Colour Size Effect Modelling

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Abstract: The visual phenomenon known as the colour size effect was investigated and two models were developed to predict the change in colour appearance of samples with six different sizes. The models are capable of transforming the colour appearance of a stimulus having a viewing field of 2° to that associated with a range of viewing fields. They are named the size effect correction and the size effect transform and are based on human perceptual attributes and human cone responses, respectively. The performance of both models was tested using the experimental data, and the results showed that the size effect transform performed better than the size effect correction. © 2010 Wiley Periodicals, Inc. Col Res Appl, 37, 4–12, 2012; Published online 2 December 2010 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.20650

Key words: colour size effect; colour appearance model; cone response function; human perceptual attributes

INTRODUCTION

The colour size effect is a colour appearance phenomenon,[1] in which the colour appearance changes according to different sizes of the same colour stimulus. The CIE 1931 (2°) and CIE 1964 (10°) standard colorimetric observers were recommended by the Commission Internationale de l'Éclairage (CIE) to represent human vision in smaller and larger than 4° viewing fields, respectively.[2] However, for a colour with a large size, such as over 20° viewing field, no standard observer can be used. Colour appearance models[3] such as CIECAM02 are capable of predicting human perceptual attributes under various viewing conditions. The current colour appearance models can not predict the colour size effect. As a consequence, colour appearance of different sizes cannot be accurately predicted and truly reproduced across different sizes. A problem that has long been experienced in the paint industry is that the paints purchased in stores usually do not look the same on the walls in a real room as shown in the package. This also causes great difficulties for homeowners, interior designers, and architects when they select colour. Furthermore, as the display size increases, the colour size effect becomes an larger for display manufacturers to precisely reproduce or to enhance the source images on different sizes of colour displays.

With the above in mind, the CIE established a technical committee, TC1-75, a comprehensive model for colour appearance with one of aims to take colour size effect into account in the CIECAM02 colour appearance model.[4]

In the authors' recent work,[5,6] six different sizes from 2° to 50° of same colours were assessed by a panel of observers using colour matching method to match surface colours using a CRT display. The colour appearance data were accumulated in terms of CIE tristimulus values. It was found a consistent pattern of colour appearance shifts according to different sizes for each stimulus.

The aim of this study is to derive models for predicting colour size effect based on the experimental data accumulated recently.[5,6] Each model is capable of transforming colour appearance from a standard size (2°) to a larger size. The size effect is a complicated effect in the human visual system. It is known that the effect is due to the nonuniform distribution of photoreceptors across the human retina. The present approach is to transform colours from a standard size at 2° field size to a larger size. However, on the other hand, an increase of the stimulus size could also cause some other psychophysical effects, such as the change of the effect of the background,[7] and the adaptation.[8] In the present study, two models were developed for transforming a 2° field of view colour to a larger size based upon both human perceptual attributes (such as lightness, colourfulness and hue composition represented by CIECAM02 correlates) and human cone response (such as red, green and blue signals similar to von Kries chromatic transformation), respectively. Their performance in term of colour difference and

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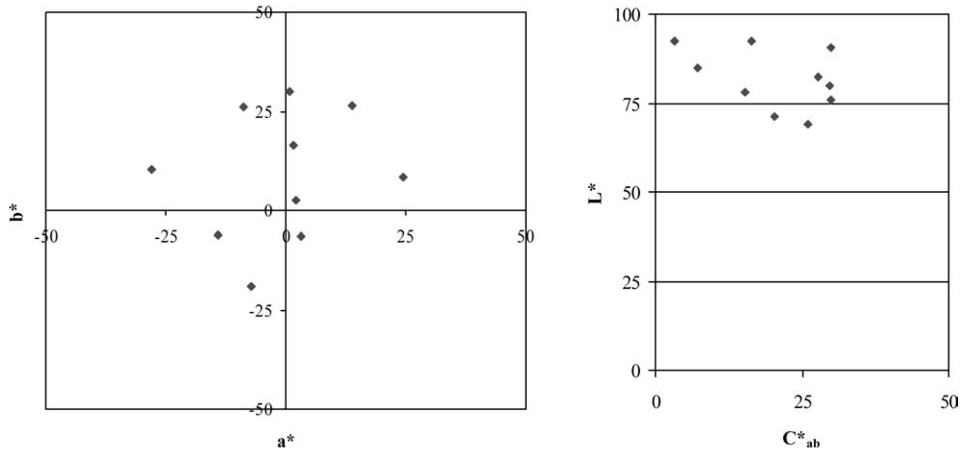


FIG. 1. Colour selections for size effect modelling: (a) a^* versus b^*; (b) L^* versus C^*_{ab}.

colour appearance are compared. Note that human cone responses are only concerned with the initial-stage of visual processing in the retina, while human perceptual attributes are considered as the post-receptor stage of human vision system.

