EVALUATION OF THE COLOR REPRODUCTION ON LCD MONITORS

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Abstract

Color reproduction on CRT monitors needs colorimetric characterization concluding two stages with 3x3 matrix and three TRCs (Tone-Reproduction Charicteristics). The 3x3 matrix is based on the additivity of RGB emissions, and the TRC represents the non-linearity between the input digital counts and the output luminance. The objective of this project is to evaluate the accuracy of color reproduction on LCD monitors using conventional CRT model(GOG model). For two different manufacturers, colorimetric characterizations of desktop LCDs have been performed. Because the transfer function for LCD is very differ from TRC of CRT, some researchers had reported that GOG model is inadequate for the colorimetric characterization of LCDs. However in our experiment, the degree of accuracy was dependent on the shape of electro-optical transfer fuctions of LCD. It has been founded that the GOG model could be applied for LCD monitors having monotonically increased Electro-optical transfer fuction.

1. Introduction

Flat-panel LCD monitors are quickly becoming a common peripheral for desktop PC. LCD monitors are well known with greater luminance, better uniformity of space, time and color as well as thin and lightweight. The objective of this study is to characterize a desktop LCD monitor's colorimetric performance.

The colorimetric characterization of CRT monitors has been achieved by an analytical model[1]. However the Electro-optical transfer function is very differ from TRC of CRT. Some researchers have reported that GOG model is inadequate for the colorimetric characterization of LCD monitors[2-3]. In this study, first spatial independence for LCD monitor is tested to determine the measurement conditions. We evaluated the accuracy of applying GOG model for two LCD monitors, one is domestic and the other is foreign product.

2. Experimental Setup and Measurements

The specification of two desktop LCDs tested are shown in Table 1.

Table 1. specifications

	A	B
Company	LG	NEC
Products	Studioworks 500LC	Multisync LCD 400
Screen Size	15 inch	14.1 inch
Resolution	1024 × 768	1024 × 768
Contrast Ratio	200:1	100:1
Brightness	150 cd/m ^{2}	180 cd/m ^{2}

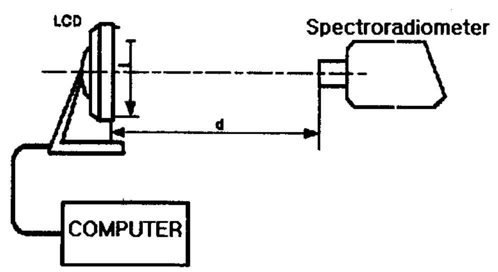


Fig 1. Non-Contact Measurement System

All monitors were set to D65 white point, 1024x768 at 75Hz, and 24-bit full color resolution. They were driven using the built-in video card (I740) of PC. Contrast and brightness levels were varied. Non-contact measurements were performed using a spectroradiometer CS-1000 of Minolta as shown in Fig1. The instrument optical axis should be the normal angle to the surface of the LCD. CS-1000 was focused with a measuring area of 1.6cm in diameter.

For testing the spatial independence, the size of displayed area was varied and the remainder of the monitor was set to various luminance and colors. From the result of spatial independence testing, the size of displayed areas fixed to h/15, and the background color was fixed to gray (127,127,127). All measurements were made after 2 hours of warmup and performed in a dark room. Moreover, image stabilization time was set 2 minutes after a displayed color change.

3. Spatial independence of LCD Monitor

Spatial independence is an assumption that the luminance and chromaticity at one pixel is stable and not dependent on the setting of other pixels in the display. As the size of displayed area is larger, the interreflection between pixel locations would be increased. This leads to the problem in additivity of the display. The additivity could be evaluated by comparing the sum of the measured luminances for RGB displayed individually with the measured luminance for the white. Table 2 shows the increase of difference as the diameter of central displayed area is increased with uniform black background for A monitor . For highest accuracy, smaller image area is better than the full screen image. However, the additivity of this LCD monitor is quite good within 0.5%. In this study, all measurements were performed for an image of h/15 diameter just larger than measuring area.

