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CRT Versus LCD Monitors for Soft Proofing: Quantitative and Visual Considerations

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CRT VERSUS LCD MONITORS FOR SOFT PROOFING; QUANTITATIVE AND VISUAL CONSIDERATIONS

by

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Quantitative and visual considerations of accuracy of colors in images displayed on two types of monitors employing a soft proofing system were accomplished in this research work. Soft proofing proposes possible savings in material and time, which are essential issues of current digital and quick turn around workflow. The investigation focuses on the quantitative evaluation process of color monitor profiles along with the color quality of software used to achieve the created profiles. Specific tests are provided to look at the color quality of the monitors and output profiles in greater details. Also, a general comparison of the CRT and LCD monitors as used in prepress for soft proofing are discussed.

Photoshop 7.0.1 demonstrates the colorimetric changes on the images. The GretagMacbeth ProfileMaker 4.1.1 Pro system is used to create the ICC profiles herein as an example of a commercially available product. The process described in this research leads to predicted results that soft proofing could work under specific conditions. It was also found that the LCD shows slightly better results than the CRT monitor. In conclusion, using certain methods consumer is able to get high-quality results when using soft proofing.

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INTRODUCTION

The world is highly dependent on color presentation of images. Thus, scientists are beginning to work with CMS (Color Management System), which helps resolve color-matching issues within the workflow of the graphic arts industry. Soft proofing is described as a process of setting up calibrated viewing conditions between originals, a monitor and hard copy proofs where the monitor shows what a job will look like when printed. Nowadays, there is a tendency to employ soft proofing using CRT's and LCD's in the prepress world. Computer-controlled CRT (Cathode Ray Tube) monitors and LCD (Liquid Crystal Display) flat panel monitors can be characterized on the basis of color theory and additional concepts of the CMS using both Macintosh and PC platforms. CRT and LCD monitors use completely different technologies, and thus have quite different display characteristics. Accordingly, special attention is given to comparison of color image presentation and profile quality for LCD and traditional CRT monitors.

Soft proofing technology has in fact been around for a number of years. The time to market is extremely important, it is more and more critical to get printed jobs out promptly. As the industry attains full digital production workflow, soft proofing offers possible savings in time and money, as well as reduced supply requirements in material and transportation. In fact, now monitors are being developed specifically for graphic designers, digital photographers and prepress professionals. Also, color management products let the users calibrate 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.

In order to establish the background and lay down terminology, fundamental concepts of color perception and measurement are presented in the first part of Literature Review along with the common mathematical models for evaluating color information.[1] Present color systems, such as CRT and LCD monitors, are reviewed. Algorithms for processing color images on display are outlined, too.

The International Color Consortium (ICC) has defined a profile format by which input, output or display devices, be they described by RGB or CMYK, are characterized by device independent color. The main factors critical to color control of display devices, such as age, warm-up time, monitor gamma, white point, black point, color temperature, color accuracy, monitor calibration and outside interference are usually evaluated.

This research describes the issues that concern with output profile – monitor profile. Two monitors were chosen to represent both groups: 17" Mitsubishi Diamond Plus 73 CRT Monitor and 17" Apple Studio LCD Display. Profiles were made for these monitors using GretagMacbeth ProfileMaker 4.1.1 software. The procedures to create and evaluate the quality of monitor profiles are schematically illustrated. The quality of monitor profiles is investigated. All tests were done on the Macintosh platform with Mac OS 10.2.3. Photoshop 7 was used to evaluate and measure the quality of displayed images and profile quality. A general comparison is given for two types of displays, CRT and LCD. For both monitors, profiles show equivalent good quality results.

The whole process of printing production is always specified by different ways. The most significant printing specification in the United States is the press proofing portion of the current Specifications for Web Offset Publications (SWOP)[2], which addresses the larger subject of the preparation and proofing of input material for reproduction by web offset and gravure publication printing. The SWOP specifications provide the necessary information for suppliers of input materials for advertising and editorial pages to magazines to do so in a uniform way.

Two output profiles were used to observe the printed proof appearance on the displays: the U.S. Web Coated (SWOP) v2 and the ANSI/CGATS TR 001-1995[3], both based on the SWOP specifications. The U.S. Web Coated (SWOP) v2 is a standard default profile of Photoshop 7.0 Color Settings menu. The ANSI/CGATS TR 001-1995 output profile was created from the ANSI Technical Report data source using GretagMacbeth ProfileMaker 4.1.1 software. The correct way in which to display images by Photoshop was chosen. It was observed in this research that only one way to soft proof on the display is correct. We also found that two profiles created from one source of data vary from one another. The results for output profiles were compared. Other features of output profiles are considered such as GretagMacbeth ColorChecker® Chart Test and ANSI/CGATS TR 001-1995 Output Profile Test.

The response of monitors to display images and to work with profiles based on concepts of Color Management System is investigated. The general comparison of CRT and LCD monitor in the terms of Lab values and ΔE color differences is presented in this study. Unsurprisingly, the results show that the LCD monitor has the equal quality and works well with the profiles. In some cases LCD behaves more precisely than the CRT.

Images are printed on the 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 done. Discussion about the image correspondence between the printed proof and the displayed one is enclosed.

LITERATURE REVIEW

Fundamentals of Color Theory

Achieving consistent color can be the most difficult part of the design production process. Color always results from interaction between the nature of light, the interaction of light and matter, and the physiology of human vision. All three elements must be present for color, as we know it to exist. Basically, we can see color when a light source that emits a particular distribution of differently colored wavelengths of light strikes a colored object. The object reflects (or transmits) that light in another particular distribution of colored wavelengths, which is then received by the photoreceptors of the human eye. [1,4]

Light & Color

Light can be described as the wavelengths of the electromagnetic (EM) spectrum, the fluctuations of electric and magnetic fields in nature. Simply, light is energy and the phenomenon of color is a product of the interaction of energy and matter. Light has the properties of both particles and waves.[5-7]

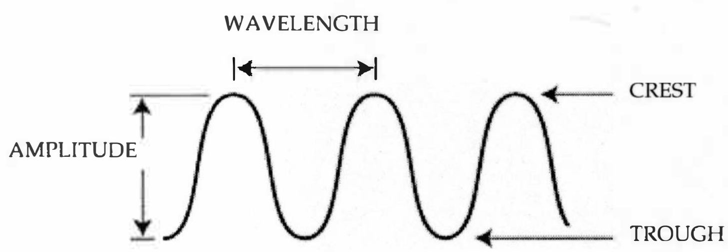

Figure 1. Light Waves

Light particles, called photons, radiate from their source in a wave pattern at a constant speed of 2.997928×10^{10} cm/s. Light waves have a crest and a trough (Figure 1). [8] The whole electromagnetic spectrum contains of several specific regions. Shorter wavelengths are higher frequency and higher energy, e.g. cosmic rays or X-Rays; longer wavelengths have lower frequencies and lower energy, e.g. radio or TV wavelengths (Figure 2). Infrared lies just below red light; ultraviolet exists just above violet light and both are invisible to humans.

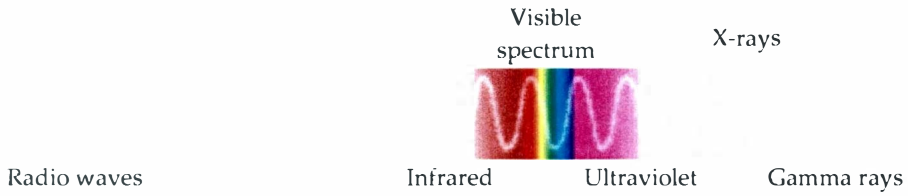

Figure 2. Electromagnetic Spectrum

Prior to the time of Sir Isaac Newton, the nature of light and color was rather poorly understood.[9,10] Newton's meticulous experiments [11,12] with sunlight and a prism helped dispel existing misconceptions and led to the realization that the color of light depended on its spectral composition. Even though Grimaldi preceded Newton in making these discoveries, his book [13,10] on the subject received attention much later, and credit for the widespread dissemination of the new ideas goes to Newton.

In 1666 Isaac Newton discovered that white sunlight is composed of all the colors of the rainbow.[11] Passing "white" light through a glass prism bends the light beam. Shorter, higher- energy wavelengths bend more than longer, lower-energy ones, thus we can see refraction of the light as rainbow with many different colors. The region of the electromagnetic spectrum visible to the human eye ranges from about 380 nanometers to 720 nanometers. This small fragment is called the visible spectrum or visible light.

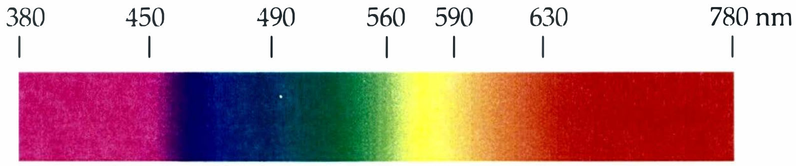

Figure 3. Visible Part of Electromagnetic Spectrum

Perception of Color

Nowadays, we are still not able to understand what happens in the brain when we see colored subject. The visual sensation occurs when light excites photoreceptors in the eye called cone cells (Figure 4).

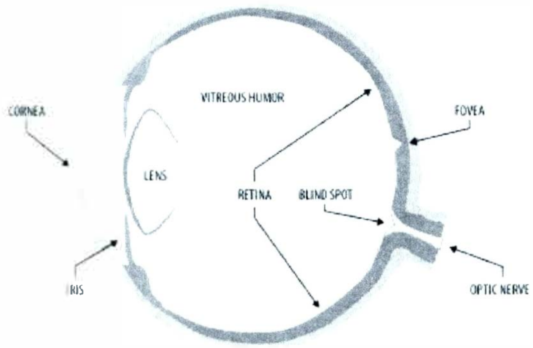

Figure 4. Human Eyeball

The eye contains two types of light sensitive cells — rods and cones, which can be found in the retina. Rod cells are sensitive to motion and to subtle differences between light and dark. Rods function when light is low, but cannot detect color. At higher light levels, three types of cone cells become sensitized and allow us to perceive color. Long-, medium-, and short-range cone cells can be found in our eye perceptive system and they present three main parts of visible spectrum; red-R, green-G, and blue-B. [5,8] The world of color is more complex; we rarely see all wavelengths at once. Color is then not simply a part of light, it is real light. In basics, the light is modified into a composition of many wavelengths. All colorful objects can be seen because each object sends to our eyes a unique composition of wavelengths.[14-16]

Human color vision is described as a trichromatic process. The visual sensation of color is as subjective as our other sensations — taste, touch, hearing, and smell. The spectral sensitivity of the eye thus varies slightly from person to person. Even the mood can influence the perception of color. In addition, external circumstances have an influence on the way a color appears. The perception and description of color involves both physical and physiological quantities. While the physical components are measurable, the physiological components are not. The physical characteristic of a color stimulus can be established with the help of color measurement devices. The concept for the description of color to date is the set of specifications established in 1931 by the Commission Internationale de l'Eclairage (CIE) on the basis of the CIE standard colorimetric observer.[17-23]

Reproduction of Color

There are only two methods of how to reproduce color – additive and subtractive.[24,25]

The additive color process begins with black, or the absence of light and therefore no color. It involves transmitted light before it is reflected by a substrate. Red, green, and blue (RGB) are the primary stimuli for human color perception and are the primary additive colors. Three beams of light, each projected through colored filter, illustrate how additive color works. The secondary colors of RGB, cyan, magenta, and yellow, are formed by the mixture of two of the primaries and the exclusion of the third. Red and green combine to make yellow, green and blue make cyan, blue and red make magenta (Figure 5.a). "White" appears where red, green, and blue overlap.[26] The most common examples of this are television screens, projection TV, stage lightening and computer monitors, which are based on additive color. The production of colored pixels by firing electron guns at red, green, and blue phosphors is the common process on the television or monitor screen.[27,28]

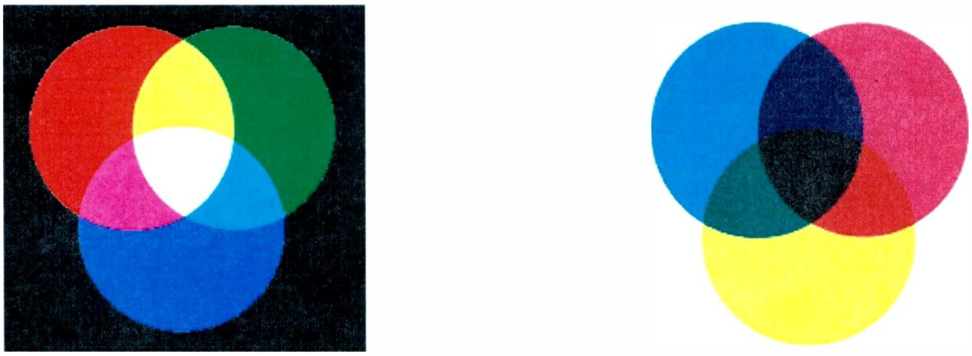

Figure 5a,b. Additive and Subtractive Color Mixing

The subtractive color process is based on light reflected from an object and which has passed through pigments or dyes that absorb or subtract certain wavelength, allowing others to be reflected. Cyan, magenta, and yellow (CMY), as used in four-color process printing, are the subtractive primaries. This is the nature of color print production and the subtractive color model in printing operates not only with CMY(K), but also with spot colors. Just as the primary colors of CMY are the secondary colors of RGB, the primary colors of RGB are the secondary colors of CMY as shown in Figure 5.b. Cyan and magenta create blue, magenta and yellow make red, yellow and cyan combine to make green.

CIE Color System

Color Temperature & CIE Illuminant

The term color temperature is used to describe the chromaticity of the basic monitor settings. Color temperature is expressed in Kelvins, a temperature scale with zero point at -273.15°C, or absolute zero. The system was developed to measure absolute temperature and published in 1848 by Lord Kelvin (William Thomson).[29]

Light sources are usually characterized by color temperature. The link between temperature and color is made by a theoretical light source called a blackbody radiator whose emitted colored light depends on its temperature. These model sources are also called Planckian radiators (after Max Planck, the German physicist who developed Planck's Law, a formula for determining the spectral power distribution of a light source based on its temperature).[7,30] This phenomenon occurs when a tungsten filament is heated until it melts. The light that it emits changes from red over white to blue. The higher the temperature of the metal, the more bluish its emitted light is.[19]

The CIE standard illuminants were first established in 1931 as a set of three, identified as A, B, and C.

- Illuminant A represent incandescent lighting conditions with a color temperature of about 2856 K; (100-watt tungsten lamp);

- Illuminant B represents direct sunlight at about 4874 K;
- Illuminant C represents indirect sunlight at about 6774 K.

Later, the CIE added a series of D illuminants, a hypothetical E illuminant, and a series of F illuminants. The D illuminants represent different daylight conditions, as measured by color temperature.[17-19] For instance, the CIE defined D_{50} as standard illuminant type; with the number 50 referring to the color temperature, in this case 5000 K. Repro specialists generally use a light source with a temperature of 5000 K. Photographers often prefer a light source with a color temperature of 6500 K, corresponding to medium daylight.[31]

CIE Standard Observer

The experiment to define the standard observer could be dated back to Isaac Newton in 1666. While Newton's experiments established a physical basis for color, they were still a long way from a system for colorimetry. In twentieth century Wright and Guild's experiments [20,21] were focused on discovering how the different colors of the spectrum can be matched by mixing the three additive primaries. The colors of the spectrum could be matched by mixing certain quantities of red, green and blue, according to the vision of a standard observer.

The CIE standard observer is a numerical model of human color sensitivity based on a sample of 17 individuals with normal color vision. The procedure used is as follows. Subjects view light from a spectral color on a white screen. A nearby part of the screen is illuminated by light from three primary colored lights (red, green and blue). The subject can adjust the three primary colors on the screen to match of the test lamp. The amounts of primary colors needed to match the spectral color are known as the color's color matching functions.

Standard observer data consist of three components: the sensitivity to red ($\bar{x}$), green ($\bar{y}$), and blue ($\bar{z}$). The CIE 1931 standard observer was defined using a viewing aperture of 2° and is know as the 2° standard observer. It is corresponding to the most sensitive region of the human eye's fovea. In 1964 the CIE performed another experiment in which a 10° field of the view was used to provide a sample representing a wider view. The 1964 standard observer is also known as the 10° standard observer.[17-19]

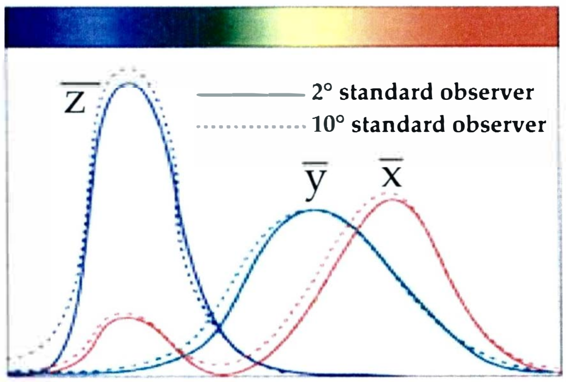

Figure 6. The CIE 1931 2° Standard Observer Color Sensitivity Curves

CIE Chromaticity Values

To make these values easier to work with, the CIE specified a system of virtual primary values, called CIE XYZ tristimulus values. These are referred to as CIE coordinates X, Y and Z, with X corresponding to a virtually red tristimulus value, Y to an imaginary green, and Z to an imaginary blue value. The spectral values associated with these standard tristimulus values are referred to as standard spectral values, and the color values calculated on this basis are called standard color values. Tristimulus values of a measured color are calculated by multiplying, for each wavelength interval used, the spectral power distribution of the light source (P), the spectral sensitivity of the standard observer ($\overline{x}$, $\overline{y}$, or $\overline{z}$), and the spectral reflectance curve of the measured sample (R) as follows.[8]

$$X = k\int PR\overline{x} \qquad Y = k\int PR\overline{y} \qquad Z = k\int PR\overline{z} \tag{1}$$

where:

k - a constant, which is a function of the power distribution

P - spectral power distribution of light source

R - spectral reflectance of object

$\overline{x}$, $\overline{y}$, and $\overline{z}$ - standard observer functions,

The standard spectral values allow for the deduction of a number of special characteristics. An ideal white features the standard spectral values X=Y=Z=100, with brightness characterized directly by the imaginary standard spectral value Y. The primary color of green light (546 nm), chosen by the CIE to define the standard observer, corresponds with overall human visual response to all color or lightness. Therefore, the Y value indicates not only a sample's green response but also its luminance or lightness value.[32-35]

CIE Chromaticity Diagram

CIE xyz chromaticity values (Eq. 2) provide a method of graphically plotting the colorimetric values of a sample in three-dimensional color space.

