Side by Side Soft Proofing with CRT and LCD Monitors

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Abstract

Having a calibrated monitor with an accurate ICC monitor profile is a necessary, but not sufficient condition for an accurate soft proofing system. Soft proofing, using a monitor to proof a printed piece on a conventional or digital printing press, is an increasingly important component for remote proofing of time critical materials. This paper examines the requirements for an accurate, useful and easily useable soft proofing system, without using the certified software available on the market. An attempt is made to obtain SWOP-like certification results by using calibration tools with available profiling software.

The accuracy of a soft proofing system depends on the utilized Color Management Module (CMM), the specified white point and, of course, how well the profile represents the device we are attempting to characterize. Results of colorimetric measurements are presented for CRT and LCD displays in RGB, CMYK and Lab modes. Surprisingly, the accuracy of the soft proof is highly dependent on the method used to display the proof. From three different methods to display a proof using Adobe Photoshop, only one gives colorimetric agreement with printed patches and values from Photoshop's Info Palette. Care must be taken when interpreting displayed Lab or CMYK values. Differences between CRT and LCD monitors are discussed. A summary of unresolved issues and some recommendations for their resolution is presented.

Keywords: Color Management, Soft proofing, Monitors, CRT, LCD.

Introduction

The world of color reproduction, whether in print, on the web, on film or on video, is highly dependent on the variability of imaging devices. Color Management Systems (Berns, 1997, Katoh, 1998, Wyble, 2000, Sharma, 2004, Fleming, 2002) (CMS) have been developed to deal with this issue. Accurately matching color, among computer Cathode Ray Tube (CRT) (Berns, 1993, 1996, Chovancova, 2000) and Liquid Crystal Display (LCD) (Day, 2004, Tamura, 2003) monitors, analog (Cummins, 1997) monitors, cinematic projection (Stauder, 2004), companion books and wearing apparel, present an apparently insurmountable challenge. The International Color Consortium (ICC 2004) was formed in 1993 by Adobe, Agfa, Apple, Kodak, Microsoft, Sun Microsystems and Silicon Graphics (Brues, 2000, Green, 1999, ICC 2004) to define the standards for color device characterization.

Soft proofing (Katoh, 1994, Sharma, 2004, 2006, Fleming, 2003) is the process of using a calibrated monitor to accurately preview reproduction on a hard copy output device, such as a digital printer or printing press. To accomplish this, it is necessary to have accurate profiles for the monitor and output devices (Sharma, 2002a, 2003a, b). Monitor profiles and output profiles are constructed by measuring displayed or printed colors (Sharma, 2002a, 2003a, b, 2004, 2006). It is important that the output profile be reversible, so that transforming between CMYK and $L^*a^*b^*$ and then back again to CMYK yields the same (or equivalent) color values. This feature is crucial for any digital proofing, hard or soft.

Significant progress has been made in evaluating the accuracy of ICC profiles (Sharma, 2002a, 2003a, b, 2004, Fleming 2002). Here we extend that process to evaluation of a soft proofing system. We consider both CRT (Cathode Ray Tube) monitor and LCD (Liquid Crystal Display) flat panel monitor. These are used for visualization on both Macintosh and PC platforms. CRT (Berns, 1993) and LCD (Day, 2004, Tamura, 2003) monitors use completely different technologies, and thus have quite different display characteristics.

Integrated Color Solutions (Herbert, 2004, O’Brien, 2004) was the first on the market to have a SWOP (SWOP, 2005) certified a soft proofing system, using its Remote Director ™ software with Apple Cinema LCD displays. The second soft proofing solution to be SWOP certified--the Kodak Polychrome Graphics (KPG) Matchprint Virtual Proofing System (O’Brien, 2004) was honored with the Graphic Arts Technical Foundation's InterTech Technology Awards. This is based on RealTimeImage’s RealTimeProof Express, which was acquired by KPG because of its purchase of RealTimeImage (O'Neill, 2004). Finally, CGS Publishing Technologies International’s ORIS Soft Proof™ has been SWOP certified using Apple Cinema LCD displays as well as Eizo’s ColorEdge CG220 LCD display (CGS, 2006). Presumably, any good computer monitor (CRT or LCD) can be SWOP certified using the methods presented here.

Monitors are now developed specifically for graphic designers, digital photographers and prepress professionals. In addition, color management products let users calibrate (Berns, 1993, Rich, 2002) and profile any CRT or LCD monitor at the workstation and can greatly help in translating what color looks like on the screen, compared to its representation in hard copy. Conventional CRT monitors are a challenge for the becoming less expensive, but high quality, LCD screens. CRTs offer numerous advantages over flat panels for some applications. While flat panels have generally higher contrast than CRTs, the CRT has better black levels. However, the most overwhelming advantage of CRTs is still their cost. LCD thin film transistor (TFT) active-matrix digital displays offer several benefits, e.g. they are compact and space saving. The white point, or color temperature, of the light is generally not the same as CRT displays. The color temperature of an LCD display differs from that of standard CRT displays. In addition, the primary colors in the display are very different from the standard CRT phosphor colors (Day, 2004, Tamura, 2003).

Experiment

This paper describes issues concerned with output profile – monitor profile combinations. In addition to calibrating/profiling the display, it is important that the hardware/software combination is properly characterized and understood. For example, some but not all CRT monitors will exhibit a measurable, if not noticeable, change in brightness as the size of a white patch is enlarged on the screen. This is presumably caused by a voltage drop associated with the load from driving all of the pixels at full intensity. Generally, areas of approximately ¼ screen or less will show the same brightness (i.e. Y value). This behavior has not been observed for LCD displays, since the uniform backlight intensity is always the same regardless of the pixel values.