EXPERIMENTAL DATA

In this study, colour appearance data for 10 colours in six different sizes were assessed. These colours were selected from the popular shade range of decorative paints and were painted in six different sizes (from visual fields of 2°–50°). Figures 1(a) and 1(b) show the sample distribution in CIELAB a^*b^* and L^*C^* diagrams, respectively.[9] The lightness values of all selected colours are above 60 indicating that all colours are quite light colours. There is a lack of darker shades which were excluded in the popular paint range, i.e., dark shades are not popular for interior use. Colour appearance of six sizes had been assessed in three different psychophysical experiments[5,6] by a colour matching technique based on a CRT display with a fixed size of 10° viewing field. The six physical sizes are categorized into three groups, named small-, large- and room- size. In the former group including three smaller sizes (2°, 8° and 19°), which were assessed in a VeriVide viewing cabinet against a mid-grey background with L^* of 50. Group 2 included two larger sizes (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 one side of wall subtended a visual field of 50° and the whole wall was assessed under the room lighting condition illuminated by D65 fluorescent lamps in the ceiling. The same D65 simulator was adopted for all three groups. In the experimental room, the ceiling and the floor were a matt-white and a dark grey carpet, respectively.

For assessing colour appearance of the six different sizes, three distinct viewing conditions were applied. To model colour appearance across different sizes, the data have to be normalized to form a single data set. This was done by applying a $BaSO_4$ diffuser placed underneath the room and cabinet and then measured using a Minolta CS1000 tele-spectroradiometer in terms of absolute CIE tristimulus values in cd/m^2 unit. Table I summarizes the measurement results.

It can be seen that the luminance of the light source in the viewing cabinet was much higher than that of room lighting, although their chromaticity coordinates are quite similar. This indicates that a colour in the viewing cabinet appeared much brighter than that under the room lighting condition. This discrepancy was realized from the matching results based on the CRT display. To bring the visual results from different viewing conditions into the same visual scale, an additional psychophysical method was employed. Ten observers, who had taken part in earlier experiments, participated in the new experiment. Each observer was first asked to view a white card presented in the viewing cabinet after they were fully adapted to the lighting conditions. He or she was then asked to memorize the white colour as a reference white having lightness of 100. After 3 min adaptation to the room lighting, each observer then viewed the same colour presented in the room and was asked to scale the lightness for the colour according to their memorized reference white. This technique was used earlier[3] and was known as a short-term memory matching method. Table II lists the visual results together with the mean value.

As shown in Table II, the average of lightness judged by the 10 observers for the white colour under real-room lighting conditions was 83.7, which is ~20% darker than perceived lightness of the colour in the viewing cabinet. Based on these experimental data, a scaling factor of 1.2 was applied to scale appearance results room lighting conditions. Because the raw data was defined by XYZ

TABLE I. Photometric and colorimetric data for the light sources in the viewing cabinet and room lighting.

	L (cd/m^2)	x	y	u'	v'	CCT
Viewing Cabinet	460	0.3134	0.3298	0.1981	0.4688	6458
Room Lighting	156	0.3142	0.3313	0.2002	0.3099	6427

TABLE II. Lightness of the reference white colour in the real room condition against that viewed in a viewing cabinet specified as 100 for each observer.

Observer	1	2	3	4	5	6	7	8	9	10	Mean
Lightness	85	80	75	80	85	85	90	87	90	80	83.7

tristimulus values, the scaling factor for luminance unit is need. By transforming the average lightness value of 83.7 back to the luminance factor (Y) using CIELAB uniform colour space, a value of 63.5 was obtained. Hence, a scaling factor of 1.57 (100/63.5) was used to divide all the corresponding colours (XYZ) in the cabinet condition for three small sizes.

After adjustment, the 10 CRT colours in terms of CIE tristimulus values for each physical size were accumulated for modeling size effect and referred as "size effect data" throughout this article. Table III shows the difference in colour appearance between the standard 2° size and the other sizes. Two measures were used based on coefficients of variation (CV)[10] and CIELAB colour difference values (ΔE^*_{ab}). For calculating CV measure, CIECAM02 lightness (J), chroma (C) and hue composition (H) attributes for 2° and the other size were first computed. The CV values between two sizes were then calculated using Eq. (1).

$$\mathrm{CV} = (100/\bar{P})\sqrt{\sum_{i=1}^{n}(G_i - P_i)^2/n} \tag{1}$$

where n represents the number of samples in G and P sets, $\bar{P}$ represents the mean value of dataset P. For example, a CV value of 20 means 20% disagreement between the small and room size's perceptual attributes. While, a CV value of zero means that there is no difference between the small and room size's perceptual attributes. Another measure used was mean ΔE^*_{ab}, which was calculated between XYZ values of 2° and that of the other size.

Table III shows that colour difference increases as sample size increases. This implicitly means that the appearances of samples with larger sizes deviate more from samples of 2° viewing field as the stimulus size is increased. Hence, the results support the need for a model that is capable of predicting the colour appearance change induced by colour stimuli with large sizes. The average difference seen in the size effect is ~12 ΔE^*_{ab} and 11, 27 and 4 CV values of colour appearance difference for lightness, chroma and hue attributes, respectively. The results here can be considered as a baseline for verifying the performance of size effect model.

TABLE III. Mean colour differences and CV values between 2° stimulus size and various larger sizes.

Size Effect	8°	19°	22°	44°	50°	Mean
CV (J)	7.5	6.5	5.7	14.6	15.9	11.4
CV (C)	6.8	10.8	25.7	27.8	36.8	27.3
CV (H)	3.2	3.7	5.5	4.1	5.2	4.4
ΔE^*_{ab}	5.2	6.1	11.1	17.0	20.7	12.0

TABLE IV. Input parameters of CIECAM02 for CRT colours.

