Color Matching with ICC Profiles—Take One

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Abstract

The introduction of ICC-based color management solutions promises a multitude of solutions to graphic arts imaging needs. To those of us who have been involving in the technology of graphic arts imaging, the best way to understand the performance of CMS is to test it. We decided to focus our initial effort on color matching aspects of the ICC profiles.

To test the degree of color matching, a number of color patches that are reproduced by a hard copy output device in CIELAB values were specified as aim points. These colors were reproduced by the same output device according to the experimental design which involves three factors: ICC-compliant profiling tool, color rendering style, and work flow. The experimental design yields 8 sets of data. The degree of color matching is judged by average ΔE between the color produced and its original colorimetric specifications. We learned that the accuracy of color matching depends on the work flow, device profiling tools, and color rendering style. An average ΔE of 6.5 represents the best scenario in this particular color matching effort. Other factors such as precision or repeatability of the desktop printer and the measurement instrument which may have contributed differences in color matching were also discussed.

Introduction

Color matching and pleasing color image reproduction are two important goals in graphic arts imaging. Due to boundary conditions existed in many process color reproduction conditions, it is difficult to achieve both goals of color reproduction at the same time.

Color matching or color accuracy is the ability of the sample (reproduction) to match as close as possible to the reference (target) in hue, saturation, and lightness. One of the motivations to study color matching, as opposed to pleasing color image reproduction, is the quantitative approach that's readily available in the analysis phase of the experiment. In this case, ΔE as a total color difference between a target color and its reproduction is used as a major parameter to judge the degree of color match.

Some say that color matching is a matter of communicating color with the use of color swatching systems like Pantone and Trumatch. Some say that color matching depends on how good is the personnel in the ink mixing room. Some say that color matching is at the mercy of press operators. Beside the above claims, the advancement of color management systems is aimed at achieving either color matching or pleasing color image reproduction by declaring a color rendering intent in a device-independent and easy-to-use manner.

This research is limited to the study of how color matching may be fulfilled with the use of ICC profiles and day-to-day variations of color measurement instrument and color hard copy output device. Specifically, we wish to learn the accuracy of color matching with ICC-based CMS approach. We're also interested to learn what are the major factors that would impact the color matching performance.

Methodology

Computer Platform

We used a PowerMac 7100 with System 7.5 and ColorSync 2.0 Extension as the computer platform. The peripherals are Apple's 16" color monitor and Apple's LaserWriter 12/600 PS color printer. In terms of consumable, paper and toners are held as constant.

Defining Reproducible Colors

In order to make sure that colors specified are all reproducible, 10 color patches representing different hue and saturation and 4 gray patches were selected from the IT8.7/3 basic (CMYK) data set. Table 1 specifies a set of CMYK values of these patches as defined in IT8.7/3 (1995). Figure 1 shows chromaticity of the 10 color patches in a* b* diagram. These color patches were output to the color printer. The target colorimetric values are defined by measuring these patches with an X-Rite 948 colorimeter under D50 illuminant and 2-deg observer.

Table 1. Definition of all 14 Target Colors.

Color	C	M	Y	K
G2	40	100	40	0
G4	40	100	100	0
G5	0	40	100	0
G9	100	40	100	0
G11	100	40	40	0
H2	20	70	20	0
H4	20	100	70	0
H5	20	70	70	0
H9	70	20	70	0
H11	70	20	70	0
B12	0	0	0	100
F3	0	0	0	75
F5	0	0	0	50
F8	0	0	0	25

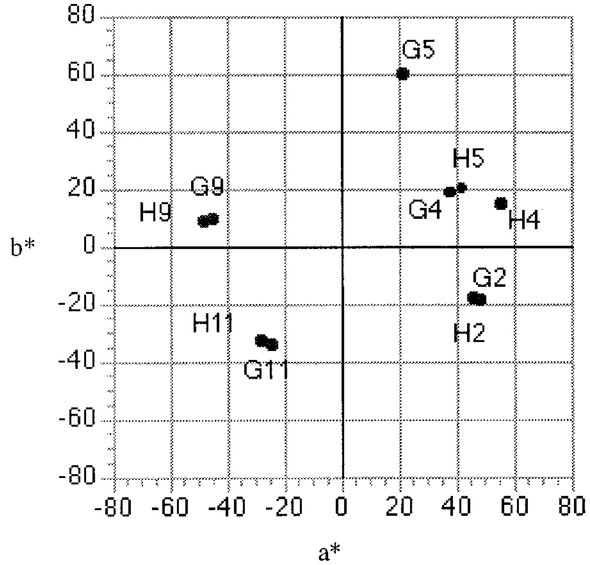

*Figure 1. Chromaticities of the 10 chromatic patches to be matched in a*b* diagram.*