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z} \qquad (2)$$

where:

X, Y, and Z are the tristimulus values of the red, green, and blue responses, respectively (source x object x observer)

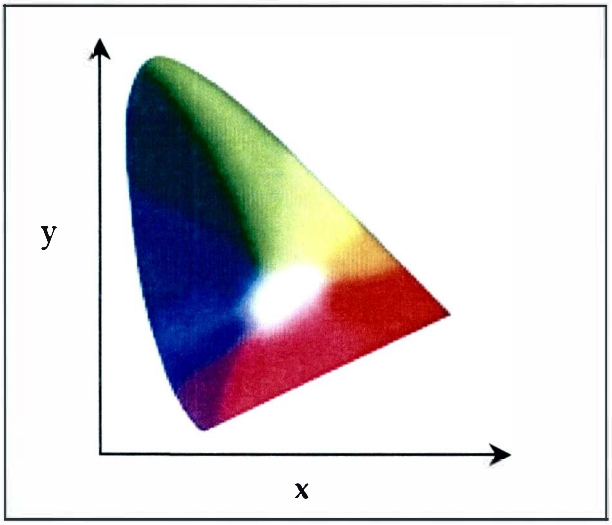

Figure 7. CIE Chromaticity Diagram

The resulting representation is known as the CIE 1931 Chromaticity diagram, or "horseshoe" (Fig. 7). The axes of this color space are similar to the HSL color space. Chromaticity coordinates x, y and z (hue and chroma) are a simple transformation of tristimulus values that can be represented on a twodimensional graph. The CIE chromaticity diagram plots x on the horizontal axes and y on the vertical axis. The third dimension is tristimulus Y (luminosity), which represent how bright the color is.[17]

CIE xyY color values are straight calculations from XYZ tristimulus values and according to this, it is possible to plot all achievable colors. All other color spaces (e.g. RGB, CMYK,) are subsets of the CIE 1931 color space and the full range of these color spaces can be represented in the context of the CIE 1931 xyY model. However, The XYZ color space is a device-independent, repeatable standard. The CIEXYZ color system is specified as an important reference color space under standard illuminant D_{50} at a viewing angle of 2 degrees.

CIELAB Color Model

A practical limitation of the CIE chromaticity diagram is that it does not provide a perceptually uniform color space. The distance between two or more colors in xyY space does not necessarily correspond with the colors' visual similarity or difference. Apart from systematic allocation of the CIE chromaticity diagram, other concepts for the creation of equidistant color system and distance formulas were developed, known as the Compensation Color Theory by Hering.[36]

The two uniform color spaces accepted by the CIE are called CIE $L^*a^*b^*$ & CIE $L^*u^*v^*$, both accepted in 1976.[19] The former is mostly used for flat reflective color, whereas the latter is used for color displays. These are mathematical transformations of the XYZ color space where the Euclidean distance between two colors is proportional to the perceived difference between both. CIE L*a*b*, also CIELAB, is almost certainly the most accepted and significant color space based on Compensation Color Theory. The CIELAB color distance formula was used mainly to standardize different LAB models developed in the past. The coordinates L*, a* and b* can be calculated from the standard color values XYZ as shown in following formula.

$$L^* = 116\sqrt[3]{\frac{Y}{Y_n}} - 16; \qquad a^* = 500\left(\sqrt[3]{\frac{X}{X_n}} - \sqrt[3]{\frac{Y}{Y_n}}\right); \qquad b^* = 200\left(\sqrt[3]{\frac{Y}{Y_n}} - \sqrt[3]{\frac{Z}{Z_n}}\right) \qquad (3)$$

where:

X, Y, and Z are the tristimulus values of red, green and blue responses

Xn, Yn, Zn – tristimulus values of illuminant and

$f(x) = x^{(1/3)}$, $x > (6/29)^3 = 0.008856\ldots = (29/6)^2 x/3 + 16/116$, $x < (6/29)^3$

In the new model, the color differences, which people perceive to be equispaced, really do correspond to those distances when measured colorimetrically. The *a* axis extends from green (-*a*) to red (+*a*) and the *b* axis from blue (-*b*) to yellow (+*b*). The brightness (*L*) increases from the bottom to the top of the three-dimensional model (Fig. 8).[17-19]

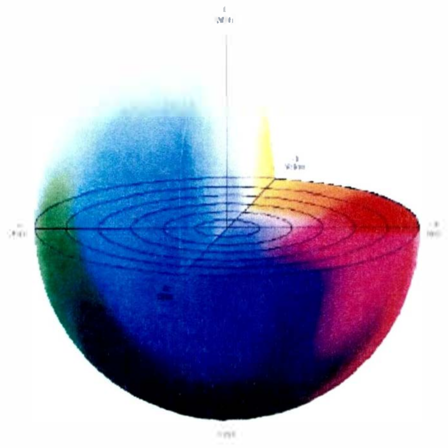

Figure 8. CIELAB Color Space

Color Difference – Delta E

CIELAB color values are often used in quality control, such as for comparing the differences in a reproduction and original. The numerical value specifying the distance between two colors in a color space system is generally indicated as Delta E (ΔE). Delta E is calculated using the distance formula to determine the distance in color space from one color to another within one color space (Equation 4).

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \quad (4)$$

where:

L_1^*, a_1^*, b_1^* – CIELAB coordinates of reference color

L_2^*, a_2^*, b_2^* – CIELAB coordinates of comparison color

Some color management system vendors prefer not to use CIELAB values for device characterization, because it is not perfectly uniform. Some manufacturers use CIE XYZ tristimulus values along with their own proprietary appearance models to compute color profiles.

When working with colorimetrically controlled reproduction systems (Color Management System), it is much easier for the untrained user to describe and edit CIELAB data in its LCH representation. Chroma C and hue angle h are calculated from values a^* and b^* as shown in formulas.[37]

$$C_{ab}^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (5)$$

$$h_{ab} = \arctan\left(\frac{b^*}{a^*}\right) \quad (6)$$

Color Measurement and Control

Color measurement is performed primarily with the aid of spectral measurement devices (spectrophotometers) or tristimulus measurement devices (colorimeters) based on spectrophotometry fundamentals.

Color measurement instruments receive color the same way our eyes receive it. They gather and filter the manipulated wavelengths of light that are reflected or emitted from an object. The combination of light source, object and receptor is needed such as in human vision system. When an instrument is the viewer, it perceives the reflected wavelengths as a numeric value. The scope and accuracy of these values depend on the measuring instrument.[38-40]

Spectrophotometry & Photometry

Spectrophotometry is a versatile analytical tool. The underlying principle of spectrophotometry is to shine light on a sample and to analyze how the sample affects the light. There are a lot of advantages in spectrophotometry. It is usually non-destructive as one can measure and recover the sample. It is selective; often a particular compound in a mixture can be measured without separation techniques. It also has a short time interval of measurement. The fundamental components of a spectrophotometer consist of a radiation source, a wavelength selector (monochromator), and a photodetector and read device.

Photometry is the measurement of the attributes of light, though it is more commonly used to refer to measuring its intensity or flux. Luminous intensity, or luminance, refers to the amount of energy in a light source and is measured in units called candelas. Luminous flux, or the amount of light radiating from a source, is measured in units called lumens.[40-42]

Colorimeters. The tristimulus color measurement process of a colorimeter is based on the idea that the spectral sensitivity of three receptors in the human eye is accurately described by the CIE terms. It is possible to measure color by means of three sensors whose spectral sensitivities are comparable to those of the receptors of the eye. Usually three color filters, whose transparencies keep up a correspondence to the standard spectral value curves, are used in these devices as shown in Figure 9. Only three measurement values have to be established which then are directly converted to the CIE standard values.

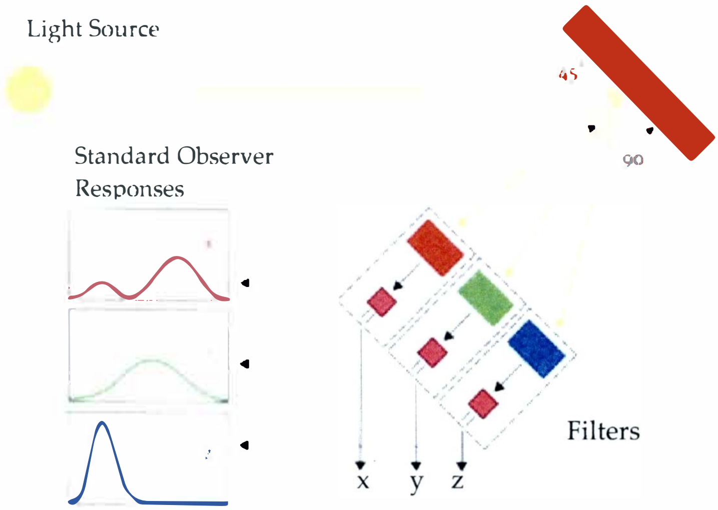

Figure 9. Measurement Principle of a Colorimeter

The spectral radiation distribution of the light source used is a critical variable. It should match as accurately as possible to the specified standard illuminant. The measurements are only compelling if the specified conditions, e.g. light source, observation angle, color filters or reproduction geometry, are guaranteed. The device establishes only the integral of the light intensity across the spectrum. As an example, the DTP92 Monitor Optimizer™ is a 4-band emissive colorimeter used to calibrate and create ICC monitor profiles or the MonacoSENSOR with precise internal sensors measure colors accurately, reducing the need for visual adjustments.

A colorimeter is better suited for establishing color differences than for absolute color measurement. To achieve accurate and more flexible color measurements, a spectrophotometer is always recommended for practical use. In practice, the use of spectrophotometers has also other advantages due to the fact that certain interfering color effects, such as metamerism, fluorescence or insufficiencies of the optical measuring system, can be detected with the aid of the spectral measurement data. This way, they can be eliminated using corresponding compensation calculations prior to their interpretation into CIE standard color values.[37]

Spectrophotometers measure color reflectance across the entire visual spectrum. They operate on the theory that each color can be described as an additive mix of spectral colors. The visible spectrum is split into miniature intervals, and the light intensities are measured individually in each wavelength interval. The Eye-One and Spectrolino from GretagMacbeth measures not only color proofs it also measures monitors, the emissive spectrum. Their iCColor is the fastest spectral chart reader, which is x/y capable, automatically reading the measurement charts both ways, vertically and laterally. The new X-Rite 939 offers the industry's premier accuracy and multi-unit agreement for hand-held spectrophotometers solutions. The X-Rite

DTP41 auto scanning spectrophotometer provides single-button operation and automation for fast, accurate results. It measures 480 color patches in less than five minutes.

Spectrophotometers can work with 10 nm intervals and thus establish roughly 30 individual light intensities across the visible spectrum. Much smaller intervals, such as 5 nm or 1 nm, can be measured in technically more sophisticated systems, but this is reflected in the higher price of such instruments (Figure 10). Spectrophotometric data are used to calculate color values, preceded by a mathematical simulation of the three receptors of the CIE standard colorimetric observers under a specific light source and at a defined observation angle. This way, the channel signal can be reduced to the defined quantities CIE XYZ for colorimetric evaluation and for following conversion to other color system, e.g. CIE $L^*a^*b^*$/CIE $L^*u^*v^*$. The software of a spectral color measurement device normally allows for direct conversion of the spectral data to the color system generally used nowadays.[37]

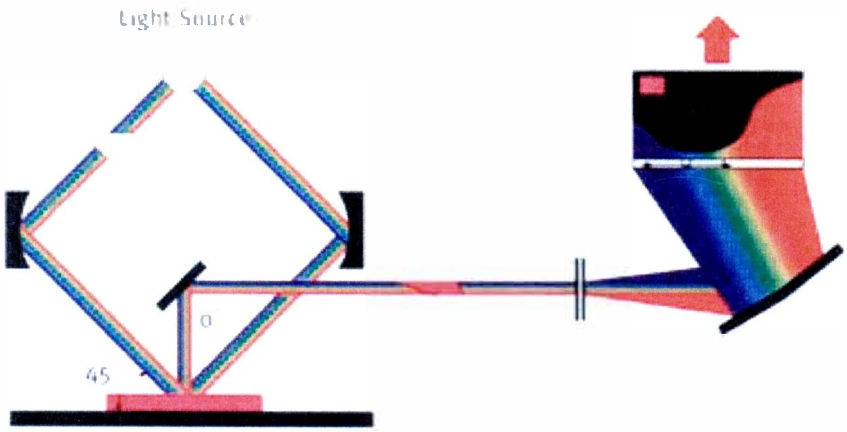

Figure 10. Measurement Principle of a Spectrophotometer

Monitors

At the various positions in the process workflow, where color precision is important (e.g., color correction, retouching and page assembly), the display serves as a soft proof device. In terms of production cost, every output of the system is quite expensive, even a proof print. Compared to that, the image on the display is relatively inexpensive.

PC monitors are not all the same any more. There are now more types of monitors being widely used. CRT displays are optical radiation sources and such as, are treated as any extended diffuse radiator.[43] LCD monitors are known as flat-panel, dual scan, active matrix and thin film transistor, TFT. LCD stands for Liquid Crystal Display. Liquid crystals are organic substances that reflect light when voltage is applied.

The Cathode Ray Tube (CRT) Monitor

The picture tube or CRT is the component to physically create colors. It contains three important parts: electron guns, a mask and a phosphor screen. The role of the electron guns in the neck of the tube is to constantly fire electrons towards the phosphor screen. In traditional CRT monitors, an electron gun continually sends out very precisely aimed beams of electrons, moving from pixel to pixel.

Monitors work with two basic types of CRT mask; aperture grill and shadow mask. In general, aperture grill is more suited to color definition and produces high contrast images with richer and brighter colors. Popular aperture grill technologies include SonicTron from ViewSonic, DiamondTron from Mitsubishi and Trinitron from Sony. Shadow mask technology on the other hand, allows a greater degree of detail to be seen on the screen because the image is displayed with more accuracy. Although general users may not realize the difference, graphic artists certainly would.

The glass of the picture tube is covered with millions of red, green and blue phosphor dots. The phosphor coating on the screen has the peculiar ability to light up, when hit by electrons, but the light quickly fades away. In practice, the electron beam hits the phosphor again, before there is any visible fading of the light as shown in Figure 11. The result is that it looks to us as a steady screen image.[42]

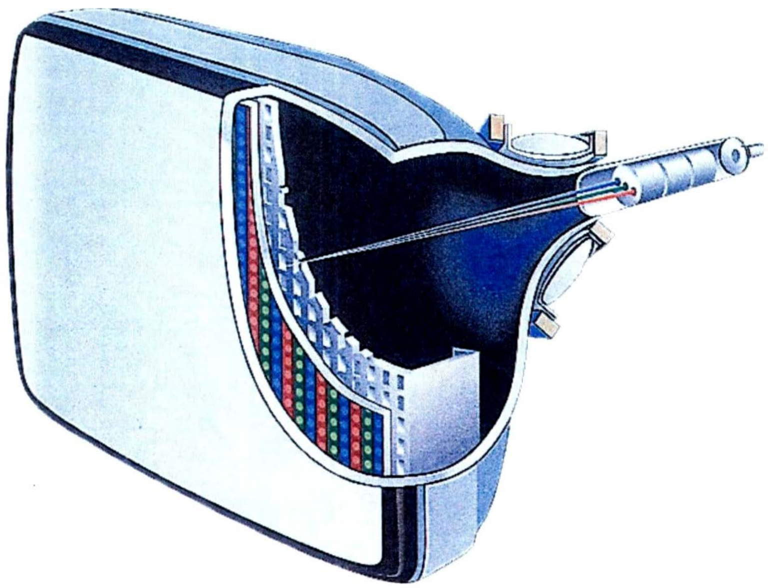

Figure 11. CRT Monitor

The Liquid Crystal Display (LCD) Monitor

As mentioned above, liquid crystals are organic substances that reflect light based on applied voltage. The display consists of a liquid suspension between two panels, glass or plastic. Liquid crystals in this suspension are naturally aligned parallel with one another, allowing light to pass through the panel. When electric current is applied, the crystals change orientation and block light instead of allowing it to pass through, turning the crystal region dark. The LCD is made of several layers that are arranged according to the following order: polarizing filter, sheet of glass, electrode, alignment layer, liquid crystals, alignment layer, electrode, sheet of glass, polarizing filter. The basic technology of LCD monitors is revealed in Figure 12.

