Specifying the Colour Appearance of a Real Room

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Abstract

In this study, an experiment was carried out to specify the colour appearance of a real room, which was painted with the same colour on four walls except the ceiling and floor. Two colour matching methods involving small colour patches were used to describe the colour appearance of different parts of one wall under two light sources (D65 and CWF). The results were used to model the size affecting colour appearance. It was found that there were changes of perceived lightness and chroma when the physical size of the same colour sample changed from a small colour patch to the wall of a room. However the perceived hue was unchanged when the physical size changed. These size effects were found to be independent of the matching methods and light sources used. Finally a model was derived.

Introduction

A colour appearance model is important for cross-media colour image reproduction. It can estimate the colour appearance of a sample under different viewing conditions such as different luminance, illuminant, background, and surround. In 1997, the CIE (Commission Internationale de l'Éclairage) recommended a colour appearance model, named CIECAM97s,[1] which was superseded by CIECAM02[2] in 2002. Since these models were mainly developed to fit earlier experimental data[3-6] based upon small size (1 by 1 cm^2) and medium size (8 by 8 cm^2) coloured patches, they are not suitable for predicting the colour appearance of larger coloured areas such as a room in a private house. However, there is a strong desire from industry to predict the colour appearance for room size colours. The typical problem facing industry is that the paints purchased in stores frequently do not appear the same when they are painted in real room conditions. This is a problem for home owners, interior designers and architects when selecting colour ranges.

In addition, two other reasons contribute to the incapability to accurately predict the colour appearance of room sized colours. One is associated with the two CIE recommend colour matching functions: CIE 1931 and 1964 standard colormetric observers[7-9] or 2^o and 10^o observers, respectively. For the 2^o observer, the stimuli used should subtend a 2^o field to an observer's eyes. For the 10^o observer, the stimuli should be about a 10^o viewing field. However, for a large size colour, the viewing angle could be up to 90^o which approximates the total field of view. Hence, neither colorimetric observers is completely satisfactory. The other reason is the complicated illumination condition encountered. The colour appearance for one wall in a room depends on not only the light directly from the light source but also the light reflected from the other walls. This is known as a mixed illumination condition.

In this study, the main aim is to model how the size affects the colour appearance. A dedicated experimental room was prepared by painting all four walls with the same colour. Two colour matching methods were used to describe the colour appearance of one side of wall under two different light sources.

Experimental

In this study, all experiments were carried out in an experimental room. It had a physical size of 4m (length) by 3m (width) by 3m (height). Two light sources were used to illuminate the experimental room: a CIE Illuminant D65 simulator having a colour temperature of 6427^oK and a typical office lighting (Cool White Fluorescent with a colour temperature of 3820 ^oK). These are referred to as a D65 and CWF, respectively throughout the paper. The ceiling was painted with a white colour and the carpet is a mid-grey colour. All four walls were painted the same colour as each other. One wall in the room was used as the target colour to be judged by the observers. It was first divided into forty-eight areas (8 by 6). Each had an equal length and height, and the colour was measured by a Minolta CS1000 tele-spectroradiometer (TSR) in terms of absolute tristimulus values in cd/m^2 units. From these measurement data, the wall was later divided into 3 (under CWF) or 4 (under D65) large areas. The colour in each area was more or less uniform judging by the colour measurement data for a particular source. The colour in each area is called *room size colour* throughout this paper. The experimental situation is illustrated in Fig. 1. Eleven different colours were used to paint all four walls of the room. These colours are plotted in the CIELAB a*b* diagram under D65/10 condition as shown in Figure 2. It can be seen that they covered a reasonable colour range.

Each colour was assessed using two different techniques: colour matching with a CRT monitor[10] and colour matching in a viewing cabinet.[11,12] These are referred to as a CMM and CMV, respectively. Note that the method used by Billger[11,12] is different from the present method in many areas. For example, all the small samples were assessed under a fixed source (D65 simulator) in the cabinet to match those wall colours illuminated by two light sources (a D65 and an incandescent). She applied many colours in one room rather than one colour painted onto four walls. She also only matches the hue appearance without considering chroma and lightness. The main problem of the experiment is that observers did not fully adapt under the typical room condition.

