Applying CIECAM02 for Mobile Display Viewing Conditions

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Abstract

Small displays are widely used for mobile phones, PDA and Portable DVD players. They are small to be carried around and viewed under various surround conditions. An experiment was carried out to accumulate colour appearance data on a 2 inch mobile phone display, a 4 inch PDA display and a 7 inch LCD display using the magnitude estimation method. It was divided into 12 experimental phases according to four surround conditions (dark, dim, average, and bright). The visual results in terms of lightness, colourfulness, brightness and hue from different phases were used to test and refine the CIE colour appearance model, CIECAM02 [1]. The refined model is based on continuous functions to calculate different surround parameters for mobile displays. There was a large improvement of the model performance, especially for bright surround condition.

Introduction

Many previous colour appearance studies were carried out using household TV or PC displays viewed under rather restricted viewing conditions. In practice, the colour appearance of mobile displays is affected by a variety of viewing conditions. First of all, the display size is much smaller than the other displays as it is built to be carried around easily. Secondly, the portability allows the display to be viewed under surround conditions varying from such as dark night to bright sunlight, and indoor and outdoor conditions. In many cases, large amount of flare are included in the displayed images.

The aim of this study is to model the change of colour appearance on mobile displays under a wide range of viewing conditions. Three different sizes of small mobile displays were used: a 2" mobile phone display, a 4" PDA and a 7" LCD display. A characterisation model was derived to transform between the tristimulus values and the monitor's RGB values for all the 3 displays studied. Twelve experimental phases were conducted under 4 surround conditions (dark, dim, average, and bright) with the luminance levels ranged from 0 to 5500 cd/m^2. Each test colour was estimated by 5 to 10 observers in terms of lightness, colourfulness, brightness and hue appearance attributes. The brightness and colourfulness are considered to be important to represent the 'absolute' appearance under different viewing conditions. The visual results were used to evaluate the CIE colour appearance model, CIECAM02 [1]. The model was then modified specifically for mobile display viewing conditions.

Experimental Setup

A Minolta CS1000 spectroradiometer (TSR) was used to measure all the colours in the experiment with a 0/45 geometry and viewing distance of 30 cm. Figure 1 shows the colour gamuts of the 2" (dashed line), 4" (solid line) and 7" (double dashed line) displays. It can be seen that the gamut of the 4" transreflective display is much smaller than that of the 2" LCD display.

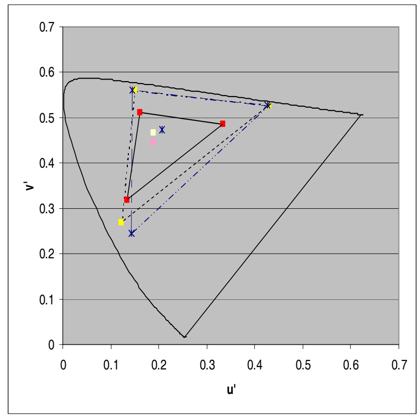

Figure 1. *The colour gamut of the three displays studied.*

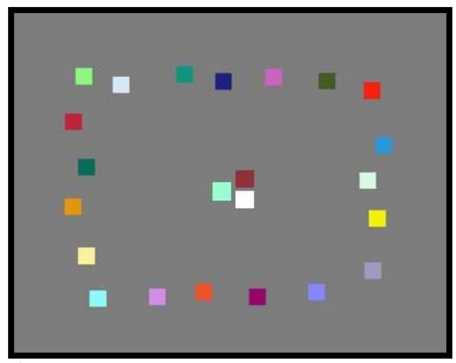

Figure 2. *The pattern used in the experiment.*

The viewing and illumination geometry was 45/0, which is typical in viewing portable displays and the viewing distance was 30 cm. The test colour to be judged was displayed in the middle of display together with the white reference and the colourfulness reference. The former is the display peak white having a lightness value of 100. The reference colourfulness is always referred to a particular physical sample viewed in a viewing cabinet. It is memorised by each observer. Twenty decorative colours on the edge of display were used to form a complex image. The physical size of the three middle colours was 1° viewing field for all displays.

Table 1 summarises the experimental conditions used in the twelve experimental phases according to four different surrounds (dark, dim, average, and bright) and 3 sizes of displays. Different colours were selected in different phases to give a reasonable coverage in CIELAB space. Different neutral grey background colours were used in each phase to clearly show the colours on the monitor with right contrast. The surround luminance was defined by measuring a reference white beside the display using the TSR under the viewing conditions for each phase. The results from the 2" display under dark, dim and average were reported earlier [2].

