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Abstract

Managing and controlling color is a major concern for the graphic communications and imaging industries. The purpose of this research was to identify the color differences (CIE L* a* b* values) that exist in the solid color areas of cyan, magenta, yellow, black, red, green, and blue (CMYKRGB) of an image displayed on the monitor vs. printer in a Color Management Workflow (CMW) to confirm the known process or CMW standards. Modern Industrial Technology Graphic Communications graduates with technical competencies in color management are, and will be, in greater demand than ever before in one of the largest industries in the United States. The findings of this research (using colorimetric data analysis) led to the conclusion that the application and implementation of color management techniques works and offers us more flexibility and control over colors and tonal values in reproducing color images.

Introduction

Managing and controlling color from a wide range of input devices (digital cameras and scanners) to multicolor output devices (digital printers and printing presses), are major concerns for the graphic communications and imaging industries. Accurate or facsimile color control from beginning to end in a printing or imaging process is important for quality output (display or printed). Advancements in science and engineering in the recent years, allow printing and imaging professionals to apply scientific applications in the prepress, pressroom, and quality control areas of the industry. Modern printing technology has evolved from the craft oriented field to more of a color imaging science. This allowed the industry to control the color between the various devices more accurate than before.

The study of color is a science and the optical aspects of color only are quantitatively analyzable and measurable. Human eye perceives color more subjectively. Input (scanners or digital cameras) and output (monitors or printers) devices produce colors differently because they depend on their own color capabilities. The color management system simplifies and improves the reproduction of color images accurately from device to device. Additionally, it solves the basic problem that no two devices can produce the same visual color from the same digital data (Hutcheson, 2001).

Overview of Color Management System (CMS)

CMS or Color Management Workflow (CMW) uses a set of hardware tools and software applications working together to create accurate color between various input, display and output devices. A CMS consists of device profiles (or characterization of devices), which control and document the working performance of the scanner, monitor, and the printer. A device color transformation engine (Color Management (matching) Module (method) or CMM) is one that interprets the color data between the scanner, display and the printer. The gamut compensation mechanism of the CMS addresses differences between the color capabilities of input, display and output device. A device independent color space (Profile Connection Space or PCS) through which all color transformation occurs from one device-dependent color space to another (see Figure 1). The PCS is based on the spaces derived from CIE color space. Apple ColorSync supports two of these spaces: L* a* b* and XYZ. The CMS is achieved by the use of PCS. Device color characterization file (profile) passes in and out of PCS to complete the transformation. The PCS of the CMS is the central hub of the CMS in which a particular color value is considered absolute and not subject to interpretation.

To address the concerns of accurate color control throughout the printing or imaging process, color management systems (CMS) have been developed (Adams & Weisberg, 2000). The International Color Consortium (ICC) was formed in 1993 by seven industry members: Adobe, Agfa, Apple, Kodak, Microsoft, Sun Microsystems, and Silicon Graphics to define the standards for color device characterization (Adams & Weisberg, 2000). Today, ICC represents more than fifty industry members (ICC, 2006). This device characterization is presented in terms of specially formatted files, which have come to be called profiles. Unfortunately, the use of color management systems has not yet solved all of the problems of color reproduction (Fleming & Sharma, 2002). However, it has made possible the quantification of problems. As always in quality control, with quantification comes the ability to control and, with control, quality management becomes possible (Fleming & Sharma, 2002).

The 3 C's (Calibration, Characterization, and Conversion) of CMS or CMW

To implement the CMS successfully, all the devices which are used for printing and imaging purposes must be calibrated, characterized (profiled) and their color capabilities (RGB and CMYK) must be converted into an independent color space (CIE L* a* b* space). A calibration process means standardizing the performance of the devices according to the device manufacturer specifications, so that the results of the devices are repeatable. A profiling process (or characterization) refers to colorimetric assessment of the device color performance and creating an ICC (International Color Consortium) profile specific to that device. Characterization process requires CMS hardware tools and software. Characterization of the devices is converted into ICC profile file format. It communicates measured color output of devices in response to known output. Conversion refers to translating a color image data from one device color space to another device space. It is also known as color transformation.