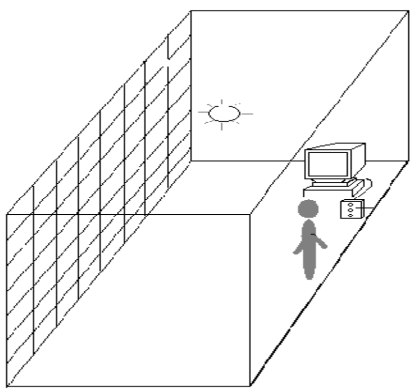


Figure 1. The CMM experimental situation

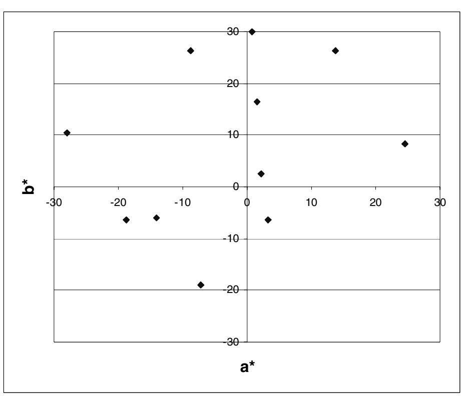


*Figure 2. The eleven wall colours poltted in CIELAB a*b* diagram under D65/10°*

Ten observers who all passed the Ishihara vision test participated in the experiments. In each observing session, each observer assessed 3 or 4 colour areas on the wall using the two matching methods under two light sources (D65 and CWF). When the light source was changed, each observer was asked to view the wall for 3 minutes to fully adapt in the new lighting condition.

For the CMM experiment, observers were asked to match the target room size colour by adjusting the colour that was displayed on a properly calibrated CRT monitor. The monitor was calibrated using the GOG model[10] with the white point adjusted to D65 or CWF according to the light source used in the room. The monitor setting was adjusted to make the white point as similar as possible to the source used in the room. After the observing session, each observer's matching colours were displayed on the screen and measured by the TSR. The monitor was placed near the centre of the room, with the face at 90° to the target wall, and the colour patch observed in the monitor was 8 x 8 cm subtended an viewing angle of about 10° at the observers' eye. The rest of the monitor screen was black. In the real experiment, it was found that all colours could be matched without any difficulty except one or two colours due to the limitation of the monitor gamut. However, it does not affect the general pattern of the data whether these colours are removed or not. Therefore, we use all the data for the analysis.

For the CMV experiment, each observer was asked to select a small chip from an NCS Colour Atlas[13] in a VeriVide viewing cabinet to give a satisfactory match to the target room size colour. The size of each chip was 1.2 x 1.8 cm. In some cases, a colour in the Atlas could not be found to match the target colour. Observers were asked to select a pair of colours, which were closest to the target colour, and gave each a weight to represent the closeness of the selected colours to the target colour. For example, the weights of two colours could be 20% and 80%. In all cases, all the other colours in the Atlas were covered by a grey mask when the final judgement was made. The D65 and CWF sources used in the viewing cabinet were produced by the same manufacturers as those used in the real room. The cabinet was painted with a mid-grey colour for the three walls and bottom panel. The colour(s) selected were measured in the viewing cabinet. For a target matched by the two colour patches, both colours were measured by the TSR and the final results in XYZ values were calculated by using the weights given by an observer.

The average colour measurement results for all observers in the CMM and CMV experiment represent mean visual results. The results in terms of tristimulus values were then transformed to CIELAB Lightness (L*), Chroma (C*), and Hue angle (h). The average colour measurement results from all positions for a room size colour were also calculated in term of tristimulus values. The results were also transformed to CIELAB L*, C* and h values.