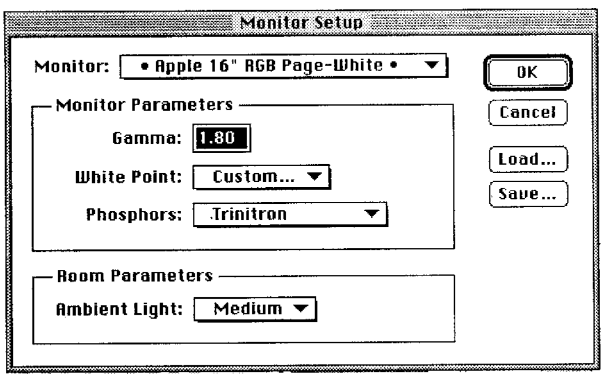

Figure 2. Dialog box of the Apple's 16" Page-White monitor profile.

Design of Experiment

The designed experiment involves testing three factors in a color management environment, namely, work flow, profiling software, and color rendering style. The following offers further explanations.

- Work flow refers to in this research as how color is specified colorimetrically and converted to CMYK values. One work flow (labeled as Profile Viewer or PV) is to measure the hard copy with a ColorTron II spectrophotometer and use its ICC-based Profile Viewer to convert the target color to its CMYK mode prior to hard copy output. The other work flow (labeled as Photoshop or PS) is to use Adobe Photoshop's Color Picker to build a series of color patches in CIELAB mode using target colorimetric values. These values are automatically converted into its RGB mode under the Apple's 16" Page-White monitor profile (Figure 2). Notice that monitor parameters (gamma, white point, and phosphors) were set to their default values. The RGB file was then converted to its CMYK file via ColorSync 2.0 CMS Export Module (Figure 3).

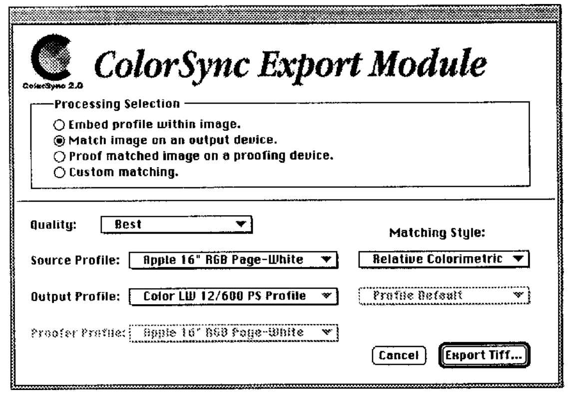

Figure 3. ColorSync 2.0 Export Module.

- In color management, a profile is a file containing information about the color rendering capabilities of a device. It takes two profiles (source and output) to render color images. Profiling software are software packages that allow users to generate ICC-based device profiles. In this experiment, two shrink-wrapped profiling software packages were used. Since software revisions have been frequent, a conscientious effort was made to keep the software packages unnamed and hereafter refer to as P1 and P2.
- Another factor which has an impact on color matching is color rendering style. In the ColorSync 2.0, the choices are perceptual, saturation, and calorimetric rendering. Perceptual rendering is to yield the most pleasing image reproduction under limitations of the device involved. Saturation rendering offers maximum chromaticity of a color for a given output device. None of the two rendering styles is the interest of this research, but the colorimetric rendering is. The goal of calorimetric rendering is to reproduce the sample exactly the same as the original. It can further be divided into relative colorimetric matching (to paper white) and absolute colorimetric matching.

To sum up, two different work flows (ColorTron/PV and Adobe/PS), two profiling software packages (Pi and P2), and two color rendering styles (Relative and Absolute calorimetric) were tested. The experiment yielded 8 reproduction conditions (Table 2). These samples were output in Photoshop environment, and were measured by an X-Rite 948 calorimeter and yielded 8 sets of data.

Major Findings and Analyses

The degree of color matching as expressed in the grand average ΔE for all 8 sets of data is 10.3 with the 6.5 ΔE being the best scenario, and 14.8 ΔE the worst case of all 8 data sets (Table 3). Further analyses of sources of ΔE (see Table 4) indicate that ΔC* contributes to the largest discrepancy. This is followed by ΔH* (hue difference, not hue angle), and finally ΔL*.

