Testing Colour Appearance Models for Mobile Phones using Complex Images

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Abstract

Park et al [3] introduced refined versions to the CIECAM02 for reducing the veiling glare for mobile displays. The first was called black correction by subtracting the amount of black level from the measured tristimulus values (XYZ) and the other was a correction of J (lightness scale). The previous work was based on single colour patch samples. In this paper, an experiment was carried out using the complex images to verify the different versions of CIECAM02. The images were processed based on CIECAM02 JMh (lightness, colourfulness and hue). The experiment was conducted by comparing the original images viewed under dim, average and bright surround conditions with the predicted image viewed under dark surround condition on two identical mobile displays. The different versions of the CIECAM02 showed similar results to each other for dim and average surround conditions but large difference was found for bright surround condition. The refined CIECAM02 with J' correction performed the best amongst all four CIECAM02 versions.

Introduction

The usage of mobile displays has grown tremendously in recent years. Park et al [1] developed a version of CIECAM02 named 'refined CIECAM02' for portable displays that experience various surround conditions. This greatly improved the performance of CIECAM02 [2] in predicting the visual results especially for bright surround condition. Furthermore, two refined versions [3] were introduced for correcting veiling glare [4]. The first was a black correction by subtracting the amount of black level from the measured tristimulus values (XYZ) and the other was the introduction of a new J (lightness).

However all the model development were based on the visual data obtained from individual coloured patches displayed on small mobile displays. In this paper, complex images were used to test the four different versions of CIECAM02: original CIECAM02, refined CIECAM02, refined CIECAM02 plus black correction and refined CIECAM02 with J correction.

In order to test the four modified CIECAM02 versions [3], complex images were chosen. Each of the four CIECAM02 versions was used to predict images' appearance under dim, average and bright viewing conditions from those under dark viewing condition via a colour management work flow. Finally, a psychophysical experiment was conducted to verify the models' performance.

Experimental Setup

Colour Appearance Models

Park et al [1] in 2007 proposed a refined CIECAM02 to improve the performance for predicting colour attributes under various surround conditions. They [3] then introduced two different corrections to the refined CIECAM02 to reduce the veiling glare caused under bright surround conditions. The first correction is a black correction which is a typical method of correcting the veiling glare by subtracting the amount of black level from the measured tristimulus values (XYZ). The other correction is the correction of J (lightness). The resulting lightness is denoted by *J'* and is given by equation (1):

$$J' = 100\left(J_{CIECAM02} - J_b \times \frac{J_b}{J_{CIECAM02}}\right)/J_W \quad (1)$$

$$J_W = 100 - J_b \times \frac{J_b}{100} \quad (2)$$

where, J_b, and $J_{CIECAM02}$ are either the original or refined CIECAM02 lightness [1] for the black level, and the stimulus, respectively. The J_b represents the effect of veiling glare in lightness. The larger the veiling glare, the larger J_b and the larger the glare term will be. Four of the six models in reference [3] are tested here. Table 1 shows the input parameters and data of each CIECAM02 version. Other than the black correction, the original data was used as the input data. The surround luminance values are 0, 5, 1000 and 5500 cd/m^2 for dark, dim, average and bright surround conditions, prospectively.

Table 1: The parameters used from different versions of CIECAM02

CAMs	Input data (XYZ)	Surround parameters	Background Luminance factor
CIECAM02	Original data	Original c F N_c	Y_b = 20
Refined CIECAM02	Original data	Refined c F N_c	Y_b = 20
Refined CIECAM02 + Black correction	Black correction data	Refined c F N_c	Y_b = 20
Refined CIECAM02 + J' correction	Original data	Refined c F N_c	Y_b = 20

(a) (b) (c) (d)

Figure 1: *Four original images used for the psychophysical experiment. They are (a) Barn, (b) Fruits, (c) Ladies and (d) MCC (Macbeth Colour Checker*

