An extension of CAM16 for predicting size effect and new colour appearance perceptions

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Abstract

CAM16 colour appearance model has been extended to predict the appearance for stimulus of varying sizes and to provide new scales to evaluate saturation, vividness, whiteness and blackness.

Introduction

Recently, a new colour appearance model, CAM16 [1], was proposed for replacing the current CIE colour apperance model: CIECAM02 [2]. CAM16 is simpler than CIECAM02 and most importantly, overcomes some mathematical problems in CIECAM02. Similar to CIECAM02, CAM16 can predict the perceptual attributes, lightness (J), Choma (C), Colourfulness (M), brightness (Q), saturation (s), hue angle (h), and hue compositions (H) for related colours under the photopic region over a wide range of viewing conditions which are defined by the illumination of adapting field, lightness of the background and surround. However, strictly speaking, it can only be used in size stimulus of 2°. Also, it does not provide some important attributes identified recently, such as whiteness, blackness, and vividness.

Our goal is to continue to develop CAM16 to make it a comprehensive model. In this paper, the CAM16 has been further extended..

Size Correction in CAT16 Cone-like Space

Size effect data were accumulated by Xiao et al [3-5] at Derby university. It included 10 colour stimuli at six different sizes. The colours were selected from a popular shade range of decorative paints at that time and were painted in six different sizes (from visual fields of 2° to 50°). Colour appearance of six sizes had been obtained using three different psychophysical experiments [3-5]. Finally, the results by matching different sizes in situ on a CRT display were used. The six physical sizes are categorized into three groups, named small-, large- and room-size. Small size group includes three smaller fields (2°, 8° and 19°), which were assessed in a viewing cabinet against a mid-grey background with L* of 50. Large size group includes two larger fields (22° and 44°) placed in the center of a mid-grey (L* of 50) wall (4 by 3 meter square) illuminated by the lights from the ceiling, named room lighting condition. The final group has size of the entire side of wall subtended a visual field of 50° and the whole wall was assessed under the room lighting from the ceiling. The same 10 observers took part in all three groups. All the illuminants used was the same type of fluorescent D65 simulator. The room size (visual field of 50°) will not be used in this study since it is an immersive environment and the viewing condition is quite different from the others so that the results were also very much different from those of the other viewing conditions.

Xiao et al [5] proposed size correction in tristimulus space first, then the performance is evaluated using the J, C, and H in CIECAM02 space. Here size correction has been developed in the CAT16 cone-like space, which can be easily and economically built in the CAM16. Let M_{16} be the CAT16 matrix [1], firstly mapping the CIE XYZ values under two degree size to cone-like space:

$$\begin{pmatrix} R_2 \\ G_2 \\ B_2 \end{pmatrix} = M_{16} \begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \end{pmatrix} \tag{1}$$

Subsequently, size correction was done in separated channel from 2 degree to θ degree in cone like space using equation (2).

$$\begin{pmatrix} R_\theta \\ G_\theta \\ B_\theta \end{pmatrix} = \begin{pmatrix} \alpha(\theta)R_2 \\ \beta(\theta)G_2 \\ \gamma(\theta)B_2 \end{pmatrix} = \begin{pmatrix} \alpha(\theta) & 0 & 0 \\ 0 & \beta(\theta) & 0 \\ 0 & 0 & \gamma(\theta) \end{pmatrix} \begin{pmatrix} R_2 \\ G_2 \\ B_2 \end{pmatrix} \tag{2}$$

Table 1 shows the optimized scaling factors for $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$. Figure 1 shows the trends of the scaling factors versus the visual angle θ. In general, the scaling factors are increasing with the increase of the size of stimulus. The scaling factors $\alpha(\theta)$ and $\beta(\theta)$ are similar and $\gamma(\theta)$ has the same trend as the other two, but had a lower slope. Table 2 summarizes its performance of look-up-table in predicting three sets of visual data, lightness, colourfulness and hue in CV value. For a perfect agreement between the visual and predicted results, CV should be zero.

Models were developed to fit the scaling factors in Table 1. It was found that $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$ in equation (3) are simple, continuous and give reasonable prediction.

$$f(\theta) = 1 + \frac{(\theta-2)}{1000}(c_0 + c_1\theta) \tag{3}$$

where the coefficients for $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$ are given in Table 3.