Note that there is a need to define the reference white in terms of tristimulus values for calculating CIELAB values. Normally, the reference white should correspond to a CIE illuminant or a real light source. However, the reference white was different from the colour of the light source used in the present study due to the reflection from the walls in the room. Therefore, when the room was newly painted, a white colour was placed underneath the light source against the floor and was measured by the TSR. The result was used as the chromaticity of the reference white. Its luminance level was fixed for all wall colours and was the averaged luminance of a painted white wall. The visual results from the white colour were excluded in the 11 colour centre because its colour was not achievable, i.e. out of the colour gamut for the CMM method.

The present experiment was designed to accumulate a data set including pairs of corresponding colours, i.e. two sets of colorimetric values having the same colour appearance. The corresponding colours in the present study are room size and small size colours. The former is represented by the results measured directly from the wall and the latter is represented by those measured from the colour patches in the viewing cabinet or on the display.

Results and Discussions

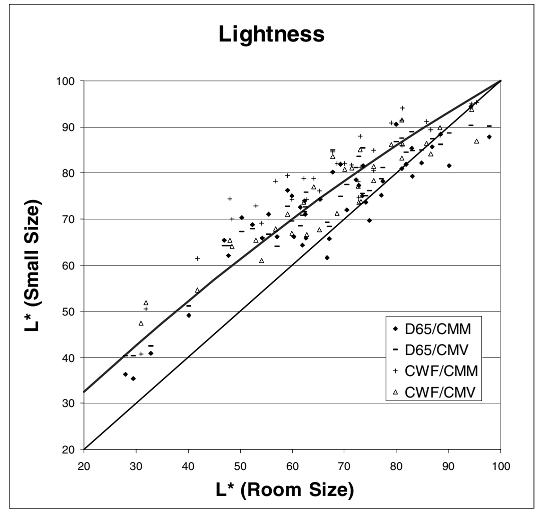
Observer Variation

The observer variation was investigated. For each target colour, the CIELAB colour-difference, ΔE^*_{ab}, was calculated between each observer's and the mean visual results. The average ΔE^*_{ab} value from the 10 observers was then calculated to represent the typical observer accuracy for a particular colour. The mean from all 11 colours was then calculated to represent the overall observer accuracy.

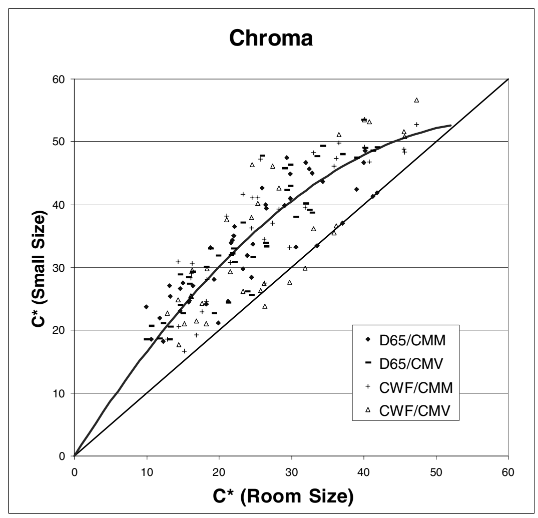
Comparing the observer accuracy between the CMM and CMV experiments, the result from the CMM experiment (a mean of 9 ΔE^*_{ab} units ranging from 6 to 10) is slightly better than that of the CMV experiment (11 from 8 to 16). This implies that a colour model can be considered to be satisfactory for a predictive error less than 10 ΔE^*_{ab} units to fit the present data set, i.e. more accurate than one of the panel of 10 observers.

