Correcting Veiling Glare of Refined CIECAM02 for Mobile Display

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Abstract

Small displays are widely used, small enough to be carried around and are often viewed under extreme surround conditions. Under bright illuminating the mobile display experiences 'veiling glare' caused by the ambient lighting. A refined version of CIECAM02 called *'Refined CIECAM02'* and original CIECAM02 were tested to predict visual results in terms of lightness, colourfulness, and brightness on a 2" mobile phone under four surround conditions (dark, dim, average, and bright). Other than the two versions of CIECAM02 using the original data, a correction to the models' predicted lightness J and a black correction to the original data were developed. Therefore six different versions were used to test and correct the veiling glare caused by the illumination. Overall, the refined CIECAM02 plus the J correction performed the best for predicting the lightness, brightness and colourfulness under all the viewing conditions especially for bright surround condition.

Introduction

High image quality on the small display of mobile phones is highly desirable for viewing static and moving images. However, the image quality is highly influenced by the large varying viewing surround conditions from bright outdoor sunlight to dark night. Hence, an experiment [1] was carried out to accumulate colour appearance data on a 2" mobile display using the magnitude estimation method. The data are expressed in terms of lightness, colourfulness, brightness and hue. The visual results from different ambient lighting levels (named bright, average, dim and dark surround conditions) were compared to reveal different colour appearance effects.

Based on the experiment results, a refined version of CIECAM02 was developed for mobile displays viewed under different surround conditions [1]. It is called '*Refined CIECAM02*' in this paper and has a set of equations to be able to accurately calculate viewing parameters of *Nc, F* and *c* from surround ratio, which is used to define surround conditions in CIECAM02 [2]. This largely improves the performance of CIECAM02 in predicting the visual results, especially under bright surround condition.

This paper describes the effects of the veiling glare and introduces a further improvement to the CIECAM02 by correcting the 'veiling glare' caused by the ambient lighting illuminating the mobile display.

Definition of Veiling Glare

As mentioned earlier, veiling glare is an important component affecting colour appearance. Veiling glare is defined as "light, reflected from an imaging medium that has not been modulated by the means used to produce the image" by ISO 12231[3]. Note that veiling glare lightens the whole image and reduces the contrast of the darker parts of an image. In CIE publication 122 [4], the veiling glare of a CRT display is referred to as ambient flare.

Modelling the Visual results

The colour appearance data set accumulated [1] were conducted under dark, dim, average and bright surround conditions. It was found that the refined CIECAM02 [1] performed much better than the original CIECAM02 [2]. However, the performance of the refined CIECAM02 under the bright surround condition is still not as good as the other conditions. The reason for this is that the data under bright surround condition was affected much more than those under dark, dim, and average surrounds conditions by veiling glare. The aim of this paper is to correct the influence of the veiling glare by either adding the black correction to the original data or adding the lightness J correction to the original and refined CIECAM02 models so that the resulting model performs as well as the refined CIECAM02 under the dark, dim and average surround conditions, but performs much better than the refined CIECAM02 under bright surround condition.

Black Correction to the Data

The typical method of correcting the veiling glare is to subtract the amount of black level from the measured value as given in equation (1).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{measured} \\ Y_{measured} \\ Z_{measured} \end{bmatrix} - \begin{bmatrix} X_b \\ Y_b \\ Z_b \end{bmatrix} \quad (1)$$

where the XYZ are the tristimulus values of the stimulus, and $X_bY_bZ_b$ are the tristimulus values of the black level of the display.

New equation J'

A new method is introduced to correct the veiling glare in correcting the visual lightness attribute *J*. The resulting lightness is denoted by *J'* and is given by equation (2):

$$J' = 100[J_{CIECAM02} - J_b \times \frac{J_b}{J_{CIECAM02}}] / J_w \quad (2)$$

where $J_W = 100 - J_b \times \frac{J_b}{100}$, J_b, and $J_{CIECAM02}$ are either the original or refined CIECAM02 lightness [1] for the black level, and the stimulus respectively. The offset term represents the effect of veiling glare in lightness. The larger the veiling glare is, the larger J_b and glare term will be.

