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MODELLING COLOUR APPEARANCE FOR UNRELATED COLOURS BASED ON CAM16

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Abstract

A colour appearance model should be capable of predicting a wide range of viewing conditions including related and unrelated colours. The current CAM16 was designed for predicting related colours and is in the process to replace the current CIECAM02 to overcome some mathematical problems existed in CIECAM02. This paper describes an extension of CAM16 for predicting brightness, hue, whiteness and colourfulness attributes for unrelated colours. The model developed in this paper will form a strong base to develop a comprehensive colour appearance model.

Keywords: CAM16, CIECAM02, unrelated colours, CAM15u.

1 Introduction

Unrelated colours are perceived areas as a target been observed in isolation from any other colours. A typical example of an unrelated colour is a self-luminous stimulus surrounded by a dark background, like a marine or traffic signal light viewed during a dark night.

A colour appearance model should be capable of predicting a wide range of viewing conditions including related and unrelated colours. The current CAM16 [1] was designed for predicting related colours and is in the process to replace the current CIECAM02 to overcome some mathematical problems existed in CIECAM02. This paper describes the extension of CAM16 for predicting unrelated colour appearance mainly developed by Li et al. [2] and further test the extension using the three sets of data accumulated by Fu and Luo [3], Withouck et al. [4], and Huang et al [5] respectively. The three datasets were named as Fu, Gent, and Huang datasets respectively in this paper. The extension of CAM16 is named as CAM16u model. All the unrelated data accumulated were carried out in aperture mode condition, i.e. stimulus was presented in a hole from a dark background.

Fu et al. [3] conducted 10 experimental phases and each stimulus was reported in terms of brightness, colourfulness and hue quadrature. The dataset includes samples with fields of view (FOVs) from 0.5° to 10° and the stimuli had a luminance (L) ranged between 0.1 cd/m^2 to 60 cd/m^2. A colour appearance model named CAM16u was developed based on the data. Samples were measured in terms of xyL.

Withouck et al. [4] also carried out the experiment to scale unrelated colours. The data generated in this study is called the Gent dataset. About 160 samples were assessed at a 10° FOV against a black background in terms of brightness, whiteness, and hue quadrature. CAM15u [4] was developed to fit the data. In this paper, sample's spectral radiance is required for using the model to generate cone response signals. Furthermore, a transformation between the XYZ and cone response signals was provided if only the samples' XYZs are available.

Huang et al. [5] also carried out experiment for assessing coloured lightings. The data generated in this study is called the Huang dataset. It had 81 stimuli at 2 illuminance levels, 280 cd/m^2 and 2400 cd/m^2. In each level, colours were covered a large colour gamut. Each colour was assessed in terms of brightness, whiteness, and hue quadrature. For this dataset, spectral radiance from each colour was also included. In order to be consistent with the Gent dataset, the cone signals were obtained following the recommendation from Withouck et al. [4]. The XYZ values were obtained from the spectral radiances measured, via a transformation between the cone signals and XYZ.

Currently, the new colour appearance model named CAM16 is considered by the CIE JTC10 on a new colour appearance model for colour management system with a goal to replace the current CIECAM02. CAM16 overcomes some problems existed with the CIECAM02 and is simpler than the CIECAM02. Similar to the CIECAM02, CAM16 only is applicable for predicting colour appearance for related colours. The present work is also highly related to CIE TC1-96 *Comprehensive colour appearance model*. Its goal is to extend CIE recommended colour appearance model to predict size effect, unrelated colour from photopic to mesopic vision together with a visual uniform colour space.

With the above in mind, the objective of this paper is to extend the CAM16 to predict the colour appearance attributes: brightness (*Q*), colourfulness (*M*), whiteness (*W*) and hue quadrature (*H*) by fitting the three data sets of unrelated colours.

2 The extension of the CAM16: CAM16u

The objective of the modelling is based on the newly developed CAM16 [1]. CAM16 or CIECAM02 were derived for predicting the related colours. Hence, there are some assumption needs to be made. Hunt reported that we adapted more or less to the CIE equal energy illuminant E. That is to say that the tristimulus values $X_W Y_W Z_W$ for the test illuminant is: [100, 100, 100]. LA is chosen as Y values of the input sample. Dark viewing condition is used. For defining the luminous factor of background (Yb), it should be set at zero. However, it is not allowed in the CAM16, so it was set to 0.005, the lower end of the mesopic region [6].

For CAM16, there is no whiteness prediction. Motivated by the work of Withouck et al. [4], the whiteness attribute is also based on the saturation (s) of the CAM16. The whiteness equation is defined in equation (1).

$$W = \frac{100}{1 + w_1 \cdot (s / w_2)^{w_3}} \tag{1}$$

Here , w_1, w_2, w_3 are parameters optimised by fitting the Gent and Huang datasets. Finally, it was found that

$$w_1 = 3.0836,\ w_2 = 50,\ w_3 = 3.3643 \tag{2}$$

Now we can test CAM16 using the above settings and the three sets of data without changing the equations for each of the attributes.