By plotting a*b* values of the 10 chromatic patches of the target and a typical sample reproduction (Figure 4), one can appreciate that the differences in chromaticity are due to less saturation in all reproduction. The gamut warn-

Table 2. Schematic Diagram of the Designed Experiment.

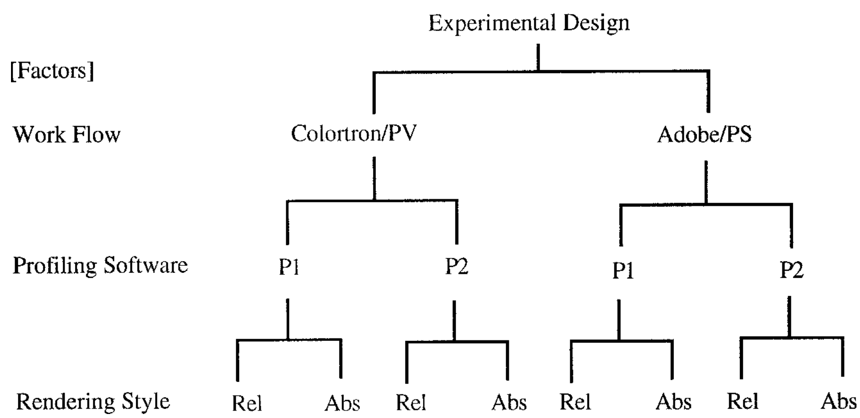

Table 3. Analyses of ΔE Based on 8 Sets of Data.

	ColorTron/PV				Adobe/PS			
	P1		P2		P1		P2	
	Rel	Abs	Rel	Abs	Rel	Abs	Rel	Abs
Average ΔE	9.4	11.5	8.8	12.2	6.5	10.3	8.8	14.8
Grand Ave.ΔE				**10.3**				

Table 4. Analyses of ΔE, ΔC, ΔL, and ΔH Based on 3 Different CMS Factors.

	All 8 data set	Work flow		Profile software		Rendering style	
		PV	PS	P1	P2	Relative	Absolute
Grand Ave. ΔE	10.3	10.5	10.1	9.4	11.2	8.4	12.2
Total ΔC*	7	7	7	6.8	7.2	6	8
Total ΔL*	2	1.1	2.8	2	1.9	1.8	2.2
Total ΔH*	4.1	4.2	4	3.5	4.7	3.3	4.9

ing signs were also observed when using the ColorTron's Profile Viewer tool.

Table 2 also shows differences in ΔE between the two work flow methods, the two profiling tools, or the two color rendering styles. At a quick glance, the largest difference in ΔE is found due to color rendering styles (8.4 ΔE vs. 12.2 ΔE). The next influential factor is profiling tools used (9.4 ΔE vs. 11.2 ΔE).

By examining all 8 color reproduction samples visually, it was noticed that the colors, G4 (reddish brown), G2 (purple), and F8 (light gray) have the widest variation in hue. Furthermore, it was noticed that differences in color matching due to color rendering style are predominantly in neutrals. Specifically, there is a noticeable bluish cast in neutrals as rendered by one of the profiling tools in the absolute color rendering style (also see Figure 5). In the case, the largest ΔE of 14.9 is observed in the quarter-tone (F8 or 25%K) reproduction.

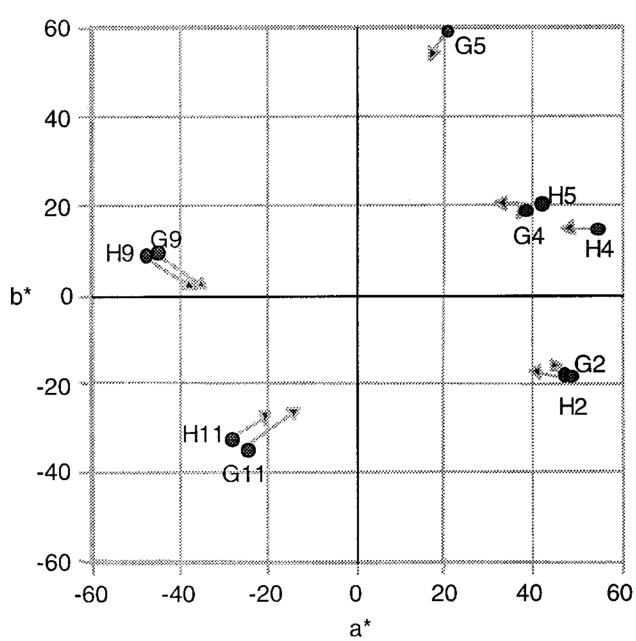

Figure 4. Color reproduced tends to be less saturated than its original.

