Methods for Measuring Viewing Parameters in CIECAM02

Chenyang Fu and M. Ronnier Luo, Department of Colour and Polymer Chemistry, University of Leeds, United Kingdom

Abstract

This is the continuation of a previous study[1] which investigated the possibility of applying a characterised digital camera to measure colours and quantify viewing parameters used in colour appearance models such as CIECAM02. The earlier results showed that a characterised digital camera can measure CRT colours with reasonable accuracy in terms of tristimulus values under average, dim and dark surround conditions. The present study investigates the effects of viewing parameters on image appearance under various surrounding conditions. Six methods were developed to determine viewing parameters such as the luminance level, the luminance factor of background and the surround conditions (two methods were described in an earlier paper[1]). The standard method was based on that recommended by CIECAM02[5] and measurements were conducted using a Minolta CS1000 tele-spectroradiometer (TSR). The performance of the other five methods were evaluated through comparison with the standard data set. Twenty four colours included in a single image were used as test colours. The results show that using an image's mean luminance value as the luminance factor of the background (Y_b) led to the best agreement with the standard method.

Introduction

It is well known that background and surround have certain impact on the appearance of an image. Many previous studies have been published on this issue. This study aims to investigate the viewing parameters used in colour appearance models, which is a crucial part of the colour management technology used for faithfully reproducing colour images across different media.

The structure of a colour appearance model includes three parts: a chromatic adaptation transform used to predict corresponding colours from one set of illumination conditions to another, dynamic response functions and a colour space.[2,3] A colour appearance model has the ability to describe the appearance of colours and to ensure a colour appearance match under a given set of conditions. CIECAM02[4, 5] was recently recommended by the CIE to industries as an international standard colour appearance model, with the following definitions:

- *Adapting field* — everything in the visual field outside of the stimulus.
- *Background* — a roughly 10 degree region immediately surrounding to the stimulus.
- *Surround* — the field outside the background[6].

A property of *surround,* the *surround ratio (S_R),* is found thus:

$$S_R = {L_{SW}}/{L_{DW}} \quad (1)$$

where L_{SW} is the luminance of surround white and L_{DW} is the luminance of media white (which can be the device white point). Luminance units are cd/m^2.

There are three categories of surround ratios[5], i.e. S_R 0.2, $S_R<0.2$ and $S_R= 0$, corresponding to three types of surround, *average*, *dim* and *dark*, respectively. After the value of S_R is obtained, the viewing conditions are defined and hence viewing parameters such as *F* (incomplete adaptation factor), *c* (lightness surround induction factor) and N_c (chromatic surround induction factor) can be determined. Values for these parameters in CIECAM02 are summarised in Table 1.

Table 1: CIECAM02 Viewing Parameters and Surround Ratio S_R

	c	N_c	F	S_R
Average surround	0.69	1.0	1.0	0.2
Dim surround	0.59	0.9	0.9	< 0.2
Dark surround	0.525	0.8	0.8	0

Note that the definition of *surround* in CIECAM02 is not the same as that in ISO 3664:2000[7]. CIECAM02 adopts the terms "*surround*" and "*background*" that were used in ISO 3664 in 1991 but which are now opposite to ISO 3664:2000. The definition of *surround* in ISO 3664:2000 is "the area adjacent to the border of an image which, upon viewing the image, may affect the local state of adaptation of the eye." For example, in the case of a reflection copy, the border is usually taken to mean the unprinted region immediately adjacent to the image and is called the *surround* of the printed image in ISO 3664:2000, but it is called background in CIECAM02. In this study, the terms "*surround*" and "*background*" have both been adopted using the definitions in CIECAM02. It should be noted that this confused situation might cause difficulties in applying colour appearance models.

Our previous study[1] showed that determining the colour and luminance levels of background and surround could be a difficult task for complex images presented under realistic viewing environments when using a conventional TSR. Therefore a characterised digital camera was used with both the earlier and present studies to collect colour data for a given viewing environment.

It should be noted that the luminance factor of background (Y_b) depends on the image contents. Green[8] found that although this effect is not significant, there is still scope for further investigation.

The aim of this study is to investigate the effects of various viewing parameters on the colour appearance of colour patches and pictorial images on a CRT under different surround conditions. To investigate how much the viewing parameters contribute to the perceived match under different viewing conditions, existing colour appearance model were evaluated to find ways of improving them.

Viewing parameters in CAMs include illuminant, luminance level, luminance of adaptation field (L_A), luminance factor of background (Y_b) and surround. This study focuses on methods for estimating L_A and Y_b. Six methods were developed to obtain these viewing parameters and CIECAM02 was used to compare the effect. Viewing parameters were obtained using a Minolta CS1000 TSR, a camera characterisation model, a weighting method for viewing field (Y_b) and a low-pass image method.

