Characterisation of a LCD colour monitor using a digital still camera

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ABSTRACT

A method for characterising a liquid crystal display (LCD) was developed using a characterised digital still camera (DSC). This paper describes both a framework for obtaining a device-independent representation of displayed colours on the monitor and a less time-consuming method for accurate characterisation. A DSC was first characterised using a polynomial regression technique and then an LCD monitor was characterised using two instruments: a tele-spectroradiometer (TSR) and the characterised DSC. In total, five characterisation methods were tested of which piece-wise linear interpolation assuming chromaticity constancy (PLCC[1]) predicted the results most accurately for the display studied.

1. INTRODUCTION

DSCs are becoming increasingly popular for measuring colours. Their accuracy is improving through the adoption of more sophisticated characterisation models obtained under stable illumination conditions. In some cases, they now rival the performance of spectrophotometers that are used in the graphic art industry. The aim of this study is to apply a DSC to characterise an LCD, to compare its performance with that of TSR and to demonstrate its potential as a built-in DSC display calibrator.

The biggest advantage of using a DSC for characterisation is that it takes much less time than a TSR or colorimeter. The latter measures one colour at a time and therefore takes a long period. For measuring a dark colour, several minutes could be required due to increased integration time. A TSR can easily spend many hours measuring enough of the colours needed to characterise a display. In the case of a DSC, however, it is possible to capture several colours in an image at a time, which significantly reduces the duration of measurement.

This work is divided into two characterisation steps: DSC and LCD monitor. The latter device was characterised using two types of instruments (DSC and TSR). A DSC itself first needs to be characterised in order to describe the camera RGB signals in terms of CIE XYZ for the captured colours. Since its purpose is to measure colours on an LCD monitor in terms of CIE XYZ values, training and testing colours were captured from the display. This is to avoid instrumental metamerism between the two instruments. From the GretagMacbeth ColorChecker DC, 181 colours were selected and displayed on the screen to be used as training data set. 24 colours from the GretagMacbeth ColorChecker 24 colour chart were used as testing data set. Each RGB digital value in the data sets was obtained by averaging the RGB values of all pixels in the colour area using Photoshop 7.0. These two sets of stimuli were used for memorisation and generalisation. (Memorisation is the back-prediction of the training data that was used to determine the characterisation model. Generalisation is the prediction of the testing data that was not used to develop the model[2].) Polynomial regression was used to convert camera RGB responses into CIE XYZ values. A number of different polynomial terms were studied and the most accurate model was chosen.

The second stage was to characterise the LCD. A number of characterisation methods for displays exist, but no single model consistently performs accurately. More details about display characterisation models are described by Kim[3]. This study evaluated various methods to determine a model that best suits the display used in this experiment. Five forward LCD characterisations were implemented: PLCC, GOG[4], three-dimensional look-up table (3D LUT)[5] using tetrahedral interpolation, third-order polynomial regression (referred to as polynomial I), and a modified third-order polynomial regression (referred to as polynomial II) method. Square root terms were included based on the assumption that they might help compensate for errors caused by leakage light in the modified polynomial model. A constant value of one is normally used to describe black but, because of the inherent leakage light of LCD, square root terms were chosen. The above five methods can be classified into two groups; neutral-trained and chromatic-trained. PLCC and GOG models belong to the former group and were trained using nine neutrals. The latter group includes 3D LUT and the two third-order polynomial models. They were trained by 125 colours (permutations of RGB values 0, 64, 128, 192 and 255). Another set of 140 colours was selected (combinations of 50, 100, 150, 200, and 250 plus five ramp colours for each channel) to evaluate the accuracy of the five models. All training and testing colours were measured by the TSR.

2. EXPERIMENTAL SETTING

A ViewSonic VE 510b LCD colour monitor was characterised using a Nikon D1X DSC and a Minolta CS-1000 TSR. The DSC is a lens-intechangeable digital SLR camera containing a 23.7 x 15.5 mm RGB CCD with 5.3 mega pixels effective capture at 12 bits colour. The work was carried out to closely follow the Video Electronics Standard Association (VESA[7]) procedure in that the distance between the LCD screen and measuring instruments (TSR and DSC) was fifty centimetres, a perpendicular geometry was adopted and all measurements were carried out in a dark room.

An optical illusion often occurs when many parallel curved lines are placed near each other to produce a pattern in the eye of the viewer that does not exist in reality. This is known as Moiré Effect. The unwanted patterns appeared when the DSC captures colour charts or uniform colour patches displayed on the screen. This effect was reduced by using a slightly defocused setting.