It is also very important that the soft proofing software properly accounts for the “paper white” when displaying the absolute colorimetry (ICC, 2004) rendering intent. For example, Adobe Photoshop, the Premier image editing software, which has been “ICC savvy” since version 4 (now at version 9), does not simulate paper white by default, even for absolute colorimetry. It specifically has to be turned on in the proof menu. It is equally absurd that “simulate paper white” can be turned on in relative colorimetry mode. In this work, we have built monitor and printer profiles and tested these modes against real screen measurements. We also created a profile ourselves from ANSI/CGATS TR001-1995 (TR001) Report data (ANSI, 1995) and compared this against the “official” SWOP profile, U.S. Web Coated (SWOP) v2, distributed by Adobe. We will discuss the quantitative differences. Along the way, we report side-by-side GretagMacbeth ProfileMaker with X-Rite MonacoPROFILER. The display of images, using profiles based on the concepts of color management, was quantitatively investigated.

The work presented here was based on using commercial profiling software and commercial image editing software, because that is what most prepress and print providers have to deal with. Our intention is to set out the principles underlying a soft proofing system, independent of how the actual images are displayed with valid software. This was complicated by some internal inconsistencies in Photoshop. Nevertheless, our conclusions are general and should be applicable, regardless of how proper display colorimetry is controlled. Research, currently in progress (ElAsaleh, 2007) addresses monitor display calibration and profiling across platforms, using custom software. This should confirm the universality of the results presented here, along with additional insights into monitor display and control.

Images were printed on an Epson Stylus Pro 5000 using the output profile of the printer. Printed proofs were put side by side with the displayed images and the visual evaluation of their equality was performed.

Experimental Setup

Two monitors were chosen to represent the two groups: a 17" Mitsubishi Diamond Plus 73 CRT Monitor and a 17" Apple Studio LCD Display. Both monitors were placed in a dark room with gray walls to sustain the same environmental and viewing conditions. To stabilize the monitors, they had been turned on for at least 12 hours before measurements took place. The stability of the displays was spot checked periodically and indirectly checked through "round trip" measurements (see below Chovancova, 2003 and Fleming, 2003). In order to obtain the most repeatable results, the investigated patches were always displayed in the center of the monitors. Profiles were made for these monitors using GretagMacbeth ProfileMaker and MonacoPROFILER software, with a GretagMacbeth Spectrolino spectrophotometer. These have been shown previously (Sharma, 2002a, 2003b, Starr, 2003) to yield good quality profiles for all profile types. The procedures to create and evaluate the quality of monitor profiles are presented elsewhere (Sharma, 2002a, 2003a, b, 2004, 2006, Fleming 2002). The quality of the monitor profiles was investigated using extended methods described below.

Two output profiles were used to simulate a printed SWOP proof appearance on the displays: the U.S. Web Coated (SWOP) v2 distributed by Adobe and one we built from the TR001 data set, both based on the SWOP specifications. The ANSI output profile was created from that report data source, using GretagMacbeth ProfileMaker software. We found that there is only one correct way to soft proof on the display, even though there are several seemingly equivalent methods. The results for output profiles were compared. Other features of the output profiles are considered such as display of the Macbeth ColorChecker® Chart (Munsell) and TR001 Output Profile data. An electronic version of this chart in Lab mode was downloaded from Colorremedies (2006) web site.

Creation of Monitor Profiles

The contrast and brightness controls on the monitors were adjusted with the help of profile making software and were kept the same from the beginning to the end of the process. This step is also called calibration of the monitor. The desired color temperature of 5000 Kelvin (D_{50}), 2° standard observer and γ value of 1.8 (the default value for Mac OS platforms) were set for the LCD and CRT monitors. Preliminary results were reported (Chovancova 2003, Fleming 2003) elsewhere.

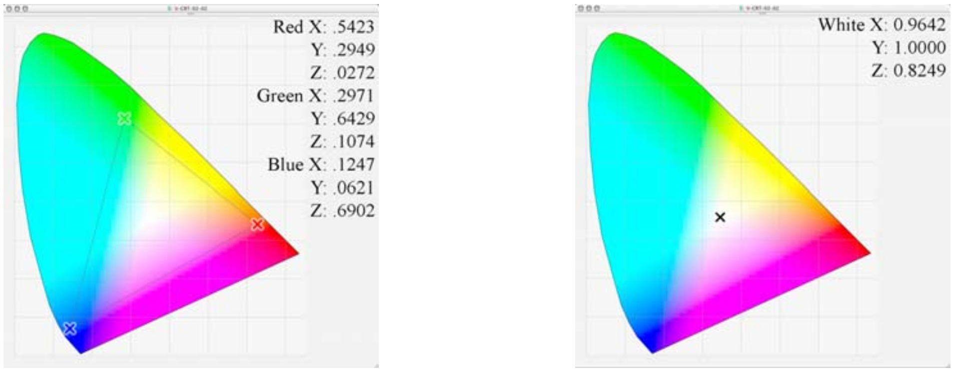
Creation of Output Profiles

For output profiles, it is necessary to print a file of known CMYK values, such as the IT8.7/3 (ANSI, 1996). The printed patches are then measured with a colorimeter or spectrophotometer. A mapping between CMYK values and $L^*a^*b^*$ values is generated and used to populate lookup tables in the profile. The mapping is complicated, because in order for it to be one to one and invertible, some sort of GCR (Gray Component Replacement) (Yule 1940, Field, 1986) or UCR (Under Color Removal) (Yule, 1940, 1961) prescription must be specified to make the effective CMYK space a function only of three variables. Specifying the $L^*a^*b^*$ value for a given CMYK value is no problem, because that is what is specifically measured. However, specifying the CMYK value for a given $L^*a^*b^*$ requires a constraint on the CMYK values.

