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APPLYING AN IMAGE COLOUR APPEARANCE MODEL FOR SIMPLE SELF-LUMINOUS SCENES

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Abstract

Colour Appearance Models (CAM) usually assume a simple test scene of a uniform flat stimulus, background and surround. To consider the spatial information and extend the predictions of CAMs to more complex scenes, Image CAMs such as 'iCAM' are developed, which takes an image as the input and outputs the perceptual attributes per pixel. This paper presents the results of a study in which the performance of iCAM to predict the effects of various parameters on brightness perception, when applied to simple self-luminous scenes, is evaluated. The results show that iCAM can predict the effect of certain background luminance scenarios, however, the outcomes for unrelated stimuli do not match with the reference data. Furthermore, the impact of saturation and of stimulus size on brightness is not predicted by iCAM since both the Helmholtz-Kohlrausch and the stimulus size effect are not included in the model. Hence, a new image CAM for self-luminous scenes is needed.

Keywords: Image Colour Appearance Model, self-luminous scene, perception

1 Introduction

To predict the human perception of object colours, several colour appearance models (CAM) such as CIECAM97s (Luo and Hunt, 1998) and CIECAM02 (Moroney et al., 2002) have been developed. However, the application of such CAMs on self-luminous stimuli faces some challenges, such as the ambiguity of the definition of the reference white and the underestimation of the Helmholtz-Kohlrausch effect (Hermans et al., 2018). To overcome these challenges, a number of colour appearance models such as CAMFu (Fu et al., 2012), CAM15u (Withouck et al., 2015b) and CAM18sl (Hermans et al., 2018) have been established, to predict the perception of a self-luminous stimulus which is either unrelated or surrounded by a uniform and neutral background.

All the aforementioned models generally assume a basic test scene which includes a uniform stimulus on a uniform background and surround. However, in real situations, self-luminous stimuli are perceived in a much more complex environment, hence, a model which considers complex spatial information for predicting the colour appearance of self-luminous stimuli is needed. Image Colour Appearance Models such as iCAM (Fairchild and Johnson, 2002), iCAM06 (Kuang et al., 2007) and the model of Reinhard et al. (Reinhard et al., 2012) have been developed to predict the colour appearances of complex images. These models are mainly applied in the field of High Dynamic Range (HDR) image rendering and video reproduction. Among these models, iCAM is a model which can output, pixel by pixel, the same perceptual attributes as traditional CAMs (brightness, hue, colourfulness, lightness, chroma and saturation).

Since a model to predict the colour appearance of complex self-luminous scenes is still lacking, the goal of this study is to investigate the performance of an existing image CAM like iCAM in predicting the influence of background luminance, stimulus saturation and stimulus size on stimulus brightness, when applied to a simple self-luminous scene.

2 Methods

The basic input for the self-luminous scenes considered in this study is the spectral radiance of both the uniform stimulus and the uniform background, which is then converted into absolute *XYZ* values (hereinafter $X_{abs}Y_{abs}Z_{abs}$) using the colour matching functions which are suitable for stimuli with an angular extension of 10˚(Stockman et al., 1999; Stockman and Sharpe, 2000; International Commission on Illumination., 2006). Y_{abs} refers to the luminance.

A virtual image of $X_{abs}Y_{abs}Z_{abs}$ values is created to represent a scene which consists of a stimulus and a background. The image size is scaled such that 1 pixel in the image corresponds to 1 cm × 1 cm in the real scene. This virtual image is then used as the input for the model.

