Accurate Colour Reproduction in Prepress

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Abstract: The adjustment of colour to achieve an acceptable match between the displayed (soft copy) and printed (hard copy) document is an important task in prepress. In order to achieve such match colour management systems are used, these systems implement standards established by the International Colour Consortium (ICC).
A key step of the colour management process is the calibration of display and output devices, the definition of the relationship between the native colour space of the device and a standard device-independent colour space. In this work the usability of the ICC colour management standard was investigated in case of flat panel LCD display calibration.

1 Introduction

1.1 Liquid Crystal Displays

Liquid crystal displays (LCDs) are replacing the traditional high quality and high contrast cathode ray tube monitors in the field of prepress, due to their ergonomic properties and low cost. Manufacturers contribute to the popularity of LCDs by specifying their product's critical parameters (response time, viewing angle) so that they appear more attractive to users less familiar with technical aspects. For example response time and viewing angle are specified as scalar quantities, although plotting the response time as a function of grey level steps or how the contrast ratio changes with viewing angle are more informative (Figure 1).

The transmission of an LCD pixel is controlled by the voltage applied to the top and bottom electrodes; an external light source is used to illumination is the array of pixels. The structure and technology of the LCD screens is diverse, the most popular is the twisted nematic (TN) structure, because of its short response time it is has a dominant position on the market among the 17-inch and smaller diameter LCD displays. The disadvantages of the TN LCDs are the small viewing angle and low contras ratio.

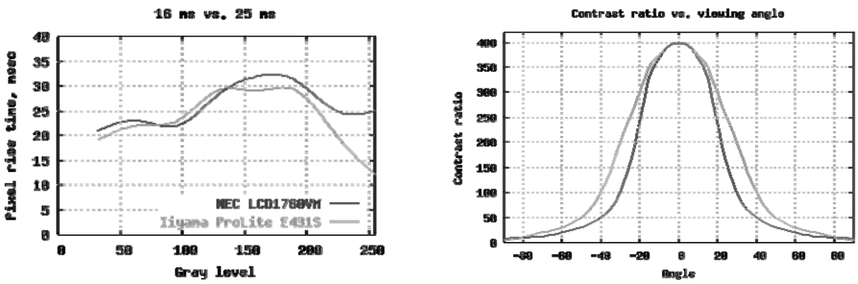

Figure 1
Pixel rise time as a function of grey level changes (left) and contrast ratio as a function of viewing angle in case of two LCD screens

In order to overcome these serious drawbacks other technologies, such as Switching (IPS), Multi domain Vertical Alignment (MVA) and Patterned Vertical Alignment (PVA) were developed. A common advantage of all three technologies over the TN displays is that if a pixel fails its transparency drops, appearing as a black dot on the screen [1]. All technologies have strengths and weaknesses, a summary of these is presented in Table 1.

Table 1
Advantages (+) and disadvantages (-) of LCD technologies

	TN	IPS	MVA	PVA
Contrast ratio			+	+
Response time	+			
Viewing angle	-	+	+	+

1.2 Colour Management in Prepress

As the colour document develops images are imported (e.g. originals are digitalized, displayed, edited, merged, etc.); during the process of prepress the use of colour management is necessary to adjust the colour scheme of the document to be printed.

Imaging, display and output devices have different primary colours and tone reproduction functions. It is the task of the colour management system to define the appropriate transformations between device primaries and tone reproduction curves to achieve accurate colour reproduction.

The majority of up-to-date graphical applications and computer operation systems are compatible with the colour management standard developed by the ICC (International Colour Consortium). According to this standard the colorimetric characterisation of the devices are stored in a separate file (ICC profile), which the users usually obtain by a colour measurement and management system, that generates and stores the appropriate profile automatically. The ICC standard allows two models to define the transformation between the device independent colour space of the monitor and the standard colour space (e.g. CIELAB): look-up table interpolation or the linear transformation of the device primaries together with the non-linear tone reproduction functions of each colour channel.

The standard offers 5 model tone reproduction functions (Table 2) including a simple power function (‘gamma function’), the ‘gain offset gamma offset’ type function, which works well with cathode ray tube monitors, and the linear extension of the latter. In an ICC profile the number of the function and the calculated parameters are stored [2].

Table 2
Tone reproduction curves offered by the ICC standard

#	Function type	Parameters
1	$Y = X^{\gamma}$	γ
2	$Y = (aX + b)^{\gamma}$ $X \ge -b/a$ $Y = 0$ $X < -b/a$	γ, a, b
3	$Y = (aX + b)^{\gamma} + c$ $X \ge -b/a$ $Y = c$ $X < -b/a$	γ, a, b, c
4	$Y = (aX + b)^{\gamma}$ $X \ge d$ $Y = cX$ $X < d$	γ, a, b, c, d
5	$Y = (aX + b)^{\gamma} + e$ $X \ge d$ $Y = cX + f$ $X < d$	γ, a, b, c, d, e, f

2 Method

Eight desktop and laptop monitors were included in the study. We were looking for the ICC tone reproduction function that produces the best match with the measured tone reproduction curve. The manufacturer, type and applied resolution of the 8 displays are listed below:

- Compaq nx7010 15.4" LCD (1680 x 1050)
- Samsung Syncmaster 710N 17" LCD (1024 x 768)

- LG Flatron L1710B 17" (1024 x 768)
- HP Omnibook xe3 15" (1024 x 768)
- Fujitsu Siemens PA 1510 (1280 x 800) (2 db)
- Sony SDM S51 15 " (1024 x 768)
- HP L1702 17 " (1280 x 1024)

We used a commercial, market leader brand colour management system consisting of a measurement unit and application software that handles the measurement data, computes the colour transformation parameters, generates the ICC profile and copies it to the specified library of the operation system without user interaction. This file was used to obtain the tri-stimulus values of the monitor primaries and the tone curves of the colour channels. Non-linear optimization was performed on the ICC model functions to achieve a best match with the measured tone reproduction curve. The cost function was the average ΔE^{*}_{ab} colour difference between the measured sample and model output.