Table 1. Summary of the viewing conditions of different experimental phases.

Display	Surround	No of Colour	Ambient Lighting Luminance (cd/m^2)
2"	Dark	40	0
	Dim	40	5
	Average	40	1000
	Bright	40	5500
4"	Dark	30	0
	Dim	30	5
	Average	30	1000
	Bright	30	5500
7"	Dark	20	0
	Dim	20	5
	Average	20	1000
	Bright	20	5500

For the bright surround, the display was placed inside a viewing booth equipped with a strong spot light. Ten normal colour vision observers, according to the Ishihara test, participated all experimental phases except bright surround pahses, for which the 5 best observers from the previous 10 were used. All observers were familiar with the magnitude estimation method. There were 3 male and 7 female observers. Each was asked to estimate test colours in terms of brightness, lightness, colourfulness and hue closely following the method used by Luo et al [2]. Lightness was scaled against the reference white having a lightness of 100 and an imaginary black, 0. An anchor patch that was assigned a colourfulness of 40 and brightness of 100 was first shown in a viewing booth. Each observer had to judge the colourfulness of the reference patch in the beginning of each phase regarding to the anchor patch. The brightness was judged according to the anchor patch having a value of 100 with an open end. The hue was judged by reporting the percentage of the two colours from the four psychological hues (red, yellow, green, and blue).

Observer variations

Observer variations in terms of observer accuracy were examined. The former was compared between each observer's repeated judgments. The accuracy was compared between each individual observer and mean visual results. The measure of Coefficient of Variation (CV) given in equation (1) was used to indicate the disagreement between two sets of data. It is a measure of the distance of the points from the 45° line in the y direction. The more the points are scattered about the line, the poorer the agreement. A perfect agreement, CV should be zero and larger the value, the poorer the agreement.

$$CV = 100\frac{\sqrt{\sum(y_i - k \times x_i)/n}}{\bar{y}} \qquad (1)$$

where x_i and y_i are the i sample in the x and y data sets; n is the number of samples; $\bar{y}$ is the mean of the y data set and k is a scaling factor, which is obtained by the least square method.

For calculating observer accuracy, the scaling factor (k) in equation 1 was set to one. The mean CV values of the 12 phases were 19, 28, 31 and 9 units for the lightness, colourfulness, brightness and hue, respectively. The accuracy results were slightly worse than those found in Luo et al's study [3] due to the property of the viewing conditions involved, i.e. small screen and

Table 2. The performance of CIECAM02 in terms of CV

Colour attributes	Surround	2 inch	4 inch	7 inch	Mean	Total mean	Observer accuracy
Lightness	Dark	38	13	29	27		
	Dim	22	13	24	20		
	Average	27	12	24	21		
	Bright	65	55	46	55	31	19
Colourfulness	Dark	31	39	26	32		
	Dim	30	29	28	29		
	Average	37	27	32	32		
	Bright	48	49	31	43	34	28
Brightness	Dark	22	20	19	20		
	Dim	8	25	21	18		
	Average	17	25	22	21		
	Bright	27	43	51	40	25	31
Hue	Dark	14	12	8	11		
	Dim	13	11	6	10		
	Average	14	9	7	10		
	Bright	13	9	7	10	10	9

large variation of surround conditions.

Results and Discussions

Testing CIECAM02

The CIECAM02 model is the colour appearance model recommended by CIE. The model's performance is evaluated using the present experimental data in terms of CV calculated between the model's predicted and visual results. The CV values are summarised in Table 2.

Table 2 shows that the model gave a reasonable prediction to the brightness and hue visual results, but performed badly for predicting lightness and colourfulness visual results, i.e. the 'total mean' values are 31, 34, 25 and 10 comparing with 19, 28, 31 and 9 of observer accuracy results for lightness, colourfulness, brightness and hue respectively. Figures 3 to 5 are the plots of lightness, colourfulness and brightness visual results against the corresponding CIECAM02 predictions, respectively. Each figure includes four diagrams which correspond to dark, dim, average and bright surround conditions from left to right respectively. Note that the hue results are not plotted here because the model predicts well to the hue visual results, i.e. most of the data points are close to the 45^{o} line.