Since iCAM requires the input to be specified in relative CIE *XYZ* 2˚ tristimulus values, the relative *XYZ* values are first computed from $X_{abs}Y_{abs}Z_{abs}$ values by normalizing for the maximum luminance ($Y_{abs,max}$) in the scene, which makes the *Y* value range from 0 (black point) to 1 (highest luminance). This normalization is also found in the implementation of iCAM06 (Kuang et al., 2007), however, in the reverse direction:

$$XYZ = \frac{X_{abs}Y_{abs}Z_{abs}}{Y_{abs,max}} \tag{1}$$

The implementation of iCAM with all the necessary equations has been described in detail by Fairchild and Johnson (Fairchild and Johnson, 2004). To adapt the implementation of iCAM to the relative CIE *XYZ* 10˚, the tristimulus values of the reference white used in the chromatic adaptation transformation are chosen as the tristimulus values of Illuminant D65 for 10˚ observer, and the conversion of *LMS* to *XYZ* is modified as follows (Smet et al., 2012):

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0{,}400101 & 0{,}707351 & -0{,}0807779 \\ -0{,}226342 & 1{,}165540 & 0{,}0457096 \\ 0 & 0 & 0{,}931776 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{2}$$

2.1 Background luminance experiment

To evaluate the iCAM model performance for predicting the influence of the background luminance on brightness perception, a set of virtual images is generated based on the scenes used in the experiments performed by Hermans et al. (Hermans et al., 2018). Each test scene is composed of a central circular stimulus with a diameter *d* = 0,35 m surrounded by a background panel of 5 m × 3 m, viewed at a distance of 2 m, which corresponds to a Field of View (FOV) of 10° and 102˚ × 70˚, respectively. The dataset consists of the combination of 1 out of 6 circular neutral stimuli (*u'* = 0,232 and *v'* = 0,491), with a luminance level ranging from 50 cd/m^2 to 900 cd/m^2, and 1 out of 15 neutral self-luminous backgrounds (*u'* = 0,231 and *v'* = 0,492), with a luminance level ranging from 0 cd/m^2 to 960 cd/m^2, resulting in a total of 90 test scenes. The corresponding virtual image size equals 500 pixels × 300 pixels with the central stimulus having a diameter of 35 pixels.

2.2 Helmholtz-Kohlrausch experiment

To investigate the ability of the iCAM model to predict the influence of saturation on brightness perception, known as the Helmholtz-Kohlrausch effect (Fairchild, 2005), input images are constructed with the same configuration as in the first experiment, but with different *XYZ* values for both the stimulus as the background. A total of 30 coloured stimuli (6 hues, 5 stimuli/hue) with a fixed luminance of 50 cd/m^2 is presented on a neutral background with $X_{abs}Y_{abs}Z_{abs} = [35{,}59 \quad 33{,}65 \quad 29{,}62]$. The chromaticity of the 30 stimuli is shown on the *u'v'* chromaticity diagram in Figure 1.

The saturation level of the stimuli is computed from iCAM by taking the ratio of Colourfulness (*M*) to Brightness (*Q*) or the ratio of Chroma (*C*) to Lightness (*J*) (Fairchild and Johnson, 2004).

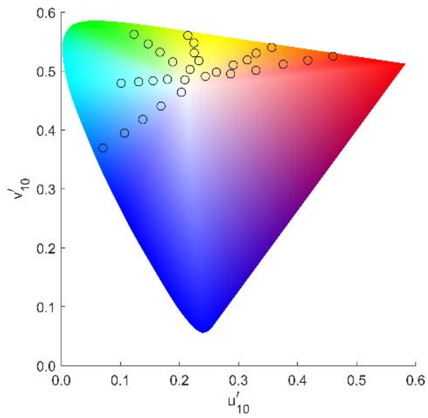

Figure 1 – Representation of the 30 stimuli, used in the second experiment, on a *u'v'* chromaticity diagram.

2.3 Stimulus size experiment

The appropriateness of the iCAM model to predict the stimulus size impact on perceived brightness is performed by aid of a set of 40 stimuli (8 Red, 8 Green, 8 Blue, 8 Yellow and 8 achromatic stimuli) with various sizes (1˚, 2˚, 5˚, 10˚, 15˚, 20˚, 25˚ and 30˚ FOV). The same image size as in previous experiments (500 pixels × 300 pixels) is chosen and the central circular stimulus is presented against a neutral background with $X_{abs}Y_{abs}Z_{abs} = [30 \quad 30 \quad 30]$. The luminance and chromaticity coordinates of the test stimuli are given in Table 1.

Table 1 – Luminance and chromaticity coordinates of the test stimuli.