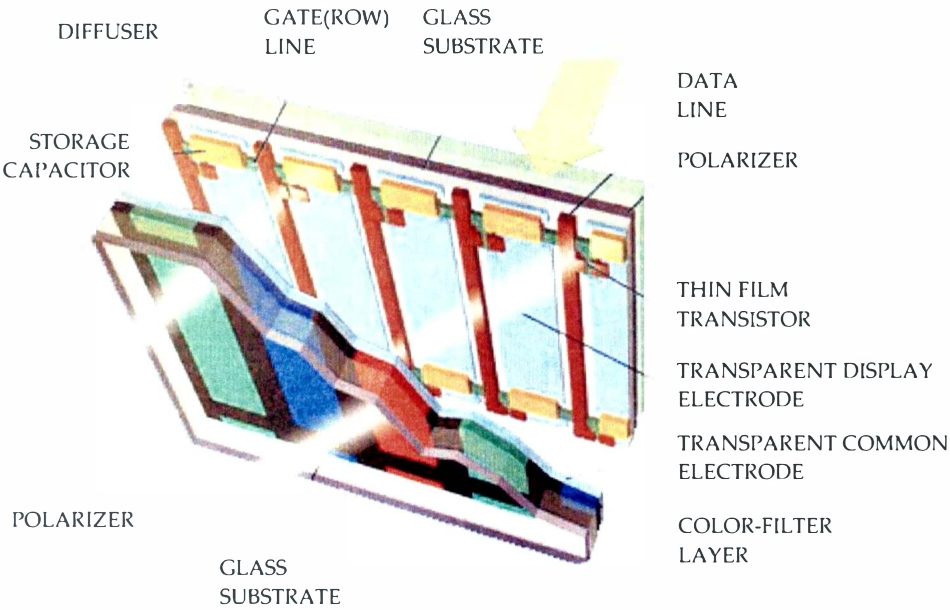

Figure 12. Principle of LCD Technology

The cross-section of the LCD panel looks like a multi-layer sandwich. At the outermost layer on either side are clear glass substrates. Between the substrates are the thin film transistor, color filter panel that provides the red, blue and green primary colors, and the liquid crystal layer. Most liquid crystal molecules are rod-shaped (Figure 13). Just like the CRT, the red, green and blue liquid crystal chambers make up one pixel – picture element. By subjecting the red, green, blue chambers to varying degrees of electrical charges, different colors can be achieved.[44]

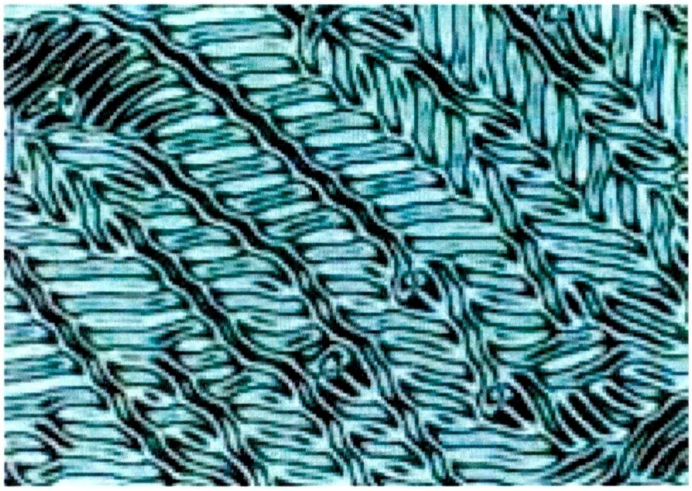

Figure 13. Image of Liquid Crystals

Liquid crystal is a substance that is neither liquid nor solid but exists somewhere in between the two. They are formed by blending certain polar materials (e.g. biphenyls, dioxene) with other materials to obtain various desired properties such as viscosity, elasticity, reflective index, etc. Under normal conditions when there is no electrical charge, the liquid crystals are in an amorphous state. LCDs use these liquid crystals because they react predictably to electric current in such a way as to control light passage.[45-47]

CRT versus LCD

Recently, conventional CRT monitors have faced something of a challenge from more expensive 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. The black level, the measure of how much light comes through a black screen, is important in video, film, and TV broadcast. Perhaps the most overwhelming advantage associated with CRTs is their economic performance—price points are three to six times lower than for comparably sized flat panels.

CRTs also have their drawbacks. They are heavy, bulky, draw lots of power (typically on the order of 100 watts versus 20 to 40 watts for LCDs), and have related high heat dissipation. Compared to an LCD, a CRT can require considerable work at setup time to achieve good screen geometry. Tuning is complicated by the fact that CRTs react differently when components are cold compared to when they warm up. Ongoing maintenance may be required to degauss some monitor components because magnetism builds up on the yoke coil and the aperture grill (or shadow mask), causing color distortion.[48]

LCD thin film transistor (TFT) active-matrix digital displays offer several benefits, e.g. they are compact and space saving. LCD monitors consume much less energy than CRT monitors. LCD monitors do not emit harmful radiation, whereas CRT monitors produce it. They also are true digital devices, and thus, provide accurate representation of digital data. The white point, or color temperature, of the light is generally not the same as

CRT displays. The color temperature of the 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.[49-51]

With CRT displays, the phosphor dots must be refreshed by the electron guns many times per second to prevent them from fading. LCD pixels, on the other hand, are either on or off, and remain that way with no fading or variation. While the maximum refresh rate of a CRT monitor is a good yardstick for its quality, this isn't the case for a comparable LCD monitor. In a cathode-ray tube, an electron beam scans the image onto the panel. The faster it can scan the panel, the better the display, and, consequently, the higher the refresh rate. In an LCD monitor, the image isn't created by an electron beam, but by pixel triads, each consisting of a red, green and blue subpixel. The image quality depends on how rapidly these diodes can be turned on and off again. This rapidity is known as the response time and it should have the advantage of reducing eyestrain.[52]

A CRT has three electron guns whose streams must converge faultlessly in order to create a sharp image. There are no convergence problems with an LCD panel, because each cell is switched on and off individually. This is one reason why text looks so crisp on an LCD monitor. There's no need to worry about refresh rates and flicker with an LCD panel - the LCD cells are either on or off, so an image displayed at a refresh rate as low as between 40-60Hz should not produce any more flicker than one at a 75Hz refresh rate.[53] Refresh rates are really only relevant for CRT monitors.[54]

Today's flat panels start to compete with CRTs. In the past, LCD panels had hard time competing CRTs for the prepress market, for example, because the critical color matching requirements of that industry demanded more than the flat panels provided. New LCD technology provides a bright display, clear focus, a wide viewing angle, and no screen flicker. The new monitors are lightweight, compact, and less energy consumable than CRT screens making them great for laptop and portable computers.[47]

Color Management

International Color Consortium (ICC)

Color management has been with us since the early '90s, and as it turned out, Apple underestimated the complexity of the assignment as well as the degree of sophistication and productivity needed by prepress and printing experts. Not long after the original ColorSync was distributed, Apple and seven other vendors decided to work together on updating the concept and the software and established the ColorSync Profile Consortium. Members including Adobe, Agfa, and Kodak, considered that the new standards should go beyond the Apple Macintosh platform, and as a result, Microsoft, and Silicon Graphics joined what was soon to be renamed the International Color Consortium (ICC)[55], which now has much more members.

The new standards were consequently designed to allow color consistency between all devices, applications and platforms involved in the printing process. The ICC device profiles are usually text documents that should be workable at any platform, not only the one on which the profile was created.

ColorSync is an enabling technology, not an application; ColorSync does not make CMYK files from RGB data or guarantee WYSIWYG color. Nowadays, a rapidly growing number of software and hardware vendors are using ColorSync to add value and functionality to their own products and make color management a workable technology.[56]

Color Management System (CMS)

The CMS provides the contribution to many fields of the imaging industry, which works with graphic images displayed on monitors. These include prepress services, advertising agencies, graphic design studios and, recently on World Wide Web pages, where users expect what-you-see-is-what-you-get (WYSIWYG) color production. Whether using an RGB or CMYK workflow, aligning scanners, monitors and printing devices will promote predictable color results every time digital images and documents are scanned, viewed, or created.

The goal of color management is to coordinate the color spaces of all devices involved to allow a data interchange, which will guarantee a true color reproduction of images and graphics throughout the process.[56-58] The color management system can be also defined as a system that uses profiles for input and output devices to transform device dependent values (RGB, CMYK) into device independent values (XYZ, $L^*a^*b^*$). This could be named as a central profile connection space (PCS). Device characterization information is stored in profiles; an input profile provides a mapping between input RGB data and the PCS, and an output profile provides a mapping between the PCS and output RGB/CMYK values. Only if the profiles represent a good characterization of the device can the system work well.[58-60] Obviously, the quality of the color profiles has a direct impact on the entire color management process. It is always important to have a quality measure for ICC profiles because this indicates how well a device has been characterized and therefore how accurate the color is likely to be in a color managed workflow.[60-62]

The appearance of the printout and the appearance of the original should be as exact as it gets. Work is no longer produced in closed systems as it was with traditional reproduction technology. Instead, we now have to work with open systems. So that working in open systems functions well enough to support reliable color reproductions, all input devices involved have to be able to communicate with all the output devices.[39]

The standardization offers the assurance that the monitor display of a scanned image looks exactly like the original and the printout looks just like the monitor image. Just as desktop computers changed publishing, color management attempts to make color adjustments automatically, so that less technical or experienced users can produce color easily, accurately, and without frustration.[8]

However, technology advances aside, the issue coming to color management is not just figuring out the right solution for some needs, but implementing the process as well. According to Iain Pike, worldwide marketing manager for X-rite: "Although the prices of color management solutions for pre-proofing and monitor color control are relatively low, the issues of implementation are a bigger challenge. A myriad of system variables leads to unique workflows in most firms, and sorting out a solution that works can be too overwhelming for many companies to take the plunge.

Instead, many creatives still rely on printing companies to resolve any technical color issues prior to approval of contract proofs."[63]

A complete CMS consists of three main parts: a tool measures actual colors and stores results as numbers; software that creates systematic profiles of colors and results from various devices and converts the colors into a standard format; and color matching software that translates the color profiles from input to output.[64] In general, the intelligence of the color management system is stored in the color profiles. This is where the system defines how colors that are theoretically not reproducible, can nonetheless be output by a printing system in such a way that the human eye will perceive them as an authentic reproduction of the original. Obviously, the quality of the color profiles has a direct impact on the entire color management process. The actual color conversion technology of the default CMM (Color Management Model) is based on simple but fast mathematical operations.

Soft Proofing

Soft Proofing Systems

There are many ways to display images on a monitor (either in RGB, Lab or CMYK mode) and print them on any of a variety of color printers. Images, either on the screen or on the sheet of paper, are created from a limited number of colors. Monitors use only red, green, and blue; the particular choices of red, green, and blue are determined by the phosphors in a CRT-based monitor or the color filters in an LCD-based monitor. With printers, the colors come from ink or dye rather than phosphors, and are cyan, yellow, magenta and black.

Whether using an RGB or CMYK workflow, aligning scanner, monitors and printing devices will allow achieving predictable color results every time digital images and documents are scanned, viewed or created. In general, there are two basic advances to calibration: the close-loop method or an ICC profile-based system. In the closed-loop calibrated system a skilled operator applies his or her understanding of how a digital file's numeric color values produced better or worse results, and applies the knowledge to make adjustments and reach the best quality outcome in the future. In other words, he generates steady soft proofing by adjusting monitor controls to more closely match originals or hardcopy proofs.[65]

An International Color Consortium profile is the core component of a calibration strategy. Device profile, part of a color management system, uses color-matching technology to calibrate an imaging system and then facilitate the accurate transfer of color from one device to another. The monitor is measured and adjusted with the measuring tool to known or standard points.

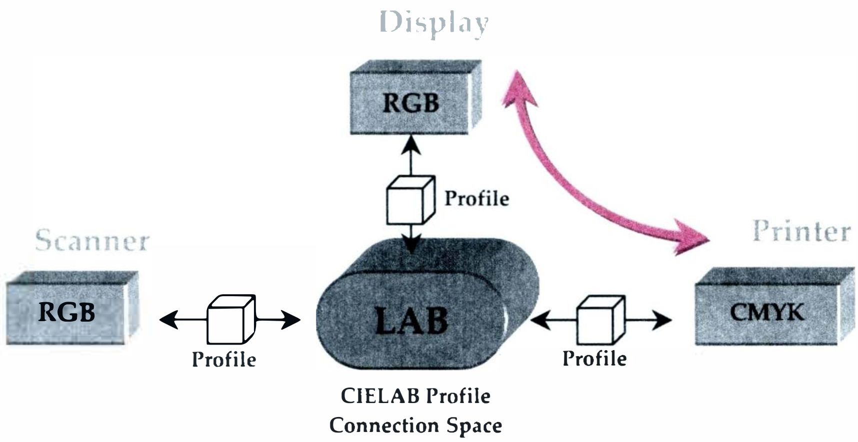

Figure 14. Soft Proofing System

The profiles enable the image's color and tones to be demonstrated precisely on the standardized monitor.[66]

The set up for soft proofing system is simply sketched in Figure 14. The image is displayed on the screen in RGB mode and the working space is set to a monitor profile. The RGB image is converted to the Lab connection space via the monitor profile information, which translates the colorimetric information. Next, the image is converted to CMYK mode using output profile information to simulate the proof 4-color conditions. Then, the proof image is returned to the profile connection space and printed on a proofing machine. The colorimetric intent may also be used when legacy CMYK images are opened.[56]

Monitor profiles are characterized by white point, also called color temperature, gamma value and tristimulus values for three primary colors (RGB). The white point is also interpreted as the temperature of a perfect Black body radiator that produces the same relative tristimulus values.[65, 67] The calibration software displays a number of color patches that are measured by the color measurement device to determine the values of the real monitor response. These values are then used to determine and display the actual color temperature, which corresponds to the white point of the monitor. The gamma value represents the progressive gradations across the color scale. It is a number that indicates the relationship between the signal values at input and output of a particular device. On the Apple Macintosh platform, the monitor gamma (γ) is typically set to 1.8, for PCs the typical monitor gamma (γ) is set to 2.2.[68] While photographic images are normally processed using the perceptual intent, the colorimetric intent is used during the facsimile reproduction of images, during soft proofing when images are evaluated on a monitor and during proofing when press images are "returned" to the profile connection space and printed on a proofing device.[62]

Conditions for Soft-Proofing Environment

Most ICC profiling software use an $L^*a^*b^*$, D_{50} and 2 degree observer as the translating color space in color conversions. The environment, under the prints are viewed, has strong effect on color perception. The color and brightness of the lighting in which that thing is viewed is critical to the whole process.[69] .Strongly colored objects or walls near the monitor or viewing area are other significant factors. Two committees, ANSI (American National Standards Institute) and ISO (International Standards Organization), approved standards to ensure universal color communication. Also, the ColorChecker Chart from Macbeth represents a test model systematically designed to assist verifying the color balance of any color rendition system.

ISO 3664:2000

ISO 3664:2000 is an updated recommendation for critical evaluation of digital output.[70] The main task here is to provide tolerance within which the viewing environment should conform. The recommendation defines the variables of room brightness, viewing booth white point and brightness level, surrounding surface colors and tolerances within each variable. The revised ISO standard is designed to communicate color viewing conditions, disregarding the actual viewing environment, to reduce color communication errors.

The ISO 3664 revision lists two levels of illumination in evaluating a digital output. The first luminance level is significantly higher than found in normal viewing environments in order to help distinguish small differences in color and tonality when compared to a reference. The P1 illuminant is recommended when comparing originals or proofs to final output. The higher illumination level helps assess the darkest tones in the image and detect small differences in color and tonality. The lower illumination level, P2, more closely resembles illumination levels common in offices, galleries and stores.

Although it is impossible to accurately predict the final illumination level in which the image will be viewed, the committee agreed the lower illumination level, P2, is fairly representative of the range of illumination levels typically encountered. Using this lower illumination level, color and tonality appraisal will be more in line to typical commercial and residential lighting levels.

The recommendation for P1 (critical comparison) is 2000 lux ± 500 lux and should be within ± 250. In contrast, P2 illumination is 500 lux ± 125. For viewing areas 1 meter square, the illumination may not fall off more than 75% from the luminance level in the center. For larger area, the requirement is reduced to 60%.

ISO 3664:2000 did not go in-depth into the complexivity of accurate calibration and optimization for current CRT, and progressively more LCD technologies. ISO 12646 Color proofing using a color display will address procedures to optimize color display performance prior to ICC profiling.[71]

In real life CRT luminance levels are normally much lower than the brightness levels in viewing booths. The current recommendation in ISO 12646 working draft is to have at least 75 cd/m^2 luminance level but should be grater than 100 cd/m^2. The brighter the monitor the less compensation is needed at the viewing booth to equalize perceived brightness levels.[72]

SWOP – Specifications for Web Offset Publications

The most significant printing specification in the United States is the press proofing portion of the current Specifications for Web Offset Publications (SWOP)[2], which addresses the larger subject of the preparation and proofing of input material for reproduction by web offset and gravure publication printing. The SWOP specifications provide the necessary information for suppliers of input materials for advertising and editorial pages to magazines to do so in a uniform way. When these specifications are followed, the input received by the printer can be reproduced at the quality level intended and desired by the publisher.[69] Once a system successfully passes the inspection, it is deemed "SWOP Certified" - that is, capable of producing proofs that match close enough to the appearance of the SWOP Certified Press Proof to be used as a contract proof in most publication printing. This certification process is repeated every two years, or more frequently if the proofing system changes. This specification has received wide acceptance and has provided the publication industry with consistent proofing of input materials [3,71]

Macbeth ColorChecker® Chart

The Macbeth ColorChecker Chart (Figure 15) is the industry standard for cinematographers and photographers alike. One of the most photographed images in the world, the ColorChecker is a unique test pattern scientifically designed to help determine the true color balance of any color rendition system.[73] The ultimate goal of any process of photography, electronic publishing, printing or television is to reproduce all colors perfectly. To help make meaningful judgments about color rendition, a totally non-subjective standard of comparison is needed. That is why the Macbeth ColorChecker chart was developed. It provides the needed standard with which to compare, measure and analyze differences in color reproduction in various processes.