Table 4 summarises its performance, again in CV values. Figure 2 shows $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$ functions versus visual angle using equation (3). Comparing Tables 2 and 4, as expected, the performance using equation (3) for $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$ are worse than that using the optimum coefficients in Table 1. However, the difference in CV value is quite small, i.e. equal performance for predicting lightness and hue results and only one unit (in CV) worse for predicting colourfulness results.

Other modifications were also made such as the extension based on lightness and colourfulness, etc. The final decision was made to use cone-like space (equation (3)) due to its simplicity and continuity. In real applications, if θ is less than 2°, it should set to 2°. Note that the size effect will not affect the accuracy to predict existing dataset such as LUTCHI and corresponding colour datasets [6,7], because they are based on 2° observer colorimetric observer.

Table 1: Scaling factors for $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$

θ	2°	8°	19°	22°	44°
α(θ)	1	1.0179	1.2313	1.3323	1.6962
β(θ)	1	1.0132	1.2339	1.3230	1.6770
γ(θ)	1	0.9842	1.2047	1.1831	1.5295

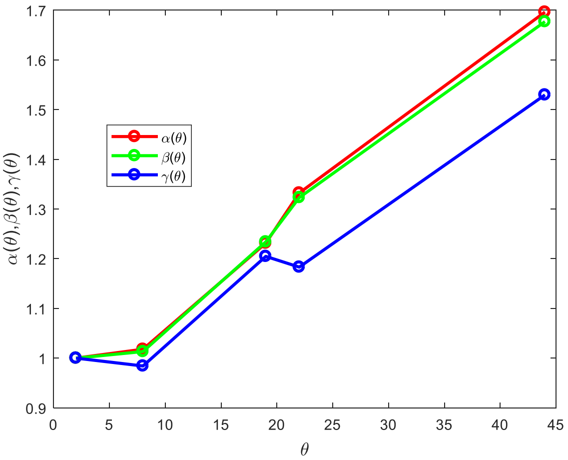


Figure 1: Scaling factors for $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta$ versus the visual angle θ using piecewise linear interpolation

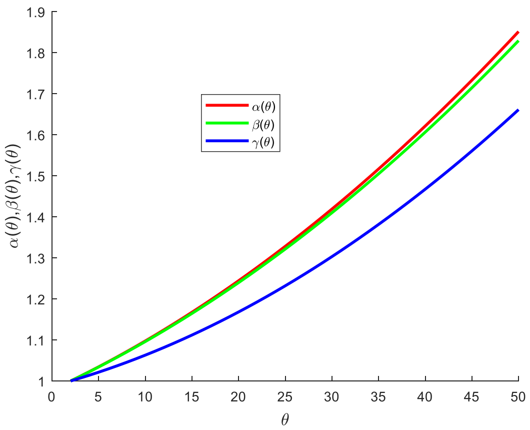


Figure 2: Scaling factors $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$ plotted against visual angle θ using equation (3) and Table 3

Table 2: Performance in CAT16 Cone-like space using piecewise linear interpolation

CV	8°	19°	22°	44°	Mean
J	8.6	6.6	5.3	4.7	6.3
C	4.5	6.9	12.5	13.3	9.3
H	3.0	3.1	3.1	3.3	3.1

Table 3: coefficients for $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$

	c_0	c_1
α(θ)	10.7964	0.1388
β(θ)	10.6742	0.1320
γ(θ)	6.3890	0.1477

Table 4: Performance in CAT16 Cone-like space using equation (3) and Table 3

CV	8°	19°	22°	44°	Mean
J	8.1	6.5	4.6	4.9	6.0
C	5.7	8.9	14.6	13.2	10.6
H	3.0	3.5	3.3	3.3	3.3

