lighting. In this article, the CIE 2015 colorimetry system is introduced followed by a description of key questions proposed by the CIE for future research needs on this important topic.

Among the standards developed by CIE Division 1, the CIE 1931 standard colorimetric observer, defined by the 2-degree CIE color-matching functions

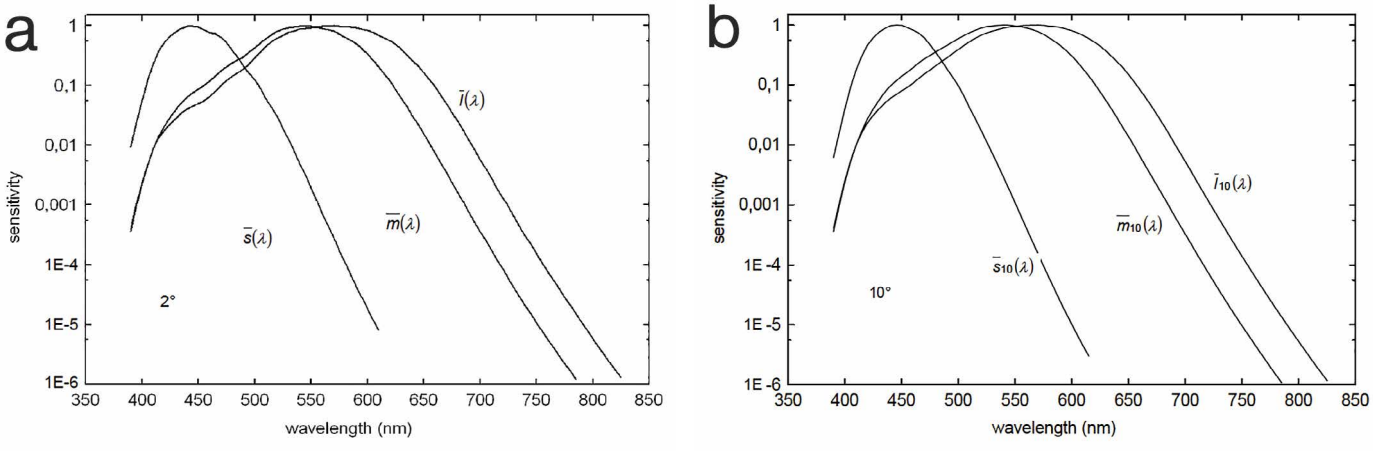
$$\bar{x}(\lambda),\bar{y}(\lambda),\bar{z}(\lambda)$$

are the most important and fundamental functions that form the basis of CIE colorimetry. Even though the CIE 1931 standard colorimetric observer has been used as the international standard for more than 85 years, it is occasionally found that the colors of objects do not visually match even though their colorimetric values are the same. Additionally, there is strong evidence that there can be significant error in the current color specification using the CIE 1931 standard colorimetric observer, especially when applied to some white LED light sources. Since colorimetry was established in 1931, considerable improvements in the metrology of the color stimulus and immense advances in the knowledge of color vision have been made. Based on the modern knowledge of the human color visual system, the CIE published a set of new color-matching functions known as the CIE 2015 observer, which takes into consideration the age of the observer and the field size of the stimulus, and provides a method for deriving the associated chromaticity diagram (CIE 170-1:2006, CIE 170-2:2015).

CIE 2015 Colorimetry

The CIE 2015 Colorimetry system was introduced in two CIE Technical Reports, CIE 170-1 and CIE 170-2, developed by CIE Technical Committee (TC) 1-36. Part 1 of the report introduces cone fundamentals for the normal observer, ranging in viewing angle from 1° to 10°, and Part 2 provides the tools to calculate the cone-fundamental-based tristimulus values, X_F, Y_F, Z_F and chromaticity coordinates, x_F, y_F.

To develop the cone fundamentals for the normal observer in Part 1, it is recommended to use as the color-matching functions (CMFs) of Stiles and Burch (1959), excluding the values of b10 (λ) beyond 505 nm. Then the spectral sensitivity functions of



Figures 1a&b: The cone fundamentals for 2° viewing field (a: CIE 170-1:2006) and 10° viewing field (b: CIE 170-1:2006)

the long-wave sensitive (L-), medium-wave sensitive (M-) and short-wave sensitive (S-) cones, measured in the corneal plane for a 10° viewing field, the so called "cone fundamentals" are derived. Next, by correcting these functions for the absorption of the ocular media and the macular pigment, and taking into account the optical densities of the cone visual pigments, all for a 10° viewing field, the low density absorbance functions of these pigments were derived. Using these low density absorbance functions one can derive, considering the absorption of the ocular media and the macula, and taking into account the densities of the visual pigments for a 2° viewing field, the 2° cone fundamentals (Figure 1a). Using the same procedure one can derive cone fundamentals for every viewing angle between 1° and 10° (Figure 1b). Effects of age can also be incorporated by application of the relationship of the absorption of the lens as a function of age.

Part 2 of the report starts with the definition of cone-fundamental-based spectral luminous efficiency functions, $V_F(\lambda)$ as a linear combination of the long-wave sensitive and the middle-wave sensitive cone fundamentals, following the proposal of Sharpe et al. (2011). Cone-fundamental-based spectral luminous efficiency functions are proposed for the 2° and for the 10° photometric observers. Then MacLeod–Boynton tristimulus values L_{MB}, M_{MB} and S_{MB} are computed in the traditional form, while chromaticity coordinates l_{MB} and s_{MB} are computed so as to preserve the equi-luminant property of the diagram. In addition, transformations of the cone fundamentals in the form of cone-fundamental-based tristimulus values, X_F, Y_F, Z_F, and chromaticity coordinates, x_F, y_F, are presented.