Figure 15. Macbeth ColorChecker Color Rendition Chart

The ColorChecker is a checkerboard array of 24 scientifically prepared colored squares in a wide range of colors. Many of these squares represent natural objects of special interest, such as human skin, foliage and blue sky.

These squares are not only the same color as their counterparts, but also reflect light the same way in all parts of the visible spectrum. Because of this unique feature, the squares will match the colors of natural objects under any illumination and with any color reproduction process.

The ColorChecker chart provides an easy way to recognize and evaluate the many factors that can affect color reproduction.[74]

<u>ANSI IT8. 7/3 Chart</u>

ANSI (American National Standards Institute) is a U.S. member of the International Standards Organizations (ISO) that develops voluntary standards for business and industry. IT8 is a set of standards developed by the ANSI committee governing color communications and control specifications. IT8 standards cover RGB, CMYK, scanning targets, and multi vendor calibration.

An IT8.7/3 target is a printed reflection target that can be used to obtain the color gamut achievable by the fingerprint test. Many devices exist today that will even automate the process of reading and interpreting the target generating a color profile of the achievable color gamut for each fingerprint test. These color profiles are governed by the ICC (International Color Consortium). They can be attached to color halftone files thus optimizing the color balance of the printed halftone itself for a particular fingerprint.[75]

Color profiles have helped to attain consistency within the printing process by permitting predictable color reproductions. It is very important to understand that a separate profile is created from each fingerprint. Failure to

utilize the appropriate profile, may result in unpredictable print. If used correctly, ICC color profiles can be a powerful tool aiding all types of printers.
[76]

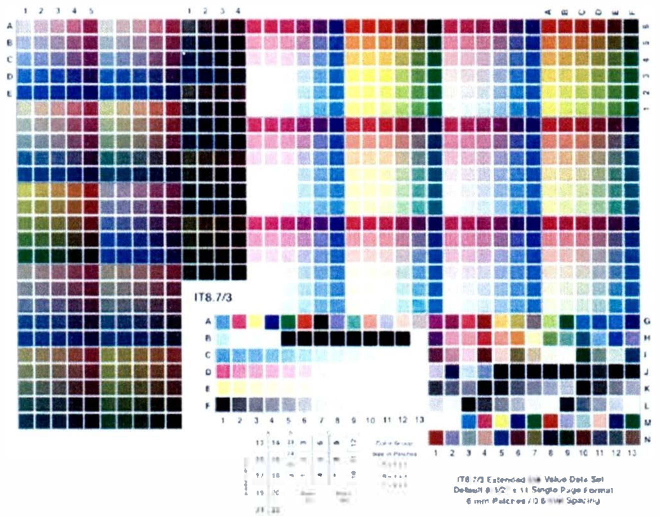

Figure 16. ANSI IT8.7/3 Target Chart

Monitor Characterization and Monitor Calibration

Computer controlled CRT displays can be illustrated by a two-stage model. The first stage consists of a linear transformation matrix relating radiometric scalars of each channel with either spectral radiance or tristimulus values. The second stage is non-linear and relates digital counts with the radiometric scalars for each channel. Γ value, defining the non-linear stage, can be characterized by either direct measurement or using a theoretical model with gain – k_g, offset – k_o, and exponential parameter – γ.[77]

When an image is characterized, it is possible to describe it either in terms of spectral radiance or in terms of tristimulus values. Berns has derived the relationship between digital and spectral data based on historical literature and hardware common to digitally controlled CRT displays. The derivation was historical and based on pioneering work in photographic sensitometry, vacuum tube physics, and broadcast television. This relationship is presented in the following equation for the red channel. Parallel expression can be written for the green and blue channels, too.[78]

$$L_{\lambda,r} = \begin{cases} k_{\lambda,r}\left[a_r\left[\left(v_{max} - v_{min}\right)\left(\dfrac{LUT_r(d_r)}{2^N - 1}\right) + v_{min}\right] + b_r - v_{C,r}\right]^{\gamma_r}; \\ \qquad v_{C,r} \leq a_r\left[\left(v_{max} - v_{min}\right)\left(\dfrac{LUT_r(d_r)}{2^N - 1}\right) + v_{min}\right] + b_r \\ 0 \qquad ; v_{C,r} > a_r\left[\left(v_{max} - v_{min}\right)\left(\dfrac{LUT_r(d_r)}{2^N - 1}\right) + v_{min}\right] + b_r \end{cases} \tag{7}$$

LUT represents the Video Look-up Table, *N* is the number of bits in the digital-to-analog converter (DAC), v_{min} and v_{max} are voltages dependent on the computer video signal generator, a_r and b_r are the CRT video amplifier gain and offset, $v_{C,r}$ is the cut-off voltage defining zero beam current, γ_r is an exponent accounting for the non-linearity between amplified video voltages and beam currents, and $k_{\lambda,r}$ is a spectral constant accounting for the particular CRT phosphor and faceplate combination. The Equation 7 is generic in that it considers signal processing common to all computer-controlled CRT displays.[79-81] This applies only for CRTs, not for LCDs.

Calibration is defined by the basic settings that are required for a specific device, e.g. monitor, or for a specific process, e.g. offset printing, to ensure uniform and consistent results over period. Whether using an RGB or

CMYK workflow, aligning your scanner, monitors and printing devices will allow achieving expected color results whenever used to scan, view, create and output digital images.[82]

The calibration of a monitor guarantees that both white and black points, as well as contrast and brightness, are set appropriately and that an acceptable color temperature is selected. In the context of color management, the terms calibration and profiling are often confused or used as synonyms. Personal computer CRT monitors display color employing red, green, and blue phosphors, which produce the sensation of white light and a specific gamut of colors when combined in varying intensities. We have to realize that spectral properties of the monitor primary colors are quite different in CRT and LCD monitors as a result of to their construction.

The monitor should be recalibrated frequently to build the most precise profiles and attain predictable color reproduction on the monitor. The lighting in the working spaces should be also controlled. Because the monitor is a relatively weak source of light radiation compared to the standard light box, the color displayed can be strongly influenced by ambient light. In addition, depending on the settings of the brightness and contrast control, the color shown on the monitor can also be noticeably influenced or ruined by aging effects of the monitor and temperature conditions. Still, the device's interpretation of color tends to change in the course of a longer time period. As a consequence, it is of primary important to calibrate the device to compensate for these fluctuations.[83]

In addition to being properly calibrated, all CRT monitors should warm up for at least half an hour (CIE recommends the time about 12 hours), before any color sensitive work. This lets the tube stabilize and fully energize the phosphors. It is necessary to avoid powering the monitor down because the phosphors will then need to be restabilized.

Lightening also plays a huge role in how colors are seen. Some colors may be metameric, which means they appear different under different lighting conditions. Incandescent light is different from daylight fluorescent. Northday light (7500 K) is much bluer than noon daylight (6500 K). The lower the color temperature, the redder the light is. The higher the temperature, the bluer it is. The standard lightening condition for color matching is D_{50}, or 5000 K, with neutral gray surrounding color.[84]

Monitor Profiling

Generally, a color management system (CMS), developed by International Color Consortium (ICC) in 1993, allows color transformation to be carried out by the operating system in conformity with universal rules for any program. ICC profiles express the color range of a device and the way it renders an image.[85]

A color profile describes the color reproduction characteristics of device specific color space on the basis of a colorimetric reference system. An ICC color profile, complying with ICC specifications, includes parameters for mathematical operations that describe the relationship between color spaces.

Like all profiling color processes, monitor profiling also distinguishes between the basic device calibration and the actual profile generation. Every time the basic monitor calibration settings are changed, the color profile previously generated will no longer be valid. A monitor calibrated at regular intervals should be re-profiled every three or four weeks. To create an accurate profile, a spectrophotometer or at least a tristimulus measurement device should be used.

When creating profiles of a monitor, the profiling software generates and measures various RGB values on the monitor. During this process, the RGB values defined by the software for the color patches constitute the reference data, while the CIELAB values measured on the monitor with a color measurement device constitute the characteristic device data. In monitor profiles, both direction of conversion (LAB→RGB and RGB→LAB) are important, because a monitor is used both for the image evaluation of original data and for creative data generation.

A good ICC profile describes the RGB corner coordinates, the gradation curves of the individual color channels, and the black and white point. The colorimetric description of a smaller number of color support points of the monitor color spaces is normally sufficient to precisely compute all other mixed colors. Profiling software offers a standard facility for creating small profiles for monitors (matrix TRC model). These settings should not be changed when working with a CRT monitor. On the other hand, the reproduction characteristics of flat screen monitors (LCD or TFT monitors) are not as linear. In these cases the reproduction function should be described with the aid of look-up tables (LUTs).

Excellent color control facilities are available for all monitors. Even lower priced monitors can have very good reproduction qualities if they have an optimized color profile. The most important characteristic of monitors in the future will be a uniform representation across the entire monitor face.[37]

EXPERIMENTAL

Experimental Setup

Two monitors: a 17" Mitsubishi Diamond Plus 73 CRT monitor and a 17" Apple Studio LCD display were plugged in the Apple Macintosh computer. Using two different video cards it is possible to independently manipulate both monitors at the same time (Figure 17a,b). The next step in this process is to ensure that the light conditions at the monitor surrounding are kept as stable as possible.

Figure 17a. Mitsubishi Diamond Plus 73; b. Apple Studio Display

Hardware:
17" Mitsubishi Diamond Plus 73 CRT Monitor
17" Apple Studio LCD Display
Power Mac G4
GretagMacbeth Spectroscan & Spectrolino Spectrophotometer
Epson Stylus Pro 5000 Ink Jet Color Printer

Software & Charts:
OS X.2.3 Operating System
Adobe Photoshop 7.0
GretagMacbeth Measure Tool 4.1.1
GretagMacbeth ProfileMaker 4.1.1
Macbeth ColorChecker Chart
Tiff.exe – Output Chart Reader
ANSI IT8.7/3 Chart
ANSI/CGATS TR 001-1995 Report

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 desire 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. Following the steps of the profile making software the monitors were characterized and information obtained from the new conditions were saved in the monitor profile. In our case, the GretagMacbeth ProfileMaker 4.1.1 software and GretagMacbeth Spectrolino spectrophotometer were used to create monitor profiles for both investigated monitors. Figure. 18.

Figure 18. Windows of GretagMacbeth ProfileMaker 4.1.1 Software in the Process of Building the Profiles for CRT and LCD Monitor

The newly created profiles were selected as the profiles separately for the CRT and LCD monitors. Then, these profiles were analyzed. The values of the primaries (RGB) and the white point information are shown in next figures 19 and 20.

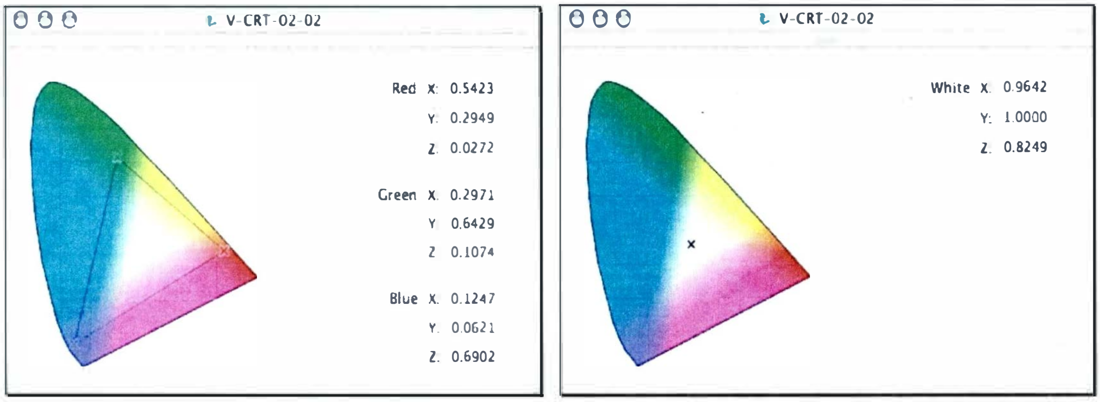

Figure 19. CRT Profile Information; RGB Primaries and White Point

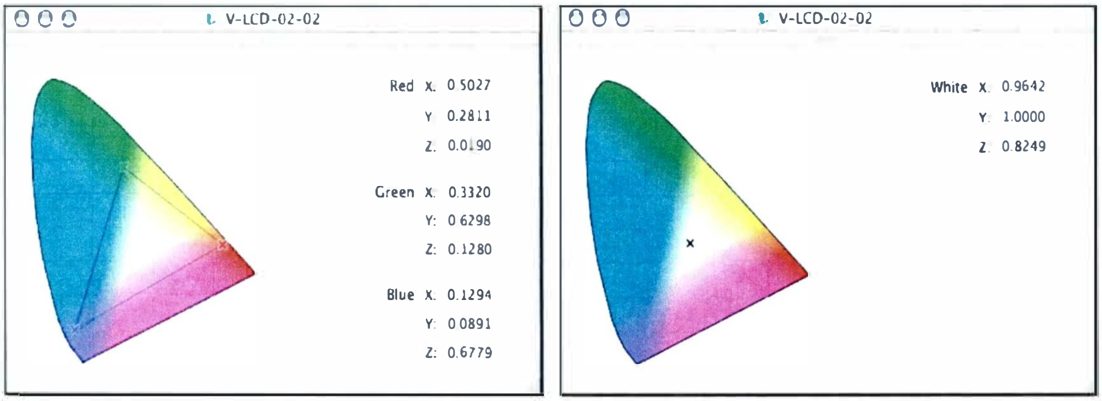

Figure 20. LCD Profile Information; RGB Primaries and White Point

Accuracy of Monitor Profiles

Using Photoshop 7, 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 LAB mode to check the accuracy of displaying color patches. The white patch represents the white point or color temperature of the monitor. In Edit>Color Settings, the Working Space was set to the specific monitor profile space, the Conversion Engine was set to the Adobe Color Engine (ACE) and rendering intent to the Absolute Colorimetric.

The gamuts of both monitors were graphically compared using CHROMiX ColorThink 2.0 software (Figure 21). Evidently, the CRT monitor provides slightly wider gamut than LCD panel.

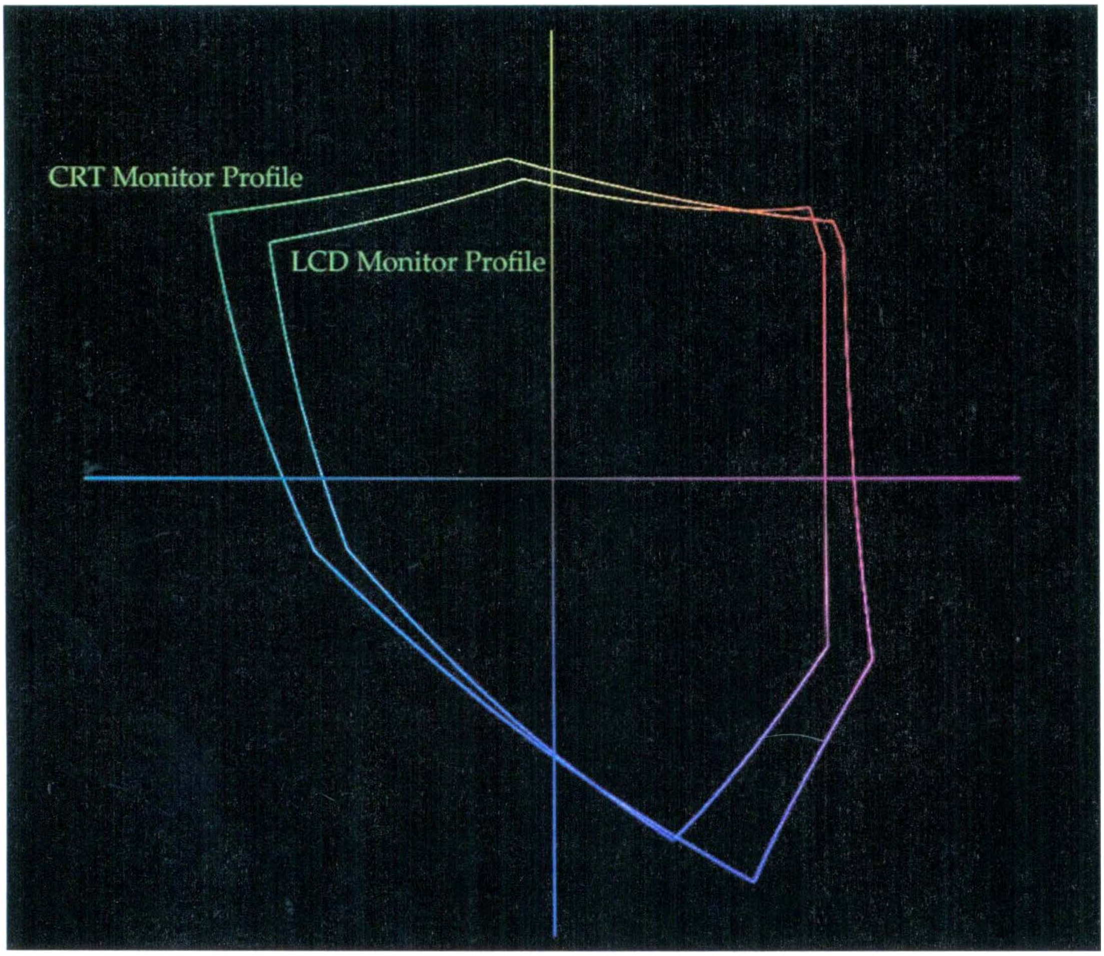

Figure 21. The Graphical Comparison of the Gamuts of CRT and LCD Monitor

The $L^*a^*b^*$ (Lab) values from Photoshop's info palette are collected to check the accuracy of displaying the colors in Photoshop software. Also, the XYZ values of each patch were measured using GretagMacbeth MeasureTool 4.1.1 and Spectrolino. The measured XYZ values were normalized to Y=100 for the white point and then converted to Lab for the chosen illuminant, D_{50}. This procedure was done for both of the monitors. The Lab values are shown in the following tables.