X_W	Y_W	Z_W	L_W	L_A	Surround
90.5	100	114.1	102.0	2.2	Average

SIZE EFFECT MODELING

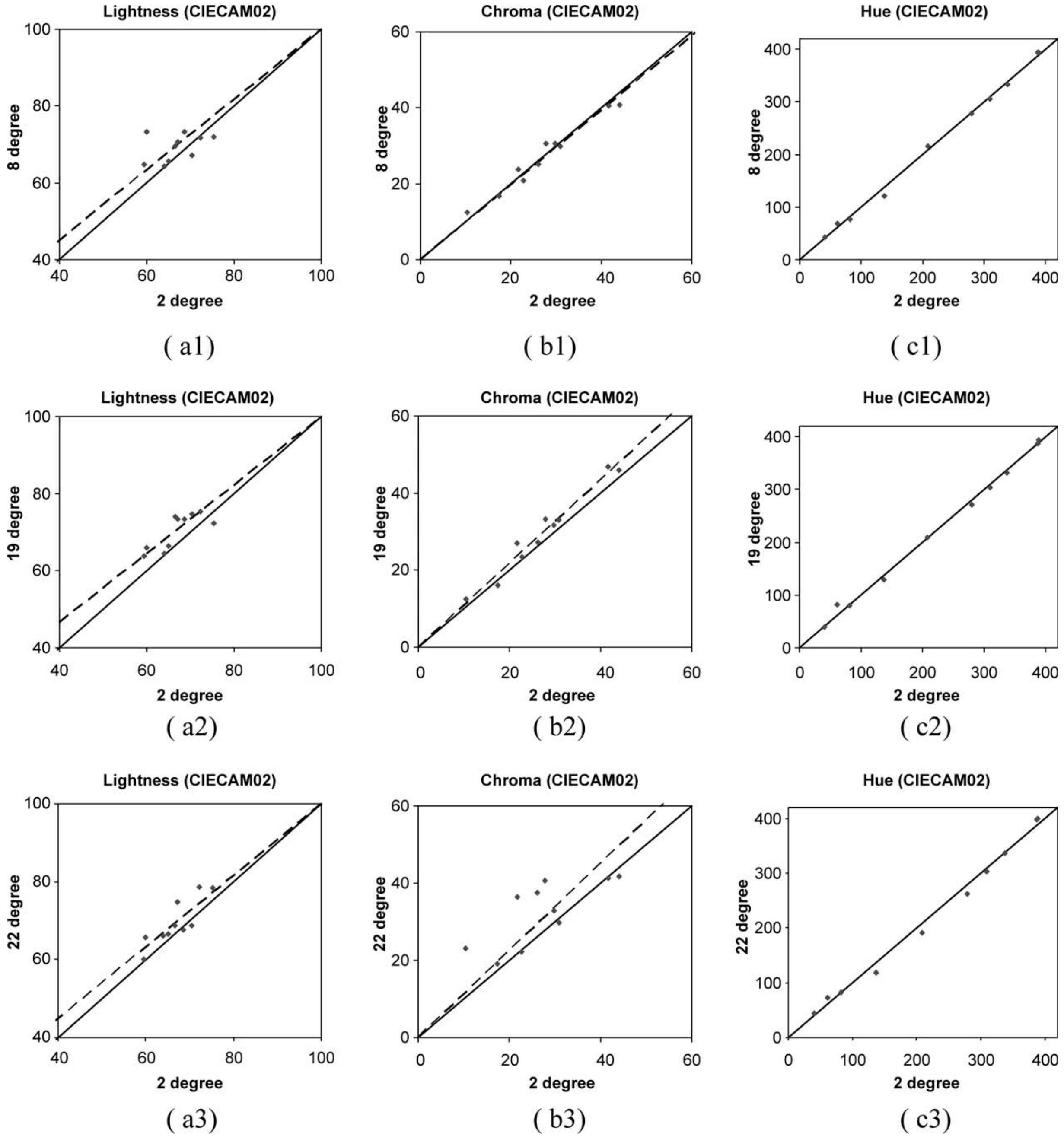
In this section, the size effect will be modeled. The lightness scaled experimental results based on Table II were used. Two models were then developed to predict colour appearance for dissimilar sizes by using two alternative approaches, named size effect correction, based on CIECAM02 colour appearance attributes and size effect transform, based on the responses of the human cones (LMS) representing long, middle and short cone response signals. The performance of each model was verified using visual data obtained from this study.

Size Effect Correction

The size effect correction model was developed to predict changes of colour appearances attributes (in terms of lightness (J), chroma (C) and hue composition (H)) between colours of the standard viewing field of 2° size and the other sizes. Subsequently, colour appearance for dissimilar sizes can be obtained by using the model from the colour appearance attribute of the 2° size. Note that CIECAM02 was used to predict human perceptual attributes of 10 colours in each of the six different stimulus sizes. Table IV lists the input parameters for calculating CIECAM02 colour appearance attributes, including the luminance and colorimetric values of a reference white, the luminance of the background and surround parameters. The parameters represent the CRT viewing conditions used in the experiment.

In the above table, X_W, Y_W, Z_W represent the stimulus of the adopted reference white, L_W represents the luminance of the adopted white in units of cd/m^2, and L_A represents the luminance of the background colour in units of cd/m^2. The surround of the viewing conditions was set as average, similar to typical office illumination level. Finally, three CIECAM02 attributes (J, C, H) were obtained for each of the 10 colours under each of the six stimulus sizes.