Size Effect

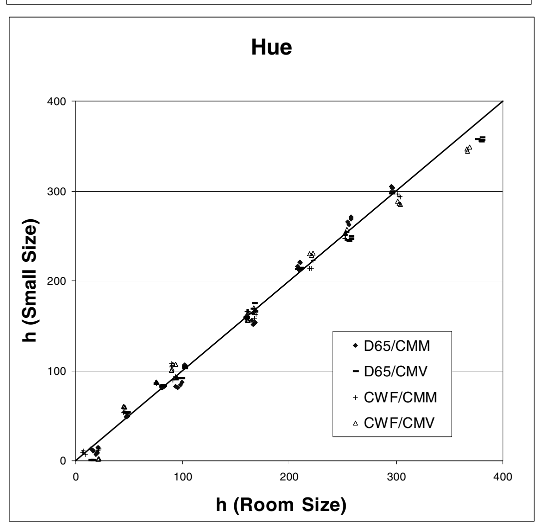
The size effect is revealed by plotting the CIELAB L*, C* and h values between the small and room size colours as shown Figures 3a for L*, 3b for C*, and 3c for h respectively. Each diagram includes 154 colours, i.e. 11 (test colours) x 7 (3 and 4 areas under CWF and D65 respectively) x 2 (CMM and CMV methods)=154. In all cases, the L* or C* values were the measured values from the chip/patch or wall respectively. For each diagram, the 45° line is drawn to indicate the agreement between two data sets. If they agree well with each other, all points should lie on this line. Figures 3a, 3b and 3c shows the plot of room size and small size colours for L*, C* and hue angle respectively. The data are plotted using diamond, minus, plus, and triangle symbols for the CMM under D65, CMV under D65, CMM under CWF and CMV under CWF conditions respectively. It can be seen that there is not much difference for the data obtained between CMM and CMV methods and between D65 and CWF sources. Therefore, the following analysis was based on the combined data set. The most obvious trend in Figures 3a and 3b is that most of the points are above the 45° line. This implies that the same colour would appear lighter and stronger for room size colour than for small size colour patch. In other words, there will be an increase of lightness and chroma when the physical size changes from a small chip or patch to room size. This visual phenomenon could be caused not only the viewing size but also inter-reflected light from all four walls. However, all points for the hue diagram are closely on the 45° line as shown in Figure 3c, which indicates that size changes have little effect on Hue.



(3a)



(3b)



(3c)

Figure 3. Rrelationship between small and room size colours in CIELAB a) L, b) C* and c) hue angle.*

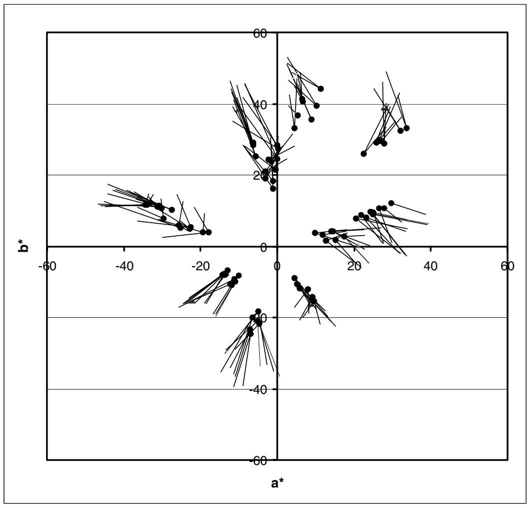


*Figure 4. The colour shifts in CIELAB a*b* diagram. The full point end of a vetctor corresponds to a room size colour and the open end for the corresponding small size colour.*

Figure 4 plots the colour shift from the small size (open end of the line) colours to room size (the full point end of the line) colours in *a*b** diagram. The pattern is again clear that colours appear to be more colourful with little shift in hue for room colours.

The size effects were modelled by fitting the best-fit curve to go through the data points in Figures 3a and 3b. The best-fit curve for each attribute was derived by minimizing the sum of the squares of the differences between the chip/patch and wall colours with some constraints. The lightness function was forced to pass through the point (100,100) and chroma function to pass through (0,0). This is because the reference white was set to 100 for scaling the white and all neutral colours had a chroma of zero.

By inspecting the trends in Figures 3a and 3b, the best-fit curve for lightness and chroma respectively are nonlinear. Hence, it was decided to use a quadratic equation to fit the lightness and chroma data given in equation (1) and (2), respectively.

$$L_S = \alpha_L L_R^2 + \beta_L L_R + 100(1 - 100\alpha_L - \beta_L) \quad (1)$$

where the subscript L stands for lightness, R for room size colour, and S for the small size colour.

$$C_S = \alpha_c C_R^{\ 2} + \beta_c C_R \quad (2)$$

Here the subscript C stands for the chroma, subscripts R and S have the same meaning as above.