CRT

	Profile Data			Info Palette Data*			Measured Data**		
MODE	**L**	**a**	**b**	**L**	**a**	**b**	**L**	**a**	**b**
LAB									
R	61	80	69	61	80	69	61	83	68
G	84	-94	71	84	-94	71	85	-91	72
B	30	55	-109	30	55	-109	31	57	-109
W	100	0	0	100	0	0	100	3	0

Table 1: Lab Values From ColorSync Utility Folder, From Info Palette in Photoshop and Measured by Spectrolino for the CRT Monitor

LCD

	Profile Data			Info Palette Data*			Measured Data**		
MODE	**L**	**a**	**b**	**L**	**a**	**b**	**L**	**a**	**b**
LAB									
R	60	75	74	59	75	74	59	77	76
G	83	-78	64	83	-78	64	84	-76	65
B	36	33	-98	36	33	-98	36	33	-96
W	100	0	0	100	0	0	100	2	1

* - Data gathered from Info palette of Photoshop 7.0.1 Software

** - Data measured by GretagMacbeth MeasureTool 4.1.1 and Spectrolino

Table 2: Lab Values From ColorSync Utility Folder, From Info Palette in Photoshop and Measured by Spectrolino for the LCD Monitor

The XYZ values from profile data set are transformed to Lab values using the equations 3 in Chapter I.

RGB→LAB Conversion

By performing the RGB→LAB conversion of the image the quality of the monitor profile can be also evaluated. In this step, the first part of the soft proofing model, sketched below is explored and evaluated. The consistency of both modes is discovered.

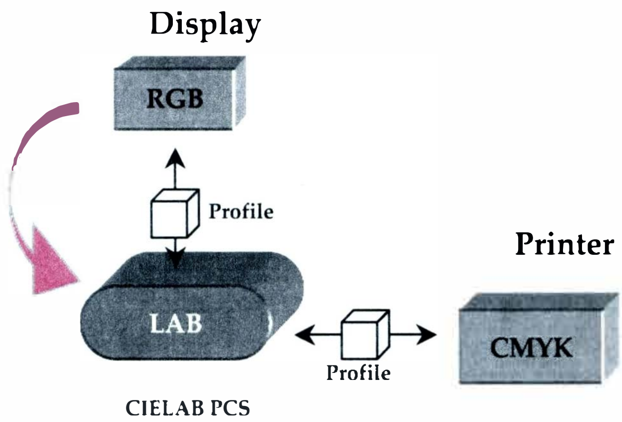

Figure 22. RGB→LAB Conversion part of Soft Proofing Setup

The same image from the first step, four patches R,G,B, and W, was displayed using the created monitor profiles as working spaces. Then, the image was converted to Lab mode (LAB) in Photoshop using Image>Mode>Convert to Profile (Lab Color). The Lab values from info palette and Lab values measured by the Spectrolino of each conversion were collected for both monitors (Table 3 and 4).

CRT

	Info Palette Data		
MODE	L	a	b
RGB			
R	61	80	69
G	84	-94	71
B	30	55	-109
W	100	0	0
LAB			
R	61	80	69
G	84	-94	71
B	30	55	-109
W	100	0	0

CRT

	Measured Data		
MODE	L	a	b
RGB			
R	61	83	69
G	85	-92	72
B	31	57	-109
W	100	4	0
LAB			
R	61	83	68
G	85	-91	72
B	31	57	-109
W	100	3	0

Table 3: Lab Values From Info Palette and Measured Values for RGB→LAB Conversion for CRT Monitor

LCD

	Info Palette Data		
MODE	L	a	b
RGB			
R	59	75	74
G	83	-78	64
B	36	33	-98
W	100	0	0
LAB			
R	59	75	74
G	83	-78	64
B	36	33	-98
W	100	0	0

LCD

	Measured Data		
MODE	L	a	b
RGB			
R	57	74	73
G	81	-78	63
B	35	33	-96
W	100	2	1
LAB			
R	59	77	76
G	84	-76	65
B	36	33	-96
W	100	2	1

Table 4: Lab Values From Info Palette and Measured Values for RGB→LAB Conversion for LCD Monitor

Creation of Output Profiles

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 connection profiles are employed in the conversion, the U.S. Web Coated (SWOP) v2 "SWOP" and one based on ANSI/CGATS TR 001-1995 "ANSI". The U.S. Web Coated (SWOP) v2 is a standard default profile of Photoshop 7.0.1 menu. The ANSI/CGATS TR 001-1995 output profile was created from the ANSI Technical Report data source[69] using GretagMacbeth ProfileMaker 4.1.1 software. Both these profiles were created with the same specifications determined by SWOP.[68]

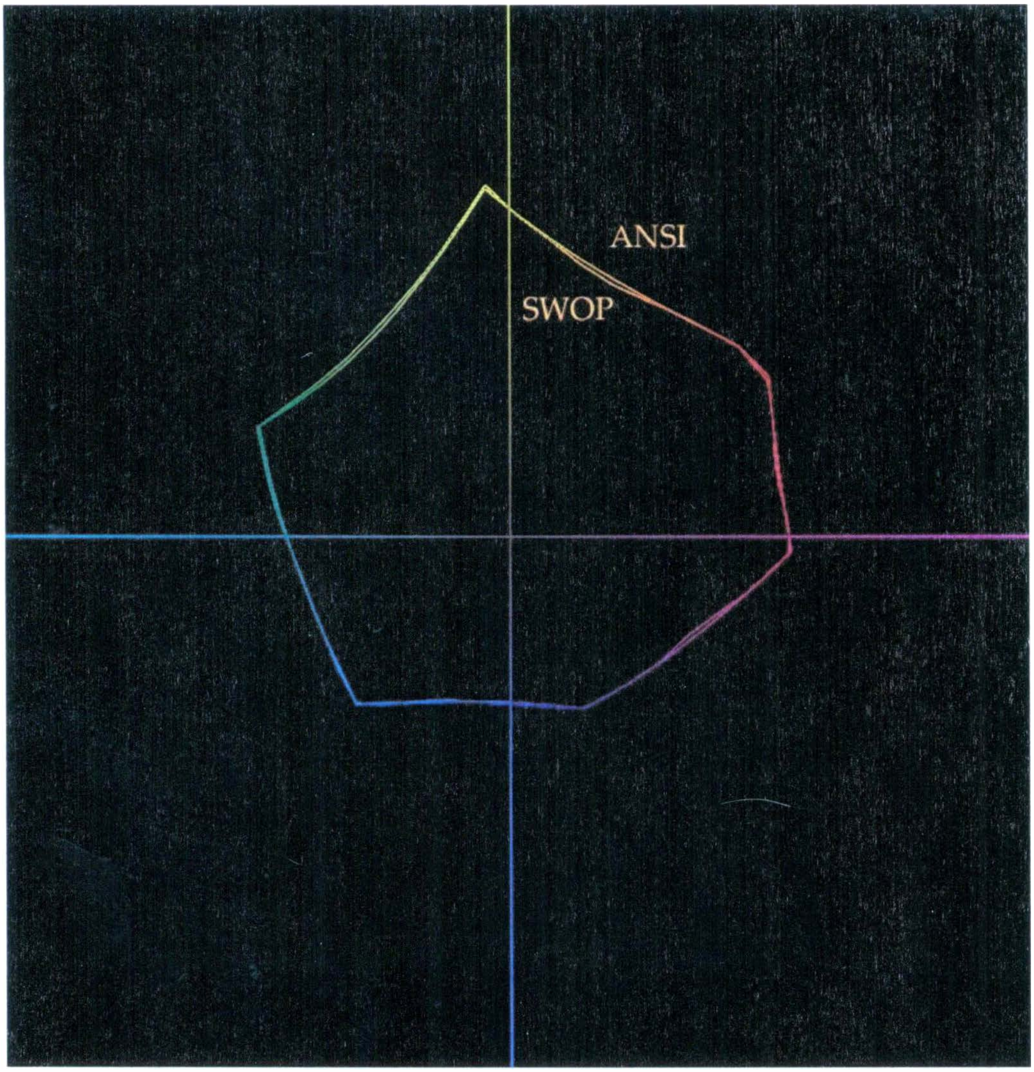

Figure 23. The Graphical Comparison of the Gamuts of ANSI and SWOP Output Profiles

In the following figure the comparison of two different output profiles is graphically illustrated. Again, CHROMiX ColorThink 2.0 was used to show differences between the two profiles.

CMYK Conversions

There is more than one method to convert an image from the RGB working space to the CMYK output space in Photoshop.

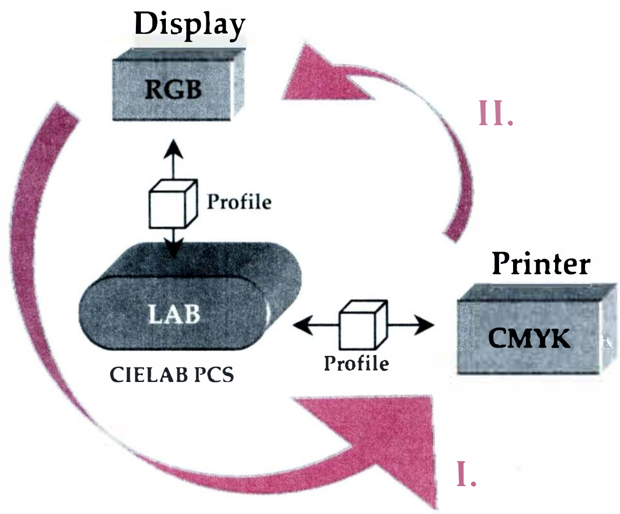

Figure 24. - RGB→CMYK→RGB Conversion Path of a Soft Proofing Setup

The conversion paths are simply sketched in the figure 24 of a soft proofing system. Creating the "mode loop", the image is transferred from RGB mode to CMYK and subsequently back and RGB mode through the Lab connection space. These tests also provide an indication of the accuracy of the colorimetric look-up table in the output profile.

CMYK Conversion Method #1

For this method, the RGB image is converted into CMYK by Image>Mode>Convert to Profile using the two output profiles, the U.S. Web Coated (SWOP) v2 and ANSI/CGATS TR 001-1995 (Path I. in the figure 24). The Adobe Conversion Engine (ACE) and Absolute Colorimetric intent is used in the Image>Mode>Convert to Profile path of conversion. Then, the CMYK image is converted back to the RGB image using Image>Mode>Convert to Profile the particular monitor profile (Path II. in the figure 24). The Lab values and the calculation of ΔE of the transformations to CMYK mode using the output profiles for CRT and LCD monitor are shown in Tables 17 to 20 in the Appendix.

CMYK Conversion Method #2

For the second method, the RGB image is converted into CMYK using again two different connection profiles but different conversion pathway. The transformations are made via View>Proof Setup>Custom menu. This configuration of the proof setup via the Custom menu option is done with no image open. If attempting to configure the setup with an image open then the existing Photoshop default soft proof profile will be retained as the default. Again, the Adobe Conversion Engine and the absolute colorimetric intent are used. After these steps are executed, the RGB image can be displayed and converted into CMYK mode with soft proof setup turned on. There are two ways how to see the image as a soft proof, either with the paper simulation turned on or off. The second set of the Lab values gathered for RGB→CMYK→RGB conversion was done with the paper simulation turned "On". The Lab values and calculated ΔE values from the info palette and measured ones of all the conversions for both monitors, which were done with the method #2, are provided in tables 21 to 24 in Appendix.

CMYK Conversion Method #3

The third set of Lab values stored for RGB→CMYK→RGB conversion is done the same way as in the method 2. In this case the paper simulation is turned "Off". The Lab values and calculated ΔE values from info palette and measured ones of all the conversions for CRT and LCD monitor done by the way 3, are presented in tables 25 to 28 in Appendix.

According to results of delta E's 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.

Macbeth ColorChecker® Chart Test

After the establishing the way to display images for soft proofing, a test with the Macbeth ColorChecker Chart was completed. This chart provides us 24 patches of 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 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. The measured Lab values and Lab from info palette of all 24 patches for both monitors are shown in Table 29 and 30 in the Appendix.

Next step was to convert RGB image to the CMYK through the output profiles by selected method, View>Proof Setup>Custom menu with paper simulation turned "On". The conversions were completed for two output profiles and the Lab values for CRT and LCD monitors for the conversions were collected (Table 31 to 34 in Appendix).

ANSI/CGATS TR 001-1995 Output Profile Test

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.

Some patches from the subset area of the IT8.7/3-1993 chart (Fig. 25) were judgeously selected. The corresponding CMYK and Lab values are copied from the ANSI/CGATS TR 001-1995 Technical Report (Tab. 5).

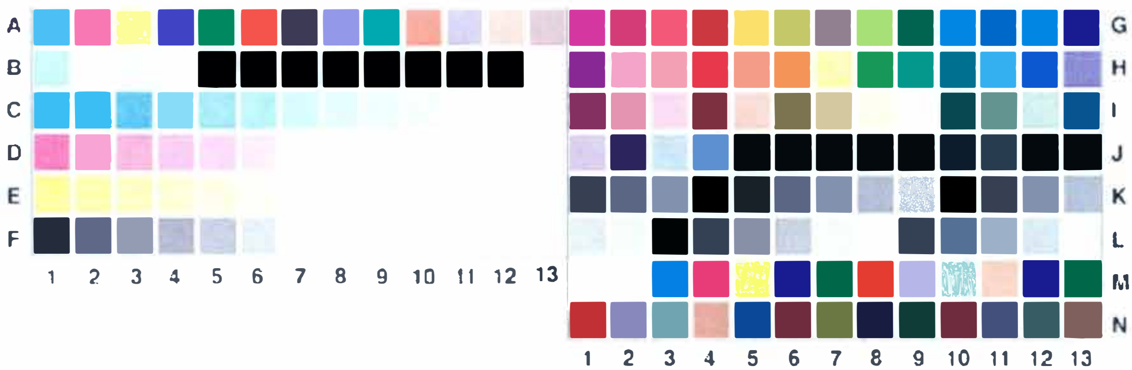

Figure 25. Subset Part from ANSI IT8.7/3-1993 Chart

The CMYK patches are created in the CMYK mode and LAB values from the info palette were compared to the given Lab values from the report. Then the soft proof conditions were assigned and numbers were collected again from the info palette. All the measured values for both monitors are shown in table 35 and 36 in the Appendix.

Patch	C	M	Y	K	L	A	B
0A01	100	0	0	0	56.02	-37.58	-40.01
0A02	0	100	0	0	47.16	68.06	-3.95
0A03	0	0	100	0	84.26	-5.79	84.33
0A04	100	100	0	0	26.57	17.6	-41.24
0A05	100	0	100	0	51.46	-61.59	26.08
0A06	0	100	100	0	46.94	62.21	41.81
0A07	100	100	100	0	24.84	-1.3	-0.51
0C07	30	0	0	0	76.68	-12.87	-12.6
0D07	0	30	0	0	74.25	19.6	-1.16
0E07	0	0	30	30	86.7	-3.6	27.15
0F07	0	0	0	0	67.67	-1.03	1.03
0G02	40	100	40	0	36.93	43.5	-3.21
0H07	20	20	70	0	68.6	-1.82	38.52
0I11	70	40	70	0	47.82	-15.05	10.23
0J04	70	40	40	0	48.26	-11.97	-7.14
0K03	60	45	45	20	42.93	-4.58	-0.47
0L08	10	6	6	10	74	-1.03	1.75
0M11	0	40	40	20	58.29	19.13	18.84
0N06	0	100	0	70	23.86	34.74	-4.21

Table 5: CMYK and Lab Values of 19 Patches Selected From the IT8.7/3-1993 Chart and ANSI/CGATS TR 001-1995 Technical Report as the Source of the Data

Printed Proof vs. Displayed Image Evaluation

At the finale part of this research the visual evaluation was performed. The CRT and LCD monitor were employed to display images. The images on the monitors were then compared to the printed images.