CAM15u [3] was developed for predicting the unrelated colour appearance using the CIE cone responses. Hence, it can be used for predicting the three datasets directly.

The present CAM16u model was derived to follow the earlier model proposed by Fu et al. [3]. CAM16u has four attributes: whiteness (*W*), brightness (Q_{un}), colourfulness (M_{un}) and hue quadrature (*H*). All the CAM16 terms are first calculated including *H*. *W* is calculated using equations (1) and (2). The Q_{un} and M_{un} are then computed using equations (3) and (4) respectively.

$$Q_{un} = A_{un} + M_{un} / 100 \tag{3}$$

and $$M_{un} = K_M\ M \tag{4}$$

where the Achromatic signal for the unrelated colours (A_{un}) is calculated using equation (5).

$$A_{un} = A + K_A\ A_s, \tag{5}$$

where the Achromatic signal for the scotopic region (A_S) *is approximate by (2.26 L)$^{0.42}$*, and K_A and K_M are calculated using equations (6) and (7) respectively as proposed by Li et al. [2].

$$K_A = (1.0577 - 0.5930 \cdot a_L) \cdot (1.1105 - 1.0800 \cdot b_\theta) \tag{6}$$

$$K_M = (1.5689 + 0.9238 \cdot a_L) \cdot (1.7930 - 0.1851 \cdot b_\theta) \tag{7}$$

Here,

$$a_L = log_{10}(L), \quad b_\theta = log_{10}(\theta) \tag{8}$$

where, θ is the visual angle and the above *L* values in equations (5) and (8) are the luminance value of the stimulus.

CAM16u modelled two visual effects on brightness (Q_{un}): Helmholtz-Kohlrausch (HK) [7] and rod intrusion [6]. The former is reflected by the inclusion of M_{un} in equation (3), i.e. a colour would appear brighter when its colourfulness is increased. This is typically illustrated by showing a series of colours having the same luminance but varying in colourfulness. The more colourful samples would appear to be brighter. The rod intrusion effect is modelled by the A_{un} in equations (3) and (5). When luminances of the stimului decrease, the contribution of the rods increase. Finally, both M_{un} and A_{un} are varied according to the luminance and visual field of stimulus, these are modelled by K_A and K_M, equations (6) and (7), respectively.

3 Performance of the three models

Now three models mentioned in the last section can be tested using three datasets. The results in terms of CV [7] values are listed in Tables 1 and 2 respectively. Tables 1 and 2 summarize the models' performance tested using the Gent and Huang datasets, and using the Fu dataset, respectively. Note that for the Gent and Huang datasets, there is no luminance level for the adapting field associated to each of the datasets. The input Y value is used as luminance L used in equations (5) and (8) for the CAM16u model, and the visual angle θ was set to 10° for the Gent and Huang datasets. For the Fu dataset, their original visual angles were used.

From Table 1, CAM16u gave the most accurate prediction to the Huang dataset. CAM15u performed the best in predicting the Gent dataset. CAM16 performed the second best in predicting either the Huang dataset or the Gent dataset. Overall, the three models performed equally well over the two sets of data with overall mean CV values of 14. Note that the performance of brightness and colourfulness were exchanged between CAM16u and CAM16. Hence the saturation scale for the CAM16u model is changed. However, when predicting the whiteness using the CAM16u model, the saturation used is the same as the original CAM16 model, hence both models gave the same prediction for the whiteness.

Table 1 – Performances of CAM16, CAM15u and CAM16u models using the Huang and Gent datasets in term of CV values

Metrics	Data	Brightness	Hue	Whiteness
CAM16	Huang	9	10	20
CAM15u	Huang	14	11	19
CAM16u	Huang	**5**	10	20
CAM16	Gent	17	6	23
CAM15u	Gent	**8**	7	23
CAM16u	Gent	20	6	23

Figure 1 shows the perceptual attributes: brightness (left diagram), whiteness (middle diagram) and hue quadrature (right diagram) predictions (vertical axis) versus visual results using the Huang dataset for the CAM16 (symbol *), CAM15u (symbol o) and CAM16u (symbol □). It can be seen that all three models gave similar performance except the whiteness predictions.

CAM15u gave the largest scattering and the other two models (CAM16 and CAM16u) gave the same results. Figure 2 shows the perceptual attributes: brightness (left diagram), whiteness (middle diagram) and hue quadrature (right diagram) predictions (vertical axis) versus visual results using the Gent dataset for the CAM16 (symbol *), CAM15u (symbol o) and CAM16u (symbol □). Figure 2 again showed that all three models gave similar performance except the brightness predictions, for which CAM15u performed the best and the other two models gave the similar extent of scattering.