Purpose and the Limitations of the Research

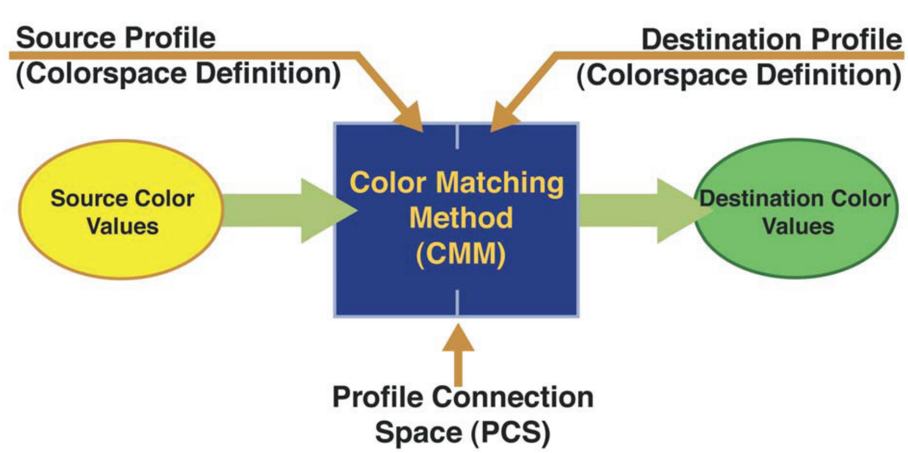
The work focused Color Management Workflow (CMW) implementation in the graphic communications laboratories. The purpose of this research was to identify the color differences (CIE L* a* b* values) that exist in the solid color areas of cyan, magenta, yellow, black, red, green, and blue (CMYKRGB) of an image displayed on the monitor vs. printer in a CMW to confirm the known process or CMW standards. Solid color is the attribute that represents overall details (color gamut) of an image. The laboratory personnel utilized this report for the CMW implementation process. Graphic communications students also required using the report for their CM laboratory work.

The image display and print characteristics associated with the monitor vs. printer are characterized by, but not restricted to, inherent limitations; for example: type of digital printer for proofing, type of paper for printing, type of toner, etc. There are several variables affecting the facsimile reproduction of color images in the CMW and most of them are mutually dependent on each other. The scope of the research was limited to the inkjet digital printing system (printing proof), liquid crystal display (LCD) monitor (image display), a flatbed scanner (image capturing) and other raw materials and color measuring devices used at the University graphic communications laboratory, and the findings were not expected to be generalizable to other CMW environments. The research methodology, experimental design, and statistical analysis were all selected in alignment with the purpose of the research with full awareness of the aforementioned delimitations. It is quite likely, however, others could find this study meaningful and useful. The prepress and printing laboratory uses color management workflow for accurate color reproduction (see Figure 2 on page 4).

Research Method

This research utilized an empirical research method. Quantitative techniques were used to collect and analyze the data. It was intended to determine the color differences that exist on the monitor vs. printed proof in a color managed workflow (CMW). A detailed method

Figure 1: Schematic of PCS of CMS (Courtesy of Adobe Systems, Inc.)



of this experiment is summarized in the following paragraphs. Prior to device profiling, image capturing, image display, and printing the proof, all devices that are used in the experiment were calibrated and characterized according to device manufacturer standards (specifications or instructions). X-Rite Monaco Profiler software was used to profile or characterize all the devices that were used in the experiment. The profiles used in the experiment were limited to the devices used for the experiment only.