Results and Discussion

Accuracy of Monitor Profiles

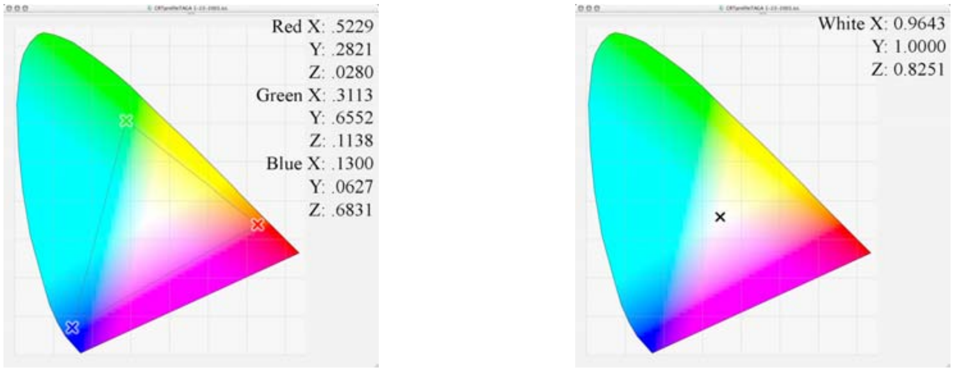
The newly created profiles were selected as the profiles separately for the CRT and LCD monitors. Then, these profiles were analyzed. (Using Photoshop), four patches consisting of RGB primaries (255,0,0), (0,255,0), (0,0,255) and a white patch (255,255,255) were displayed on the monitors in RGB and LAB mode to check the accuracy of the profile for displaying color patches. The white patch represents the white point or equivalently the color temperature of the monitor. The RGB Working Space (default RGB space) was set to the specific monitor profile space, the CMM was set to the Adobe Color Engine (ACE) and rendering intent to Absolute Colorimetric. The values of the primaries (RGB) and the white point (WP) information are shown in figures 1-4.



Red X: .5423
Y: .2949
Z: .0272
Green X: .2971
Y: .6429
Z: .1074
Blue X: .1247
Y: .0621
Z: .6902

White X: 0.9642
Y: 1.0000
Z: 0.8249

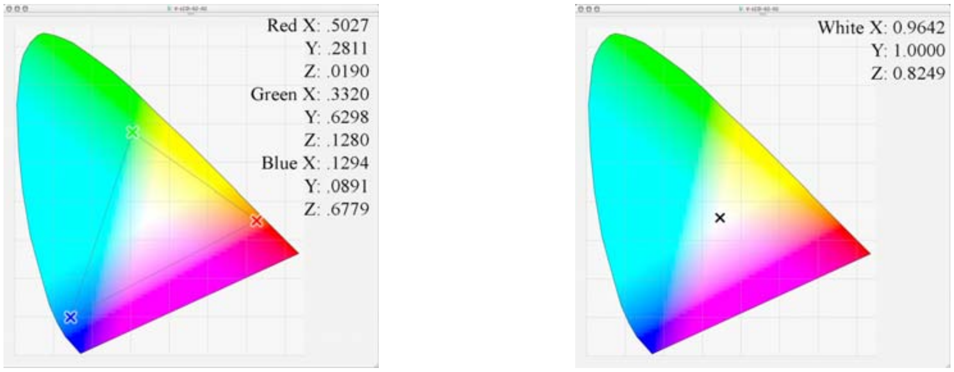
Figure 1. CRT Profile Information from ProfileMaker; RGB Primaries and WP



Red X: .5229
Y: .2821
Z: .0280
Green X: .3113
Y: .6552
Z: .1138
Blue X: .1300
Y: .0627
Z: .6831

White X: 0.9643
Y: 1.0000
Z: 0.8251

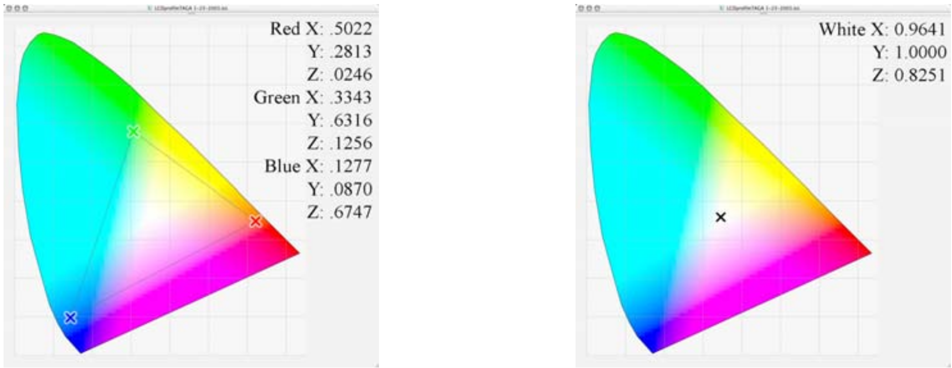
Figure 2. CRT Profile Information from MonacoPROFILER; RGB Primaries and WP



Red X: .5027
Y: .2811
Z: .0190
Green X: .3320
Y: .6298
Z: .1280
Blue X: .1294
Y: .0891
Z: .6779

White X: 0.9642
Y: 1.0000
Z: 0.8249

Figure 3. LCD Profile Information from ProfileMaker; RGB Primaries and WP



Red X: .5022
Y: .2813
Z: .0246
Green X: .3343
Y: .6316
Z: .1256
Blue X: .1277
Y: .0870
Z: .6747

White X: 0.9641
Y: 1.0000
Z: 0.8251

Figure 4. LCD Profile Information from MonacoPROFILER; RGB Primaries and WP.