Predicting new colour scales: Saturation, Vividness, Whiteness and Blackness

This section describes the development of new CAM16 scales of saturation, vividness, whiteness and blackness. The visual data were accumulated by Cho et al [8,9] at Leeds. There are 120 samples specified in XYZ under a fluorescent D65 simulator. They identified two scales are important to describe the third dimension of a colour, i.e. saturation and vividness, rather than chroma or colourfulness. Also, whiteness and blackness are important perceptions which are widely used in daily life and industry. In their experiment, each sample was assessed in terms of saturation, vividness, whiteness and blackness by about 50 observers, half Korean and half British. In total, 132 observers took part the visual experiment. The results showed little difference between observers between two countries. Hence, the combined dataset including British and Korean was used to derive colour scales [9]. From their study, it was found that the Berns' proposed scales [10], Depth (D_{ab}*), Clarity (T_{ab}*) and Vividness (V_{ab}*) based on CIELAB can give a reasonable fit to the data (see equations (4)-(6)), The results showed that D_{ab}* had a strong positive and negative correlation to the visual saturation and whiteness data, respectively. This indicates that the two perceptions are opposite (or reverse) to each other. V_{ab}* had a negative correlation to the blackness data, but unexpectedly did not fit well to Cho et al's vividness data. In contrast, T_{ab}* did give reasonable prediction to the vividness data.

From we learned from above, equations (4) to (7) are proposed to be the baseline scales to develop new saturation (s'), vividness (V), whiteness (W) and blackness (B), respectively. Note that s' is called new saturation here to differentiate the existing s (equation (8)). All baseline equations are based on CAM16 colour coordinates (lightness J, redness-greenness a_M, yellowness-blueness, b_M).

$$s' = \sqrt{(100 - \mathrm{J})^2 + (a_M)^2 + (b_M)^2} \qquad (4)$$

$$\mathrm{V} = \sqrt{(50 - \mathrm{J})^2 + (a_M)^2 + (b_M)^2} \qquad (5)$$

$$\mathrm{W} = 100 - \sqrt{(100 - \mathrm{J})^2 + (a_M)^2 + (b_M)^2} \qquad (6)$$

$$\mathrm{B} = 100 - \sqrt{(\mathrm{J})^2 + (a_M)^2 + (b_M)^2} \qquad (7)$$

$$\mathrm{s} = 100 \cdot (\frac{\mathrm{M}}{\mathrm{Q}})^{0.5} \qquad (8)$$

where M and Q are CAM16 colourfulness and brightness, respectively.

The baseline scales have a common structure as given in equation (9).

$$p1 = x_1 + x_2\sqrt{(J - x_3)^2 + x_4 \cdot (a_M - x_5)^2 + x_6 \cdot (b_M - x_7)^2} \quad (9)$$

Equation (9) can be simplified as equations (10) and (11).

$$p2 = x_1 + x_2\sqrt{(J - x_3)^2 + x_4 \cdot (a_M)^2 + x_5 \cdot (b_M)^2} \quad (10)$$

$$p3 = x_1 + x_2\sqrt{(J - x_3)^2 + (a_M)^2 + (b_M)^2} \quad (11)$$

where variables of x_1 to x_n can be obtained by optimization to fit a particular visual attribute in the Cho et al data [7]. The performance of the new scales are given in Table 5.

Equation (11) was later rewritten as equations (12)-(15) for the new CAM16 saturation, vividness, whiteness and blackness, respectively.