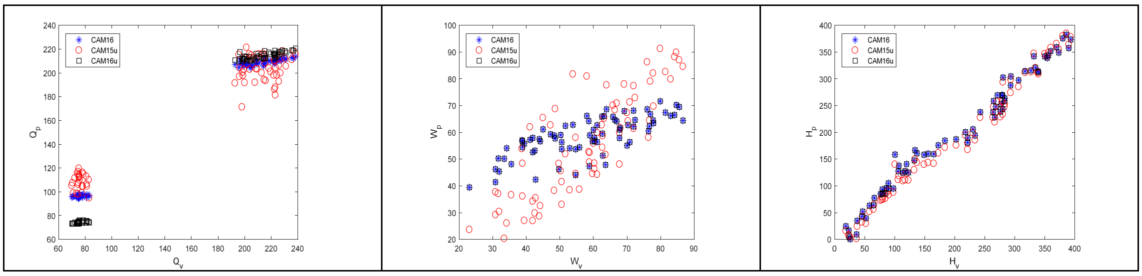

Figure 1 – The visual results of the Huang dataset plotted against the predictions of Brightness (left diagram), Whiteness (middle diagram) and Hue quadrature (right diagram) from CAM16 (symbol *), CAM15u (symbol o) and CAM16u (symbol □), respectively.

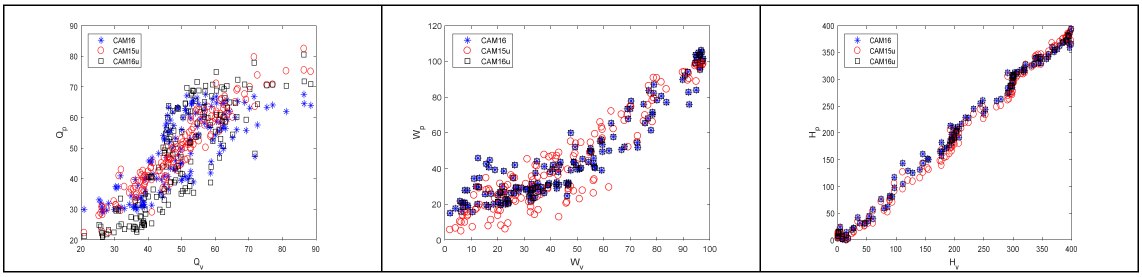

Figure 2 – The visual results of the Gent dataset plotted against the predictions of Brightness (left diagram), Whiteness (middle diagram) and Hue quadrature (right diagram) from CAM16 (symbol *), CAM15u (symbol o) and CAM16u (symbol □), respectively.

Table 2 summarizes the results of the three models using the Fu dataset. The dataset has 10 phases. Each phase has different luminance levels and different visual angles. In the first column of Table 2, symbol x-y means luminance level and visual angle (field of view) for x and y respectively. For example, 60-10 means that for this phase, luminance level is 60 cd/m^2 and visual angle is 10 degree. Similarly, 0.1−0.5 means for this phase, luminance level is 0.1 cd/m^2 and visual angle is 0.5 degree. The mean CV values are given in the last row. It can be seen that CAM16u model performs the best for each of the brightness (*B*), and Colourfulness (*M*) attributes. The CAM16 performs the worst for Colourfulness (*M*) and CAM15u performs the worst for the Brightness (*B*). For Hue quadrature (*H*), the three models perform equally well. Overall, CAM16u model now performs the best and then followed by CAM16. The CAM15u performs the worst.

4 Conclusions

The paper describes an extension of CAM16 to predict the colour appearance for unrelated colours. The extension model is named as CAM16u. CAM16u can predict perceptual attributes brightness, colourfulness, hue quadrature and whiteness. Different models' performance was tested using the Fu, Gent and Huang datasets. CAM16u performs equally well with CAM15u for the Huang and Gent datasets. However, for the Fu dataset, CAM16u is much better than CAM15u. The results are important to the CIE TC1-96 *Comprehensive colour appearance model*.

Table 2 – Performances of CAM16, CAM15u and CAM16u models using the Fu dataset in term of CV values for each of the 10 phases and the overall dataset.

Phase	CAM16			CAM15u			CAM16u		
	B	H	M	B	H	M	B	H	M
60−10	15	11	29	19	10	27	13	11	28
60−0.5	9	12	24	19	11	25	8	12	24
5−10	9	10	24	22	9	21	8	10	23
5−0.5	10	10	29	25	9	24	9	10	30
1−10	11	9	27	26	9	27	10	9	26
1−0.5	12	11	45	35	9	40	14	11	47
0.1−10	21	12	51	33	15	46	12	12	38
0.1−2	16	9	46	43	9	43	17	9	39
0.1−1	17	8	32	41	11	41	16	8	36
0.1−0.5	26	10	41	52	12	43	30	10	43
Mean	**15**	**10**	**35**	**32**	**10**	**34**	**14**	**10**	**33**

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