Human Visual Assessment for Colour Characterisation of CRT Displays

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ABSTRACT

This paper describes a visual method for characterising CRT displays. The monitor characterisation model is based on the well known GOG model. The current method provides the data required to operate the model. The visual method is based upon the concept of psychological hues including red and green, and yellow and blue, two pairs of complementary colours. Two experiments were conducted: one to understand the variations between the visual results, and another to evaluate the accuracy of the method developed using a number of displays. Special software was developed to perform magnitude production tasks in both experiments. By the end, the method developed did supply reasonably accurate data. The typical difference between the models based on colour measurements and visual results was about 4.5 ΔE_{ab}*, which is much more accurate comparing with the typical observer variation of 6.0 ΔE_{ab}*.

1. INTRODUCTION

Berns *et al* [1,2] developed a CRT characterisation model, known as GOG model for effectively use the CRT displays in colour management and vision research. The model gave the good performance and was recommended by CIE for correlating between RGB digital signal and CIE colorimetric data for computer controlled CRT displays. It is a two-stage model. In Stage 1, some neutral colours measured in terms of CIE tristimulus values are required to estimate gamma and offset of each channel for converting the raw RGB digital signals to CRT luminance. In Stage 2, colorimetric data of each channel of peak output have to be inputted to transform CRT RGB luminance to CIE XYZ tristimulus values using additive colour mixtures. All the colorimetric data can be obtained by directly measuring colours using colorimeters or tele-spectroradiometers (TSR)[3]. However, although the instrument can provide the most accurate and consistent results, it is not possible for ordinary users to apply these expensive equipment and to set them up correctly. They could also give poor agreement between instruments. Therefore, it is desirable to apply visual method rather than instrument measurements for certain applications in which absolute accuracy is not critical.

The aim of this study is to develop a method to supply the colorimetric data to be used in Stage 2 of the GOG model via an exercise of visual assessments. The underline theory of the method is based on the concept of the psychological hues as defined by the NCS system.[4] There are four psychological hues, or unitary hues: red and green, and yellow and blue, which forms two pairs of complimentary hues located in x and y axes. Two psychological hues in each axis cannot be seen simultaneously. For example, an orange could be described as 60% of red and 40% of yellow with zero contents of green and blue. This method has been widely used in the authors' experiments for scaling colour appearance.[5] It was found that the psychological hues do not vary much across a large number of observers. In a way, this is similar to those so called 'memory colours' such as banana, apple, skin, green grass, blue sky, for which their appearance are well memorised.

A computer software was developed for observers to match the four pure red, yellow, green, blue and a white in their memory. The results were recorded and optimised to correspond to the peak channel output. Finally, the RGB data were transformed to CIE colorimetric data to be inputted into Stage 2 of the GOG model.

2. EXPERIMENTAL

Psychophysical experimental is of primary importance in this study because the data used for building the CRT characterisation model were based on the visual data. Five colours including four psychological hues and a white were adjusted by 10 observers who all passed the Ishihara vision test.

Experimental 1 was carried out on a properly calibrated monitor having characteristics similar to those of an ideal sRGB monitor[6]. In practice, all CRTs suppose to be adjusted as close to sRGB monitor as possible. The experimental results here were used to investigate the variation of matched colours between different observers. Experimental 2 was carried out using four different displays, each was set at three white points with different colour temperature. [7] Based on the experimental results, the data used in the GOG characterisation model were optimised.

2.1 Experimental 1

An Hewlett-Packard P1100 CRT was adjusted via a tele-spectroradiometer so that its character was similar to sRGB such as colour temperature of the white point, luminance level, gamma factor, etc. By using the self-implemented computer interface, an 8 x 8 cm^2 colour patch was displayed in the middle of the monitor against a black background to cover the whole screen. Each observer adjusted the colour patch using three CIELAB attributes: lightness (L*), chroma (C*) and hue (h). Observers were asked to generate 5 colours including a pure red, a pure yellow, a pure green, a pure blue and a neutral white based on their memory colour using a CRT display. Each observer's visual results were measured by a Minolta CS1000 TSR in terms of tristimulus values. The experimental technique used here is called magnitude production, i.e. observers generated a colour according to their memory colour.

The averaged L*, C* and h values from all observers for each test colour were calculated to represent panel results and are listed in Table 1. The averaged and maximum ΔE^*_{ab} values between each individual observer and the panel results for each colour are also given in Table 1. The mean value indicates the typical variation for each colour, i.e. around 6.0 ΔE^*_{ab} units.