For each attribute, the relationship between colours in 2° and each of other five stimulus sizes are illustrated in Fig. 2. The subscripts a, b, c represent the perceptual attributes of lightness, chroma and hue, respectively. For each attribute, there are also five sub-figures to show the relationship between colours in 2° field and each of the 8°, 19°, 22°, 44° and 50° (each size is arranged in a different row); the results for each size are denoted as 1 to



(a1) (b1) (c1)

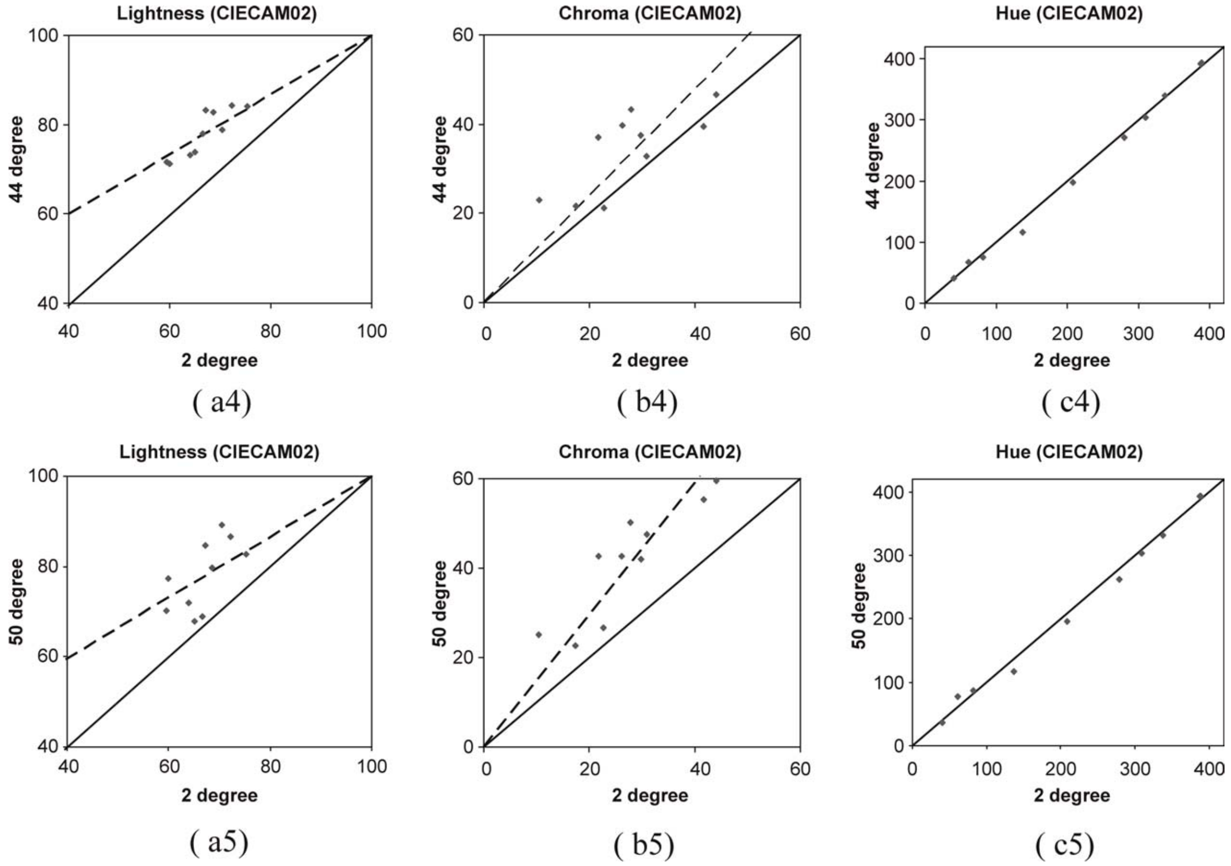
(a2) (b2) (c2)

(a3) (b3) (c3)

FIG. 2. Relationship between colours in 2° and other 5 sizes in terms of three human perceptual attributes based upon CIECAM02.

5, respectively. For instance, the comparison of lightness values between 2° and 22° stimulus sizes is given in Fig. 2-a3, where a and 3 stand for lightness and 22° stimulus size, respectively. In each sub-figure, the horizontal axis represents attributes for the 2° stimulus size, while the vertical axis represents the attributes for the other five stimulus sizes.

A linear best-fit curve for the lightness and chroma attributes was fitted to go through the 10 data points. They were derived by minimizing the sum of the squares of the differences between the value of each appearance attribute for each size of colour and the predicted value of that attribute. The best-fit lines were obtained with the following constraints: the lightness function was forced to pass through the point (100 100) since all six sizes of colour have the same reference white; the chroma function was forced to pass the point (0,0) because the assumption has been made that the chroma attribute does not change for neutral colours when the stimulus size increases. All figures 2(a) showed a consistent trend that colours appear brighter when the sample sizes are increased. Figures 2(b) also showed a clear trend that colours appear more colourful when sample sizes are increased. There was no hue difference between different sizes [see Figures 2(c)].