Figure 2: Schematic of Color Management Workflow

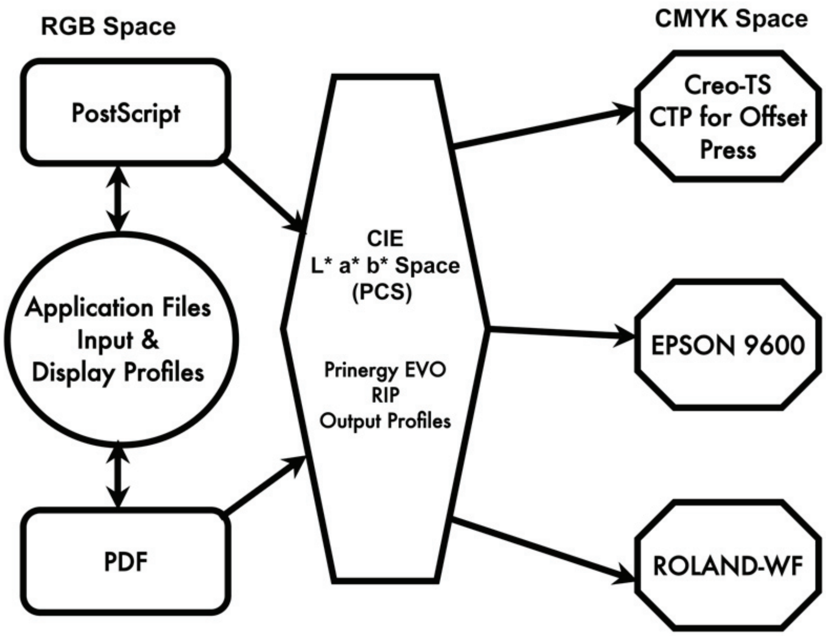
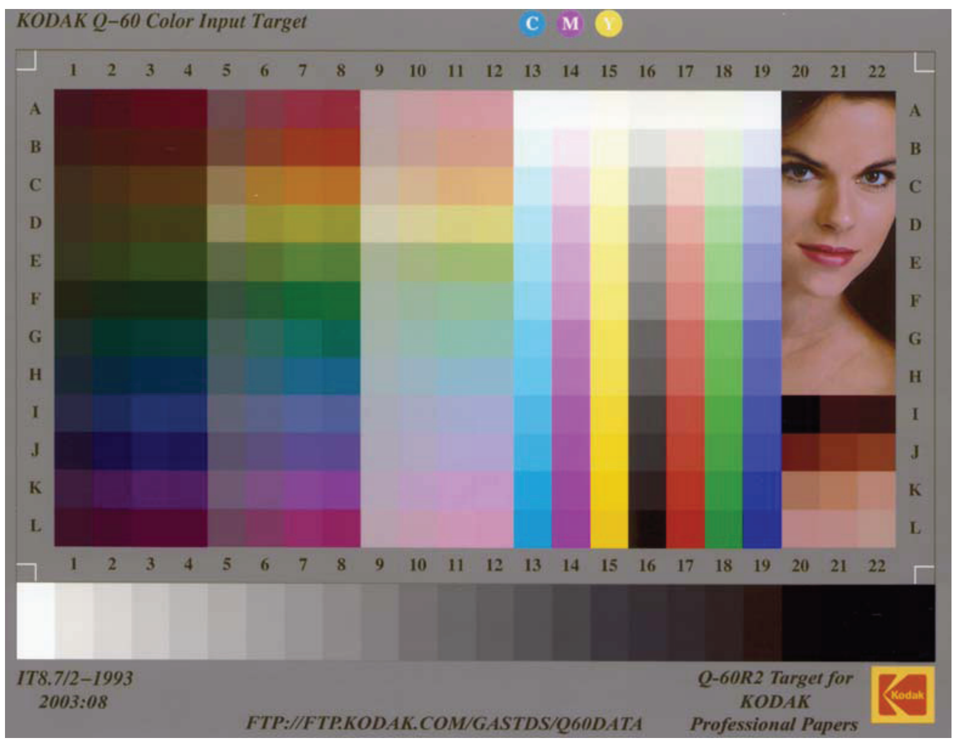


Figure 3: A Kodak ANSI/ISO IT8.7/2 Target for Scanner Profile



Monitor Profile

An Apple G4 computer LCD monitor was profiled by using the Monaco OPTIX colorimeter and Monaco Profiler 4.60. Existing default profile of the monitor was disabled in the Apple G4 Operating System (OS) prior to profiling the monitor. The contrast and brightness controls on the monitor were adjusted with the help of the profile making software and were kept the same from the starting point to end point of the profiling process. This step also called calibration of the monitor. The desire temperature of 5000 Kelvin (D50), 2° standard observer and ϒ value of 1.80 (the default gamma value for Apple OS platforms) were set for the Monitor (Sharma, 2004). The new profile was kept active in OS (see Figure 5).