The results show that the hue angle does not demonstrate any size dependence,i.e.

$$h_S = h_R, \quad (3)$$

The above three equations formed a model to correlate the colour appearance between room and small size colours. The model's performance can be tested by plotting the perceptual attributes of the room size colour against the corresponding predicted results by the models. When the visual and predicted room size colours were plotted for lightnes, chroma and hue respectively, it was found that although there are still some scatter between the two data sets, the points are equally scattered on either side of the 45^o line. The performances were also measured by the CIELAB Colour-difference between the visual results and the model's predictions. The results showed that the model's performance (a mean of 9) is more accurate than the mean observer accuracy results (10).

A Model for Predicting the Colour Appearance of the Room Size Colour

As described earlier, the relationship of the colour appearance between room and small size colours was modelled. However, the reference white has to be determined by measuring a white sample when the room is painted. This is not practical for real applications. Hence, a method was developed to model the mixed illuminant [14] which is caused by the light reflected from the walls in the room and the light source used. In fact, this idea came from CIE TC8-04, which is aimed to recommend a colour model for considering mixed illumination condition. Therefore, the reference white is modelled as the following:

$$X_n = fX_w + (1-f)X, \quad Y_n = fY_w + (1-f)Y, \quad Z_n = fZ_w + (1-f)Z, (4)$$

where X_w,Y_w,Z_w are the tristimulus values of the light colour used, and the X,Y,Z are the tristimulus values of the wall colour measured. The f value is the parameter to be determined and X_n,Y_n,Z_n are the tristimulus values of the newly predicted reference white. However, X_n,Y_n,Z_n should be normalised so that the Y_n value is 100. This value was optimised by minimising the agreement between the model's prediction and the visual results.

By combining the equations (1) to (4), a generic model is formed as given in Figure 5.

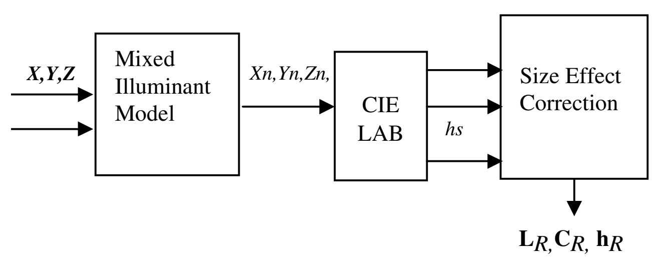


Figure 5. Processing for predicting colour appearance for room colours

The model requires the input of tristimulus values of X,Y,Z of the small size colour and X_w,Y_w,Z_w of the reference white of the light source. The mixed illuminant model (equation (4)) was used to calculate the X_n,Y_n,Z_n. The X,Y,Z and X_n,Y_n,Z_n were then enter to CIELAB for calculating the L*, C* and h attributes for the small size colour. Finally, the size effect model (equations (1) to (3)) was used to obtain the L*, C* and h attributes for room size colour. The predictive error of the final model in predicting the present experimental data was about 8.7 ΔE^*_{ab} units, which is a further improvement from only applying the size effect model.

Conclusions

In this study, the colour appearance of a coloured wall in a room was carefully studied. Psychophysical experiments were conducted using two colour matching techniques in order to specify eleven paint colours under D65 and CWF sources. The relationship of colour appearance between room and small size colours was compared. It was found that the size of the coloured area changing from a small patch to room size has a large effect on lightness and chroma attributes, but little effect on the hue attribute. It is also found that these effects are independent of the light source used. According to the available data, a colour appearance model for predicting the change of colour appearance from the small to room size colours was successfully developed. It performed more accurately than a single observer in the current panel of observers.

Future work will be conducted to map corresponding colours in order to extend the current colour appearance model such as CIECAM02 for predicting size effect. However, more experimental results are required. New experiments have already carried out using the CMM and CMV methods to assess colour appearance of a series of samples having same colour with different sizes.

Acknowledgement

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Biography

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