Experimental Conditions

The experiment was conducted in a laboratory in which a CIE Illuminant D65 simulator with dimmer control was used to set up the desired viewing environment. In order to minimise flare reflected off the CRT display, a black cloth covered objects in front of the monitor (behind the TSR/camera). The flare on the CRT display was measured was and found to be around 0.15 cd/m^2 under average viewing conditions. This value was less than 0.5% of the CRT maximum luminance. The viewing distance was 70 cm from the CRT display according to the office working environment. A camera-characterisation model was developed with which images were taken to determine the viewing parameters under different surround conditions.

Experimental Set-up

A 24-bit graphic card, an HP P1100 CRT monitor and a 6.1 effective mega pixel Nikon D1X digital camera were used. The CRT monitor was adjusted to a CCT of 6500K. The luminance of the CRT's white point was set to around 67 cd/m^2 which was obtained from the results of testing monitor's channel and spatial independence[9].

The CRT monitor and digital camera were carefully characterised as described in the earlier studies.[1] Note that the camera characterisation model developed using polynomial regression[10] was derived using digital colour patches displayed on the CRT. These colour patches were all uniform colours generated from the captured colour chart in a viewing cabinet illuminated by a D65 simulator. Adobe Photoshop was used to obtain the average RGB values for each colour patch. Using these average RGB values, digital uniform colour patches were created. A digital colour chart with 240 colour patches was used as training data for camera characterisation[1]. A digital 24-colour chart with 24 colour patches generated from a captured GretagMacbeth ColorChecker 24 was used as the test colours in this study.

A viewing environment was created with a reference white located in the adapting field. This was regarded in this viewing environment as the surround white. The CRT peak white was treated as the device white. The entire viewing environment is illustrated in Figure 1.

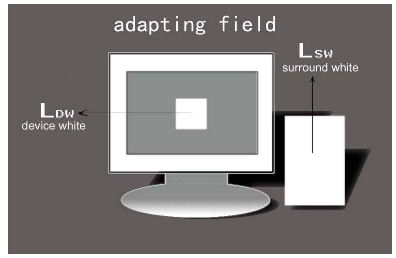

Figure 1. The experimental set up

Methods for Quantifying Viewing Parameters

Each of the colour patches in the digital 24-colour chart was presented in the centre of the CRT monitor (as shown in Fig 1) and measured by using the TSR. The device white (CRT peak white) L_{DW}, and surround white (the reference white in adapting field) L_{SW} were measured using the TSR. The surround ratio S_R was calculated using Eq (1). Measured L_{DW}, L_{SW} and calculated S_R in the real experiment are summarised in Table 2. For each surround condition, three sets of tristimulus values for each colour patches $X_i Y_i Z_i$ ($i = 1$ to 24) were measured using the TSR and the luminance values for the adapting field (L_A) and luminance factor of background (Y_b) were estimated in six different ways.

Table 2: L_{SW}, L_{DW} and Surround Ratio S_R Used in the Experiment under Three Surround Conditions

	L_{DW}	L_{SW}	S_R
Average	68.07	23.3	0.342
Dim	67.85	4.34	0.064
Dark	66.65	0.10	0.001

Note that it has been suggested[4] that "for a self-luminous display, the device white point refers to the colour generated by setting each of the self-luminous primaries to the maximum possible value." Therefore, the device white used in this study was set with a square peak white patch (digital counts $R=G=B=255$) displayed in the centre of the HP P1100 monitor with a black colour (digital counts $R=G=B=0$) as background.

Method 1: In CIECAM02[5], it is recommended that the chromaticity and luminance value of the monitor peak white should be measured using a TSR. L_A (the luminance value of adapting field) was calculated by Eq. (2).

$$L_{A1} = L_{DW} \times Y_{b1}/100 \quad when \quad Y_{b1} = L_{background}/L_{DW} \times 100 \qquad (2)$$

where L_{DW} is the luminance of device white (the peak white of CRT display in this study). Luminance units are cd/m^2 and Y_b is the luminance factor of background.

This method was derived from the recommendation of CIECAM02[5] and measurement was conducted using the TSR. The advantage of this instrument is that the measurement results correspond to the actual viewing conditions. Therefore, this data set (L_{A1} and Y_{b1}) was used as the standard for comparison with the results obtained from the other 5 methods.