The gamuts of both monitors were graphically compared using CHROMiX ColorThink software (Figure 5). As seen there, the CRT monitor provides a slightly wider projected gamut than the LCD panel. This represents the projection of all the gamuts onto the a^*, b^* plane.

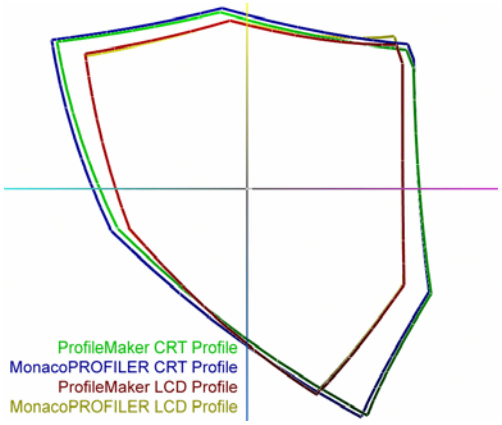


Figure 5. The Graphical Comparison of the Gamuts of the CRT and LCD Monitors

The $L^*a^*b^*$ (Lab) and RGB values from Photoshop's info palette were collected to check the consistency of displaying the colors in Photoshop software. In addition, the XYZ values of each patch were measured. The measured XYZ values were normalized to Y=100 for the white point and then converted to Lab for the chosen illuminant, D_{50}. It is important to do this for consistency of nominal and measured values, since the color temperature of an emissive light source is invariant under a uniform scaling of X, Y and Z (Sharma, 2002a). This procedure was done for both of the monitors with both sets of profiles.

In order to summarize the agreement between measured values, profile values and Info Palette values, we examine the ΔE values. These are given for all patches (R, G, B and W) for both monitors and both profiling programs in Table 1. The actual Lab values are given elsewhere. (Chovancova, 2003, Fleming, 2003)

Table 1: ΔE Values comparing profile data to Info Palette data and measured data for CRT and LCD Monitor for image displayed in RGB mode.

	CRT		**LCD**	
	ProfileMaker	MonacoPROFILER	ProfileMaker	MonacoPROFILER
	ΔE	**ΔE**	**ΔE**	**ΔE**
Profile Data & Info Palette Data				
R	0.23	0.46	1.00	0.32
G	0.33	0.51	0.45	0.58
B	0.31	0.44	0.38	0.66
W	0.00	0.02	0.00	0.02
Mean	**0.21**	**0.36**	**0.46**	**0.40**
RMS	**0.25**	**0.41**	**0.58**	**0.47**
Profile Data & Measured Data				
R	3.1	0.8	3.4	8.5
G	2.8	1.8	5.7	2.8
B	2.0	5.0	2.6	1.6
W	4.0	4.5	2.2	2.0
Mean	**3.0**	**3.0**	**3.5**	**3.7**
RMS	**3.1**	**3.5**	**3.7**	**4.7**

The overall agreement between the different measurements and the different profiles is seen to be very good. The largest discrepancy is for the red primary of the LCD monitor. This is explained by the fact that this primary has a very small Z value. The raw Z values were 1.2 and 1.1 for ProfileMaker and MonacoPROFILER, respectively. The corresponding normalized values were 1.5 and 1.4, respectively. The corresponding normalized values from the profiles were 1.9 and 2.5, respectively. The wide variation in b^* value from 69-77 (Chovancova, 2003, Fleming, 2003) is largely explained by the large derivative of b with respect to Z for small Z;

$$\partial b^*/\partial Z|_{Z\sim 1} \sim -6 \tag{1}$$

This is compounded by variations in Y values of 19.7 (24.8 normalized) for ProfileMaker and 21.2 (26.3 normalized) for MonacoPROFILER. The corresponding normalized value in both profiles was 28.1.

RGB-Lab Conversion

By performing the RGB-Lab conversion of the image, the quality of the monitor profile can be also evaluated. This enables us to check the consistency of the two modes.

The same image was displayed using the different monitor profiles as working spaces. Then, the image was converted to Lab mode (using Photoshop). The Lab values from the Info Palette and Lab values measured by the Spectrolino of each conversion were collected for both monitors.

In order to summarize the agreement between measured values, profile values and Info Palette values, we examine the ΔE values. These are given for all four patches (R, G, B and W) for both monitors and both profiling programs in Table 2.

Table 2: ΔE Values comparing profile data to Info Palette data and measured data for CRT and LCD Monitor for image displayed in Lab mode.

	CRT		LCD	
	ProfileMaker	MonacoPROFILER	ProfileMaker	MonacoPROFILER
	ΔE	**Δ E**	**Δ E**	**Δ E**
Profile Data & Info Palette Data				
R	0.23	0.51	1.00	0.32
G	0.33	0.46	0.45	0.58
B	0.31	0.44	0.38	0.66
W	0.00	0.02	0.00	0.02
Mean	**0.21**	**0.36**	**0.46**	**0.40**
RMS	**0.25**	**0.41**	**0.58**	**0.47**
Profile Data & Measured Data				
R	3.1	0.8	3.4	1.2
G	2.8	1.8	5.7	8.2
B	2.0	5.0	2.0	1.1
W	4.0	4.5	2.2	2.1
Mean	**3.0**	**3.3**	**2.5**	**3.1**
RMS	**3.0**	**3.6**	**2.5**	**4.3**

Other measures of accuracy, stability and precision of profiles is seen by the comparison of colorimetric values for transforming Lab back to RGB mode and the corresponding round trip values. These are given elsewhere. (Chovancova, 2003, Fleming, 2003)

The variation in Lab values upon mode conversion is a measure of both the accuracy and precision of the profile. Ideally, there will be no variation upon change from RGB to Lab mode, since the intention of the transformation is to maintain colorimetric values.