	L_{10}(cd/m^2)	u'_{10}	v'_{10}
Red	20,00	0,4571	0,5239
Blue	22,33	0,1446	0,2686
Yellow	19,86	0,2165	0,5513
Green	20,35	0,0967	0,5654
Achromatic	102,23	0,1958	0,4690

3 Results

3.1 Brightness prediction of a neutral stimulus on a neutral background

Previous studies have demonstrated that the perceived brightness of a stimulus depends not only on the luminance of the stimulus itself, but also on the luminance of the background (Arend and Spehar, 1993; Bodmann and Toison, 1994; Hermans et al., 2018); the perceived brightness of the stimulus increases with increasing stimulus luminance and with decreasing background luminance.

As the brightness computation of CAM18sl (Hermans et al., 2018) is developed based on the visual assessments of the experimental scenes with a high correlation to the observers' data, the brightness outcome of CAM18sl is used as the ground-truth to evaluate the performance of iCAM for predicting the influence of stimulus and background luminance on brightness perception. The iCAM brightness is plotted against the CAM18sl brightness in Figure 2, with the red circles indicating the scenes with a background luminance of 0 cd/m^2 (completely dark background).

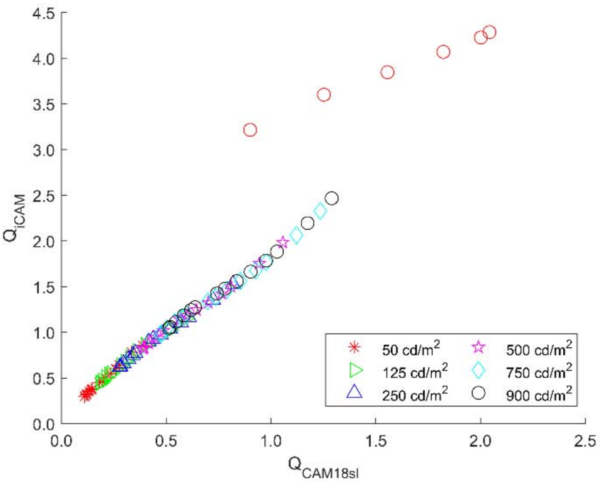

Figure 2 – Comparison between the brightness predicted by CAM18sl and the brightness predicted by iCAM. Red circles are the data points where the background luminance equals 0 cd/m².

With the exception of the scenes with a zero-luminance background, the results from Figure 2 suggest that iCAM is capable of predicting the relative changes in perceived brightness when the stimulus and background luminance vary: the stimulus is perceived as brighter with increasing stimulus luminance and with decreasing background luminance, and vice versa. Consequently, iCAM and CAM18sl show a strong linear correlation, resulting in a Spearman rank-order correlation of 0,9988 and a Pearson's linear correlation coefficient of 0,9983.

Nevertheless, it is clear that for the scenes with a dark background (L_b = 0 cd/m²), the computed brightness of the stimulus is strongly overestimated. This is the result of the computation of the chromatic adaptation transformation, for which a division by the low-pass filtered image is involved: since the kernel size is relatively large, the background pixel *XYZ* values contribute more to the computation of the *XYZ* values of the low-pass filtered image. When the background is at zero luminance, the *XYZ* values of the low-pass filtered image become lowest, resulting in a significant rise in the stimulus *XYZ* values.

3.2 Prediction of the Helmholtz-Kohlrausch effect

The Helmholtz-Kohlrausch (H-K) effect is a well-known colour phenomenon which states that for 2 stimuli with equal luminance, the stimulus with the higher saturation is perceived to be brighter (Fairchild, 2005). The brightness of all 30 stimuli used in the second experiment, computed with the iCAM model, is plotted against their saturation in Figure 3.