Figure 3 shows that CIECAM02 lightness is predicted well to the visual results under dim surround conditions but is overestimated those of the other surrounds and especially bright surround conditions. Figure 4 show that CIECAM02 predicts the colourfulness reasonably well for all surrounds except average surround conditions. Figure 5 shows that the brightness predicted poorly by the CIECAM02 under all surround conditions, especially in bright and average surround. Overall, CIECAM02 gave the poorest prediction to all the visual results under bright surround conditions.

Refinement of CIECAM02

In the last section, it was found that the performance of CIECAM02 is somewhat dissatisfactory, i.e. the results in terms of CV in predicting current results are much worse than those in predicting LUTCHI data [2]. Hence, various trials were made to improve the model's performance for predicting visual data. The general strategy was to modify CIECAM02 model as little as possible. The modification was made only for the surround parameters under various viewing conditions: c, F and N_c .

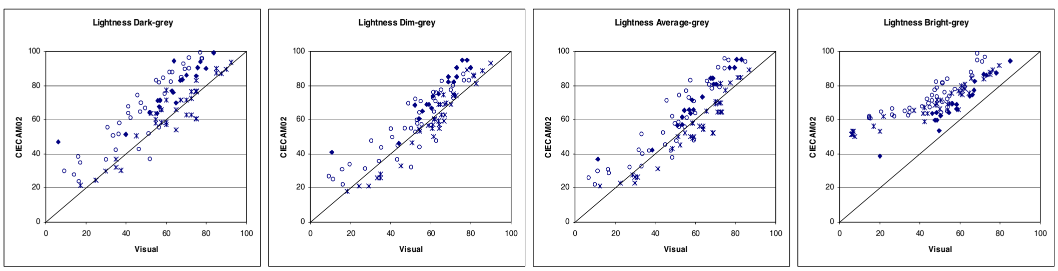

Figure 3. *CIECAM02 predicted lightness results plotted against visual results for four 4 surround conditions (from left to right: dark, dim, average, and bright). The symbols of square, cross and circle represent the data for 7", 4" and 2" displays, respectively.*

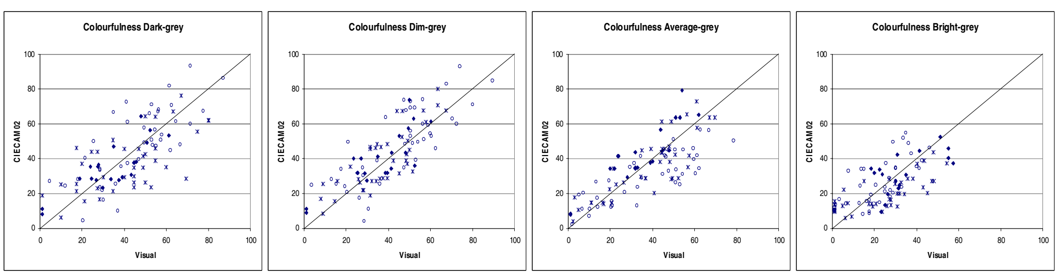

Figure 4. *The same as Figure 3 except that the colourfulness results are plotted.*