Soft proofing setup

To look at the image under soft proof conditions, the image has to be converted to CMYK mode using the profile created for particular output device under specific conditions. In this research, two different output profiles were employed for conversion, the U.S. Web Coated (SWOP) v2 "SWOP", distributed by Adobe, and one based on TR001 "ANSI" that we built using ProfileMaker. The U.S. Web Coated (SWOP) v2 is a standard default profile of Photoshop 6-9 and InDesign 2-4 Color Settings menus. The TR001 output profile was created from the ANSI Technical Report data source. These profiles should be equivalent because they were created from the same data source defined by SWOP.

We note that there is no discernable difference between the projected gamuts of the two profiles (Figure 6).

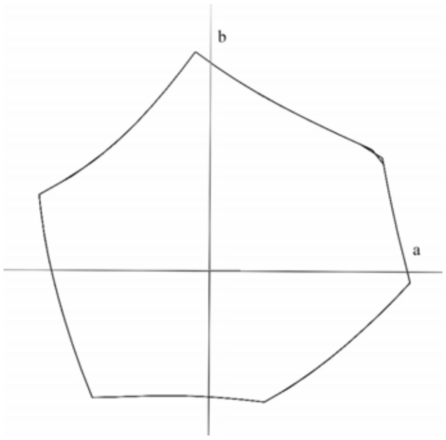


Figure 6. The Graphical Comparison of the Gamuts of ANSI and SWOP Output Profiles

CMYK Conversions

In subsequent analyses, only the ProfileMaker monitor profiles are used, but it is expected that the MonacoPROFILER profiles will give equivalent results, since, for practical purposes, they are identical. There are several methods to convert an image from the RGB working space to the CMYK working space using Photoshop (here using version 7). As stated above, it is most important to properly simulate "paper white" for quantitative soft proofing. These are illustrated below.

CMYK Conversion Method #1

For this method, the RGB image is converted into CMYK by converting the image to the two output profiles, the U.S. Web Coated (SWOP) v2 and TR001. The color patches were measured with the GretagMacbeth Spectrolino. The CMYK image was converted back to the RGB image using the particular monitor profile and the patches were measured again. The results are summarized in Table 3.

Table 3: ΔE Values of CMYK and RGB Mode for Conversion Method #1

	CRT Monitor		**LCD Monitor**	
	SWOP	ANSI	SWOP	ANSI
MODE	**Δ E**	**Δ E**	**Δ E**	**Δ E**
CMYK				
R	19.	14.3	19.6	16.8
G	10.6	9.8	10.1	9.8
B	16.4	12.7	16.5	10.2
W	13.2	12.1	12.6	11.9
Mean ΔE	**14.9**	**12.2**	**14.7**	**12.2**
RMS ΔE	**15.2**	**12.3**	**15.2**	**12.5**
RGB				
R	4.9	4.5	4.6	3.7
G	1.1	1.0	1.3	1.9
B	7.8	6.0	0.64	1.9
W	3.7	3.7	2.7	2.1
Mean ΔE	**4.4**	**3.8**	**2.3**	**2.4**
RMS ΔE	**5.0**	**4.2**	**2.8**	**2.5**

CMYK Conversion Method #2

For the second method, the RGB image was converted into CMYK, again using the two different output profiles, but a different conversion pathway. The transformations were made using the Proof Setup mode and “Simulate Paper White” was turned on. Again, the Adobe Conversion Engine and the absolute colorimetric intent were used. The RGB image was then displayed and converted into CMYK mode. The second set of the Lab values gathered for this RGB→CMYK→RGB conversion. It is not clear why this option should be separate from rendering intent or that specifying “Absolute Colorimetric” does not imply “absolute paper simulation” (Borg, 2004). The results are summarized in Table 4 below.

CMYK Conversion Method #3

The third set of Lab values stored for RGB-CMYK-RGB conversion was done the same way as in the method #2, except that the paper simulation was turned “Off”. The results are summarized in Table 4 below. The Lab values and calculated ΔE values from the Info Palette and measured ones of all the conversions for CRT and LCD monitor done by this method were given by Chovancova (2003). Again, it is not clear what it means to turn off “paper simulation” with “Absolute Colorimetric” rendering intent. Likewise, it is not clear what paper simulation “On” means for Relative Colorimetric Rendering Intent, although this choice is available.

According to these results for ΔEs, the ways to display images for soft proofing were considered. The conversion method #2, View>Proof Setup>Custom menu with the paper simulation turned “On” was chosen for the further investigation of the soft proofing system, because it was the only one that gave consistent agreement among measured

RGB and CMYK modes and info palette results. We also note that conversion methods #1 and 2 give equivalent quality and the actual measured values are essentially the same (Chovancova, 2003, Fleming, 2003).