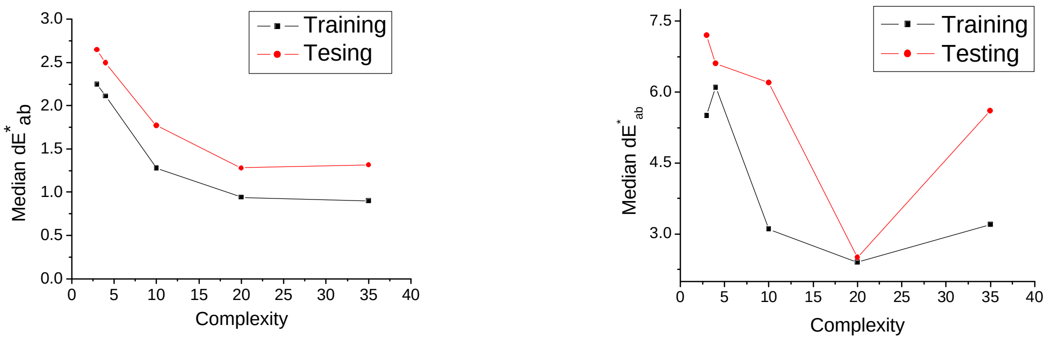
3. CHARACTERISATION OF DSC

In order to apply a DSC to LCD characterisation, it needs to be characterised using a colour chart that is displayed on the screen. This process needs two kinds of measurements: CIE XYZ values and camera RGB responses of the colour patches. To measure the CIE XYZ values of the colour patches, each colour patch was displayed in the middle of the monitor with the remainder black. Each was measured serially by the TSR. To measure RGB values, all colours were displayed altogether as a single image on the monitor with a black backgroundI; its 180° rotated image was captured by the DSC. The two sets of RGB values were averaged using Photoshop 7.0 in order to compensate for spatial uniformity variations in the monitor[3]. Linearisation performed between camera responses and input colorimetric values using a greyscale. From the two measurements, the relationship between the output (CIE XYZ) and input (linearised RGB) values of the LCD monitor can be established by polynomial regression. This method gives accurate results with fewer measurements than other methods such as neural networks or 3D LUT. Cheung et al[2] compared the performances between neural networks and polynomial regression method and concluded that the polynomial technique was recommended for DSC characterisation over neural networks. Their performances were more or less the same, however neural networks are relatively more difficult to use and take longer. Johnson[6] argued that 3D LUT models need a large number of measured colours. Finally, polynomial models were used to perform a mapping between a vector of camera RGB responses, C, and a vector of tristimulus values, T:

$$T = AC \qquad (1)$$

where A is the system matrix which can include a variety of terms.

The results of the DSC characterisation show that the training errors of the DSC characterisation plummeted as the complexity of the model increased, as can be seen in Figure 1. The graphs describe the effect of a number of terms in the polynomial transform method on training and testing performance difference. On the other hand, the testing errors from DSC characterisation showed the same trend as the training error, however this error increased slightly at a complexity of 35. Hence, the polynomial transform model with 3×20 terms was used to estimate the CIE XYZ values of colours captured by the DSC. At a complexity of 3×20, the median values of the training and testing errors were 0.9 and $1.3\,\Delta E^*_{ab}$ respectively. The overall trend of the plot was similar to the results of Cheung et al[2]. They carried out DSC characterisation using hardcopy colour samples under a given illuminant and found that the error for the training data set decreases as the complexity increases. Whilst the error for the testing data set shows the same trend, a small increase in error was found for the 3×35 polynomial model.



(a) (b)

Figure 1: DSC characterisation showing the effect of the number of terms in the polynomial transform model on training and testing performance difference in terms of (a) median and (b) 95% percentile

4. CHARACTERISATION OF LCD

Table 1 summarises the performance of the five models tested in terms of median, 95% percentile and maximum ΔE^*_{ab} values. PLCC and GOG models were trained using nine neutral steps. The 3D LUT and the two third-order polynomial models were trained using 125 colours (combinations of 0, 64, 128, 192 and 255). 140 colours were selected (combinations of 50, 100, 150, 200 and 250 plus five ramp colours for each channel) to test the five models. All training and testing colours were measured using the TSR.