(a4) (b4) (c4)

(a5) (b5) (c5)

FIG. 2. (Continued)

The functions for each of the attributes are given in Eqs. (2)–(4).

$$J' = 100 + K_J \times (J - 100) \tag{2}$$

$$C' = K_C \times C \tag{3}$$

$$H' = H \tag{4}$$

Table V lists the K_J and K_C coefficients. where K_J represents coefficient for lightness, K_C represents coefficient for chroma.

Table V shows that K_J became smaller when size increases, which indicates [from Eq. (2)] that lightness increases with increasing stimulus size. K_C has the trend of increasing with the increasing of size, which also indicates [see Eq. (3)] that a colour appears more colourful when its stimulus size increases. The changes in the K_J and K_C coefficients express the extent of the appearance change that is due to variations in sample sizes, which are defined by their angular subtense. Figure 3 revealed the relationships between stimulus size and the coefficients K_J and K_C.

A best-fit curve was obtained for both lightness and chroma coefficients as a function of stimulus size; the equations of these lines are expressed in Eqs. (5) and (6). Table VI lists the coefficients, α_J, β_J, α_C and β_C, for each line which were optimised to fit all data points in each figure. The R^2 was used to indicate the goodness of fitting. They were calculated for both lightness and chroma as given in Figure 3.

$$K_J = \alpha_J \theta + \beta_J, \tag{5}$$

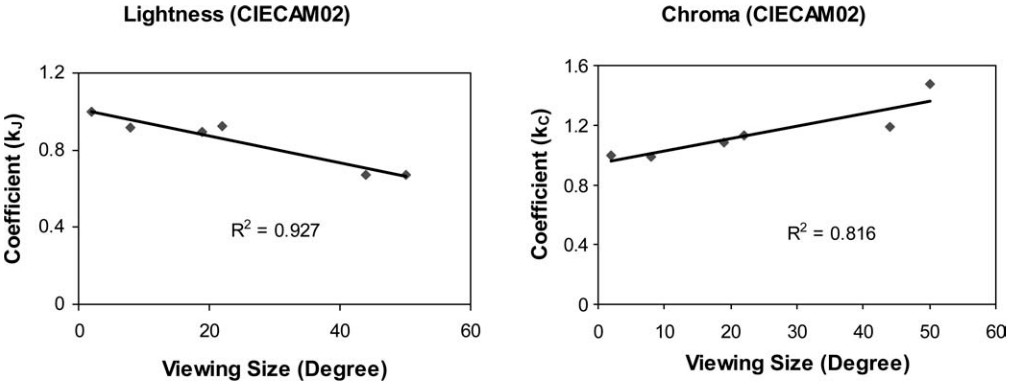
$$K_C = \alpha_C \theta + \beta_C, \tag{6}$$

where K_J and K_C represent scaling factors for lightness and chroma, respectively. The symbol θ represents the stimulus size defined by angular subtense. The results in terms of R^2 were 0.927 and 0.816 for lightness and chroma, respectively. This implies that the best fit line represents the relationship between stimulus size and coefficients very well.

Finally, a model called the size effect correction was developed. By using Eqs. (5) and (6), the K_J and K_C values for lightness and chroma for different sizes were first calculated. Colour appearance in terms of lightness, chroma and hue for stimuli with dissimilar sizes can then be predicted by using Eqs. (2)–(4), respectively.

TABLE V. Coefficients of best-fit curves for lightness and chroma attributes.

Coefficients	8°	19°	22°	44°	50°
K_J	0.917	0.893	0.913	0.662	0.668
K_C	0.985	1.089	0.987	1.045	1.293



(a) (b)

FIG. 3. Viewing angle versus K_J and K_C in CIECAM02 space: (a) Lightness and (b) Chroma.

Figure 4 shows the work flow of the size effect correction model including the following four steps:

Step 1: To calculate or measure tristimulus values of a 2° stimulus size and input a target stimulus size (θ).
Step 2: To predict CIECAM02 *J*, *C*, and *H* for colours with 2° stimulus size.
Step 3: To compute the scaling factors (K_J and K_C) based on the inputted target stimulus size (θ) using Eqs. (5) and (6) with the corresponding coefficients for the lightness and chroma attributes, respectively.
Step 4: To predict colour appearance attributes of the colour stimulus with the target size by applying Eqs. (2)–(4) with the scaling factors obtained in Step 3.

Size Effect Transform

A different approach for modeling size effect was also derived. It is named size effect transform between CIE tristimulus values for dissimilar sizes of colours. Such a transform is, in a sense, similar to a chromatic adaptation transform to predict corresponding colours across various illuminants.[11] Here, the transform is focused on the various stimulus sizes. As size effect is related to the sensitivity of cone responses in the human retina, one hypothesis is that the changes of sensitivity in the photoreceptors are independent of sizes. The size effect transform was modeled here by applying a direct transform to the (*LMS*) cone responses.

A set of spectral sensitivity functions of cones in the human retina was adopted to model the responses of the real cones in the retina. These sensitivity functions are based on the CIE standard colorimetric observer. The cone responses can also be transformed linearly from the intensity of colour stimulus as given in Eq. (7), which has been used widely in colour appearance models, such as RLAB, Nayatani models.[3] In this study, this equation was also adopted to convert CIE *XYZ* tristimulus values to *LMS* tristimulus values for the six sizes of colour data.