Table 4: Δ E Values of CMYK and RGB Mode for Conversion Methods #2 and #3

	CRT Monitor		**LCD Monitor**	
	SWOP*	ANSI**	SWOP	ANSI
MODE	**Δ E**	**Δ E**	**Δ E**	**Δ E**
Conversion Method #2				
CMYK				
R	5.3	4.8	3.7	2.1
G	4.5	4.4	4.1	4.7
B	8.7	7.2	6.2	5.2
W	4.7	4.9	4.5	3.6
Mean ΔE	**5.8**	**5.3**	**4.6**	**3.9**
RMS ΔE	**6.0**	**5.4**	**4.7**	**4.1**
Conversion Method #3				
CMYK				
R	15.1	13.4	15.8	14.1
G	9.2	8.1	9.5	8.5
B	14.0	10.9	9.1	9.2
W	13.1	11.8	12.3	7.2
Mean ΔE	**12.8**	**11.0**	**11.7**	**9.7**
RMS ΔE	**13.0**	**11.2**	**12.0**	**10.1**
RGB				
R	5.3	4.6	3.7	2.6
G	4.2	4.4	5.7	4.4
B	7.4	7.1	5.8	4.7
W	3.8	5.0	3.1	2.8
Mean ΔE	**5.2**	**5.3**	**4.6**	**3.6**
RMS ΔE	**5.4**	**5.4**	**4.7**	**3.9**

Macbeth ColorChecker® Chart Test

After the establishing the methodology to display images for soft proofing, a test with the digital version of the Macbeth ColorChecker Chart in $L^*a^*b^*$ mode was conducted. This chart provides 24 patches with a wide range of colors. Many of these squares represent natural objects of special interest, such as human skin, foliage and blue sky. The patches on the printed chart also reflect light the same way in all parts of the visible spectrum.

In the first step, the chart was downloaded (Colorremedies, 2006) as a Tiff image and opened in LAB mode in Photoshop. The image was then converted to RGB mode by Image>Mode>Convert to Profile using the monitor profiles. ΔE values are calculated from data of Info Palette and measured ones. The results are summarized below in Table 5.

Table 5: ΔE Values of the ColorChecker® Chart Displayed in RGB Mode

MODE	**CRT Monitor**	**LCD Monitor**
RGB		
Mean ΔE	**3.1**	**2.5**
RMS ΔE	**3.4**	**2.7**

The next step was to convert the RGB image to CMYK using conversion method #2 described above. The conversions were completed for two output profiles and the Lab values for CRT and LCD monitors for the conversions were collected. The calculated ΔE's comparing Info Palette and measured data of all patches are presented in table 6.

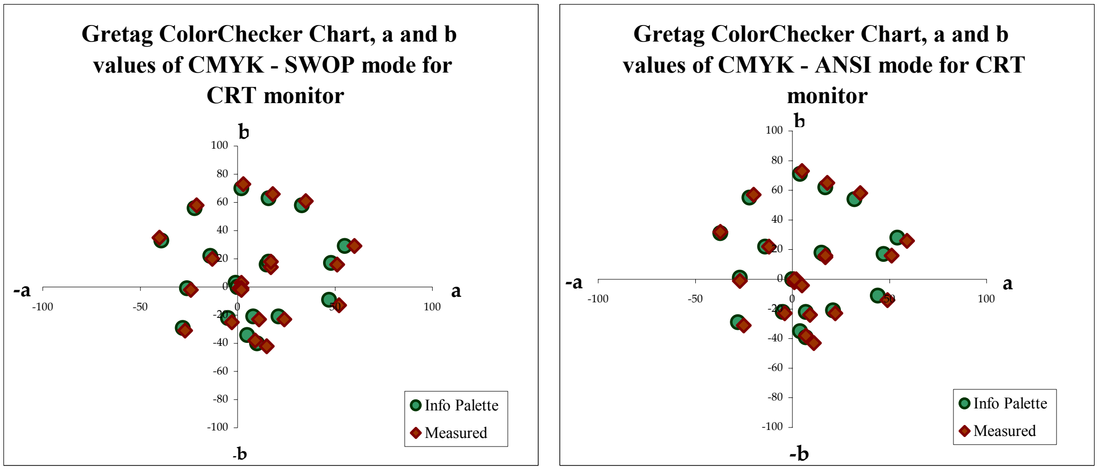
Table 6: ΔE Values of CMYK Mode for Conversion Method #2

	CRT Monitor		**LCD Monitor**	
MODE				
CMYK	SWOP	ANSI	SWOP	ANSI
Mean ΔE	**3.1**	**3.1**	**2.3**	**2.0**
RMS ΔE	**3.3**	**3.5**	**2.4**	**2.2**

The ColorChecker Chart Test provides better and more precise results to check the quality of the profiles, because it samples a larger portion of the color gamut. In this case, a whole series of patches were used to check the accuracy of the profiles and the response of Photoshop software to display these color patches in the soft proofing mode.

The values of the ΔEs have the same trend as the values for RGB mode. In addition, for this part of the experiment, the quality of the output profile and the ability of Photoshop to work under soft proofing conditions are good. The LCD panel again appears slightly more stable than the CRT monitor does, when displaying the images under soft proofing conditions.

Graphs were plotted to compare two different Lab color spaces: the measured values of the chart the values of Photoshop's Info Palette. Only a and b values were considered to plot, due to the investigation of 'color' properties, and not the luminance attribute L. These graphs, comparing the color assets of CMYK mode for both conversion profiles and both monitors, are given in the Figures below.


Gretag ColorChecker Chart, a and b values of CMYK - SWOP mode for CRT monitor

Gretag ColorChecker Chart, a and b values of CMYK - ANSI mode for CRT monitor

Figure 7. The a and b values of CMYK SWOP and ANSI mode for CRT, respectively.