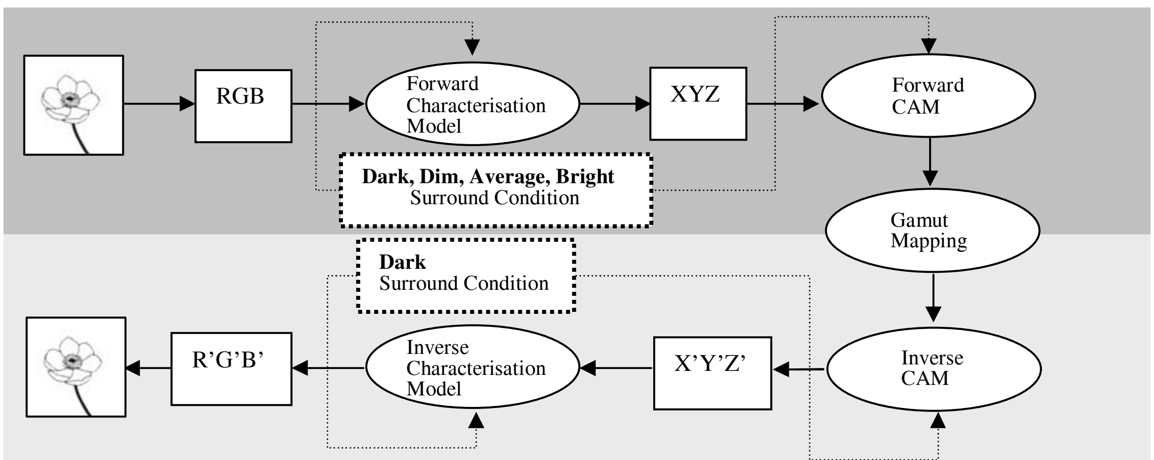


Figure 2: *The colour management workflow*

Image reproduction (Predicting image appearance under various surrounds from dark surround)

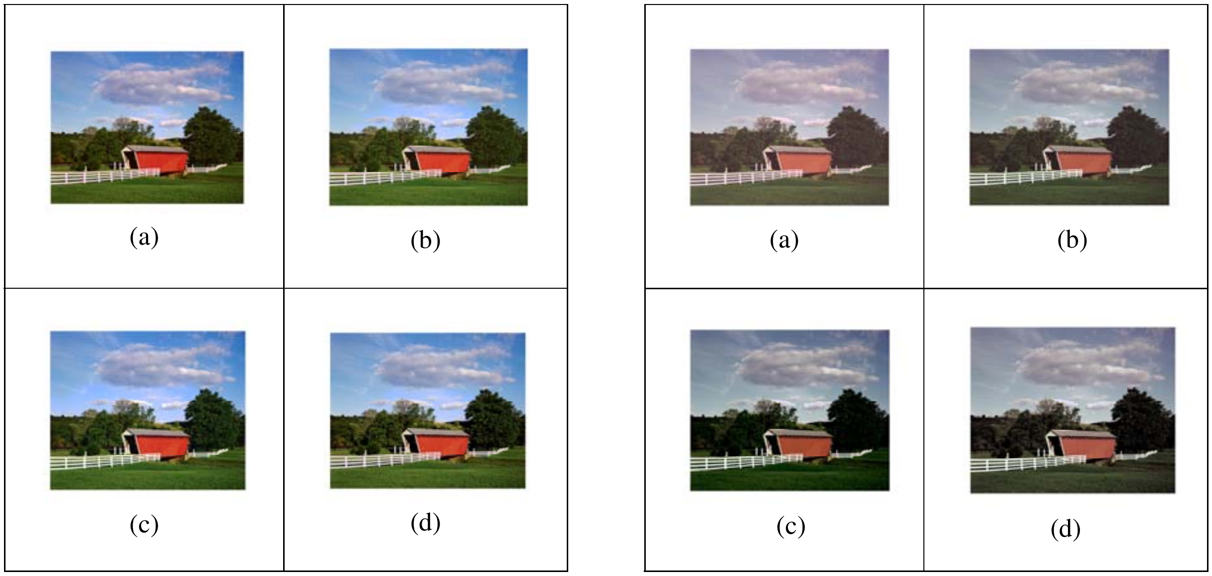
Figure 1 show the four images used in the experiment. The four images under dark surround condition viewed on a 2-inch mobile display were taken as standard. Using the JMh (lightness, colourfulness and hue) space from the modified CIECAM02 versions as the connection space, the standard images viewed under dark surround condition were predicted under dim, average and bright surround conditions. Note that two identical 2-inch mobile displays were used, one for displaying the original images and the other for displaying those predicted. Figure 2 shows the colour management workflow used to predict the original image when viewed under dim, average and bright surround conditions.

The workflow contains different components including a display characterisation model, colour appearance model and the SGCK gamut mapping algorithm as suggested to study by CIE [5].