Table 1: L* C* and h of 5 colours and observer variation for each colour

Experiment 1	*L**	*C**	*h*	*Mean* ΔE^*_{ab}	*Maximum* ΔE^*_{ab}
Red	37.1	57.2	29.30	5.8	7.3
Yellow	82.8	83.9	87.60	6.7	9.4
Green	39.2	38.7	147.7	6.9	9.0
Blue	43.3	39.8	264.0	6.8	8.9
White	89.5	4.10	277.4	3.7	5.4

2.2 Experimental 2

In this experiment, four different CRT monitors, two Hewlett-Packard P1100, a Sony Trinitron CRT and a Viglen CRT (designated as HP1, HP2, Sony and Viglen, respectively). Each monitor was set to three different white points corresponding to chromaticity coordinates close to D50, D65 and D93 for producing 5 colours. In order to control colour easily by non-expert users, the software used in Experiment 1 was modified to be able to adjust the colour on a CRT by using only one attribute rather than three. For generating four psychological primaries, the colour on screen can only be adjusted following the CIELAB hue direction, while L* and C* were fixed as those values given in Experiment 1 as shown in Table 1). For neutral white, a series of white colours were pre-calculated corresponding to different correlated colour temperature.[7] Observers were asked to select one to be a 'neutral white'.

The differences of the visual results for the 5 colours between the monitors with the same white point, and between the monitors with different white points were investigated separately. The overall observer variation in this experiment for each monitor with different white points was about 4.5 ΔE^*_{ab} units. Figures 1a and 1b show the visual results of the four primary colours and neutral white plotted in a*b* diagram, respectively. It can be seen that for each colour, the hue angle of visual results given by different CRT displays are quite close even with monitors having different white points. The mean colour difference for the four primary colours was about 4 ΔE^*_{ab} units. This implies that the observers can generate the four primary colours independent of monitor settings. Also, all observers' psychological primaries are quite similar to each other.

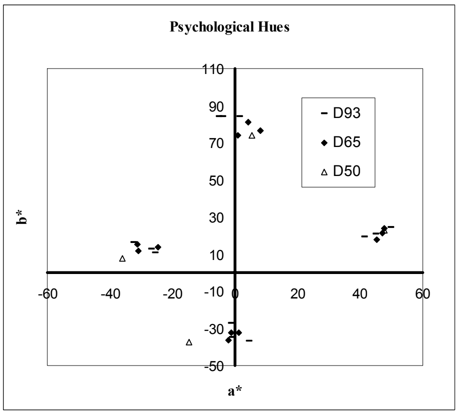

Figure1: Experimental results for primary colours

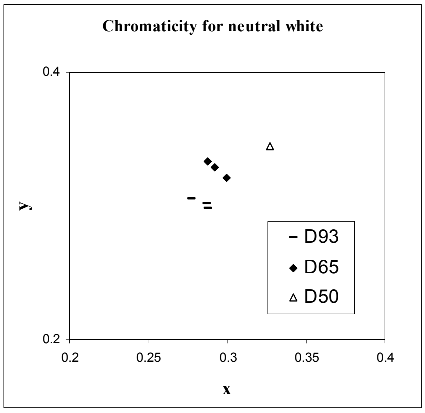

Figure 2: Experimental results for neutral white

For the neutral white colour, experimental results showed that there were only little variations between monitors with the same white point. However, large variations occurs when monitor white point was changed as shown in Figure 2. This is undesired to obtain the correct white point data for the monitor characterisation. However, it was found that for various white point settings, the observers' visual results agreed well with the instrument measurements. Finally, it was decided that to use the chromaticity values of the CIE D50, D65 and D93 illuminants to define the neutral white. This information need to be supplied by operators because only they know which white point on the display was selected**.**

In this experiment, the L*, C* and h values of the four colours were achieved via a software for observers to generate these colours. These data together with a particular monitor white point will be used to develop the matrix coefficients in the GOG model.