Table 2. The difference between white and the sum of individual RGB primary measurements

Spot	W	R	G	B	R+G+B	Diff.(%)
$h/15$	185.8	46.97	113.6	25.02	185.59	0.11
$5h/15$	187.2	47.30	114.5	25.15	186.95	0.13
$9h/15$	188.0	47.51	114.9	25.10	187.51	0.26
$13h/15$	188.5	47.66	115.3	25.03	187.99	0.27
$15h/15$	189.0	47.80	115.6	25.01	188.41	0.31
Full	189.6	47.93	115.9	24.87	188.70	0.47

Next, the spatial dependence on the 9 colors of background was evaluated for A monitor. The tristimulus of white displayed on the center of the screen were measured varying to background color. These included black (0,0,0), gray (127,127,127), white (255, 255,255), two reds {(255,0,0), (127,0,0)}, two greens {(0,255,0), (0,127,0)}, and two blues {(0,0,255), (0,0,127)}. The color difference induced by background color is listed in Table 3.

We can see that spatial independence is affected by the luminance and chromaticity of the background. However these color differences were minimal with the MCDM(mean color difference from the mean) of 0.24. This indicates that there is very little spatial dependency for A monitor. From these results, we could assumed that the spatial independence of the LCD monitor is very good and not a limiting factor in its colorimetric characterization.

Table 3. ΔE^*_{ab} and MCDM for spatial independence measurements of A monitor.

Back Color	X	Y	Z	[illegible]	[illegible]	ΔE^*_{ab}	MCDM
0	177.8	186.4	176.4	0	0	0	
127	178.2	186.8	176.6	0.08	0.07	0.11	
255	180.3	188.9	178.3	0.52	0.20	0.56	
127r	178.0	186.6	176.6	0.04	0.01	0.04	
255r	179.1	187.1	176.7	0.15	0.61	0.62	0.24
127g	177.9	186.6	176.5	0.04	0.09	0.10	
255g	178.5	187.7	176.7	0.27	0.61	0.67	
127b	177.7	186.3	176.1	-0.02	0.08	0.08	
255b	177.8	186.2	177.1	-0.04	0.38	0.38	

4. Characterization of Electro-optical Transfer Function A monitor

Fig 2. shows the chromaticity coordinates for A monitors. A series of 16 DAC spaced steps in red, green, blue and neutral were measured. A triangle of chromaticity diagram shows color gamut of LCD monitor.

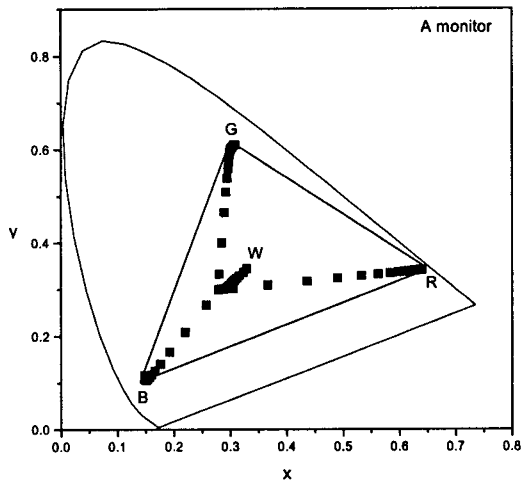


Fig 2. Chromaticities of R, G, B primaries and Neutrals of A monitor

Fig. 3 shows the Electro-optical transfer fuctions of A monitor for four different brightness and contrast settings. These data were obtained by measuring the luminance of a neutral ramp at 17 levels (0 to 255 increment of 16). We can see that the gradient of all curves are monotonically increased like CRT minitors. Fig 4. shows the measured data and fitted GOG model for a reset setting. This figure shows very good consistency. The parameters of GOG model for four curves were obtained using Origin software. Table 4 shows the fitted offset, gain, and gamma coefficient of A monitor. Figs. 5 illustrates the residual error between predicted and measured data for four different settings. The errors for all settings are comparable with CRT monitors with values ranging between -0.005 and 0.005. Closer examination of Figs. 5(a)-(d) reveals that there is a tendency of decreasing error as the contrast increases.