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.400 & 0.708 & -0.081 \\ -0.226 & 1.165 & 0.046 \\ 0.000 & 0.000 & 0.918 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (7)$$

To transform *LMS* tristimulus values from one size to another, a matrix Mat_θ was used to map $(L, M, S)^{\mathrm{T}}_{2^\circ}$ to $(L, M, S)^{\mathrm{T}}_{\theta}$, i.e.,

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix}_{\theta p} = \mathrm{Mat}_\theta \begin{bmatrix} L \\ M \\ S \end{bmatrix}_{2^\circ}, \qquad (\theta = 8^\circ, 19^\circ \ldots, 50^\circ) \quad (8)$$

where $(L, M, S)^{\mathrm{T}}_{\theta}$ is the transpose of the vector of cone response for a particular size of a colour stimulus with a subtending angle θ (=8°, 19°..., 50°). The symbol "*p*" represents the model's prediction. Although a matrix Mat_θ can be determined to produce $(L,M,S)^{\mathrm{T}}_{\theta p}$ as close to $(L,M,S)^{\mathrm{T}}_{\theta}$ as possible, it was found that there is no obvious relationship between the matrix coefficients and stimulus sizes. Hence, the following model was derived.

TABLE VI. Coefficients for relationship between subtending angle and scaling factors for lightness and chroma attributes in CIECAM02 colour space.

CIECAM02	α_J	β_J	α_C	β_C
Coefficents	−0.007	1.1014	0.008	0.94

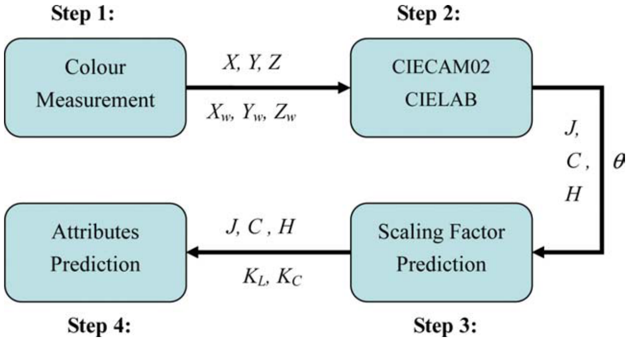


FIG. 4. The flow chart of size effect correction model. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE VII. Coefficients of α, β, and γ for colours in 5 different sizes.

Coefficients	8°	19°	22°	44°	50°
α	0.56	0.64	0.67	0.89	0.96
β	0.56	0.64	0.67	0.88	0.95
γ	0.58	0.63	0.65	0.85	0.91

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix}_{\theta} = A \begin{bmatrix} \alpha(\theta) & & \\ & \beta(\theta) & \\ & & \gamma(\theta) \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}_{2^\circ}$$

$$(\theta = 8^\circ, 19^\circ \ldots, 50^\circ),$$

where

$$A = \begin{bmatrix} 1.306 & 0.328 & 0.193 \\ -0.632 & 2.176 & 0.274 \\ -0.543 & 0.047 & 2.241 \end{bmatrix} \tag{9}$$

where $\alpha(\theta)$, $\beta(\theta)$, $\gamma(\theta)$ represent the changes in cone responses between a target stimulus size of θ and 2° and are determined so that $(L, M, S)^{\mathrm{T}}_{\theta p}$ is as close to $(L, M, S)^{\mathrm{T}}_{\theta}$ as possible.

Both the matrix A and parameters α, β and γ were optimized to transform a given colour stimulus from 2° to a specific size. Table VII lists the coefficients for α, β and γ.

Figure 5 shows the relationships of α, β and γ values versus stimulus size (θ). They were modeled by using a quadratic best-fit curve for each channel as given in Eq. (10). The R^2 values of 0.990, 0.992 and 0.995 were obtained for each following curve, respectively indicating a successful curve fitting.

$$\begin{aligned} \alpha(\theta) &= 0.000062\theta^2 + 0.005800\theta + 0.5106 \\ \beta(\theta) &= 0.000064\theta^2 + 0.005556\theta + 0.5154 \\ \gamma(\theta) &= 0.000090\theta^2 + 0.002800\theta + 0.5484 \end{aligned} \tag{10}$$

Thus, a model to predict the tristimulus values of a colour in a specific size from its tristumulus values for a 2° size was developed, and the procedure is described below and is also given in Fig. 6.

Step 1: To calculate or measure CIE XYZ tristimulus values under 2° and to input a target stimulus size (θ).
Step 2: To transform the CIE XYZ tristimulus values to cone response values $L(2^\circ)$, $M(2^\circ)$, $S(2^\circ)$ by using Eq. (7).
Step 3: To compute the three cones response $L(\theta)$, $M(\theta)$, $S(\theta)$ under subtending angle θ by using Eqs. (9) and (10).
Step 4: To transform the cone responses $L(\theta)$, $M(\theta)$, $S(\theta)$ to CIE XYZ tristimulus values under subtending angle θ using Eq. (11).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\theta} = \begin{bmatrix} 0.400 & 0.708 & -0.081 \\ -0.226 & 1.165 & 0.046 \\ 0.000 & 0.000 & 0.918 \end{bmatrix}^{-1} \begin{bmatrix} L \\ M \\ S \end{bmatrix}_{\theta} \tag{11}$$