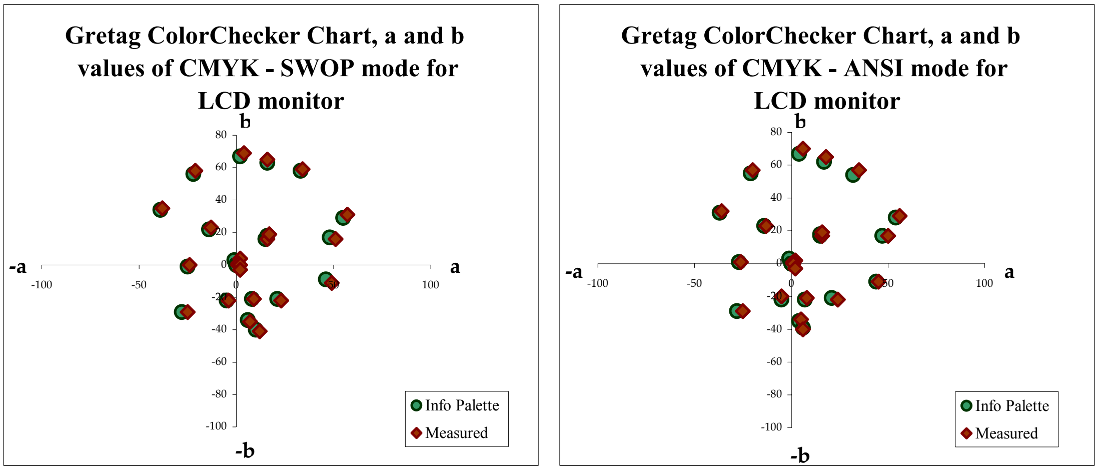


Figure 8. The a and b values of CMYK SWOP and ANSI mode for LCD, respectively.

ANSI/CGATS TR 001-1995 Output Profile Test

An additional test for output profile was carried out in this research. The ANSI Standard IT8.7/3-1993, graphic technology - input data for characterization of 4-color process printing, was developed to provide a common CMYK data set to facilitate the development of characterization data that would meet the needs of most users.

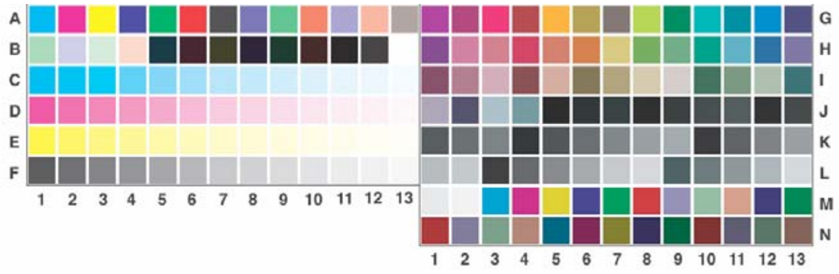


Figure 9. Subset Part from ANSI IT8.7/3-1993 Chart

Some patches from the subset area of the IT8.7/3-1993 chart (Figure 9) were critically selected (Chovancova, 2003, Fleming, 2003). The corresponding CMYK and Lab values were taken from the TR001 Technical Report.

The CMYK patches are created in the CMYK mode and Lab values from the info palette were compared with the Lab values given in the report. The soft proof conditions were assigned and values were observed from the Info Palette.

Three sets of a and b values are plotted in the graphs below (Figures 10.a and b). The evaluated color values of CMYK mode for both conversion profiles and both monitors are sketched below. In the graphs, are compared with the a and b values from the TR001 Report, a and b values from Info Palette and measured ones for the CRT and LCD monitors.

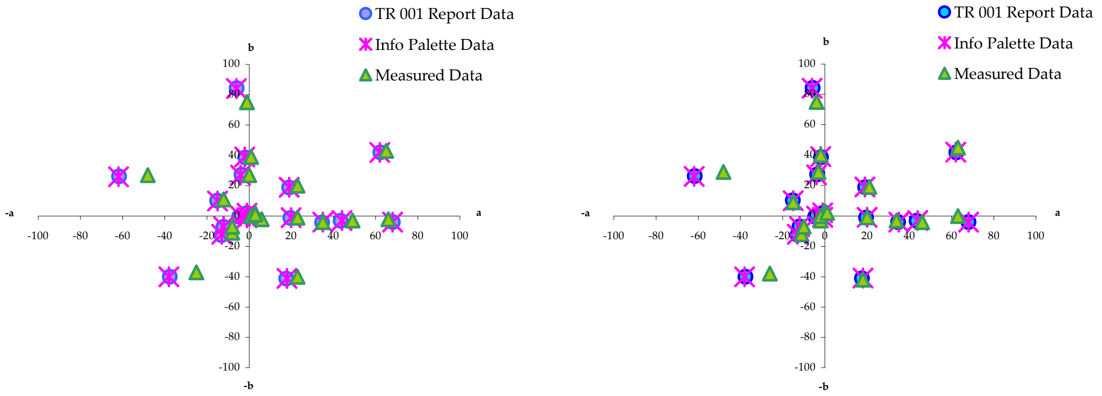


Figure 10. a and b. Comparison of a and b Values From the ANSI/CGATS TR001-1995 Report, from the Info Palette and Measured Ones for the CRT Monitor and LCD Monitor, respectively.