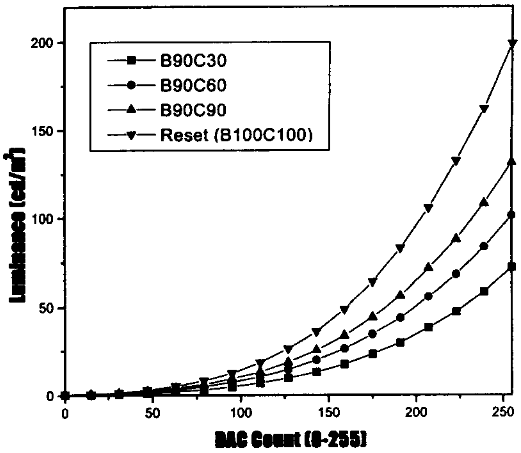


Fig 3. Electro-optical transfer functions of A monitor for four different settings.

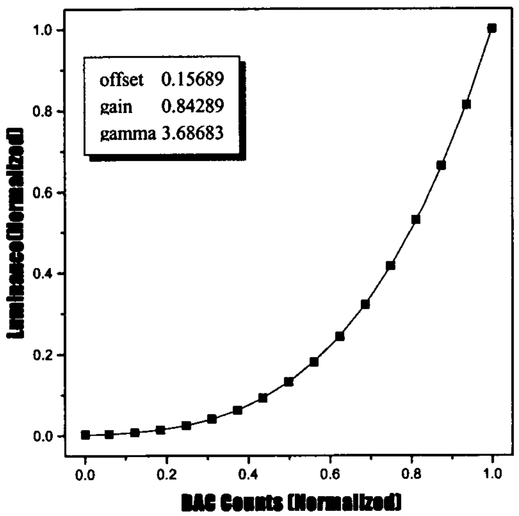
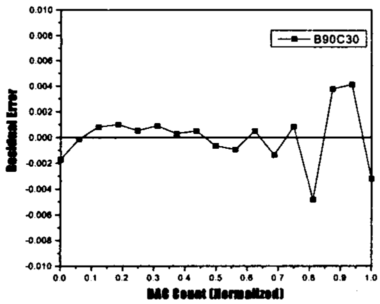


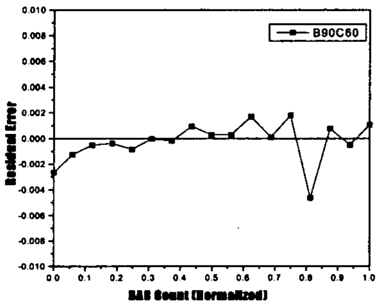
Fig 4. Comparison of measured data and fitted GOG model at a reset setting.

Table 4. Parameters of A monitor

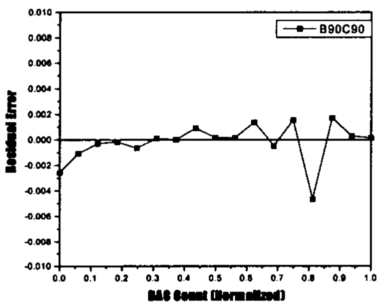
	Offset	Gain	Gamma
B90C30	0.2249	0.7742	4.096
B90C60	0.1667	0.8336	3.577
B90C90	0.1755	0.8245	3.659
Reset(B100C100)	0.1569	0.8429	3.690



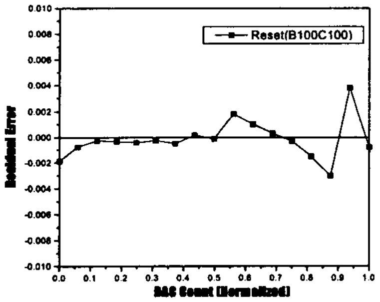
(a) B90 C30



(b) B90 C60



(c) B90 C90



(d) B100 C100

Fig 5. Redisual errors between predicted and measured data for four settings.