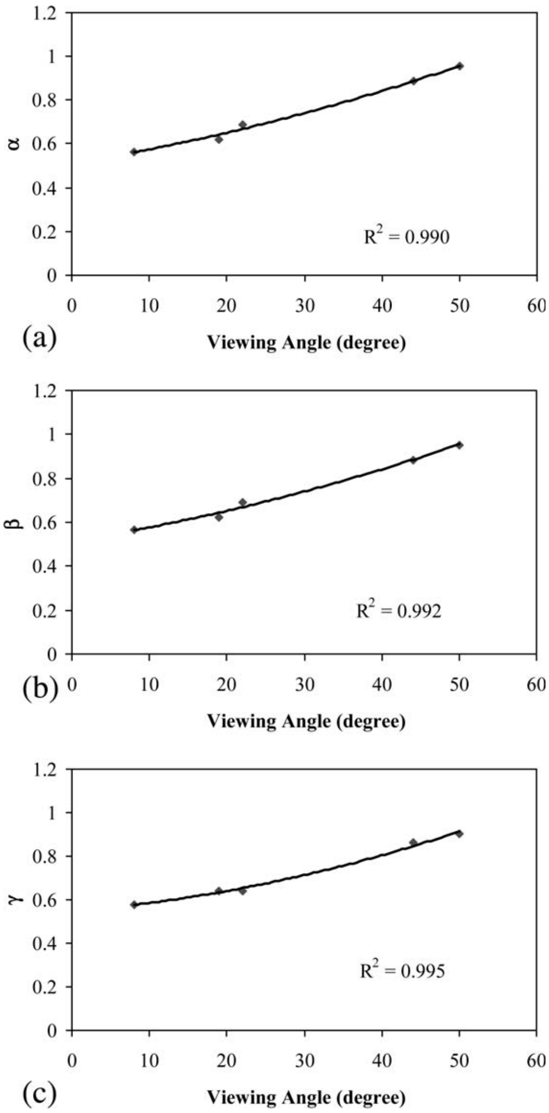


FIG. 5. The coefficients of α, β, γ versus stimulus size (in degree) and the best-fit curves: (a) α versus subtending angle, (b) β versus subtending angle, and (c) γ versus subtending angle.

MODEL PERFORMENCE

The size effect has been modeled by both size effect correction model based on CIECAM02 appearance attributes and size effect transform model based on (LMS) cone

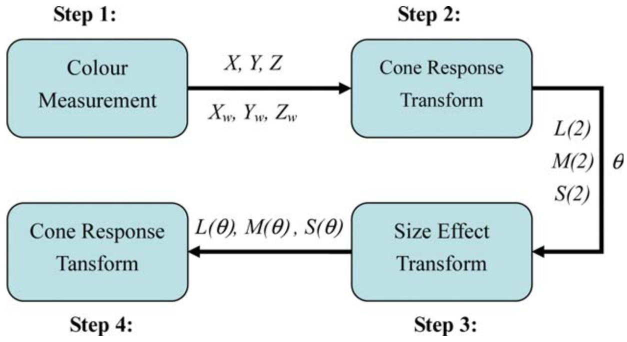


FIG. 6. The flow chart of size effect transform model. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

responses. To verify the prediction performance of each approach in terms of colour appearance prediction for large size of colours, the size effect data of 2° size were entered into each model, and colour appearance attributes were then predicted for the other five different sizes. Both the CV value for *J*, *C* and *H*, and ΔE^*_{ab} values were used to measure colour appearance difference and colour difference between the experimental results and the results predicted by the model, respectively.

Performance of Size Effect Correction Model

To test the size effect correction model in CIECAM02 colour space, first, the size effect data of 2° stimulus size were input to CIECAM02 colour appearance model. By using the input parameters, the colour appearance attributes (*J*, *C*, *H*) of those colours in the 2° size were predicted. The size effect correction model was then used to predict the colour appearance attributes of the same colours in five other stimulus sizes (8°, 19°, 22°, 44° and 50°). Table VIII summarizes the performance of the correction model.

By comparing Tables III and VIII, it can be seen that by using the size effect model, the colour appearance difference due to the size effect is significantly reduced for both lightness and chroma attributes.

To investigate the model performance in terms of colour difference, the predicted *J*, *C*, and *H* values for each colour were transformed back to CIE *XYZ* tristimulus values by using the CIECAM02 reverse model. CIELAB colour difference formula was then employed to predict the colour difference between the predicted results and the observers' visual results for each colour. The mean ΔE^*_{ab} are also given in the last row of Table VIII. It can be seen that the predictive error is smaller than the colour difference caused by the size effect (ΔE^*_{ab} of 12 in Table III), which showed that the model was implemented correctly and fit the experimental data very well.

Performance of Size Effect Transform Model

The performance of the size effect transform model was also evaluated. The CIE tristimulus values of colours with a 2° stimulus size from the size effect data were input to the model. The predicted results from the model were again compared with the visual results for each of the five target sizes (8°, 19°, 22°, 44° and 50°). To this end, the model performance was evaluated in terms of both colour difference and colour appearance difference using ΔE^*_{ab} and CIECAM02, respectively.

TABLE VIII. Model's performance of size effect correction in CIECAM02 colour space for colours in five sizes.