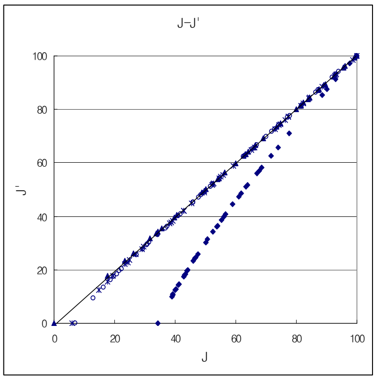


Figure1: *The lightness J plotted against J' for the original CIECAM02 under the dark (triangles), dim (crosses), average (circles) and bright (squares) surround conditions respectively.*

Figure 1 shows the lightness for the original CIECAM02 plotted against the new J' formula using the accumulated data sets. The triangle, cross, circle and square represent the data under the dark, dim, average, and bright surround conditions respectively. The straight line is the 45° degree line. It can be seen that all triangles are located on the 45° degree line. All crosses and circles are located on or close to 45° degree line for lighter samples and are slightly away from 45° degree line for very darker samples. In general *J'* formula is similar to the original *J* under the dark, dim and average surround conditions. On the other hand, the squares are located far away from the 45° degree line at lower lightness end, which means that under the bright surround condition, *J'* formula is much different from original *J*. Hence it is expected that lightness correction to the colour appearance models will improve the performance under the bright surround condition and will not affect the performance under other surround conditions.

Performance of the Model

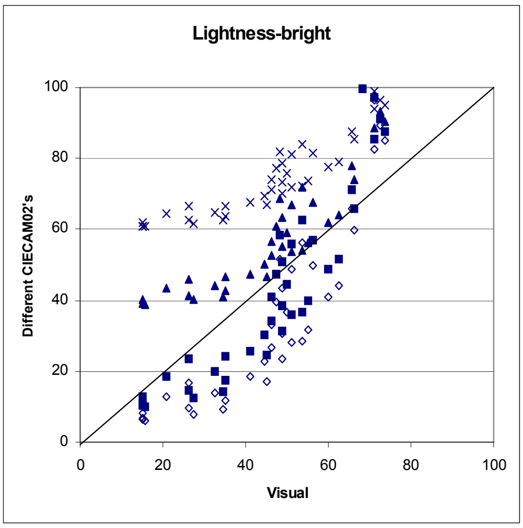
Since two models (CIECAM02 and refined CIECAM02) and two corrections are considered, there are 6 combinations or models. Each combination can be considered a colour appearance model. Table 1 lists the six different models. For example, Model 1 is

Table 1: Different versions of CIECAM02

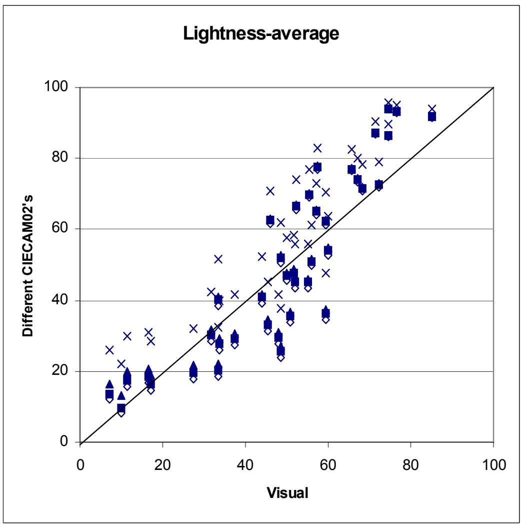
Model	1	2	3	4	5	6
CIECAM02 versions	Original CIECAM02	Original CIECAM02	Original CIECAM02 J'	Refined CIECAM02	Refined CIECAM02	Refined CIECAM02 J'
Data	Original	Black Correction	Original	Original	Black Correction	Original

Table 2: Performance of predicting lightness between different CIECAM versions in terms of CV measure.

Surround	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dark	38	37	35	28	28	28
Dim	35	34	33	28	28	28
Average	27	25	25	22	24	23
Bright	63	24	26	32	36	28



(a)



(b)

Figure 2: *The predicted lightness of Model 1 (crosses), Model 4 (triangles), Model 5 (diamonds) and Model 6 (squares) is plotted against the visual data under the bright surround (a) and average surround (b) respectively.*

the original CIECAM02 applied with the original data (or data without black correction), and Model 5 is the refined CIECAM02 applied with the data with black correction. All other models can be similarly explained.

Lightness

Table 2 lists all the CV values for the lightness attributes for the six versions of the CIECAM02 under dark, dim, average and bright surround conditions. The measure of Coefficient of Variation (CV) is used to indicate the disagreement between visual and model predicted results. It is a measure of the distance of the points from the 45° line. The more the points are scattered around the line, the better the agreement.

From Table 2, it can be seen that under each of the dark, dim, and average surround conditions, the CIECAM02 related Models 1, 2, and 3 have the same performance, which confirms that the glare corrections do not affect the resulting models performance under each of the dark, dim, and average surround conditions. This is also true for the refined CIECAM02 related Models 4, 5, and 6. Furthermore, it can be seen that the refined CIECAM02 related Models 4, 5, and 6 are better than the original CIECAM02 related Models 1, 2, and 3. Under the bright surround condition, Model 2 is the best. Models 3 and 6 are ranked the second and the third. Finally, if we assess each model under the four conditions, Model 6 is the best.