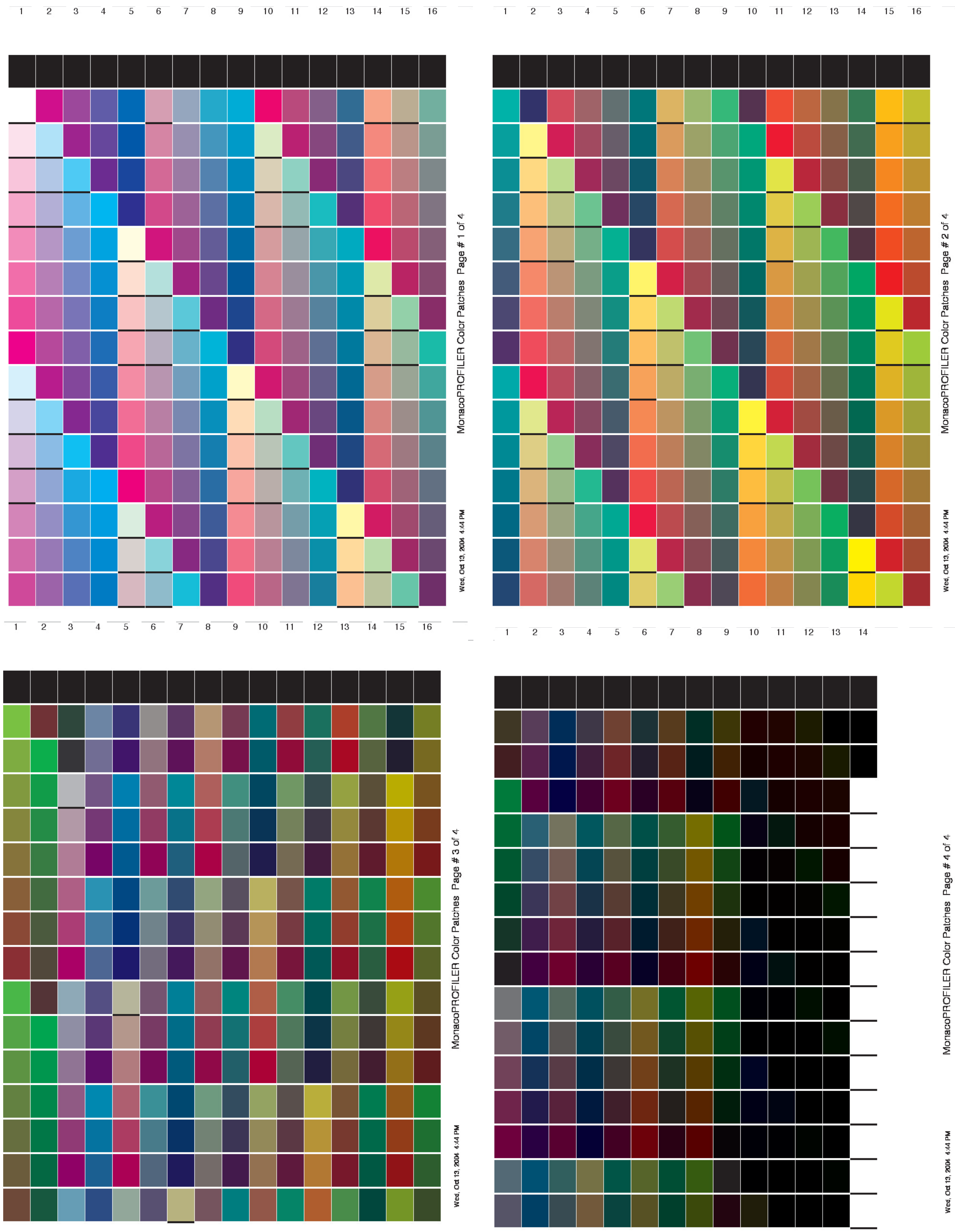
Scanner Profile

An ANSI/ISO (American National Standard Institute/International Standards Organization) Kodak IT8.7/2 scanner target (see Figure 3) was scanned at 200 pixels per inch to create the profile for the EPSON Perfection Photo-4870 scanner that was used in the experiment Prior to scanning the target all the color management and color correction options were disabled in the scanner software. The scanner profiling is the process of determining the precise color characteristics of a scanner. To build the scanner profile (see Figure 5 on page 6), with the use of IT8.7/2 target the scanned target was cropped and run through the Monaco Profiler 4.60 software (Gold). During the profiling process, the software compares the color data generated by the scanner to the known colorimetric values of the pre-measured target (IT8.7/2 Target Q-60 reference data file) to generate the profile.