Figure 3 shows the processed images which are the predictions of appearances of the 'barn' image under the average (1) and bright (2) surround conditions. In Figure 3, the plots of (a) (b), (c) and (d) are the predicted images using CIECAM02, refined CIECAM02, refined CIECAM02 plus black correction, and refined CIECAM02 with J' formula, respectively. It can be seen that the four images in Figure 3(1) appear quite similar to each other. However, the images that predict the appearance under the bright surround condition in Figure 3(2) are largely different from those of the other conditions. The images using the CIECAM02 (a) and refined CIECAM02 (b) in Figure 3(2) seem to look washed away. (However, refined CIECAM02 plus the black correction (c) has a higher lightness contrast but has colourfulness contrast predicted higher. The refined CIECAM02 J' formula (d) shows similar colourfulness with the refined CIECAM02 (b) and similar lightness contrast with the black correction (c). Same trends were found for the other three images.

Psychophysical experiment

A psychophysical experiment was conducted as illustrated in Figure 4. The original image displayed under dim, average or bright surround conditions controlled by a lighting panel was compared with the predicted images under dark surround. Two identical 2" Samsung mobile displays were used to display the images in each surround condition. In Figure 4, the light source of the left viewing cabinet was used to illuminate the original image and the source of the right cabinet was switched off to view the predicted image under the dark surround condition.



(1) ***(2)***

***Figure 3:** The prediction of the barn image calculated from (a) CIECAM02, (b) Refined CIECAM02, (c) Black Correction and (d) J' Correction under (1) average and (2) bright surround condition.*

The experiment had 48 pairs of images (4 images x 4 models x 3 surround conditions). Each was judged in terms of degree of match by ten normal colour vision observers, 5 females and 5 males. They sat in the middle of the two viewing booths and observing each image one field at a time. Each observer had to estimate the pair according to the extent of colour match using a 5 point categorical judgement method. Point 5 represents a perfect match, 1 was a bad match and 3 was an acceptable match. All neighbouring points have the same visual difference in the scale. This technique is known as short-term successive memory categorical judgement.

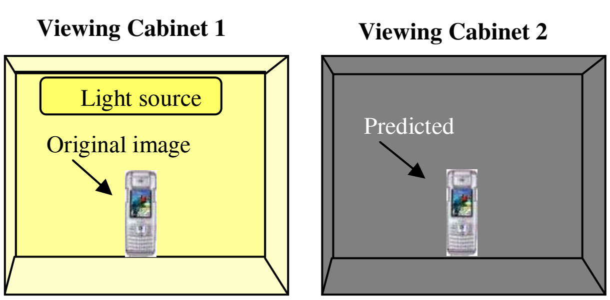


***Figure 4:** Experiment setup*

Results and Discussions

Each observer's score was averaged to represent the mean visual results. The Standard Deviation (STD) was also calculated to represent the spread of data. The results are summarised in Figures 5 and 6.

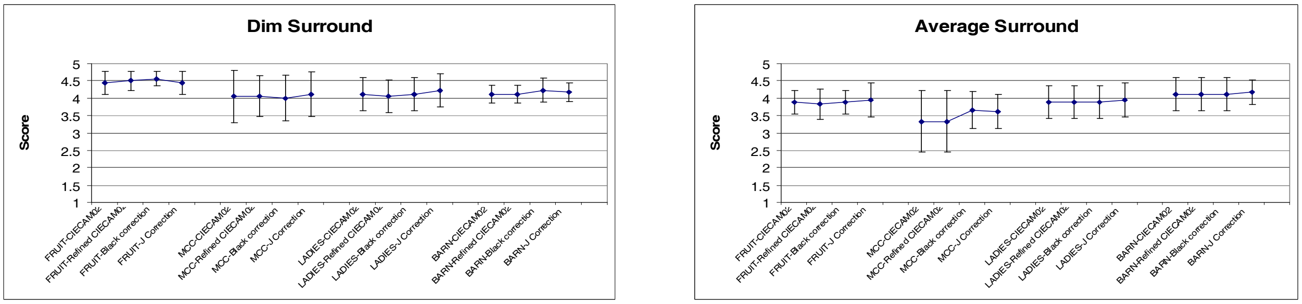
Dark Surround Condition

The CIECAM02 and the characterisation model used are mathematically reversible. In theory, the images to predict the dark surround condition should appear the same as the original image; because the same viewing parameters were used in the workflow in Figure 2 When the images were displayed simultaneously in the same viewing field to compare the observers may find difference between two images. However, this may not be the case when they are shown consecutively in the current memory matching. This is proven in the current results, i.e. average scores between 4 to 4.5. This implies that observers are unwilling to give the extreme answer (5).