3. CRT CHARACTERISATIONS

For each CRT display with a particular white point setting, after the experiment, the RGB values and their corresponding colorimetric values are available for each of the five colours. The colorimetric values are those given in Table 1. The data were used for training the GOG characterisation model, which is given in equation (1). Similar equations are for the blue and green channels Equation (1) includes 15 coefficients, for which 6 of them are the gamma and offset parameters, and 9 of them are the matrix coefficients related the tristimulus values corresponding to peak red, green and blue channels. For the gamma and offset parameters, it is assumed that they are available in this study. In practice, they can be obtained by a separate visual calibration method,[3] which has been implemented in some CRT calibration software, such as Adobe Gamma ®**.**

$$R = \begin{cases} \left[k_{g,r}\left(\dfrac{d_r}{2^N-1}\right)+k_{o,r}\right]^{\gamma_r}, & \left[k_{g,r}\left(\dfrac{d_r}{2^N-1}\right)+k_{o,r}\right] \geq 0 \\ 0, & \left[k_{g,r}\left(\dfrac{d_r}{2^N-1}\right)+k_{o,r}\right] < 0 \end{cases}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{r,\max} & X_{g,\max} & X_{b,\max} \\ Y_{r,\max} & Y_{g,\max} & Y_{b,\max} \\ Z_{r,\max} & Z_{g,\max} & Z_{b,\max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

In order to obtain the other 9 matrix coefficients, a mathematical optimisation method was developed and all the computations were performed on a PC using the Solve function in the Microsoft Excel®. The objective measure for optimisation is given in equation (2).

Minimize: $[\Delta E^*_{ab}(R)]^2 + [\Delta E^*_{ab}(Y)]^2 + [\Delta E^*_{ab}(G)]^2 + [\Delta E^*_{ab}(B)]^2 + [\Delta E^*_{ab}(W)]^2$ (2)

where ΔE^*_{ab} is the CIELAB colour difference and $\Delta E^*_{ab}(R)$ is the colour difference between the tristimulus values of the model predicted and the target of the primary red (R). Other terms have the similar meanings.

In order to test the performance of the GOG model derived using the experimental results, the monitor was characterised by using the GOG model based on the TSR measurement results. Thus, for each set of RGB values, two sets of tristimulus values can be compared by using the optimised and measured GOG models. The ΔE^*_{ab} calculated between the two models for a number of colours was used as a indicator how successful is the method developed here. The 8-bit RGB values for each channel was sampled at 5 interval from 0 to 255. Hence, 52x52x52 sets of RGB digital signals were generated for the testing purpose. The mean and maximum ΔE^*_{ab} were computed and listed in Table 2 for each monitor with different settings. The best performed monitor was HP1 CRT with D93 white point with a variation of 2.6 ΔE^*_{ab} units, and the worst was HP1 CRT with D50 white point with a 6.4 ΔE^*_{ab} units. The mean differences for all the monitors studied was 4.3 ΔE^*_{ab} units. The mean of the maximum differences was 13.6 ΔE^*_{ab} units. Table 3 lists the mean and maximum colour differences between the tristimulus values calculated from the sRGB transformation and the measured GOG model. The results presented here assume all monitors are the standard sRGB monitor. It can seen that the performance is rather poor with an overall mean of 7.3 and a maximum of 24 ΔE^*_{ab} units.

Table 2: Comparing the optimised and measured GOG model in ΔE^*_{ab} units

Model	D93			D65			D50	
Performances	HP 1	HP 2	Viglen	HP 1	HP 2	SONY	Hp 1	Mean
Mean	2.6	4.2	4.3	3.6	4.4	4.9	6.4	4.3
Maximum	7.3	12.2	14.2	10.2	13.3	11.2	13.3	13.6

Table 3: Comparing the sRGB and measured GOG model in ΔE^*_{ab} units

Model	D93			D65			D50	
Performances	HP 1	HP 2	Viglen	HP 1	HP 2	SONY	Hp 1	Mean
Mean	4.4	7.9	6.0	4.6	9.7	5.9	10.6	7.0
Maximum	16.6	29.8	16.8	21.4	35.3	23.6	27.0	24.3

4. CONCLUSIONS

A visual method was developed here to characterise a CRT. Psychophysical experiments were conducted on different CRT displays to generate matches in terms of CIE colorimetric data for four psychological hues and a neutral white. The observer variations were investigated, and it was found that observers had similar perception for the 5 colours selected. It was also found that the visual results of four psychological hues were independent of CRT display with different white points. However, for neutral white, observer results were highly dependent on the white point of CRTs. By using the experimental results, the coefficients of the GOG model were estimated by mathematical optimisation. The model was tested by comparing with that accurately determined by the colour measurement data. It was found that the current method gave reasonably accurate performance, i.e. with an error of 4.5 ΔE^*_{ab} units in comparison with a typical variation from a group of 10 observers (6.0ΔE^*_{ab} units).

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