Printer Profile

An ANSI/ISO IT8.7/3 printer target with 963 patches (see Figure 4 on page 5) was printed on the EPSON Stylus PRO 9600 printer. Prior to printing the patches, the printer was calibrated

Figure 4: ANSI/ISO IT8.7/3 Printer Target (963 Patches), Created by Monaco Profiler 4.60

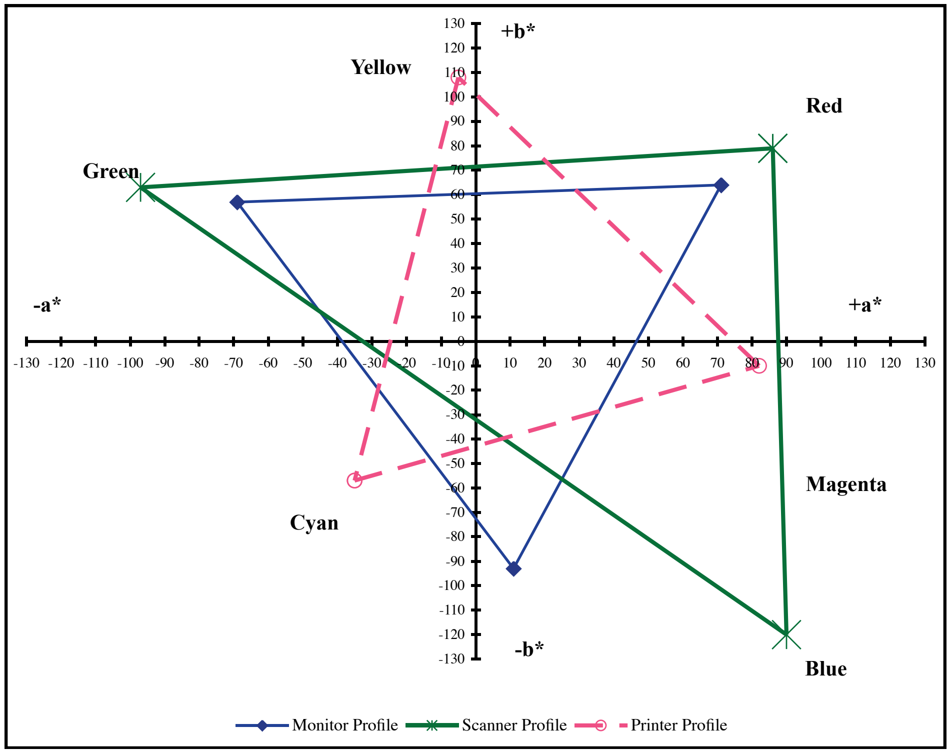


according to its manufacturer specifications. All the color management and control options were disabled in the RIP (raster image processor) software. Printed patches were measured in CIE L* a* b* space with a Gretag Eye-One spectrophotometer and the data was run through the Monaco Profiler 4.60 to create the printer profile (see Figure 5). IT8.7/3 is a printed reflection target that can be used to obtain the color gamut of a printing device or printer. Upon completing all these devices profiles, they were inspected with ColorThink software for profile accuracy, extracting L* a* b* values and creating profiles L* a* b* graphs (see Figure 5).

The experiment had successfully created all the device profiles (scanner, monitor and printer) for the use in the remainder of the experiment. Visual examinations of all the device profiles indicate that the monitor and printer profiles are smaller than the scanner profile. Each profile is an indication that they have different color capabilities because they come from different manufacturers. The goal of the experiment is to see is there any color gamut differences exists in the output (display or printed) color gamut.

Color gamut mapping can be completed by one of the four ICC recognized colorimetric rendering intents: perceptual, absolute, relative, and saturation. The rendering intent determines how the colors are processed that are present in the source gamut but out of gamut in the destination (output). For this experiment, absolute colorimetric intent was chosen. It intends to produce in-gamut color exactly and clips out-of-gamut colors to the nearest reproducible hue, by scarifying saturation (chroma or vividness) and lightness (value).

Figure 5: Device Profile Comparison in 2D CIE L* a* b* Space



Application of Profiles for Printing

A Kodak PROFESSIONAL Q-60 (ANSI/ISO IT8.7/2) reflective test color (CMYKRGB) image was scanned at 300 pixels per inch (PPI) for proofing printing use in the experiment. The image was manufactured according to ANSI/ISO standards by using KODAK EKTACOLOR paper, which was developed primarily for use by the prepress area of the printing industry. This target can also be used by professional photographers, desktop publishers, and in the emerging hybrid imaging area. The test color image contained the following elements: a black and white grayscale, CMYKRGB tone scales, and IT8.7/2 patches for colorimetric data.