Dim Surround & Average Surround Condition

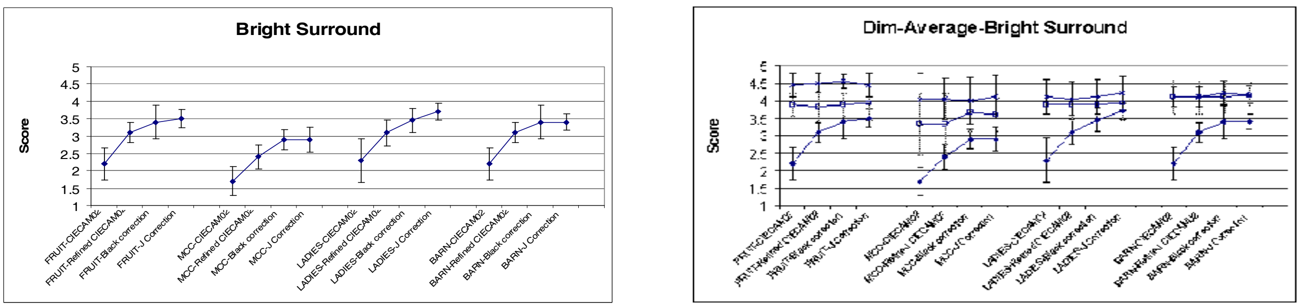
Figure 5(a) shows the visual matching score of each model prediction for each image under the dim surround condition. There were 16 points in the figure corresponding to four images for each of the four CIECAM02 versions. It can be seen that the data are located in the 4 to 4.5 region, which indicate the results from all models performed similarly and the results are similar to those under the dark surround condition. It can also be seen from Figure 5(a) that the MCC images have larger STD values than those from the other images. This means that the results for the MCC image have larger scatter of scores compared with other images. This implies that for images including some patches, the CIECAM02 itself is sufficiently accurate to predict the colour appearance.

Figure 5(b) shows the resulting scores for predicting the average surround condition. It shows similar trends to those for dim surround (see Figure 5(a)), but the scores are slightly lower ranging from 3.8 to 4.3. It is shown here again, as the dim surround condition results, that there is hardly any difference amongst the different versions of CIECAM02.



(a) (b)

Figure 5: Average score of match and STD under dim (a) and average (b) surround conditions for four images and four versions of *CIECAM02*



(a) (b)

***Figure 6**: Average score of match and STD under bright (a) and all three (b) surround conditions for four images and four versions of CIECAM02*

Bright Surround Condition

Different from the other surround conditions, the bright surround showed a large difference amongst the CIECAM02 versions tested. Figure 6(a) also shows that all four images have the same trend. The highest score for each image comes from the refined CIECAM02 plus J' correction and then followed from the refined CIECAM02 with black correction. All images except the MCC image have an average score above 3 for the refined CIECAM02 related models. (Note that Score 3 represents an acceptable match.) Therefore, the results show that the images are predicted fairly well except for the original CIECAM02. However, even for the MCC image, the refined CIECAM02 plus black correction and J' correction showed higher scores. Unlike the other complex images, the MCC image including 24 colour patches implies that an image with simpler content will be easy to discern colour difference.

Figure 6(b) summarises all the results for easy comparison for all images under different surround conditions. The cross, circle and diamond represent the data obtained under dim, average and bright surround conditions respectively. As discussed before, the results for the dim and average surrounds are independent from the images and CIECAM02 versions. However the colour appearance under the bright surround condition is predicted in an acceptable level by the refined CIECAM02 plus black correction and plus J' formula.

Conclusion

The four versions of the CIECAM02, the original CIECAM02 [2], the refined CIECAM02 plus black correction and the refined CIECAM02 J correction [3], were tested using complex images using experimental results. Their predictions were similar to each other for dim and average surround conditions. However the four models showed large differences when predicting an image under the bright surround condition. The refined CIECAM02 plus both black and plus J corrections performed well for predicting the image appearance under the bright surround condition, which included large veiling glare on display. However the refined CIECAM02 with J' correction performed the best amongst all four CIECAM02 versions. Hence it is the most effective for discounting the veiling glare. The model should be further verified for the other size of displays.

References

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Author Biography

YungKyung Park received her BS and Masters in physics from the Ewha Womans University (Korea) and her Master in Digital Imaging Science from the University of Derby (UK). Since then she has been a PhD student in Leeds University (UK) and has recently become a researcher at the Ewha Color Design Institute, at the Ewha Womans University. Her PhD work has been focused on colour appearance modelling for mobile displays.