Two output printer profiles were used to print out the images, the previously created profile from the ANSI/CGATS TR 001-1995 Report and new created profile of the printer. The newly profile of the printer was created using GretagMacbeth ProfileMaker 4.1 again. The ANSI IT8.7/3-1993 chart was printed on the Epson Stylus Pro 5000 printer and then automatically read by GretagMacbeth SpectroScan spectrophotometer. The output profile of the printer was calculated for D_{50} illuminant and 2 degree observer and afterward stored.

The procedures described before were completed 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 the viewing booth.

RESULTS AND DISCUSSION

Evaluation of the Accuracy of Monitor Profiles

Using Photoshop 7.0, four patches consisting of RGB primaries and a white patch were displayed on the monitor in LAB mode. The Lab values are collected to check the accuracy of displaying the colors in Photoshop software. The Lab values are shown in the tables 1 and 2 in the experimental part. The Delta E value is calculated every time for two sets of data.

In the early steps, the values given by profile software shown through the ColorSync Utility folder and values from Photoshop's info palette are taken to confirm the accuracy of Photoshop to display the primary colors. The Lab values of profiles were calculated from XYZ values given by Profile folder using the formula 3 mentioned in the first part of the paper. Delta E's are presented for all four channels (R,G,B and W) for both monitors (Tab. 6).

CRT	Profile Data & Info Palette Data
	Δ E
R	0.00
G	0.00
B	0.00
W	0.00

LCD	Profile Data & Info Palette Data
	Δ E
R	1.00
G	0.00
B	0.00
W	0.00

Table 6: Δ E Values Comparing Profile Data from ColorSync Utility Folder to Photoshop's Info Palette for CRT and LCD Monitor

From the numbers above it is clear that the profile is working along with the Photoshop to give essentially exact results for the three primaries and for white patches for both monitors.

In the following tables the measured values are compared to Profile folder values and info palette values for the LCD and CRT monitors. The capability of the monitors to show colors with profiles applied is evaluated.

CRT	Profile Data & Measured Data	Info Palette Data & Measured Data
MODE	Δ E	Δ E
LAB		
R	3.16	3.16
G	3.32	3.32
B	2.24	2.24
W	3.00	3.00
Mean ΔE	**2.30**	**2.93**
RMS ΔE	**2.96**	**3.00**

LCD	Profile Data & Measured Data	Info Palette Data & Measured Data
MODE	Δ E	Δ E
LAB		
R	3.00	2.83
G	2.45	2.45
B	2.00	2.00
W	2.24	2.24
Mean ΔE	**2.42**	**2.38**
RMS ΔE	**2.45**	**2.40**

Table 7: Δ E values Comparing Profile Inspector Data, Info Palette Data to Measured Ones for CRT and LCD Monitor in LAB Mode

By this step we measure the color values on the display and compare them to the values shown in the Info Palette of Photoshop software. We can also say that we are confirming the fact: What You See Is What You Get (WYSIWYG). The difference of two sets of Lab values is not significant in either case. The RMS Delta E values vary from of 2.40 to 3.00. This range of Delta E values is considered good. Only the eyes of trained people can see difference between colors at this level. Generally, better results are seen from the sets of numbers for LCD display. The agreement in both cases is probably within the normal fluctuation of the display devices.

The Lab values from RGB mode were compared the same way as above for both monitors. The image of four patches is displayed in RGB mode and the monitor profile was assigned to it. (Tab. 8)

CRT	Info Palette Data vs. Measured Data
MODE	Δ E
RGB	
R	3.00
G	2.45
B	2.24
W	4.00
Mean ΔE	**2.92**
RMS ΔE	**3.00**

LCD	Info Palette Data vs. Measured Data
MODE	Δ E
RGB	
R	2.45
G	2.24
B	2.24
W	2.24
Mean ΔE	**2.29**
RMS ΔE	**2.30**

Table 8: Δ E Values Comparing Info Palette Data With Measured Ones of RGB Mode for CRT and LCD Monitor

The Delta E's calculated for RGB mode show the same tendency as those for LAB mode. The Δ E values are in the range of 2.29 to 3.00 and are considered as acceptable. Also in this case, the LCD panel provides slightly better results than CRT.

RGB→LAB Conversion

By performing the RGB→LAB conversion of the image the quality of the monitor profile can be also evaluated. As done before, the same image was displayed in RGB mode using the created monitor profile as a working space. Then, the image was converted to LAB using Image>Mode>Convert to Profile (LAB Color). The delta E color differences were calculated for two modes; RGB vs. LAB. (See tables 3, 4).

CRT	RGB Mode vs. LAB Mode
	Δ E
Info Palette	0.00
Measured	0.75

LCD	RGB Mode vs. LAB Mode
	Δ E
Info Palette	0.00
Measured	2.45

Table 9: Δ E's Comparing Lab Values of the RGB and LAB Mode

Two sets of data were considered. In the first set, the Lab values from Info Palette of RGB and LAB mode were compared followed by the comparison of the Lab values of RGB and LAB mode measured by the spectrophotometer. The Delta E values for Info Palette and measured values are shown in the tables above.

The conversion from RGB to LAB mode using created profiles is working accurately. There is no significant divergence between Lab values of RGB and LAB mode in the Photoshop Info Palette. The Photoshop software provides excellent results when working with accurate profiles.

On the other hand, the Lab values measured by spectrophotometer vary a little. The high quality sensors of the measuring device uncovered some inequalities when measuring the Lab values of two modes. The difference of measured Lab values between RGB and LAB mode are in the range of 0.75 for CRT monitor to 2.45 for LCD panel. Again, this is likely within normal fluctuations.

In the conclusion, the Photoshop software is able to produce good colors in that Lab values do not vary from Lab values measured by spectrophotometer. The LCD panel provides slightly better results than the CRT, which could lead to the assumption that the LCD panels are genuinely good competitors to CRT monitors for precise color work. Also, the monitor profiles were checked providing appropriate results.

LAB→CMYK Conversions

Three methods to convert image from RGB space to the CMYK and back to RGB mode are analyzed here. Creating the "mode loop", the image is transferred from RGB mode to CMYK and subsequently back and RGB mode through the Lab connection space. The tests also provide an indication of the accuracy of the colorimetric look-up table in the output profile.

Method #1

The RGB image was converted into CMYK by Image>Mode>Convert to Profile using the two output profiles "SWOP" and "ANSI", the U.S. Web Coated (SWOP) v2 and ANSI/CGATS TR 001-1995. Afterward, the image was switched back to RGB mode to check the consistency of whole procedure. The Lab values of the transformations are shown in Tables 17 to 20 in the Appendix. The delta E values of R,G,B primaries and White channel were calculated from Info Palette values and measured values. They are presented in the table 10 for CMYK and RGB conversion modes of both, CRT and LCD monitor.

	CRT Monitor		LCD Monitor	
	SWOP*	ANSI**	SWOP	ANSI
MODE	**Δ E**	**Δ E**	**Δ E**	**Δ E**
CMYK				
R	19.76	14.66	19.91	17.09
G	11.02	10.18	10.41	10.07
B	16.62	12.91	11.18	10.42
W	13.63	12.51	12.89	12.17
Mean ΔE	**15.26**	**12.57**	**13.60**	**12.44**
RMS ΔE	**15.60**	**12.67**	**14.11**	**12.75**
RGB				
R	5.1	4.65	4.78	3.85
G	0.91	1.01	1.34	1.89
B	7.86	6.06	0.76	1.89
W	3.72	3.83	3.05	2.21
Mean ΔE	**4.40**	**3.89**	**2.48**	**2.46**
RMS ΔE	**5.06**	**4.30**	**2.94**	**2.59**

SWOP* - Lab values of the conversion using U.S. Web Coated (SWOP) v2 conversion profile
ANSI** - Lab values of the conversion using ANSI/CGATS TR 001-1995 conversion profile

Table 10: Δ E Values of CMYK and RGB Mode for Conversion Method #1

Method #2

In the second set, the transformations are made via View>Proof Setup>Custom menu. The Lab values gathered for the conversion RGB→CMYK→RGB were measured with the paper simulation turned "On". The Lab values form Photoshop's Info Palette and measured ones are provided in tables 21 to 24 in Appendix. The delta E values of R,G,B primaries and White of both conversion modes for CRT and LCD monitor are in the table 11.

	CRT Monitor		**LCD Monitor**	
	SWOP*	ANSI**	SWOP	ANSI
MODE	**Δ E**	**Δ E**	**Δ E**	**Δ E**
CMYK				
R	5.43	4.92	3.71	2.18
G	4.39	4.21	4.03	4.65
B	8.73	7.21	6.19	5.20
W	4.77	4.96	4.51	3.56
Mean ΔE	**5.83**	**5.33**	**4.61**	**3.90**
RMS ΔE	**6.08**	**5.44**	**4.71**	**4.06**
RGB				
R	5.43	4.64	3.71	2.60
G	4.17	4.22	5.60	4.40
B	7.52	7.16	5.79	4.71
W	3.88	5.06	3.14	2.83
Mean ΔE	**5.24**	**5.27**	**4.56**	**3.64**
RMS ΔE	**5.44**	**5.39**	**4.70**	**3.75**

Table 11: Δ E Values of CMYK and RGB Mode for Conversion Method #2

Method #3

The third set of Lab values stored for RGB→CMYK→RGB conversion was done the same way as in the method #2. In this case the paper simulation is turned "Off". The Lab values and calculated ΔE values from info palette and measured ones of all the conversions for CRT and LCD monitor done by the method #3, are presented in tables 25 to 28 in Appendix.

Again, the delta E values of R,G,B primaries and White of the CMYK and RGB conversion modes calculated from Info Palette values and measured values are in the table 12. For both types of monitor two types of output printer profiles were used to determine the Lab values.

	CRT Monitor		LCD Monitor	
	SWOP*	ANSI**	SWOP*	ANSI**
MODE	**Δ E**	**Δ E**	**Δ E**	**Δ E**
CMYK				
R	15.52	13.77	15.95	14.20
G	9.60	8.49	9.59	8.58
B	14.22	11.11	9.18	9.23
W	13.54	12.18	12.39	7.24
Mean ΔE	**13.22**	**11.39**	**11.78**	**9.81**
RMS ΔE	**13.40**	**11.55**	**12.08**	**10.16**
RGB				
R	5.43	4.64	3.71	2.60
G	4.17	4.22	5.60	4.40
B	7.52	7.16	5.79	4.71
W	3.88	5.06	3.14	2.83
Mean ΔE	**5.25**	**5.27**	**4.56**	**3.64**
RMS ΔE	**5.44**	**5.39**	**4.70**	**3.75**

Table 12: Δ E Values of CMYK and RGB Mode for Conversion Method #3

By converting images into the CMYK mode using the U.S. Web Coated (SWOP) v2 as well as the ANSI/CGATS TR 001-1995 output profile, the ΔE values rapidly increase for method #1. Due to the high RMS and average ΔE, about 12 to 15 for method #1, the differences are significant and disturbing. By looking at the tables above, similar results, the ΔE values about 10 to 13, were obtained from the Photoshop Proof Setup mode, when "simulate paper white" was turned off. However, when "simulate paper white" is activated the measured values become in agreement with the info palette of Photoshop 7.0 software more closely. As seen by Table 11, the average and RMS ΔE values are about 4 to 6, which is almost 3 times smaller than the other two modes.

The ΔE values of next step, going back to RGB image using the profiles of the monitor, have the same trend as those at the beginning of the process. They differ, from the original values because of the "gamut clip" resulting from passing through the output profiles.

There is also another issue occurring during the experiment. As far as we know that both types of output profiles were created from the same data source, we would expect the same results in our CMYK conversions. To put options of displaying CMYK image side by side, the profile created from ANSI/CGATS TR 001-1995 data source seems to be working more precisely.

According to ensuing numbers of delta E's 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.

GretagMacbeth ColorChecker® Chart Test

The RGB image was displayed and converted to the CMYK through the output profiles by selected method, View>Proof Setup>Custom menu with paper simulation turned "On".

MODE	CRT Monitor	LCD Monitor
RGB		
Mean ΔE	3.19	2.23
RMS ΔE	3.47	2.49

Table 13: Delta E Values of the ColorChecker® Chart Displayed in RGB Mode

Lab values of RGB mode for CRT and LCD monitor can be found in tables 13 and 14 in Appendix. Delta E values are calculated from data of Info Palette and measured ones. (Tab. 13)

Both monitors provide equally good results. The values are below in the table 14, which are considered as acceptable numbers to evaluate the color difference. The LCD display has an even smaller number Δ E by about 1 unit. This leads to the statement mentioned before, that the technology of LCD panels is improving in these days. The accuracy of monitor profile could be deemed as excellent.

The conversions to CMYK mode were completed for two profiles, SWOP and ANSI, and the Lab values of CMYK mode for CRT and LCD monitors for the conversions were collected (Table 31 to 34 in Appendix). The calculated delta E's of all patches are presented in the following table 14.

	CRT Monitor		**LCD Monitor**	
MODE				
CMYK	SWOP	ANSI	SWOP	ANSI
Mean ΔE	**3.24**	**3.28**	**2.09**	**2.03**
RMS ΔE	**3.46**	**3.64**	**2.27**	**2.25**

Table 14: Delta E Values of CMYK Mode for Conversion Method #2

The ColorChecker Chart Test provides better and more precise results to check the quality of the profiles. In this case, not only four patches (RGB and W) are considered, but also whole series of patches to help 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 Δ E's have the same trend as the values for RGB mode. Also, by this part of the experiment, the quality of the output profile and the ability of Photoshop to work under soft proofing conditions as good. The

LCD panel again slightly out performs the CRT monitor in quality of displaying the images under soft proofing conditions.

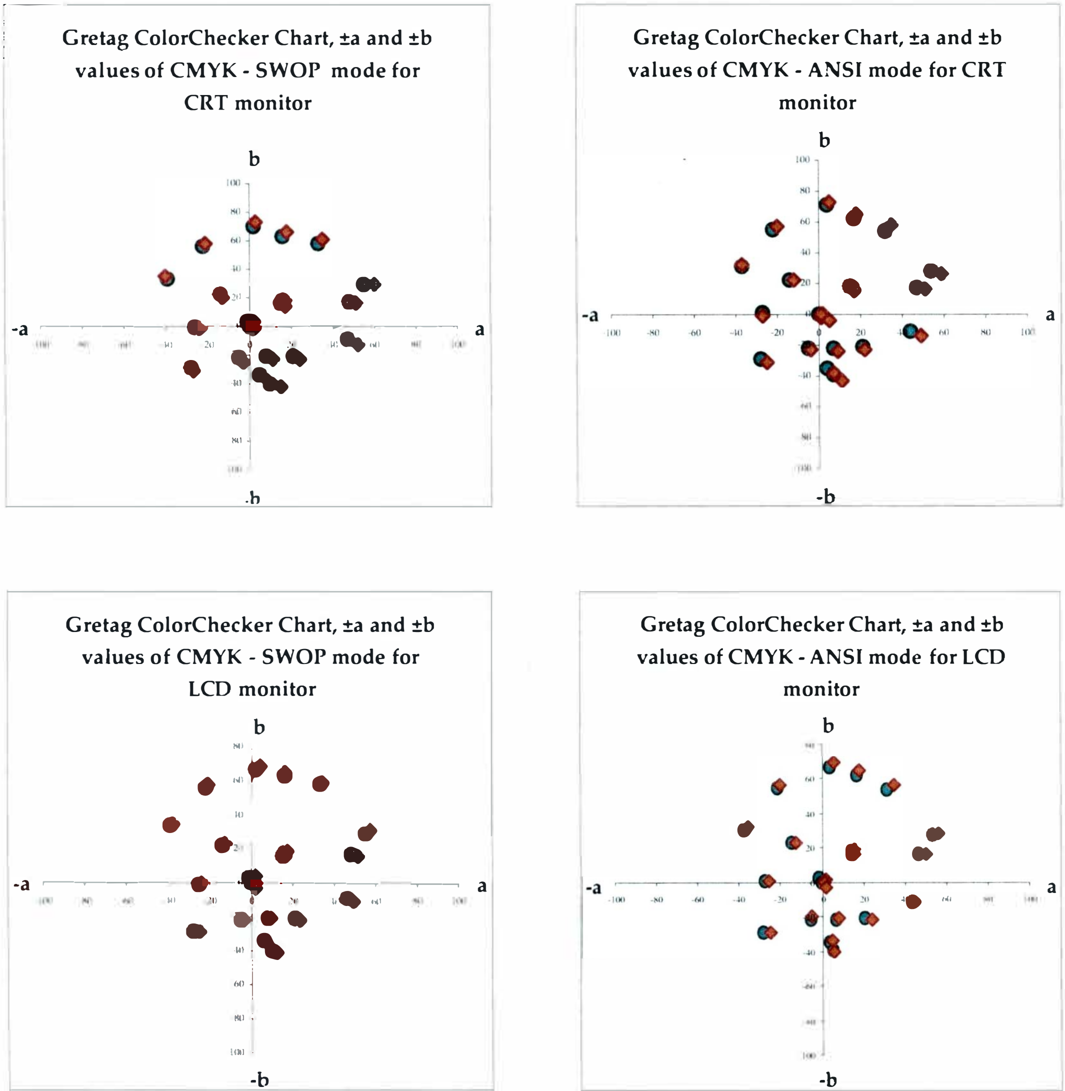

Figure 26. The ±a and ±b values of CMYK mode (SWOP and ANSI) for CRT and LCD monitor

The 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. Above are four graphs comparing the color assets of CMYK mode for both conversion profiles and both monitors (Fig. 26).