Scanned test image was opened with Adobe PhotoShop-CS and displayed onto the Apple G4 LCD monitor. All the device profiles were embedded (or assigned) to the test image in the Adobe PhotoShop-CS application with an absolute colorimetric rendering intent. The CIE L* a* b* data of an image on the monitor was recorded for the later comparison with the printed proof and the image was then saved. Later, the saved image was imported into the page layout program (QuarkXPress 6.00) and a PostScript (PS) file was made. The PS file was rasterized (or ripped) by using Creo Prinergy EVO raster image processor (RIP). Printer profile was attached with the ripped file and the file was sent to the EPSON Stylus PRO 9600 printer to print the proof (see Figure 2). The CIE L* a* b* values of the printed proof were measured with a Gretag Eye-One spectrophotometer using ColorShop X application interface. Table 1 presents the variables, materials, conditions, and equipment associated with the scanner, monitor and printer of this experiment (see Table 1 on page 7).

Data Analysis and Research Findings

Printed proof was analyzed by using a Gretag Eye-One Spectrophotometer and CIE L* a* b* values of CMYKRGB colors were measured at the solid color areas on the printed proof. Colorimetric computations were used to analyze the data. Color difference (ΔE) was also calculated to see the noticeable color differences exist between the CIE L* a* b* values of monitor vs. printed proof. In comparing the color differences between two colors, a higher ΔE is an indication that there is a more color variation and lesser the ΔE is an indication of less color variation. However, the subjective judgment of color difference could differ from person to person. For example, we see colors in an image not by isolating one or two colors at a time (Goodhard & Wilhelm, 2003). We see colors by mentally processing contextual relationships between colors where the changes in lightness (value), hue, and chroma (saturation) contribute independently to the visual detection of spatial patterns in the image (Goodhard & Wilhelm, 2003). Analyzed results are presented in the following section.

Color Variation in the Solid Color Area of Monitor vs. Printer

The CIE L* a* b* values associated with the CMYKRGB colors in solid color area of monitor vs. proof are compiled in Table 2. Numerical color differences (ΔE) were found when comparing the color in the solid area of the monitor to the printed proof on all seven-colors (CMYKRGB). In addition, noticeable visual color difference was found in the solid color area of the monitor reflectance (L*), color hue, and chroma (a* and b*) values for CMYK RGB color to the printed proof. Overall, both devices have similar color gamut in the solid area (see Figure 6) except the printed proof consists of higher color value for the green.

The 2D color gamut comparison (see Figure 6 on page 8) reveals that the color of the image displayed on the monitor closely matches with the printed proof. The goal was to match the displayed image color to the printed image. The comparison is an indication that in a CMW, color matching of a target image can be achieved from device to device regardless of device color characterization and original colors.

Conclusions

The conclusions of this study are based upon an analysis of the data and major findings. The findings of this study represent specific printing or testing conditions. The monitor, scanner, printer, instrument, software, and paper that were used are important factors to consider when evaluating the results.