As seen in figures above, the data gathered from the TR001 Report are very close to those from the Info Palette. This confirms that both output profiles are working correctly and have the same database, as expected. Furthermore, Photoshop correctly displays to the screen and the Info Palette. The ΔE's are shown in table 7. The values of ΔE are small enough that they can be considered as equivalent, though not necessary identical (different GCR). This is markedly apparent from the graphs above.

Table 7. ΔE Values Calculated from Lab Values of the ANSI/CGATS TR 001-1995 Report and Photoshop's Info Palette Displayed in CMYK Mode

	CRT Monitor	**LCD Monitor**
	Report vs. Info Palette	**Report vs. Info Palette**
Mean ΔE	**0.63**	**0.63**
RMS ΔE	**0.74**	**0.74**

On the other hand, the measured values are a little bit shifted from the two sets of a and b values, which were compared above. In Table 8, the ΔE values for the measured Lab values compared to data from the report are shown. The values demonstrate the small color shifts. Although the average color shifts are reasonably small, the magnitudes of the deviations were dominated by three patches, which were out of the gamuts of both monitors. These are points A01, A03 and A05, 100% C, 100% Y and 100% CM, respectively. This was confirmed by both the measured and profile predicted values. In addition, point A02, 100% M was out of Gamut for the LCD monitor, both from the measurements and the profile prediction.

Table 8. ΔE Values Calculated from Lab Values of the ANSI/CGATS TR 001-1995 Report and Measured Ones Displayed in CMYK Mode

	CRT Monitor	**LCD Monitor**
	Report vs. Measured	**Report vs. Measured**
Mean ΔE	**2.9**	**3.9**
RMS ΔE	**3.9**	**5.4**

Printed Proof vs. Displayed Image Evaluation

As a final confidence test, a visual evaluation was performed. The CRT and LCD monitors were employed to display images. The images on the monitors were then compared to printed images.

Two output printer profiles were used to print out the images, the previously created profile from the TR001 Report and a newly created profile for the printer. The new profile of the printer was created using GretagMacbeth ProfileMaker. The ANSI IT8.7/3-

1993 chart was printed on the Epson Stylus Pro 5000 printer and then automatically read by the GretagMacbeth SpectroScan spectrophotometer. The output profile of the printer was calculated for D_{50} illuminant and 2 degree observer and stored.

The procedures described above were followed to obtain the soft proofing system pathway. Images were opened in Photoshop and converted to CMYK mode. Then the selected conversion method was chosen and the images were displayed at the screen as soft proofs. They were compared to printed images placed in a 5000 K viewing booth.

No experiments with human observers and ranking were employed to qualitatively or quantitatively summarize the results. The visual comparison was consistent with the numerical comparison, but is not definitive because of lack of observer tests.

Conclusions

In a soft proofing system, a monitor is supposed to show what a hard copy will look like from a target output device. Quantitative considerations were accomplished in this research work to provide these results. The process was focused on separate parts of a soft proofing system and each of the steps was quantitatively evaluated.

The first part of the experiment explored the evaluation process of color monitor profiles, along with the color quality of software used to achieve these profiles. Two monitor profiles each, for CRT and LCD monitors were created and the quality of the profiles was determined. The ΔE values obtained are more than satisfactory. It was shown that the profiles, along with Photoshop software, give essentially exact results within the normal fluctuation of display devices. Generally, slightly better results were seen for the LCD display, suggesting that its values are slightly more stable. By performing the RGB-LAB conversion of the image, the quality of the monitor profile was further evaluated. The ΔE values were again in the acceptable range, but in this case, slightly better results were seen with the CRT monitor.

Three methods to convert image from RGB space to the CMYK were analyzed. Surprisingly, only one was acceptable. To preview the image most accurately, it is advised paper simulation be turned “On”. The other two options reveal significant discrepancies, which will be investigated in the future. Because images could be displayed by “too many” ways, everybody should be aware of how the image should be displayed to match requirements. The conversion method #2, with the paper simulation turned “On” was chosen for all further investigation of the soft proofing system.

Another issue arose during this research. As far as we know, both output profiles were created from the same data source. Thus, we would expect the same results in our CMYK conversions. The diversity of two output profiles, the U.S. Web Coated (SWOP) v2 as well as the ANSI/CGATS TR 001-1995, should be verified in future work. The colorimetric difference between these two profiles is not significant. However, subtle details of the profile building process, such as GCR strategy, black threshold, etc. could lead to unexpected differences for some colors. Thus, the fact that profiles created from the same source of data can vary, is further illustrated.

The GretagMacbeth ColorChecker® Chart Test and ANSI/CGATS TR 001-1995 Output Profile Test were chosen to more precisely assess the color quality of the monitors and output profiles in greater detail. These showed similarly good quality results. The accuracy of the monitor profiles can be deemed as excellent. The output profiles are also working acceptably. From the results found here, the LCD Display shows not significant, but still better, results than the CRT monitor. This confirms that the technology of LCD panels has developed sufficiently for their use in precise color work. The enhanced quality of LCD monitor profile could be based on the technology used to transform values. The profile making software usually uses a matrix for CRT's and Look Up Tables (LUT) for LCD's.

The CRT and LCD monitors were employed to display images and visual evaluations were performed. The images on the monitors were then compared to the printed images. The procedures described in the experimental part were completed to obtain the soft proofing set up. Images were opened in Photoshop and converted to soft proofing mode by the selected conversion method. They were compared to printed images placed in the viewing booth under D_{50} light conditions. Looking at the images, soft proofing set up was satisfying, but not definitive. The whole process described in this research leads to predicted results that soft proofing can work under very specific conditions. Using these methods, designers, prepress professionals and the ultimate customer are able to achieve high-quality quantitative results.

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