In Figures 2a and 2b, the visual lightness values (horizontal axis) versus lightness values predicted by four Models under the bright (2a) and average (2b) surround conditions respectively. The cross expresses the results from Model 1, triangles and diamonds represent results from Models 4 and 5 respectively. The squares are predictions of Model 6.

Comparing Figures 2a and 2b, it can be clearly seen that for the average surround condition, relatively less affected by the veiling glare, the prediction of the lightness is fairly similar to each other with and with out the black correction. This is true under dark and dim conditions as well.

From Figure 2a it can be seen that the lightness attribute is much over predicted by Model 1 (the CIECAM02 [2]) and Model 4 (the refined CIECAM02 [1]) especially for dark colours under the bright surround conditions. Models 5 and 6 perform better compared with Models 1 and 4.

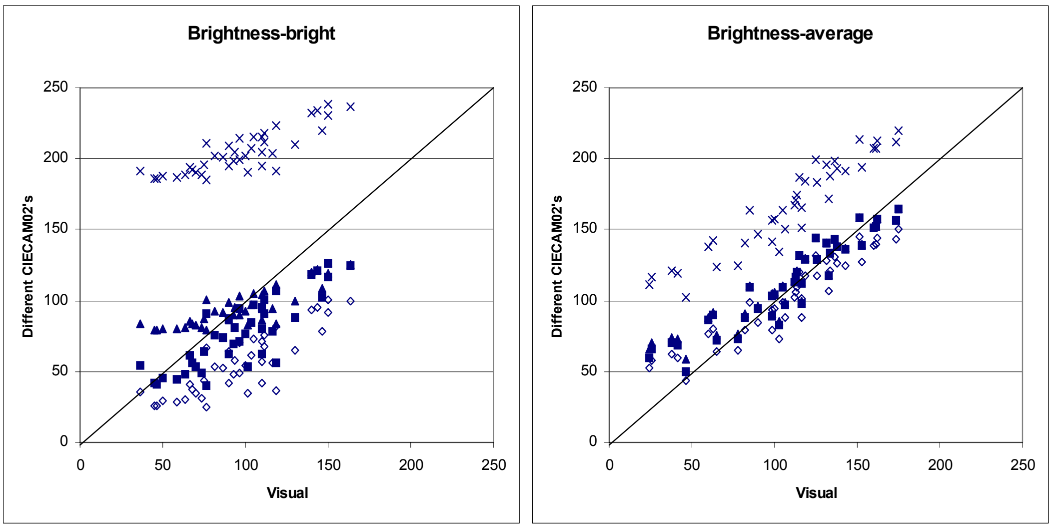
Brightness

As the brightness is derived from the lightness, the brightness predicted by the six Models was calculated. Table 3 lists the CV values which show the performance of predicting the brightness using six different CIECAM02 versions. Similar to the lightness, Models related to the refined CIECAM02 are better than Models related to the original CIECAM02. For overall performance under the four viewing conditions, Models 4 and 6 perform equally the best.

Figure 3 shows the results for those under bright and average surround conditions respectively. The symbols have the same meanings as in the lightness case in Figure 2. As shown in Figure 3, the crosses are located far above the 45˚ line, which means Model 1 predicts the brightness poorly under the bright and

Table 3: Performance of predicting brightness between different CIECAM02 versions in terms of CV measure.

Surround	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dark	74	63	70	15	15	14
Dim	49	41	48	13	13	12
Average	56	40	51	16	16	14
Bright	113	44	62	22	46	27