Method 2: The mean value of the absolute Y tristimulus value (luminance channel) for the 24 digital colour patches was calculated by:

$$Y_{b2} = \sum Y_i / 24 \quad (3)$$

where Y_i, is the absolute Y tristimulus value for each colour patch. L_{A2} was then determined using Eq (4).

$$L_{Ai} = Y_{bi} \times L_{DW} / 100 \quad (4)$$

where L_{Ai} is the luminance of adaptation field of each method i, L_{DW} is the device white. Luminance values are in units of cd/m^2.

Method 3: This method uses a camera characterisation model to predict tristimulus values of test colour patches, to predict device white and surround white, and finally to determine the viewing parameters for CIECAM02. This method was described in the earlier study.[1]

An illustration of this viewing environment is shown in Figure 1 which displays a peak white patch which was first captured using the digital camera under three surround conditions, set up by adjusting the ambient illumination. A camera-characterisation model was developed using a polynomial regression method[10]. Prediction worked well under three surround conditions. The model was used to obtain the predicted device white (X_{DWp} Y_{DWp} Z_{DWp}) and the predicted surround white (X_{SWp} Y_{SWp} Z_{SWp}), from which L_{SWp}, L_{DWp} were derived. Next, the surround ratio S_{Rp} was determined using Eq. (1).

Accordingly, a digital 24-colour chart (see Figure 2) was captured and the camera characterisation model used to predict the tristimulus values for each of the 24 colour patches X_{ip} Y_{ip} Z_{ip} ($i = 1$ to 24). L_{A3} was determined using Eq. (4) with L_{DWp}, and then Y_{b3} was obtained from Eq. (2).

Figure 2. The experimental set up displaying the digital 24-colour chart

Method 4: The same procedure as for Method 3 was used to capture the image of 24-colour chart which was treated as one complex stimulus image. Y_{b4} was derived from the mean value of the luminance channel of the captured image (the 24-colour chart itself) using image processing algorithms at each pixel location. L_{A4} was then determined using Eq. (4).

Method 5: The method of using a weighting function to determine Y_b, which was developed by Green[7], was used in this phase. Weights for the captured image and for the background luminance values were calculated by "integrating the weighting function with the relative angular substance occupied by the fields."[8] A Gaussian function was employed as the weighting function, i.e. greater weight was given to the middle of the image and gradually less towards its edges. Table 3 shows the weights for the image and for the background under a CRT viewing environment (shown in Figure 2). Y_{b5} was calculated by "multiplying each element in the column of weights by the corresponding total luminance for the field and summing these individual contributions to the total background luminance."[8] L_{A5} was determined by Eq. (4).

Table 3: Weightings for Image and Background in Calculating Background Factor Y_{b5} Under Dark Surround Condition

Dark	Flare	Mean Y	Distance	Weight	Y_{b5}
Background	0	1.76	0.48-1.0	0.33	19.66
Image	0.15	27.98	0.0-0.48	0.67	

Methods 6(1) and 6(2): Recently, imaging technologists and scientists realised the importance of the spatial components in an image[11, 12, 13]. It is known that sensitivity of the visual system is different at different spatial scales. Therefore, it is possible that using image processing algorithms to reduce the undetectable details in an image might not influence observers' perception of the image. This step might not necessarily result in lower image quality. Many researchers[10, 11, 12] developed the contrast-sensitivity function in the colour-difference evaluation of complex images and lately it has been incorporated into colour appearance models. For example, in iCAM[11, 12] which was developed by M.D. Fairchild and G.M. Johnson, the luminance of the image (low-pass filtered) and the surround was used to modulate the exponents.

In this study, low-pass filtered images were used to investigate the influence of different parts of an adapting field on viewing parameters and the degree of contribution of different parts to the perceived image match under various viewing conditions. The luminance values for the adapting field (L_{A61}, L_{A62}) were obtained from low-pass images of the luminance channel. The two low-pass filtered images used here included the captured 24-colour chart itself (Figure 3b) and the chart plus the surround condition (Figure 3a) respectively. The values of Y_{b61} and Y_{b62} were determined using Eq. (2) with L_{A61}, L_{A62} and L_{DW} as the variables.