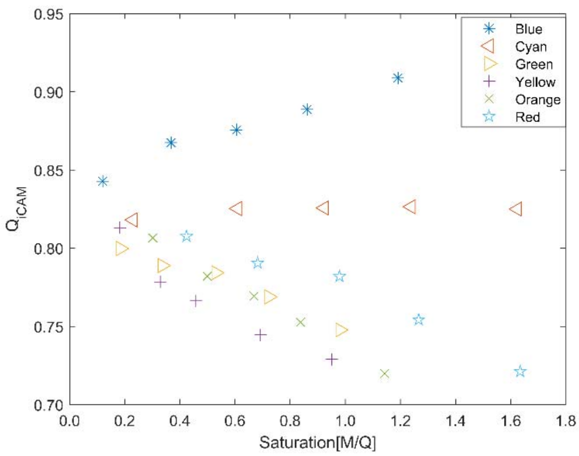

Figure 3 – Predicted brightness *Q* by iCAM as a function of stimulus saturation.

The results indicate that the model fails to predict the H-K effect: predicted brightness even drops when saturation increases, except for blue and cyan stimuli. This inconsistency is the result of different changing rates of *LMS* cone responses with increasing stimulus saturation. In this experiment, it is observed that for red, green, orange and yellow stimuli, the *L* and *M* cones responses only change slightly with increasing saturation level compared to the high decrease of the *S* cone response. This leads to the decline in brightness since in iCAM, brightness is derived from a set of transformations from *LMS* cones signals (Fairchild and Johnson, 2004). On the other hand, for blue stimuli, the *S* cone signal rises significantly when the saturation increases, while the contribution of the changes in the two other cone signals to the computation of brightness is less important. This results in an increasing brightness with increasing saturation level. Note that the model does not explicitly incorporate an additional H-K term in the brightness expression as opposed to CAM97u (Hunt, 1991), CAM15u (Withouck et al., 2015b) and CAM18sl (Hermans et al., 2018).

3.3 Prediction of the stimulus size effect on brightness perception

In previous literature, it has been reported that for stimuli with equal luminance and chromaticity, the perceived brightness increases when the stimulus size increases (Xiao et al., 2011; Fu et al., 2012; Xiao et al., 2012; Withouck et al., 2015; Wei et al., 2017). However, from the brightness outcome of iCAM for stimuli with different sizes as illustrated in Figure 4, this conclusion cannot be drawn: for red, yellow and blue stimuli, the brightness does not show any notable change, while for green and achromatic stimuli, even a slight decrease in brightness is observed when the stimulus size increases. The impact of stimulus size effect on perceived brightness is not included in most of the non-imaging CAMs such as CAM97u, CIECAM02 and CAM18sl either. Nevertheless, it could be appropriate for image-based CAMs to include this effect in an elegant way.

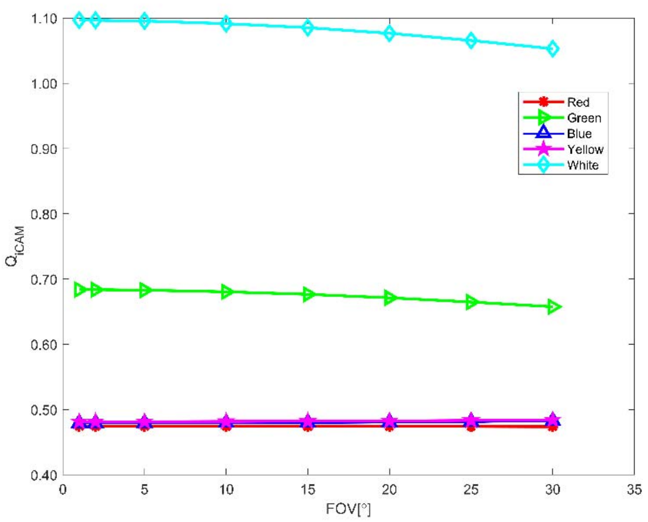

Figure 4 – Predicted brightness *Q* by iCAM as a function of stimulus size.

4 Conclusion

In this study, 3 different tests were performed to investigate the applicability of iCAM to basic self-luminous scenes. The results show that the model is capable to predict the background luminance effect, on the exception of unrelated stimuli (dark background).
However, the impact of saturation level and stimulus size on perceived brightness is underestimated, the former because the H-K effect is not included in the model. Hence, this calls for a new image colour appearance model dedicated to complex self-luminous scenes.

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