Model performances	8°	19°	22°	44°	50°	Mean
CV (*J*)	6.6	4.0	6.2	3.8	7.6	5.8
CV (*C*)	7.0	6.8	23.0	24.8	17.8	18.7
CV (*H*)	3.2	3.7	5.5	4.1	5.2	4.4
ΔE^*_{ab}	6.2	5.6	6.8	7.4	8.0	6.8

TABLE IX. Model's performance of size effect transform for colours in five sizes.

Model performances	8°	19°	22°	44°	50°	Mean
CV (*J*)	7.6	8.5	6.3	3.0	8.4	6.7
CV (*C*)	13.3	8.4	12.3	7.4	19.5	12.2
CV (*H*)	3.2	2.2	2.1	1.8	3.3	2.5
ΔE^*_{ab}	4.5	4.0	4.6	3.1	8.3	4.9

Table IX shows that the average colour difference between the model prediction, and the observers' visual assessments was about 4.9 ΔE^*_{ab} units, which is more accurate than either without size effect correction (12.0 ΔE^*_{ab}) or the prediction from the earlier size effect correction model based on the CIECAM02 colour space (6.8 ΔE^*_{ab}). For colour appearance prediction, the average CV values calculated between model predictions and the experimental results for lightness, chroma and hue (composition) were 6.7, 12.2 and 2.5, which performed better than either without size effect correction (11.4, 27.3, 4.4) or using the size effect correction model based upon CIECAM02 (5.8, 18.7, 4.4). This demonstrates that the colour size effect correction model based on CIECAM02 performed worse than the size effect transform model based on cone response functions.

DISCUSSION

Two types of colour size effect models were developed. They are the size effect correction and size effect transform, and are capable of predicting colour appearance across dissimilar sizes of colours accurately. Their performances were verified by showing to fit the experimental data well and are therefore considered to be effective. Size effect correction is to correct the attribute correlates of colour appearance model. Hence, it is dependent on the colour appearance model used because predictions of human perceptual attributes are different for different colour appearance model. When a different colour appearance model is applied, all coefficients need to be re-optimized.

Size effect transform model is independent to colour appearance because it is based on CIE tristimulus values. It is also shown to have better performance in fitting the visual results than that in size effect correction. Therefore, size effect transform is more accurate to predict colour size effect. To develop a new colour appearance model, it is suggested to combine the size effect transform with a von Kries type transform in the first stage of the colour appearance model, since both have a similar structure in their modeling.

However, although the mechanisms of human vision that contribute to the size effect were considered during the design of the model structure, the model's coefficients were derived empirically based on the accumulated size effect data from this study. These coefficients could be further refined once more experimental data are available. New results including more colour sizes and a wider range of colours are encouraged to further verify the performance of the model developed here. Note that there were no independent testing data to evaluate the models' performance in this study. All the data will be contributed to CIE TC 1-75 to develop a comprehensive colour appearance model.

CONCLUSIONS

In this article, colour size effect was modeled based upon colour appearance data including six dissimilar sizes. Two methods, size effect correction and size effect transform, were developed to transform a stimulus having a 2° field of view to a larger size based upon both human perceptual attributes and human cone response, respectively. The performances for both methods were evaluated and shown to be effective based on our experimental results. Size effect transform performed better than size effect correction. Both can be used for the development of a comprehensive colour appearance model.

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NEWS

Graduate Programs in Color Science at the Rochester Institute of Technology

The Rochester Institute of Technology (RIT) is seeking outstanding applicants for its M. S. and Ph. D. degree programs in Color Science.

The degree programs in Color Science revolve around the activities of the Munsell Color Science Laboratory (MCSL) located within the Center for Imaging Science at RIT. The MCSL is the pre-eminent academic laboratory in the U.S. devoted to the study of Color Science, and for more than 25 years its faculty and staff have trained students and conducted cutting-edge research in the field. Current research topics include: color and appearance measurement, spectral and 3D surface capture, color and material appearance models, high dynamic range and spectral imaging, image quality metrics, data-visualization, color management, color and material psychophysics, archiving and reproduction of fine art, multi-ink printing, and advanced display systems.

The M. S. and Ph. D. programs provide graduate-level study in both the theory and the practical applications of color science. The programs give students a strong foundation in the fundamental concepts and practices of the field and afford them the unique opportunity of specializing in an area appropriate to their background and interest. These objectives are accomplished through the programs' core courses and electives and a student's thesis/dissertation project.

Graduates of the program are in high demand, and the placement rate has been 100% since the inception of the graduate program more than 25 years ago. Graduates are employed in engineering, management, and research positions in a wide range of fields including color measurement, colorant formulation, testing and quality control, hardware and software development, and electronic and hardcopy imaging. Companies that have hired graduates include Apple, Benjamin Moore, Canon, Disney, Dolby, DuPont, Eastman Kodak, Hallmark, Hewlett Packard, HunterLabs, International Paper, Microsoft, OmniVision, Pantone, Philips, Qualcomm, Ricoh, Samsung, Texas Instruments, Xerox, and X-Rite.

Teaching and research assistantships are available to qualified students to cover tuition and living expenses.

More information on the programs can be found at www.cis.rit.edu/mcsl/GradProgramOverview or by contacting Prof. James A. Ferwerda, Graduate Program Director at jaf@cis.rit.edu.

Application materials are due by January 15, 2012 for study starting Fall 2012.

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