B monitor

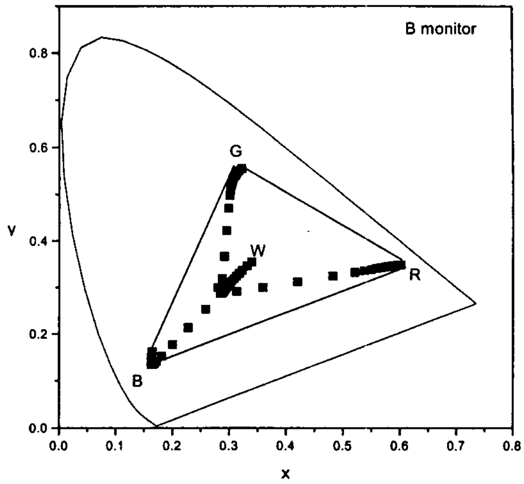


Fig6. Chromaticities of R, G, B primaries and Neutrals of B monitor

Fig 6. shows the chromaticity coordinates of 16 gray ramps for B monitors. The amount of coordinates shift is very similar with A monitor, but the color gamut of B monitor is smaller than A monitor. Fig. 7 shows the Electro-optical transfer fuctions of B monitor for four different brightness and contrast settings. All curves show the typical s-shape of LCD, and the curve for the highest contrast is severely saturated above 170 counts. We examined one curve for reset setting. Fig. 8 shows the comparison of the measured data and fitted GOG model fitted line. There is large difference compared with that of A monitor. The fitted GOG model is too high for low digital counts and too low for high DAC counts. This is because of the S-shape of LCD monitors. The residual error between predicted and measured data with values ranging between –0.04 and 0.03 are illustrated in Fig. 9.

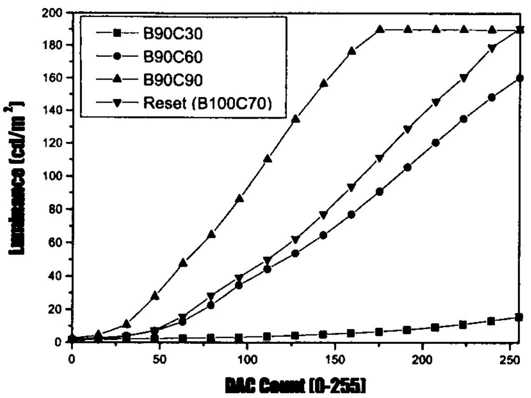


Fig 7. Electro-optical Transfer Functions of B monitor for four different settings.

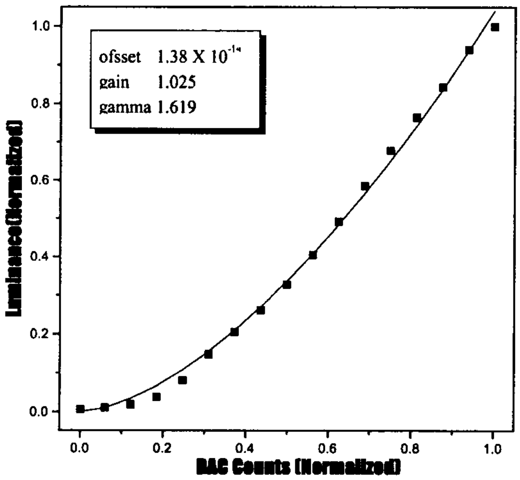


Fig 8. Comparison of measured data and fitted GOG model at a reset setting.

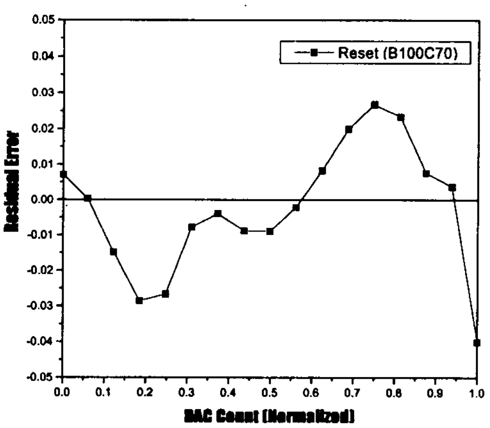


Fig 9. Redisual errors between predicted and measured data at a reset setting.

5. Conclusion

Spatial independence of LG Studio-Works 500LC was tested in terms of additivity, independence on background color. With the experimental data, we could assumed that the spatial independence of the LCD monitor is very good and not a limiting factor in its colorimetric characterization.

This study is to evaluates the possibility of applying GOG model to colorimetric characterization of two LCD monitors. A monitor shows good consistency and B monitor shows large differences. It could be concluded that the accuracy of applying GOG model depends on the shape of Electro-optical transfer functions of LCD monitors. As a conclusion, the applying GOG model is probably adequate for the LCD monitor having monotonically increased Electro-optical transfer fuction.

6. Reference

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(3) Ching-Yu Tsai, Ming-Jiun Liaw, and Han-Ping D. Shieh, Color Reproduction of Twist Nematic LCD by Polynomial Regression Applied in Primary-Invariance Model, SID, 1999