3 Results

Tables 3 and 4 present the average colour differences between the measured colour reproduction curves of the colour channels of each monitor and the ICC functions optimized for best match. However results are shown for only three curves: the measured tone reproduction curve (f_0), the 'gamma function' (f_1), and the 3rd tone reproduction function (f_3).

Values in the f_0 column of the tables indicate, that in many cases the linear transformation of the primaries already produces significant error even with the measured tone reproduction curve. This error is caused by the colour channel being non-independent of each other.

The importance of column f_1 (the 'gamma function') is due to the fact, that the profiles, generated by the colour management system contained exclusively this function to model the measured tone reproduction curves. However in many cases the 3rd model function results more accurate reproduction of the tone curve.

We have experienced no improvement with the 4th and 5th model functions of Table 2, therefore results are not shown to save space.

Table 3

Average ΔE^*_{ab} colour differences between the model output and the measured samples for each colour channel (Red, Green, Blue), f_0 is the measured tone reproduction function f_1 is the first, f_3 is the third tone reproduction curve of Table 2

	Colour channel	F_0	F_1	f_3
Monitor 1	R	1,6	1,9	1,4
	G	3,0	3,0	3,0
	B	5,9	5,6	5,6
Monitor 2	R	1,5	1,4	1,4
	G	2,9	2,9	2,9
	B	5,0	4,8	4,8
Monitor 3	R	3,3	5,4	3,4
	G	3,5	4,8	3,7
	B	5,8	5,7	5,7
Monitor 4	R	4,4	5,8	4,2
	G	3,5	4,3	3,6
	B	7,8	8,0	7,8
Monitor 5	R	1,5	1,4	1,2
	G	1,1	1,1	1,1
	B	1,8	1,5	1,3
Monitor 6	R	0,8	0,8	0,7
	G	2,4	2,4	2,4
	B	4,5	4,0	3,9
Monitor 7	R	1,6	1,7	1,3
	G	1,2	1,1	1,1
	B	2,4	2,2	1,9
Monitor 8	R	1,4	1,5	1,3
	G	1,3	1,7	1,4
	B	2,8	2,5	2,5

We measured relatively small average colour differences between the measured samples and the model output. In cases when the ΔE^*_{ab} value was not greater than 5 we also calculated CIEDE2000 [3] colour difference values (Table 4.), this novel formula predicts perceivable colour differences more accurately. Laptops are among the first 4 monitors in the list, it can be seen, that the other desktop LCDs can be modelled better according to the ICC standard.

Conclusions

In our experiment with LCD monitors we have found computed colour differences between displayed samples and the output of the ICC model predictions well within the visible range. The main cause of the errors was the lack of colour channel independence.

The investigation of the generated profile ICC profile found out that the automatic colour management system uses the simple power function to model measured tone reproduction curves in all cases; however we have achieved better matches using the 3rd function ('gain-offset-gamma-offset') of the ICC standard.

Table 4

Average CIEDE2000 colour differences between the model output and the measured samples, f_0 is the measured tone reproduction function f_1 is the first, f_3 is the third tone reproduction curve of Table 2

	Colour channel	f_0	f_1	f_3
Monitor 1	R	1,6	0,9	0,7
	G	1,4	1,4	1,4
	B			
Monitor 2	R	0,7	0,7	0,6
	G	1,3	1,3	1,3
	B	2,4	2,7	2,7
Monitor 3	R	1,7		2,0
	G	1,8	2,8	1,9
	B			
Monitor 4	R	2,5		2,4
	G	1,7	2,3	1,7
	B			
Monitor 5	R	0,6	0,6	0,7
	G	0,5	0,5	0,5
	B	0,7	0,7	0,8
Monitor 6	R	0,4	0,4	0,4
	G	1,1	1,1	1,1
	B	1,9	2,1	2,4
Monitor 7	R	0,6	0,7	0,8
	G	0,4	0,4	0,4
	B	1,0	1,2	1,3
Monitor 8	R	0,5	0,9	0,8
	G	0,6	1,0	0,7
	B	1,2	1,7	1,7

References

[1] X-bit's Guide to Contemporary LCD Monitor Parameters and Characteristics http://www.xbitlabs.com/articles/other/display/lcd-guide_26.html

[2] Specification ICC.1:2004-10. www.color.org/ICC1V42.pdf

[3] M. R. Luo, G. Cui, B. Rigg: The Development of the CIE 2000 Colour-Difference Formula: CIEDE2000, Color Res. Appl. 27, pp. 126-127, 2001