$$s_C = 7.8 + \sqrt{(J - 77)^2 + (a_M)^2 + (b_M)^2} \quad (12)$$

$$V_C = 4.9 + \sqrt{(J - 58)^2 + (a_M)^2 + (b_M)^2} \quad (13)$$

$$W_C = 117 - \sqrt{(J - 100)^2 + (a_M)^2 + (b_M)^2} \quad (14)$$

$$B_C = 106 - \sqrt{(J - 12)^2 + (a_M)^2 + (b_M)^2} \quad (15)$$

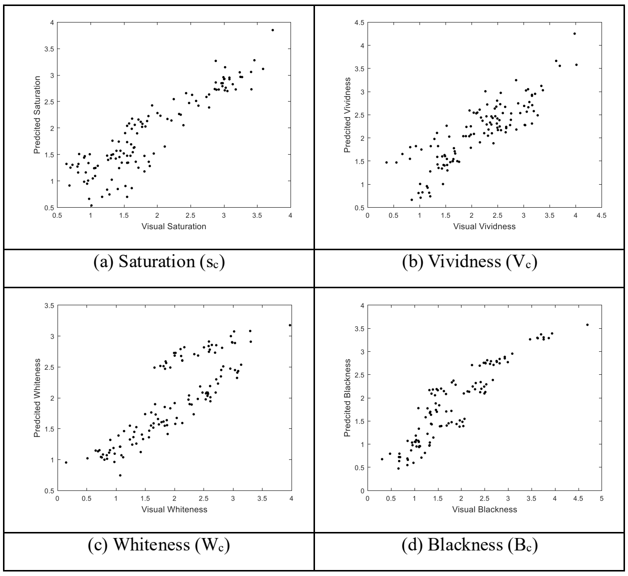
Table 5 The performance of all the newly derived model: (s) saturation, (V) vividness, (W) whiteness, (B) Blackness

	s	s	V	V	W	W	B	B
	r	CV	r	CV	r	CV	r	CV
Base-line	0.84	27	0.77	29	0.85	23	0.91	27
p1	0.91	17	0.87	18	0.87	19	0.92	18
p2	0.91	17	0.86	19	0.86	20	0.92	19
p3	0.91	18	0.86	19	0.85	21	0.91	19
Eq. 12-15	0.91	18	0.86	19	0.85	20	0.91	19

The results in Table 5 are very promising. All p1, p2, p3 scales outperformed baseline scales. The p1 scales did perform the best, but they only gave slightly more accurate prediction by one unit in CV. The most encouraging is that the new CAM16 scales are simple and give reasonable prediction to the visual results. For the new saturation scale (equation (12)), it is much more accurate than equation (8), which had r and CV values of 0.71 and 31 respectively.

Figures 3a to 3b show the plot of predictions against visual results for saturation (using equation (12)), vividness (using equation (13)), whiteness (using equation (14)) and blackness (using equation (15)) respectively. It can be seen that in general, the new scales gave good prediction to the visual results. The scatter is quite small in each figure.

These new scales can be divided into two groups: 1) saturation and vividness, and 2) whiteness and blackness. Figure 4 is the schematic diagram to illustrate each new scale in CAM16 JM plane. For the group including saturation and vividness scales, colours appear higher saturation or more vivid when it moves away from the neutral colours of J= 77 and 58, respectively. For the group including whiteness and blackness scales, when the colour is closer to the reference neutral colour of J of 100 and 12, it would appear to be whiter and blacker, respectively. The scales correspond to Cho et al's experimental condition. It implies that neutral colours having J values of 77, 58, 100, 12 roughly correspond to the least saturated, background, the whitest and blackest anchoring points, respectively.



(a) Saturation (s_c) (b) Vividness (V_c)

(c) Whiteness (W_c) (d) Blackness (B_c)

Figure 3: Plot of predictions against visual results for a) saturation, b) vividness, c) whiteness and d) blackness.

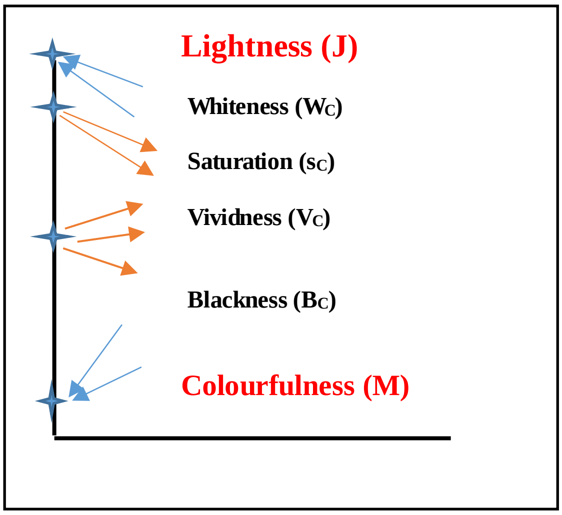


Figure 4: The schematic diagram to illustrate the whiteness, saturation, vividness, blackness scales.

Conclusions

This paper describes the extension of CAM16 colour appearance model to predict the visual size effect and to include some important new colour appearance scales. Now, it can predict colour appearance from 2o upwards to cover most of the typical viewing conditions. Four new colour scales, saturation, vividness, whiteness and blackness are also developed. The extended model gave good prediction to the visual data.

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