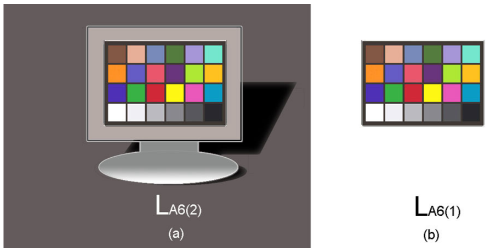

Figure 3. Different parts of captured images in Method 6 for calculating Y_{mean}

Evaluation of Different Methods

The six methods were evaluated by comparing the measured data (Method 1) with data calculated from each method. Note that in these methods, the surround ratio was first obtained using Eq. (1) with measurement results for L_{DW} and L_{SW}. Next, this ratio was used to determine the viewing parameters c, N_c and F according to Table 1. To simplify the evaluation, except for Method 3[1], the TSR was used to measure the XYZ tristimulus values for each colour patch as well as the luminance values for the device white (L_{DW}) and surround white (L_{SW}). Only the viewing parameters were determined using each of the methods. Note that the fundamental image information was first derived from the camera characterisation model in Methods 4, 5 and 6.

The tristimulus values, XYZ, were transformed to CIECAM02 J, a_M, b_M colour space (based on J, M and h polar space) with corresponding viewing parameters. In order to take into account viewing conditions, the J, a_M, b_M colour space was used here rather than CIELAB. Colour spaces such as JCh and QMh which are approximately uniform colour spaces, are used in CAMs. They are similar in that they all provide redness-greenness and yellowness-blueness scales to form rectangular coordinates (like CIELAB). Note that in the study[14] to evaluate colour difference using colour appearance models, the CIECAM02 "J, a_M, b_M colour space performed slightly better than J, a_c, b_c"[14]. Therefore, J, a_M, b_M were used in this study. The colour difference of each colour patch between the data measured using TSR in Method 1 and those obtained from other methods based on camera model (excluding Method 2) was calculated using Eq. (5).

$$\Delta E_{Jab} = \sqrt{\Delta J^2 + \Delta a_M{}^2 + \Delta b_M{}^2} \qquad (5)$$

where $a_M = M\cos(h)$, $b_M = M\sin(h)$ and J, M, h represent CIECAM02 attributes lightness, colourfulness and hue angle.

Results and Discussion

To evaluate these methods, a digital colour chart was presented on the same CRT display. The image of this viewing environment (as shown in Figure 1) was captured using the same digital camera under three viewing conditions (i.e. average, dim and dark).

The viewing parameters were obtained using various methods, including predicted data using a camera-characterisation model, calculated weights for image and background and the data from a low-pass version of the image. The TSR was used to measure the XYZ values for each colour patch and the luminance values for device white (L_{DW}) and surround white (L_{SW}), excluding Method 3 in which the predicted data were used for all viewing parameters. It should be noted that in Method 6, the viewing parameter L_A was derived from a low-pass image of the luminance channel. The low-pass filtered images were chosen from different parts of a captured image (shown in Figure 3 as L_{A61}, a digital colour chart itself and L_{A62}, the chart with viewing environment together, respectively). The data achieved from Methods 2 to 5 were compared with those derived from measurement data (L_W) from the TSR (Method 1) in CIECAM02. Table 4 shows the viewing parameters, L_A, Y_b, L_{SW}, L_{DW} and surround ratio S_R, used in CIECAM02 obtained from the six methods under average surround conditions.

Table 5 and 6 show the comparison results between Method 1 and the other methods in terms of colour difference in CIECAM02 J, a_M, b_M colour space under average and dark surround conditions. The viewing parameters used here to calculate CIECAM02 J, a_M, b_M were the obtained from the five methods (Methods 2 to 5). Note that for the Method 6, when the L_A was obtained from low-pass images of a different part of the captured image (Figure 3), the results were quite different than when under dark and under average surround conditions.

Table 4: Viewing Parameters used in CIECAM02 Under Average Surround Conditions

Average	Name	L_{DW}	L_{SW}	S_R	L_A	Y_b
Method1	TSR	68.07	23.3	34.23	13.61	19.7
Method2	TSR	68.07	23.3	34.23	13.61	21.67
Method3	Camera	69.19	24.6	35.33	13.84	18.6
Method4	Picture	68.07	23.3	34.23	14.03	20.61
Method5	Weights	68.07	23.3	34.23	19.04	27.97
Method6(1)	Low-pass(1)	68.07	23.3	34.23	20.61	30.28
Method6(2)	Low-pass(2)	68.07	23.3	34.23	16.59	24.37

Table 5: Mean and Maximum ΔE_{Jab} Values in CIECAM02 J a_M b_M Colour Space Between the Data Obtained from Method 1 and Those Obtained from Other Methods Under Average Surround Conditions

Average	Name	L_{DW}	L_{SW}	S_R	L_A	Y_b
Method1	TSR	68.07	23.3	34.23	13.61	19.7
Method2	TSR	68.07	23.3	34.23	13.61	21.67
Method3	Camera	69.19	24.6	35.33	13.84	18.6
Method4	Picture	68.07	23.3	34.23	14.03	20.61
Method5	Weights	68.07	23.3	34.23	19.04	27.97
Method6(1)	Low-pass(1)	68.07	23.3	34.23	20.61	30.28
Method6(2)	Low-pass(2)	68.07	23.3	34.23	16.59	24.37