ANSI/CGATS TR 001-1995 Output Profile Test

Few patches from the subset area of the IT8.7/3-1993 chart were picked displayed in the CMYK mode. Then, the soft proof conditions were assigned and the values from Info Palette were compared to the given Lab values from the report and also to the measured values. (Tab. 35, 36 in Appendix).

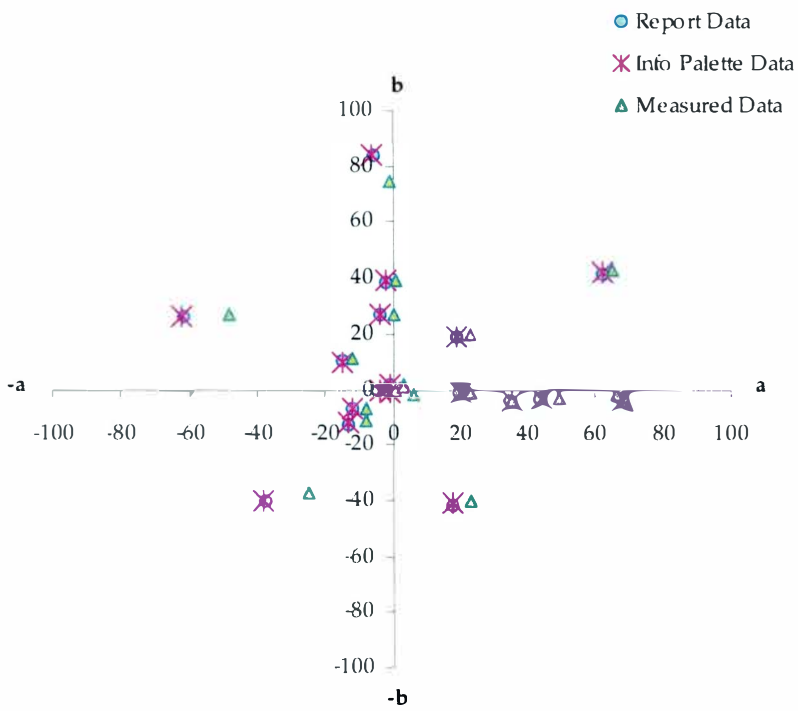

Figure 27. Comparison of the ±a and ±b Values From the ANSI/CGATS TR 001-1995 Report, From the Info Palette and Measured Ones for the CRT Monitor

Three sets of ±a and ±b values were plotted in the graphs above. The values evaluated color assets of CMYK mode for both conversion profiles and both monitors are sketched below. In the graphs (Fig. 27 and 28), compared were the ±a and ±b values from ANSI/CGATS TR 001-1995 Report, ±a and ±b values from Info Palette and measured ones for CRT and LCD monitor.

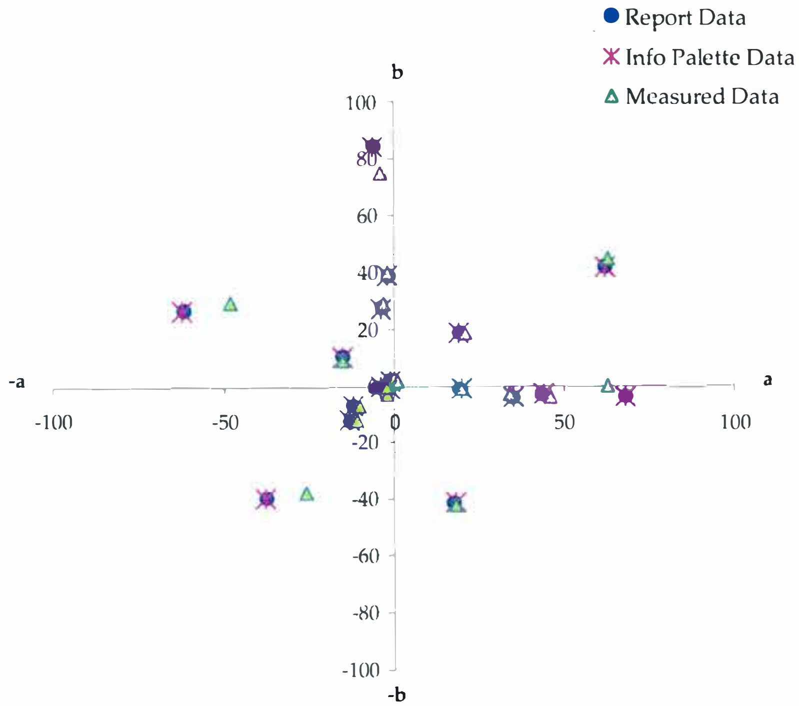

Figure 28. Comparison of the ±a and ±b Values From the ANSI/CGATS TR 001-1995 Report, From the Info Palette and Measured Ones for the LCD Monitor

As seen by Figures 27 and 28, the data gathered from the ANSI/CGATS TR 001-1995 Report are very close to those from Photoshop's Info Palette. This leads to the statement that the output profile for these particular conditions is working correctly. Also, Photoshop is able to show the right colors with the similar values in the Info Palette. The ΔE's are shown in table 15. The same results are predicted because of the fact the system is working only with created output profile and the monitor profiles are not involved in this part of investigation. The values of ΔE are small and these kinds of agreements are still considered to be almost identical. This fact could be markedly seen from the graphs above.

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

Table 15. Delta E Values Calculated From Lab Values of the ANSI/CGATS TR 001-1995 Report and Photoshop's Info Palette Displayed in CMYK Mode

On the other hand, the measured values are little bit shifted from the two sets of the ±a and ±b values, which were compares above. In table 16 the ΔE values for the measured Lab values compared to data from report are shown.

	CRT Monitor	LCD Monitor
	Report vs. Measured	Report vs. Measured
Mean ΔE	5.56	3.92
RMS ΔE	6.45	5.37

Table 16. Delta E Values Calculated From Lab Values of the ANSI/CGATS TR 001-1995 Report and Measured Ones Displayed in CMYK Mode

The values demonstrate the small color shifts. Over again, in this part it was found that the LCD panel could provide better results.

CONCLUSION

In a soft proofing system a monitor is supposed to show what a job will look like when printed. Quantitative and visual 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 the created profiles. Two monitor profiles, for CRT and LCD monitor, were created and the quality of the profiles was considered. The obtained ΔE values of this experimental part are more than agreeable. It is supposed that the profiles working along with the Photoshop software give essentially exact results within the normal fluctuation of display devices. Generally, better results are seen for the LCD display. By performing the RGB→LAB conversion of the image the quality of the monitor profile was also evaluated. The numbers of ΔE are again in the right range, but in this case the better results were seen with the CRT monitor.

Following, three methods to convert image from RGB space to the CMYK were analyzed. Surprisingly, only one way seems to be acceptable. To preview the image the most accurately advised is the following option "View>Proof Setup>Custom menu" conversion with paper simulation turned On. Other two options, "Image>Mode>Convert to Profile" Conversion & "View>Proof Setup>Custom menu" Conversion Path with paper simulation turned Off, reveal significant discrepancies that will be investigated in the future. Due to the fact that 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, View>Proof Setup>Custom menu with the paper simulation turned "On" was chosen for the further investigation of the soft proofing system.

There is also another issue occurring during the experiment. 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 difference between these two profiles is not significant. The fact that every single profile, which is created from the same source of data, can vary is considered here.

GretagMacbeth ColorChecker® Chart Test and ANSI/CGATS TR 001-1995 Output Profile Test were done to look at the color quality of the monitors and output profiles in grater details and more precisely. The monitors provided similarly good quality results. The accuracy of monitor profiles could be deeming as excellent. The output profiles are also working acceptably. Also, Photoshop is able to show the right colors with the similar values in the Info Palette.

From the results found throughout the paper the Liquid Crystal Display shows not significant but still better results than the Cathode Ray Tube monitor. This again leads us to the statement mentioned before, that the technology of LCD panels is developing very fast in recent times. Enhanced quality of monitor profile of LCD panel could be based on the technology used to transform values. Profile making software usually uses a matrix for CRT's and Look Up Tables for LCD's.

The CRT and LCD monitor were employed to display images and visual evaluation was performed. The images on the monitors were then compared to the printed images. The procedures described in 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 considered as very successful. The appearance of both, the displayed and printed proofs were close in terms of details and colors. The whole process described in this research leads to predicted results that soft proofing could work under very specific conditions. Using certain methods consumer is able to get really high-quality results.

In conclusion, color management is an important element in most creative studios whether prepress or art. Along with the explosion of digital devices all around the world, it will be more and more crucial to employ color management in the workflow.

APPENDIX

Table 17: Lab Values of CMYK Conversion via Image>Mode>Convert to Profile Using U.S. Web Coated (SWOP) v2 Conversion Profile for CRT Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b
RGB						
R	61	80	69	61	83	69
G	84	-94	71	85	-92	72
B	30	55	-109	31	57	-109
W	100	0	0	100	4	0
CMYK						
R	49	58	40	53	73	52
G	59	-42	40	66	-48	45
B	36	-2	-40	36	4	-55
W	88	-1	3	100	4	0
RGB						
R	49	58	40	49	63	40
G	59	-42	40	59	-41	40
B	36	-2	-40	34	4	-45
W	89	-1	3	89	3	2

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
0.24	10.79	0.01	**3.32**
1.33	5.98	1.31	**2.94**
1.12	3.41	0.12	**2.16**
0.00	16.07	0.00	**4.01**
19.50	237.57	133.43	**19.76**
55.06	36.84	29.46	**11.02**
0.00	36.44	239.76	**16.62**
155.71	22.94	7.00	**13.63**
0.06	25.74	0.16	**5.10**
0.08	0.76	0.00	**0.91**
2.38	36.42	22.99	**7.86**
0.03	13.37	0.47	**3.72**

Table 18: Lab Values of CMYK Conversion via Image>Mode>Convert to Profile Using ANSI/CGATS TR 001-1995 Conversion Profile for CRT Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b
RGB						
R	61	80	69	61	83	69
G	84	-94	71	85	-92	72
B	30	55	-109	31	57	-109
W	100	0	0	100	4	0
CMYK						
R	54	47	42	61	59	48
G	62	-38	31	70	-43	35
B	42	-3	-36	46	1	-48
W	84	0	0	96	3	-3
RGB						
R	54	47	42	54	52	41
G	62	-38	31	63	-37	31
B	42	-3	-36	41	2	-39
W	84	0	0	85	4	-1

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
0.24	10.79	0.01	**3.32**
1.33	5.98	1.31	**2.94**
1.12	3.41	0.12	**2.16**
0.00	16.07	0.00	**4.01**
42.77	141.75	30.37	**14.66**
61.53	23.28	18.73	**10.18**
12.29	19.05	135.28	**12.91**
136.88	10.53	9.13	**12.51**
0.06	20.81	0.79	**4.65**
0.31	0.63	0.09	**1.01**
0.37	24.50	11.81	**6.06**
1.15	12.92	0.57	**3.83**

Table 19: Lab Values of CMYK Conversion via Image>Mode>Convert to Profile Using U.S. Web Coated (SWOP) v2 Conversion Profile for LCD Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b
RGB						
R	60	75	74	57	74	73
G	83	-78	64	81	-78	63
B	36	33	-98	35	33	-96
W	100	0	0	100	2	1
CMYK						
R	50	56	46	56	68	61
G	62	-37	44	70	-41	50
B	38	-5	-39	41	-5	-50
W	88	-1	3	100	2	1
RGB						
R	50	56	46	49	61	47
G	62	-37	44	62	-36	45
B	38	-5	-39	39	-5	-39
W	88	-1	3	90	1	5

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
3.82	0.33	0.81	**2.23**
4.10	0.00	0.97	**2.25**
0.26	0.05	5.14	**2.34**
0.00	1.04	1.68	**2.14**
30.58	150.15	215.61	**19.91**
56.33	19.87	32.12	**10.41**
8.27	0.08	116.64	**11.18**
151.13	9.33	5.80	**12.89**
0.44	21.38	1.04	**4.78**
0.05	0.67	1.07	**1.34**
0.58	0.00	0.00	**0.76**
3.32	2.70	3.30	**3.05**

Table 20: Lab Values of CMYK Conversion via Image>Mode>Convert to Profile Using ANSI/CGATS TR 001-1995 Conversion Profile for LCD Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b
RGB						
R	60	75	74	57	74	73
G	83	-78	64	81	-78	63
B	36	33	-98	35	33	-96
W	100	0	0	100	2	1
CMYK						
R	54	47	47	61	58	58
G	63	-36	32	72	-41	34
B	43	-2	-35	48	-1	-44
W	84	0	0	96	1	-1
RGB						
R	54	47	47	55	50	49
G	63	-36	32	64	-34	32
B	43	-2	-35	43	0	-35
W	84	0	0	85	2	1

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
3.82	0.33	0.81	**2.23**
4.10	0.00	0.97	**2.25**
0.26	0.05	5.14	**2.34**
0.00	1.04	1.68	**2.14**
49.36	120.69	121.85	**17.09**
75.75	20.40	5.30	**10.07**
24.19	1.16	83.14	**10.42**
146.33	1.10	0.70	**12.17**
0.38	9.37	5.08	**3.85**
0.50	2.81	0.25	**1.89**
0.17	3.34	0.07	**1.89**
1.16	2.67	1.06	**2.21**

Table 21: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "On" Using U.S. Web Coated (SWOP) v2 Profile for CRT Monitor

MODE	Info Palette L	Info Palette a	Info Palette b	MeasureTool 4.1.1 L	MeasureTool 4.1.1 a	MeasureTool 4.1.1 b
RGB						
R	61	80	69	61	83	69
G	84	-94	71	85	-92	72
B	30	55	-109	31	57	-109
W	100	0	0	100	4	0
CMYK						
R	49	58	40	50	62	36
G	59	-42	39	60	-38	38
B	36	-2	-40	37	7	-42
W	88	-1	3	89	4	4
RGB						
R	54	52	40	50	62	36
G	62	-34	32	61	-38	38
B	42	5	-37	37	5	-42
W	84	5	2	89	3	3

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
0.24	10.79	0.01	**3.32**
1.33	5.98	1.31	**2.94**
1.12	3.41	0.12	**2.16**
0.00	16.07	0.00	**4.01**
0.78	12.83	15.83	**5.43**
1.59	15.64	2.03	**4.39**
0.77	72.39	3.12	**8.73**
1.06	21.25	0.41	**4.77**
0.78	12.83	15.83	**5.43**
2.81	14.04	0.50	**4.17**
1.36	52.85	2.42	**7.52**
1.56	13.43	0.05	**3.88**

Table 22: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "On" Using ANSI/CGATS TR 001-1995 Profile for CRT Monitor

MODE	Info Palette L	Info Palette a	Info Palette b	MeasureTool 4.1.1 L	MeasureTool 4.1.1 a	MeasureTool 4.1.1 b
RGB						
R	61	80	69	61	83	69
G	84	-94	71	85	-92	72
B	30	55	-109	31	57	-109
W	100	0	0	100	4	0
CMYK						
R	55	47	42	54	52	40
G	62	-38	31	62	-34	32
B	42	-2	-36	42	5	-37
W	84	0	0	84	5	2
RGB						
R	55	47	42	54	51	41
G	62	-38	31	62	-34	31
B	42	-2	-36	42	5	-37
W	84	0	0	85	5	1

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
0.24	10.79	0.01	**3.32**
1.33	5.98	1.31	**2.94**
1.12	3.41	0.12	**2.16**
0.00	16.07	0.00	**4.01**
0.57	20.81	2.78	**4.92**
0.14	16.41	1.14	**4.21**
0.13	51.01	0.78	**7.21**
0.19	21.09	3.34	**4.96**
0.35	19.28	1.92	**4.64**
0.06	17.76	0.02	**4.22**
0.01	50.88	0.35	**7.16**
0.27	24.48	0.90	**5.06**

Table 23: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "On" Using U.S. Web Coated (SWOP) v2 Profile for LCD Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b	$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
RGB										
R	60	75	74	57	74	73	3.82	0.33	0.81	**2.23**
G	83	-78	64	81	-78	63	4.10	0.00	0.97	**2.25**
B	36	33	-98	35	33	-96	0.26	0.05	5.14	**2.34**
W	100	0	0	100	2	1	0.00	1.04	1.68	**1.65**
CMYK										
R	50	56	46	50	58	43	0.00	4.80	8.93	**3.71**
G	62	-37	44	62	-34	42	0.04	12.02	4.19	**4.03**
B	38	-5	-39	39	0	-35	0.83	25.07	12.46	**6.19**
W	88	-1	3	88	3	5	0.01	14.47	5.88	**4.51**
RGB										
R	50	56	46	50	57	42	0.08	1.34	12.33	**3.71**
G	62	-37	44	62	-32	42	0.02	25.35	5.95	**5.60**
B	38	-5	-39	40	-1	-35	3.12	17.60	12.81	**5.79**
W	88	-1	3	89	1	5	0.96	4.27	4.65	**3.14**

Table 24: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "On" Using ANSI/CGATS TR 001-1995 Profile for LCD Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b	$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
RGB										
R	60	75	74	57	74	73	3.82	0.33	0.81	**2.23**
G	83	-78	64	81	-78	63	4.10	0.00	0.97	**2.25**
B	36	33	-98	35	33	-96	0.26	0.05	5.14	**2.34**
W	100	0	0	100	2	1	0.00	1.04	1.68	**1.65**
CMYK										
R	54	47	47	55	49	46	0.43	3.97	0.32	**2.18**
G	63	-36	31	64	-31	32	0.37	20.72	0.52	**4.65**
B	43	-2	-35	44	2	-32	0.27	18.71	8.02	**5.20**
W	84	0	0	84	2	3	0.02	4.31	8.31	**3.56**
RGB										
R	54	47	47	55	49	45	0.43	2.42	3.92	**2.60**
G	63	-36	31	63	-32	30	0.16	18.67	0.53	**4.40**
B	43	-2	-35	44	2	-32	1.15	12.73	8.35	**4.71**
W	84	0	0	84	2	2	0.01	5.74	2.26	**2.83**