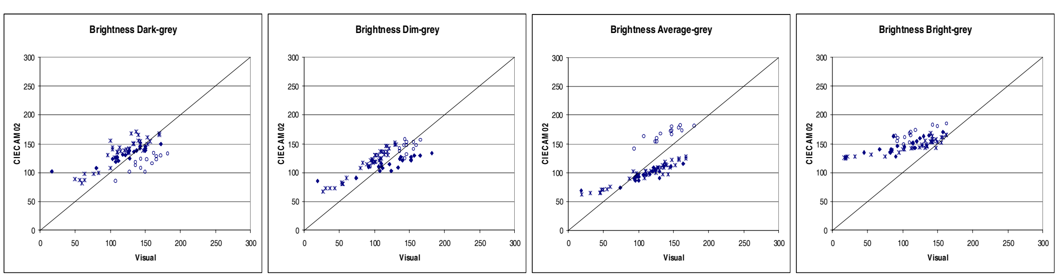

Figure 5. *The same as Figure 3 except that the brightness results are plotted.*

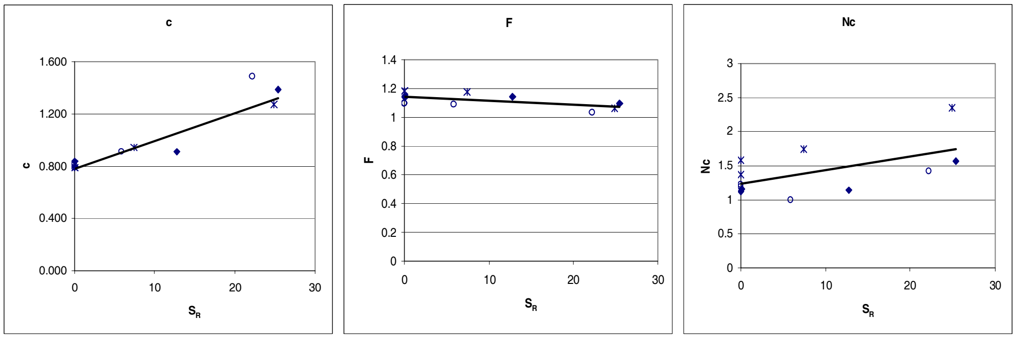

Figure 6. *The optimized c, F and N_c values are plotted against the S_R. The best fitted lines are also plotted. The symbols of square, cross and circle represent the data for 7", 4" and 2" displays, respectively*

Table 3. Surround parameters in CIECAM02

Surround	C	F	N_c
Average	0,690	1,0	1,0
Dim	0,590	0,9	0,9
Dark	0,525	0,8	0,8

The main viewing parameter studied in the present experiment is 'surround'. Table 3 gives the three surround parameters defined in CIECAM02. They are divided into three surrounds: average, dim and dark. These are determined by S_R (Surround ratio), in equation (2).

$$S_R = \frac{L_{SW}}{L_{DW}} \quad (2)$$

Where L_{SW} the luminance of the surround is white and L_{DW} is the luminance of the device white. If S_R is 0 then a dark surround is appropriate. If S_R is less than 0.2 then a dim surround should be used while an S_R of greater than or equal to 0.2 corresponds to an average surround.

Table 4. The S_R values for each display under each surround condition.

Surround	2 inch display	4 inch display	7 inch display
Dark	0	0	0
Dim	0.03	0.03	0.06
Average	6	7	13
Bright	22	25	25

CIECAM02 defines only three surrounds which are insufficient for the use of portable displays. For this reason, it was decided to develop a continuous function to define surround parameter for each phase of viewing conditions. Firstly, S_R values for the 12 phases were calculated as given in Table 4. It can be seen that the values vary from 0 to 38. The CV values calculated between the visual and the CIECAM02 predictions were

Table 5. CV values for testing the refined CIECAM02

Colour attributes	Surround	2 inch	4 inch	7 inch	Mean	Total mean	Observer accuracy
Lightness	Dark	28	22	18	23		
	Dim	28	13	17	19		
	Average	22	26	17	22		
	Bright	32	22	17	24	22	19
Colourfulness	Dark	29	33	28	30		
	Dim	27	23	28	26		
	Average	40	26	39	35		
	Bright	46	40	37	41	33	28
Brightness	Dark	11	15	15	14		
	Dim	16	36	16	23		
	Average	9	17	24	17		
	Bright	12	33	14	20	18	31
Hue	Dark	14	12	8	11		
	Dim	13	11	6	10		
	Average	14	9	7	10		
	Bright	13	9	7	10	10	9