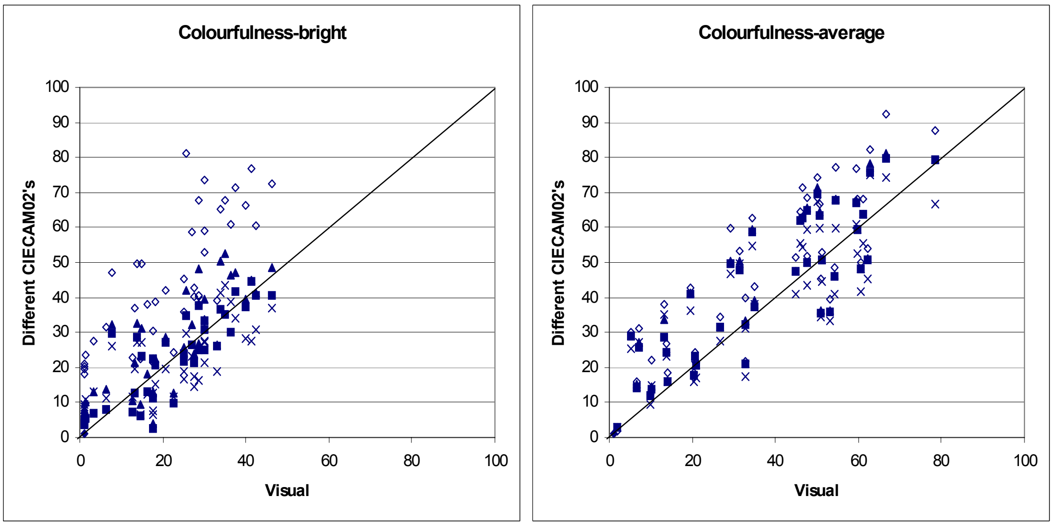


(a) (b)

***Figure 3:** The predicted brightness of Model 1 (crosses), Model 4 (triangles), Model 5 (diamonds) and Model 6 (squares) is plotted against the visual data under the bright surround (a) and average surround (b) respectively.*

Table 4: Performance of predicting colourfulness between different CIECAM02 versions in terms of CV measure.

Surround	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dark	32	30	33	24	28	22
Dim	31	30	29	25	24	24
Average	32	37	30	35	42	33
Bright	41	92	47	45	117	32



(a) (b)

***Figure 4:** The predicted colourfulness of Model 1 (crosses), Model 4 (triangles), Model 5 (diamonds) and Model 6 (squares) is plotted against the visual data under the bright surround (a) and average surround (b) respectively.*

average conditions. By observing Figure 3a, the diamonds are located slightly far below the 45˚ line. While the triangles and squares are around the 45˚ line. However, triangles have a trend having slope smaller than 1 and the squares have a trend with slope close to 1. Thus, under the bright condition, Model 6 is the best. This is also true under the average surround condition as shown in Figure 3b.

Colourfulness

Since the change of lightness in the CIECAM02 may alter the performance of the colourfulness prediction, further tests with the colourfulness prediction were carried out as well. Table 4 are the CV values of the colourfulness prediction for the six Models under the dark, dim, average, and bright surround conditions. It can be seen from this table that Models 1, 3, 4, and 6 performs better than Models 2 and 5. Model 6 performed the best under each viewing conditions.

Figure 4 shows the results of the prediction of the colourfulness from four Models plotted against the visual results under bright and average surround conditions. The symbols have the same meanings as for the lightness in Figure 2.

Figure 4b shows the results for average surround condition and it can be seen that no significant difference is shown among the different Models. However in Figure 4a, large differences amongst the Models are shown clearly. Especially the Models using the black correction performed the worst.

Model 5 over-estimate the colourfulness for the bright surround condition. However the other Models predict the colourfulness close to the visual results and Model 6 performs the best since the filled squares representing Model 6 in Figure 4a are less scattered around the 45° line.

The black correction and the J' formula improve the lightness predictions under the bright surround condition. However the black correction over-predicted the colourfulness.

Conclusion

Two methods were developed for correcting veiling glare. It was found that each of the correction methods does not affect the resulting model performance under the dark, dim and average surround conditions. It was also found that, for the lightness prediction, the refined CIECAM02 plus the J correction (Model 6) performed the best. For the brightness prediction, refined CIECAM02 plus black correction (Model 5) and plus J correction (Model 6) performed equally the best. For the colourfulness prediction, models with black correction performed the worst and the refined CIECAM02 plus the J correction (Model 6) performed the best. Overall, the refined CIECAM02 plus the J correction (Model 6) performed the best for predicting the lightness, brightness and colourfulness under all the viewing conditions.

Reference

[1] Y.K. Park, C.J. Li, M.R. Luo, Y.S. Kwak, D.S. Park, and C.Y. Kim, "Applying CIECAM02 for Mobile Display Viewing Conditions ", CIC 15th, Alburquerque, New Mexico (2007)

[2] CIE Publication 159-2004: A colour appearance model for colour management systems: CIECAM02 (2004).
[3] ISO 12231: Photography. Electronic still picture imaging. Vocabulary
[4] CIE Publication 122-1996: The Relationship Between Digital and Colorimetric Data for Computer-Controlled CRT Displays (1996)

Author Biography

Yung Kyung Park received her BA and Master Degree in physics from Ewha Womans University (Korea, 2001, 2003) and MSc in colour science from University of Derby (UK, 2003). Currently she is a PhD student in colour science at University of Leeds (UK). Her work has focused on the colour appearance of mobile displays.