Table 25: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "Off" Using U.S. Web Coated (SWOP) v2 Profile for CRT Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b
RGB						
R	61	80	69	61	83	69
G	84	-94	71	85	-92	72
B	30	55	-109	31	57	-109
W	100	0	0	100	4	0
CMYK						
R	49	58	40	54	71	46
G	59	-42	39	67	-45	44
B	36	-2	-40	39	5	-52
W	88	-1	3	100	4	0
RGB						
R	49	58	40	50	62	36
G	59	-42	39	61	-38	38
B	36	-2	-40	37	5	-42
W	88	-1	3	89	3	3

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
0.24	10.79	0.01	**3.32**
1.33	5.98	1.31	**2.94**
1.12	3.41	0.12	**2.16**
0.00	16.07	0.00	**4.01**
29.24	170.61	41.02	**15.52**
60.46	7.30	24.38	**9.60**
11.29	51.79	139.21	**14.22**
151.28	25.36	6.65	**13.54**
0.78	12.83	15.83	**5.43**
2.81	14.04	0.50	**4.17**
1.36	52.85	2.42	**7.52**
1.56	13.43	0.05	**3.88**

Table 26: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "Off" Using ANSI/CGATS TR 001-1995 Profile for CRT Monitor

MODE	Info Palette L	a	b	MeasureTool 4.1.1 L	a	b
RGB						
R	61	80	69	61	83	69
G	84	-94	71	85	-92	72
B	30	55	-109	31	57	-109
W	100	0	0	100	4	0
CMYK						
R	55	47	42	60	59	46
G	62	-38	31	69	-39	35
B	42	-2	-36	46	3	-45
W	84	0	0	95	5	-2
RGB						
R	55	47	42	54	51	41
G	62	-38	31	62	-34	31
B	42	-2	-36	42	5	-37
W	84	0	0	85	5	1

$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
0.24	10.79	0.01	**3.32**
1.33	5.98	1.31	**2.94**
1.12	3.41	0.12	**2.16**
0.00	16.07	0.00	**4.01**
29.18	145.37	15.12	**13.77**
53.18	1.44	17.41	**8.49**
15.45	27.71	80.32	**11.11**
116.33	27.70	4.30	**12.18**
0.35	19.28	1.92	**4.64**
0.06	17.76	0.02	**4.22**
0.01	50.88	0.35	**7.16**
0.27	24.48	0.90	**5.06**

Table 27: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "Off" Using U.S. Web Coated (SWOP) v2 Profile for LCD Monitor

MODE	Info Palette			MeasureTool 4.1.1			$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
	L	a	b	L	a	b				
RGB										
R	60	75	74	57	74	73	3.82	0.33	0.81	**2.23**
G	83	-78	64	81	-78	63	4.10	0.00	0.97	**2.25**
B	36	33	-98	35	33	-96	0.26	0.05	5.14	**2.34**
W	100	0	0	100	2	1	0.00	1.04	1.68	**1.65**
CMYK										
R	50	56	46	56	67	56	35.41	123.60	95.46	**15.95**
G	62	-37	44	69	-39	50	53.40	3.94	34.57	**9.59**
B	38	-5	-39	42	-1	-46	14.47	13.56	56.25	**9.18**
W	88	-1	3	100	3	2	138.19	13.35	2.05	**12.39**
RGB										
R	50	56	46	50	57	42	0.08	1.34	12.33	**3.71**
G	62	-37	44	62	-32	42	0.02	25.35	5.95	5.60
B	38	-5	-39	40	-1	-35	3.12	17.60	12.81	5.79
W	88	-1	3	89	1	5	0.96	4.27	4.65	**3.14**

Table 28: Lab Values of CMYK Conversion via View>Proof Setup>Custom Menu "Off" Using ANSI/CGATS TR 001-1995 Profile for LCD Monitor

MODE	Info Palette			MeasureTool 4.1.1			$(\Delta L)^2$	$(\Delta a)^2$	$(\Delta b)^2$	ΔE
	L	a	b	L	a	b				
RGB										
R	60	75	74	57	74	73	3.82	0.33	0.81	**2.23**
G	83	-78	64	81	-78	63	4.10	0.00	0.97	**2.25**
B	36	33	-98	35	33	-96	0.26	0.05	5.14	**2.34**
W	100	0	0	100	2	1	0.00	1.04	1.68	**1.65**
CMYK										
R	54	47	47	61	57	55	46.48	91.88	63.25	**14.20**
G	63	-36	31	71	-37	34	63.83	1.92	7.96	**8.58**
B	43	-2	-35	48	2	-42	23.40	15.61	46.18	**9.23**
W	84	0	0	88	3	5	15.16	7.86	29.43	7.24
RGB										
R	54	47	47	55	49	45	0.43	2.42	3.92	**2.60**
G	63	-36	31	63	-32	30	0.16	18.67	0.53	**4.40**
B	43	-2	-35	44	2	-32	1.15	12.73	8.35	**4.71**
W	84	0	0	84	2	2	0.01	5.74	2.26	**2.83**

Table 29. Gretag ColorChecker Chart, Lab Values of RGB Mode for CRT Monitor

Patch	Info Palette			MeasureTool 4.1.1			
	L	a	b	L	a	b	Δ E
1	38	15	16	37	18	13	4.55
2	67	16	18	67	18	18	1.89
3	50	-5	-22	51	-3	-24	3.03
4	43	-14	22	43	-12	20	2.41
5	55	9	-25	56	12	-27	3.52
6	71	-32	0	72	-31	0	1.68
7	62	35	61	62	37	62	2.44
8	40	9	-43	40	12	-46	3.95
9	52	48	17	51	51	16	3.54
10	31	21	-21	31	23	-23	3.11
11	72	-23	57	73	-21	58	2.31
12	73	19	68	73	20	70	2.16
13	29	19	-54	29	23	-57	4.87
14	55	-39	33	56	-39	34	1.74
15	42	56	29	41	59	28	3.61
16	82	5	78	82	7	75	3.22
17	51	50	-13	51	54	-17	5.40
18	50	-28	-29	51	-26	-31	2.89
19	96	0	0	97	3	-1	2.67
20	81	0	0	82	2	-1	2.04
21	67	0	0	67	6	-3	6.56
22	52	0	0	52	1	-1	1.60
23	36	0	0	36	1	-1	1.50
24	20	0	0	18	5	-3	5.81

Table 30. Gretag ColorChecker Chart, Lab Values of RGB Mode for LCD Monitor

Patch	Info Palette			MeasureTool 4.1.1			
	L	a	b	L	a	b	Δ E
1	38	15	16	36	15	17	**1.63**
2	67	16	18	66	17	19	**1.88**
3	50	-5	-22	50	-5	-21	**0.69**
4	43	-14	22	42	-14	23	**1.13**
5	55	9	-25	55	9	-24	**1.05**
6	71	-32	0	70	-31	0	**1.11**
7	62	35	61	62	37	64	**3.54**
8	40	9	-43	39	10	-44	**1.71**
9	52	48	17	51	51	16	**3.01**
10	31	21	-21	29	23	-23	**3.05**
11	72	-23	57	72	-23	59	**2.36**
12	73	19	68	73	20	70	**1.92**
13	29	19	-54	26	20	-57	**4.29**
14	55	-39	33	55	-40	34	**1.79**
15	42	56	29	41	57	31	**2.64**
16	82	5	78	81	7	75	**3.88**
17	51	50	-13	50	53	-13	**3.20**
18	50	-28	-29	49	-25	-29	**2.93**
19	96	0	0	96	2	1	**2.02**
20	81	0	0	81	1	0	**1.31**
21	67	0	0	67	1	1	**1.20**
22	52	0	0	51	1	1	**1.35**
23	36	0	0	35	-1	0	**1.12**
24	20	0	0	18	2	-4	**4.79**

Table 31. Gretag ColorChecker Chart, Lab Values of CMYK - SWOP Mode for CRT Monitor

Patch	Info Palette			MeasureTool 4.1.1			
	L	a	b	L	a	b	Δ E
1	38	15	16	37	17	14	**3.22**
2	67	16	18	67	17	18	**1.48**
3	50	-5	-22	50	-3	-25	**3.46**
4	43	-14	22	42	-13	20	**2.30**
5	55	8	-21	55	11	-23	**3.53**
6	67	-26	-1	68	-24	-2	**2.33**
7	61	33	58	61	35	61	**3.13**
8	40	5	-34	39	9	-38	**5.33**
9	52	48	17	51	51	16	3.47
10	31	21	-21	30	24	-23	3.94
11	72	-22	56	72	-21	58	**2.52**
12	71	16	63	71	18	66	**3.14**
13	31	10	-40	31	15	-42	**5.36**
14	56	-39	33	56	-40	35	**2.48**
15	42	55	29	41	60	29	**4.86**
16	79	2	70	80	3	73	**3.59**
17	51	47	-9	50	52	-13	**6.29**
18	50	-28	-29	51	-27	-31	**2.54**
19	88	-1	3	89	2	3	**3.03**
20	81	0	0	82	2	-1	**2.07**
21	67	0	0	68	2	-1	**2.33**
22	52	0	0	52	1	-1	**1.53**
23	36	0	0	35	1	-1	**1.88**
24	20	0	0	17	2	-2	**4.02**

Table 32. Gretag ColorChecker Chart, Lab Values of CMYK - ANSI Mode for CRT Monitor

Patch	Info Palette			MeasureTool 4.1.1			
	L	a	b	L	a	b	Δ E
1	38	16	17	37	17	15	**2.71**
2	66	15	18	66	17	16	**2.23**
3	50	-5	-22	50	-4	-23	**1.44**
4	43	-14	22	43	-12	22	**1.71**
5	54	7	-22	55	9	-24	**3.26**
6	67	-27	1	68	-27	-1	**1.91**
7	61	32	54	61	35	58	**5.21**
8	40	4	-35	40	7	-38	**4.62**
9	51	47	17	50	51	16	**4.44**
10	31	21	-21	30	22	-23	**2.64**
11	71	-22	55	71	-20	57	**2.82**
12	70	17	62	70	18	65	**2.96**
13	33	7	-39	33	11	-43	**6.03**
14	55	-37	31	55	-37	32	**1.39**
15	43	54	28	41	59	26	**5.82**
16	78	4	71	78	5	73	**1.92**
17	51	44	-11	50	49	-14	**5.74**
18	50	-28	-29	51	-25	-31	**3.53**
19	84	0	0	85	2	0	**2.66**
20	81	0	0	81	2	-1	**2.53**
21	66	0	0	67	2	-1	**2.77**
22	52	0	0	52	1	-2	**1.95**
23	36	0	0	35	1	0	**1.54**
24	20	0	0	17	5	-4	**6.78**

Table 33. Gretag ColorChecker Chart, Lab Values of CMYK - SWOP Mode for LCD Monitor

Patch	Info Palette			MeasureTool 4.1.1			Δ E
	L	a	b	L	a	b	
1	38	15	16	37	16	16	**1.57**
2	67	16	18	66	17	19	**1.77**
3	50	-5	-22	50	-4	-22	**1.03**
4	43	-14	22	43	-13	23	**1.00**
5	55	8	-21	55	9	-21	**1.53**
6	67	-25	-1	67	-24	0	**1.43**
7	61	33	58	61	34	59	**1.57**
8	40	6	-34	39	7	-35	**1.37**
9	52	48	17	51	51	16	**3.70**
10	31	21	-21	30	23	-22	**2.25**
11	72	-22	56	72	-21	58	**1.92**
12	71	16	63	71	16	65	**2.10**
13	31	10	-40	29	12	-41	**2.62**
14	56	-39	34	55	-38	35	**1.87**
15	42	55	29	41	57	31	**2.78**
16	80	2	67	80	4	69	**2.93**
17	51	46	-9	50	49	-11	**3.44**
18	50	-28	-29	49	-25	-29	**3.28**
19	88	-1	3	88	2	4	**3.28**
20	81	0	0	81	1	0	**1.35**
21	67	0	0	67	1	0	**1.01**
22	52	0	0	52	1	1	**1.18**
23	36	0	0	36	2	0	**1.64**
24	20	0	0	19	2	-3	**3.64**

Table 34. Gretag ColorChecker Chart, Lab Values of CMYK - ANSI Mode for LCD Monitor

Patch	Info Palette			MeasureTool 4.1.1			
	L	a	b	L	a	b	Δ E
1	37	15	17	37	16	17	1.61
2	66	15	18	66	16	19	1.38
3	50	-5	-22	50	-5	-20	2.12
4	43	-14	23	43	-13	23	0.91
5	54	7	-22	55	8	-21	1.54
6	67	-27	1	67	-26	1	1.27
7	61	32	54	60	35	57	3.98
8	40	4	-35	40	5	-34	1.14
9	51	47	17	51	50	17	3.15
10	31	21	-21	30	24	-22	2.84
11	71	-21	55	71	-20	57	2.52
12	70	17	62	70	18	65	3.06
13	33	6	-39	33	6	-40	0.77
14	55	-37	31	55	-36	32	0.92
15	43	54	28	42	56	29	2.20
16	78	4	67	79	6	70	3.34
17	50	44	-11	51	45	-11	1.39
18	49	-28	-29	50	-25	-29	3.46
19	85	-1	3	85	2	2	2.67
20	81	0	0	81	1	0	1.36
21	66	0	0	67	1	1	1.29
22	52	0	0	52	1	1	1.37
23	36	0	0	36	1	0	0.71
24	20	0	0	19	2	-3	3.61

Table 35: Lab Values From ANSI/CGATS TR 001-1995 Report, Info Palette Shown in Photoshop and Measured by Spectrolino Displayed in CMYK Soft Proof Mode for CRT Monitor

Patch	ANSI/CGATS TR 001-1995			Info Palette			MeasureTool 4.1.1		
	L	a	b	L	a	b	L	a	b
0A01	56.0	-37.6	-40.0	56	-38	-40	58	-25	-37
0A02	47.2	68.1	-4.0	47	68	-4	49	66	-2
0A03	84.3	-5.8	84.3	84	-6	84	84	-1	75
0A04	26.6	17.6	-41.2	27	18	-41	28	23	-40
0A05	51.5	-61.6	26.1	51	-62	26	53	-48	27
0A06	46.9	62.2	41.8	47	62	42	48	65	43
0A07	24.8	-1.3	-0.5	25	-1	-1	27	6	-2
0C07	76.7	-12.9	-12.6	77	-13	-12	77	-8	-11
0D07	74.3	19.6	-1.2	74	20	-1	74	23	-1
0E07	86.7	-3.6	27.2	87	-4	27	87	0	27
0F07	67.7	-1.0	1.0	68	-1	-1	68	3	2
0G02	36.9	43.5	-3.2	37	44	-3	37	49	-3
0H07	68.6	-1.8	38.5	69	-2	39	69	1	39
0I11	47.8	-15.1	10.2	48	-15	10	49	-12	11
0J04	48.3	-12.0	-7.1	48	-12	-7	49	-8	-7
0K03	42.9	-4.6	-0.5	43	-4	0	43	1	0
0L08	74.0	-1.0	1.8	75	-1	2	75	3	1
0M11	58.3	19.1	18.8	58	19	19	59	23	20
0N06	23.9	34.7	-4.2	23	35	-4	26	35	-4

Table 36: Lab Values From ANSI/CGATS TR 001-1995 Report, Info Palette Shown in Photoshop and Measured by Spectrolino Displayed in CMYK Soft Proof Mode for LCD Monitor

Patch	ANSI/CGATS TR 001-1995			Info Palette			MeasureTool 4.1.1		
	L	a	b	L	a	b	L	a	b
0A01	56.0	-37.6	-40.0	56	-38	-40	57	-26	-38
0A02	47.2	68.1	-4.0	47	68	-4	48	63	0
0A03	84.3	-5.8	84.3	84	-6	84	84	-4	75
0A04	26.6	17.6	-41.2	27	18	-41	25	18	-42
0A05	51.5	-61.6	26.1	51	-62	26	52	-48	29
0A06	46.9	62.2	41.8	47	62	42	46	63	45
0A07	24.8	-1.3	-0.5	25	-1	-1	22	-2	-3
0C07	76.7	-12.9	-12.6	77	-13	-12	76	-11	-12
0D07	74.3	19.6	-1.2	74	20	-1	74	20	-1
0E07	86.7	-3.6	27.2	87	-4	27	87	-3	29
0F07	67.7	-1.0	1.0	68	-1	-1	67	0	3
0G02	36.9	43.5	-3.2	37	44	-3	35	46	-4
0H07	68.6	-1.8	38.5	69	-2	39	68	-2	40
0I11	47.8	-15.1	10.2	48	-15	10	47	-15	9
0J04	48.3	-12.0	-7.1	48	-12	-7	48	-10	-7
0K03	42.9	-4.6	-0.5	43	-4	0	42	-2	0
0L08	74.0	-1.0	1.8	75	-1	2	74	1	2
0M11	58.3	19.1	18.8	58	19	19	58	21	19
0N06	23.9	34.7	-4.2	23	35	-4	23	34	-3

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