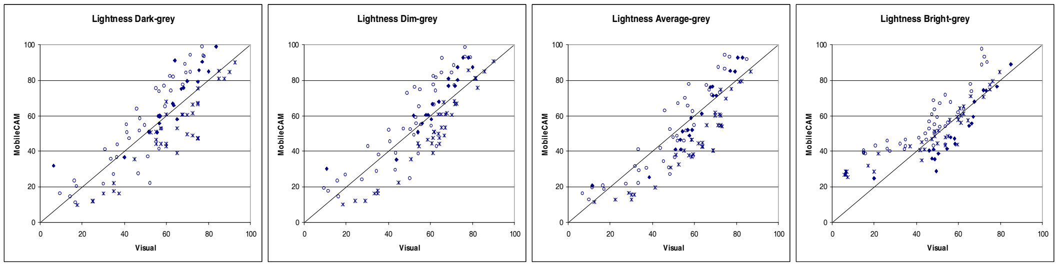

***Figure 7.** The same as Figure 3 except that the refined CIECAM02 lightness predictions are plotted.*

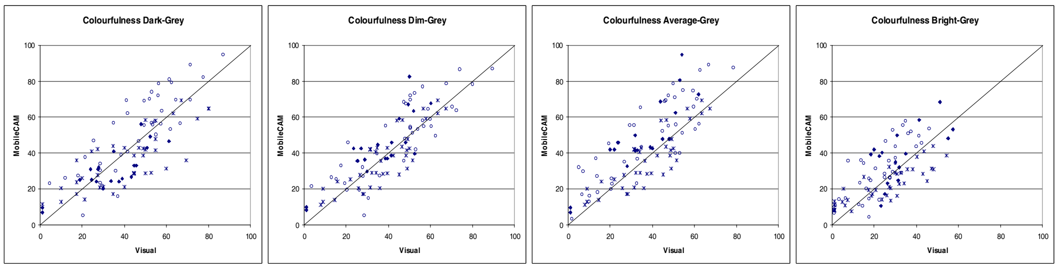

***Figure 8.** The same as Figure 4 except that the refined CIECAM02 colourfulness predictions are plotted.*

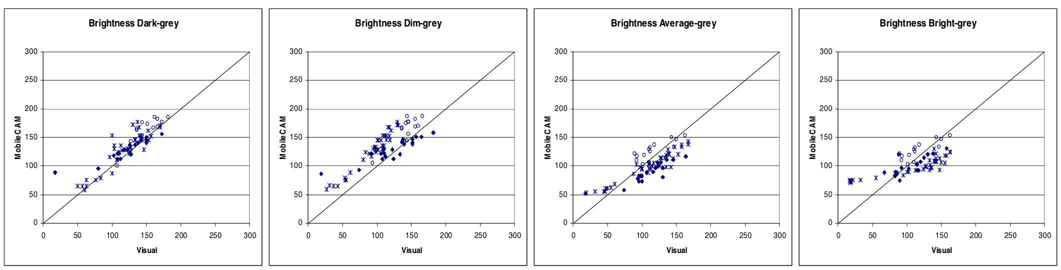

***Figure 9.** The same as Figure 5 except that the refined CIECAM02 brightness predictions are plotted.*

minimised by optimising the c, F and N_c variables. This was performed for all 12 phases. Each set of the optimised c, F and N_c values were then plotted against the S_R in Figure 6. It can be seen strong linear relationships between the S_R and surround parameters. A line was fitted to each of the three surround parameters as defined by equations 3 to 5 respectively.

$$c' = 0.023 S_R + 0.7887 \tag{3}$$

$$F' = -0.003 S_R + 1.1474 \tag{4}$$

$$Nc' = 0.0203 S_R + 1.2369 \tag{5}$$

The new equations are named c', F' and Nc' respectively. These were used to replace the fixed parameters in Table 3 to be used by CIECAM02. Its predictions and visual results are plotted in Figures 7 to 9 for lightness, colourfulness and brightness results respectively. Also the CV values are summarised in Table 5.

Table 5 shows that there is a good prediction of the refined CIECAM02. It can be seen clearly in Figures 7 to 9 that the largest improvement can be found in brightness, followed by lightness and colourfulness the smallest. The improvement is large marked for bright surround conditions. The findings can also be shown in Table 5, for which the refined CIECAM02 was tested in terms of CV unit using the present data.

In conclusion, there are marked improvements from the original CIECAM02 i.e. from CV values of 31, 34, 25, 10 to 22, 33, 18, 10 for lightness, colourfulness, brightness and hue, respectively. It performs equal to or better than the typical observer accuracy from the panel of observers.

Conclusion

In this study, a refined version of CIECAM02 was developed for mobile displays viewed under different surround conditions. A set of equations based on S_R was derived to be able to accurately define surround parameters. This greatly improves the performance of CIECAM02 in predicting the visual results.

Reference

[1] CIE Publication 159-2004: A colour appearance model for colour management systems: CIECAM02 (2004).

[2] YungKyung Park ChangJun Li, M. R. Luo Wonhee Choe, Seongdeok Lee and Changyeong Kim, "Colour Appearance Modelling for Mobile Displays", CIC 14th, scottsdale, arizona (2006)

[3] M.R. Luo, A.A Clarke, P.A. Rhodes, S. A. R. Scrivener, A. Schappor, C. J. Tait,"Quantifying Colour appearance. Part1. LUTCHI data", Colour Res. Appl., Vol 16, pp 166-180 (1991).

Author Biography

YungKyung Park received her BS and Masters in physics from the Ewha Womans University (Korea) and her Master in colour science from Derby University (UK). Since then she is a PhD student in Leeds University (UK). Her research has been focused on Colour Appearance modelling for Mobile Displays.