The modified third-order polynomial and PLCC models gave the most accurate prediction. As can be seen in Table 1, the maximum error of the polynomial model is much higher than that of PLCC. In addition, it is not suitable for display characterisation because of its non-invertibility. This model, however, might be appropriate for colorimetric camera characterisation because reversibility is not generally required when characterising an input imaging device. Hence, it can be concluded that PLCC is the most suitable model for this experiment.

Table 1: CIELAB colour difference of five models

	PLCC	GOG	3D LUT	Polynomial I	Polynomial II
Median	1.5	2.7	2.5	1.9	0.8
95% percentile	3.2	15.8	5.2	3.9	7.7
Maximum	4.7	23.8	6.3	10.8	14.5

To evaluate LCD characterisation model accuracy, the performance between the two types of measuring equipment (DSC and TSR) was compared, as given in Table 2. The DSC model was trained and tested by DSC measurements and the TSR model was trained and tested by TSR measurements. In total, 30 colours were used as a testing data set, including four equally stepped colours for each channel and 18 RGB natural mixture colours taken from the GretagMacbeth ColorChecker 24 colour chart (excluding greyscale). Since PLCC showed the best performance in Table 1, when the five methods were tested, PLCC was chosen for the performance comparison between DSC and TSR. When the DSC model was tested, all of the colours were displayed in an image. The DSC captured this and its 180° rotated image to compensate for spatial non-uniformity. The average RGB values were found using Photoshop 7.0[3]. DSC performance did not match that of the TSR; however it is apparent that the results from the DSC would be sufficiently acceptable to allow its possible use for colour measurement. It should be noted that the maximum error of the DSC was high. It appears that it did not predict the correct values – especially for the ramp colours – because they were taken from outside the DSC colour gamut. This is a major drawback to using a DSC as a measuring device. The badly predicted colours were, however, quite limited (ramp colours) and the performance for the 18 natural mixture colours sampled from ColorChecker 24 chart of DSC was similar to that of TSR.

Table 2: CIELAB colour difference between DSC and TSR for ramp and RGB mixture colours using PLCC

	DSC			TSR		
	Ramp	Mixture	All	Ramp	Mixture	All
Median	2.6	2.0	2.4	2.2	1.6	1.9
95% percentile.	14.9	3.5	10.0	2.9	3.2	3.2
Maximum	19.6	5.6	19.6	3.0	3.6	3.6

5. RELATIVE MEASUREMENT DIFFERENCE BETWEEN INSTRUMENTS

To investigate the relative difference of the results between the two sets of measurements, their measurements of 24 colours from the ColorChecker chart were compared in terms of CIELAB colour difference. This gave a median of 1.3, 95% percentile of 2.5 and a maximum of 2.8 ΔE^*_{ab}.

There is another way to find out the relative difference between them. A hypothetical 52 × 52 × 52 RGB grid covering the entire colour gamut was computed and the corresponding tristimulus values were estimated using the two characterisation models, TSR-PLCC and DSC-PLCC. The difference between the two different instrument modes can be described by the median CIELAB colour difference of 2.2, 95% percentile of 6.7, and maximum of 11.5. A histogram of their difference is given in Figure 2. The horizontal axis represents CIELAB colour difference and the vertical axis represents frequency.

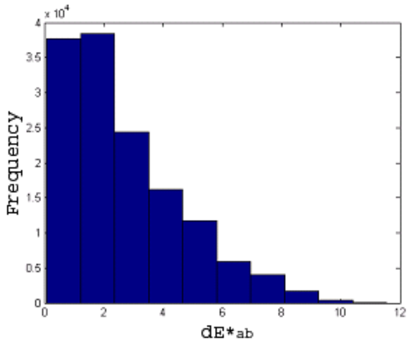


Figure 2: Histogram of output differences between the TSR and DSC models in terms of CIELAB colour difference

6. CONCLUSION

A considerable number of digital imaging devices have been developed and every device has its own characteristics. It is generally agreed that when device variability is taken into account, high fidelity colour reproduction can be achieved. Thus we should be aware of the importance of accurate measurement for device characterisation. However, this can be very time consuming using conventional colour measurement instruments (e.g. TSR). This study was encouraged by this situation. With the advantage of a less time-consuming approach, using a DSC for the characterisation of an LCD colour monitor was carried out in this way. Although its performance did not match that of the TSR, the results from the DSC demonstrate an optimistic future opening up the possibility of its use for many applications related to colour measurement. For example, a built-in DSC display calibrator would further improve this method. It is expected that DSC calibration can give better accuracy than conventional visual calibration. Determining those features of DSC that affect accuracy and optimising their settings are left as a future study to develop a commercial DSC display calibrator.

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