Table 6: Mean and Maximum ΔE_{Jab} Values in CIECAM02 J a_M b_M Colour Space Between the Data Obtained from Method 1 and Those Obtained Using Other Methods Under Dark Surround Conditions

ΔE_{Jab}	mean	max	min	Std	Y_{b1}	Y_{bn}	L_{A1}	L_{An}
M1 vs M2	0.17	0.20	0.02	0.04	19.7	20.96	13.33	13.97
M1 vs M3	1.94	3.30	1.15	0.58	19.7	18.6	13.33	13.06
M1 vs M4	0.19	0.23	0.02	0.05	19.7	18.91	13.33	12.60
M1 vs M5	0.08	0.10	0.01	0.02	19.7	19.52	13.33	13.01
M1 vs M6(1)	1.34	1.62	0.15	0.33	19.7	28.37	13.33	18.91
M1 vs M6(2)	2.90	3.86	0.33	0.87	19.7	6.58	13.33	4.39

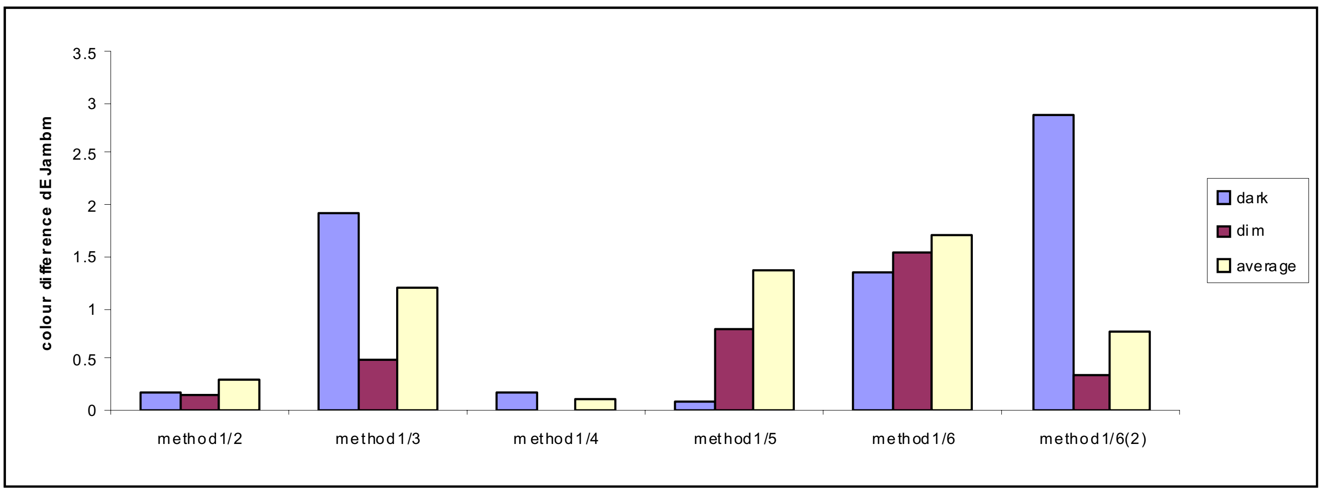

Figure 4. Mean colour difference ΔE_{Jab} values in CIECAM02 J a_M b_M colour space of comparisons between Method1 and others respectively (under three surround conditions).

Comparisons between Method 1 and the other methods were made for three different surround conditions (i.e. average, dim and dark). As shown in Figure 4, Method 4 (in which the captured image of 24-colour chart itself was treated as a complex stimulus from which the mean value of the luminance channel Y_b was derived) was found to perform well with the smallest colour difference in CIECAM *J*, a_M, b_M colour space. Method 5 also performed well under dark conditions, but relatively worse than those under dim conditions, and even worse for average conditions. This might be due to the fact that Method 5 is dependent on the luminance level for the surround area and image contents. More images and psychophysical experiments are required to evaluate these methods.

It should be noted that all the results were obtained from one single image – the digital 24-colour chart. The method (Method 4), which has the best agreement with the standard method (Method 1), uses the mean value of the luminance channel for the captured image as the luminance factor of background (Y_b) which is dependent on image contents. This method performs well with colour patches under specific viewing conditions but there is still room for investigation of complex images under complex viewing conditions and the psychophysical experiment is ongoing.

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