Figure 2 compares the spectrum locus of the cone-fundamental-based chromaticity diagram and that of the CIE 1931 chromaticity diagram.

More recently, CIE TC 1-97, **Age- and Field-Size-Parameterized Calculation of Cone-Fundamental-Based Spectral Tristimulus Values** has been established with the aim to recommend a procedure for age- and field-size-parameterized calculation of cone-fundamental-based spectral tristimulus values, compliant with the principles of the CIE XYZ concept and to deliver a computer program for the calculations.

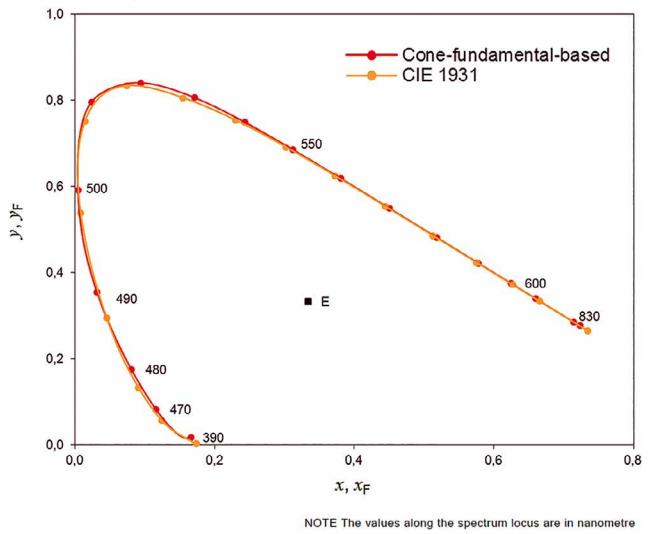
Future Research Plan

As introduced above, the CIE 1931 colorimetric system needs to be improved, possibly by adopting the CIE 2015 cone-fundamental-based colorimetric system for the calculation of colorimetric parameters to be used for the computation of lighting quality data. Therefore, intensive field trials are required to help the color, imaging and lighting industries to gain confidence on CIE 2015 cone-fundamental-based colorimetry.

Firstly, the results of the use of the CIE 1931 (2°), CIE 1964 (10°) and CIE 2015 cone-fundamental-based color-matching functions, need to be compared, especially when applied to LED lighting and in imaging applications. How accurate are cone-fundamental-based colorimetry results compared with those of 1931 and 1964 in predicting typical colorimetry observations such as color difference, color appearance, whiteness, color rendering, etc.?

There is also a need to quantify observer metamerism. Evidence suggests that the earlier CIE method underestimates these effects. There is a need to investigate whether or not the cone-fundamental-based colorimetry could be used to quantify the age metamerism effect and/or the size metamerism effect. Also a recommended method for calculating the CIE 2015 cone-fundamental-based color-matching functions needs to be agreed upon.

The CIE 2015 cone-fundamental-based colorimetry system has established a better link between colorimetry and physiology. This link will improve the understanding of color, will be useful for education and will offer novel opportunities to solve problems of color measurement and color perception in everyday life and industry. ■



NOTE The values along the spectrum locus are in nanometre

Figure2: Spectrum locus of the (x_F, y_F) cone-fundamental-based chromaticity diagram (blue curve) and spectrum locus of the CIE 1931 (x, y) chromaticity diagram (magenta curve) (CIE 170-2:2015)

References:

- CIE 170-1:2006 Fundamental Chromaticity Diagram with Physiological Axes - Part 1
- CIE 170-2:2015 Fundamental Chromaticity Diagram with Physiological Axes – Part 2: Spectral Luminous Efficiency Functions and Chromaticity Diagrams
- SHARPE, L.T., STOCKMAN, A., JAGLA, W., JÄGLE, H. 2011. A luminous efficiency function, V*D65(λ), for daylight adaptation: A correction. Color Research and Application, 36, 42–46

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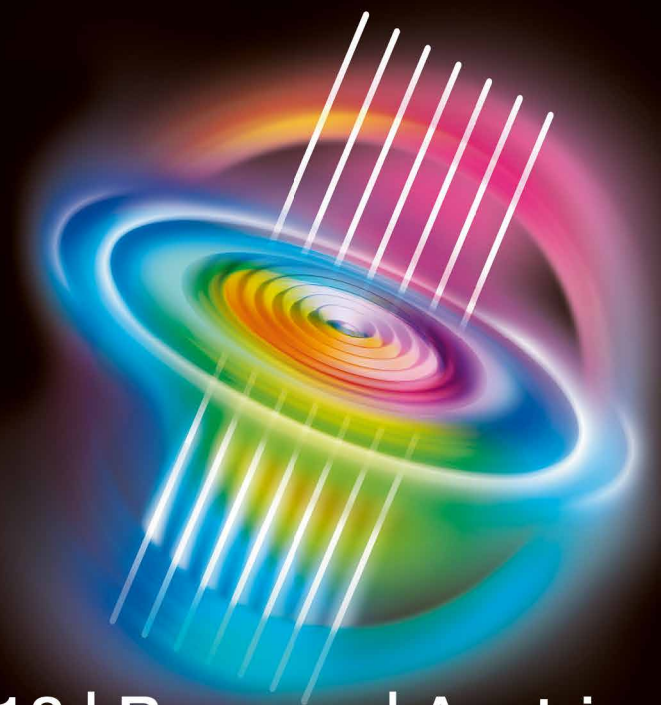

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