The findings of the study cannot be

Table 1. Experimental and Controlled Variables

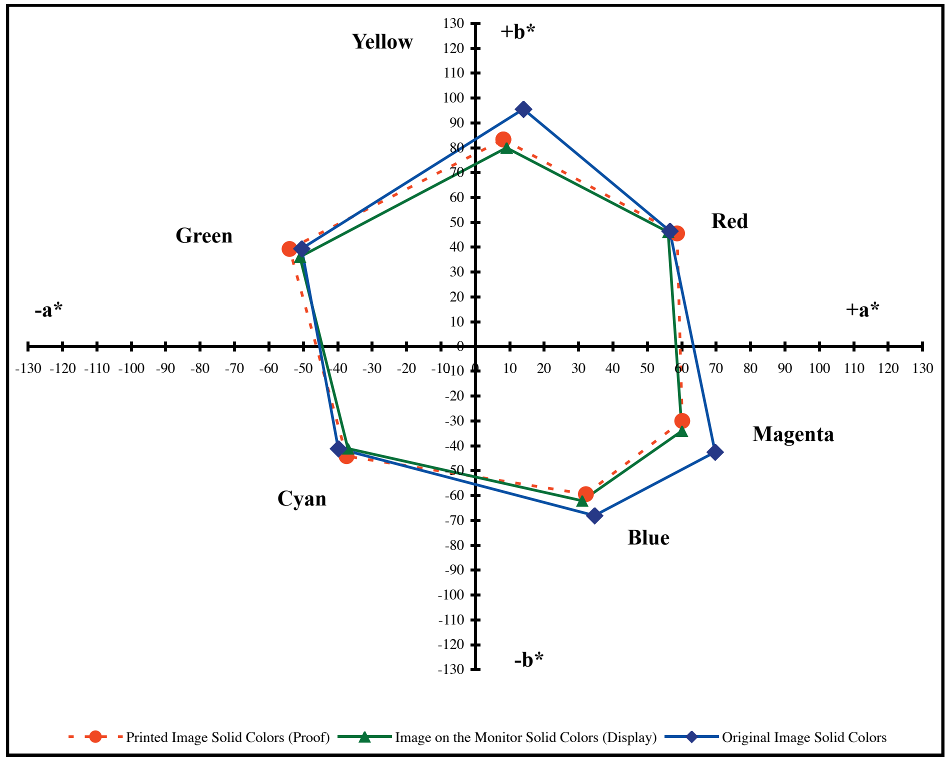
Variable	Material/Condition/Equipment
Test Image	Kodak IT8.7/2 (2003)
Scanner	EPSON Perfection 4870-Photo
Scanner Target	ANSI/ISO IT8.7/2
Profiling Software	Monaco Profiler 4.60 (Gold)
Profile Inspection Software	ColorThink & Monaco GamutWorks
Image Editing Software	Adobe PhotoShop-CS
Page Layout Software	QuarkXPress 6.00
Color Management Module (CMM)	Adobe (ACE) CMM
Rendering Intent	Absolute Colorimetric
Computer & Monitor	Apple G4/LCD
Raster Image Processor (RIP)	Creo Prinergy EVO
Printer	EPSON Stylus PRO-9600
Printer Target	ANSI/ISO IT8.7/3 (963 Patches)
Toner	EPSON Inkjet
Paper (web)	Precision Imaging Contract Proof
Type of Illumination/Viewing Condition	D50
Color Measurement Device	Gretag Eye-One Spectrophotometer & Monaco OPTIX Colorimeter
Data Collection/Analysis Software	X-Rite ColorShop X & MS-Excel

Table 2. Color Variation in the Solid area of CMYKRGB Image on the Monitor vs. Printer

Color(s)	Printer L* Color 1	a*	b*	Monitor L* Color 2	a*	b*	Color Difference ΔE
Yellow	77.95	8.17	83.33	80.00	9.00	80.00	3.99
Red	40.32	58.66	45.53	43.00	56.00	46.00	3.80
Magenta	39.20	60.14	-29.96	44.00	60.00	-34.00	6.27
Blue	17.19	32.10	-59.34	22.00	31.00	-62.00	5.60
Cyan	54.38	-37.48	-44.16	55.00	-37.00	-41.00	3.25
Green	45.17	-54.00	39.21	46.00	-51.00	36.00	4.47
Black	14.07	-1.37	1.56	11.00	-1.00	-5.00	4.77

generalized to other CMW. However, other graphic arts educators, industry professionals, and researchers may find this study meaningful and useful. The findings of this research, comparing monitor vs. printer color gamut is similar. This is due to integration of color management in our existing workflow. As seen in the device profiles (profile graphs), all the devices present us a very different color gamut. However, the application of CMS offered us more flexibility and control over colors and tonal values in reproducing color images. It allowed us to accurately and consistently reproduce color with predictable results from device to device. Application of CMS cannot match output (display or printed) with the original image. It will be impossible to accomplish this. In addition, it may not be possible to match exactly a color gamut of one device to another device. The goal of CMS is that it allows us to ensure that colors we see on the monitor are a close match to that of the output of the printer.

Figure 6: CIE L* a* b* Model for Solid area of Image Color Comparison of Monitor and Printed Proof vs. Original Image Colors



As a result of this experiment, we learned that the CMS works, it offered us more flexibility and control over our color reproduction images. We also learned that only the optical aspects of color are quantitatively analyzable and measurable because we humans perceive color subjectively. It will be hard to document and measure the color values we see or detect. Additionally, implementation of CMW is costly, time consuming and a tedious process. However, it benefits those who implement color management workflow in the prepress and printing areas to get consistent color from device to device. Future study is needed to determine the color image differences of color management workflow vs. non-color management workflow. This study was limited to inkjet printer only. Future study can be conducted by using offset printing process.

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