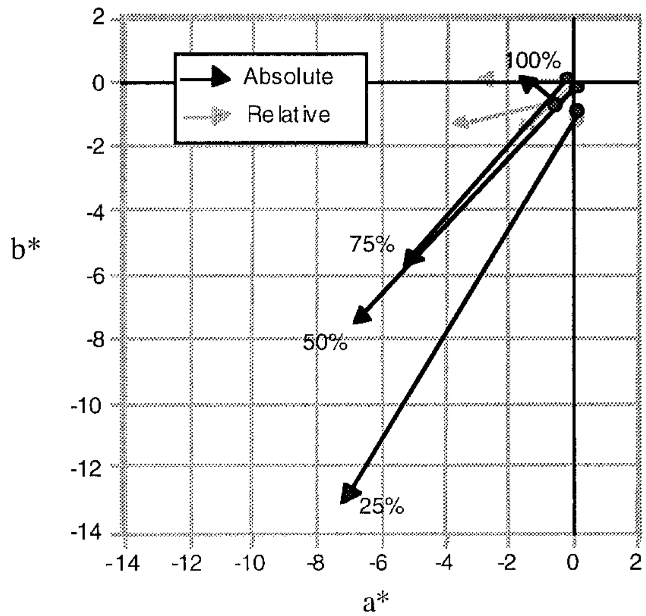

Figure 5. Larger ΔE are found in neutrals between absolute rendering and relative rendering style in one of the profile tools used.

Discussion

This research represents our first documented color matching experiment with the use of ICC profiles. We feel good about being enabled by the open system's approach to color matching. The use of a number of color and neutral patches from the IT8.7/3 target for color matching testing proves to be simple and useful.

ΔE is a useful metric for judging color match. As a rule of thumb, the visual interpretation of ΔE in the magnitude of less than 2 between the reference and the sample is considered an excellent match. When ΔE is in the magnitude of 4–6, it's considered a fair match. As ΔE gets larger and larger, e.g., greater than 9, it's no longer considered as a match.

Previous research reported that 6 ΔE is an acceptable color tolerance in packaging printing applications (Stamm, 1981). Our initial testing indicates that color matching with ICC profiles resulted in average ΔE ranging from 6.5 to 14.8. This is by no means a good mark, but an important benchmark point to improve upon.

The comparison of two different work flows suggests that there is a need to obtain CMYK values that would match a colorimetrically specified color by using one device profile as opposed to using two profiles. Currently, this can only be done in the ColorTron II's Profile Viewer tool.

We also learned that the color matching performance of ICC-based profiles depends on the profiling tool and color rendering style used. We were surprised that larger ΔEs were observed in the absolute colorimetric rendering style than the relative colorimetric style even though the paper white is not altered. Chances are that some of the systematic errors, e.g., all colors reproduced are less saturated than its original, may be corrected through fine-tuning of device profile parameters, or via user-controllable profile editors. Further research work has been initiated to see if monitor profile parameters, particularly white point and gamma may be adjusted to improve the color matching via ICC profiles.

We are aware that other sources of experimental error include variability in color measurement instruments and the variability of the color printer. In this regard, we have been conducting gage capability study on colorimeters and spectrophotometers. Similar efforts were made to study process capability of printing devices such as offset presses and desktop printers. Such efforts should help shed light on the impact of process characterization and its subsequent conformance on color matching with ICC profiles for standardized printing devices, e.g., SWOP (CGATS.6, 1996).

Another outgrowth of this research is to apply ICC profiles to simulate ink-on-paper printing by means of a digital color proofing device (Chung, 1996). This application is very significant and needed in the digital printing and computer-to-plate work flow environment.

Acknowledgment

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References

1. Graphic Technology—Input Data for Characterization Of 4-Color Process Printing, ANSI IT8.7/3, NPES, Reston, VA, 1993.
2. ColorSync Software: Overview, Apple Computer, Inc., Updated: June 14, 1995.
3. ICC Profile Format Specification, International Color Consortium, 1995.
4. "An Investigation of Color Tolerance," by Scott Stamm, *TAGA Proceedings*, 1981, pp. 156-173.
5. Graphic Technology—Specifications for Graphic Arts Printing—Type 1, CGATS.6, NPES, Reston, VA, 1996.
6. "CMS Work Flow & Practices," by Bob Chung. *GAA Annual Convention Proceedings*, GAA, Rochester, NY, 1996.

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