ICC-based CMS & Its Color Matching Performance

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Abstract: Color matching between proofs and press sheets has not been a trivial task. Differences in colorants, solid ink density, and dot gain between hard copy output devices are some of the reasons that proofs and press sheets don't match. The International Color Consortium (ICC) has developed a system-level color management tool which is aimed at improving color rendering between various imaging devices. In this paper, the ICC-based color matching experiments were performed with the use of a four-color sheet-fed offset press, a film-based color proofer, and a thermal dye transfer process. Specifically, we investigated if ICC-based CMS can help an analog color proofer and a continuous-tone digital color proofer improve its color matching to a reference press sheet. Experimental findings based on observer analysis using rank ordering, and colorimetric analysis between proofs and press sheets were discussed.

Introduction

The graphic arts industry used to address color management issues, e.g., from scan to print and from proof to press sheet, either by the use of proprietary technologies or by trial-and-error methods. The former was expensive and the latter was time-consuming and ineffective.

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ICC (International Color Consortium) was founded in 1993 with the purpose to create and promote the standardization of an open, vendor-neutral color management system (CMS). The scientific approach deployed in the ICC-based CMS includes (a) definitions of device profiles, (b) the use of CIELAB as the profile connection space (PCS), and (c) the use of a system-level CMM (color matching module) to transform color images from its source profile to its output profile according to a color rendering intent. Today, ICC-based CMS has been implemented in the Macintosh (ColorSync) and Windows (ICM) operation system environment (Figure 1).

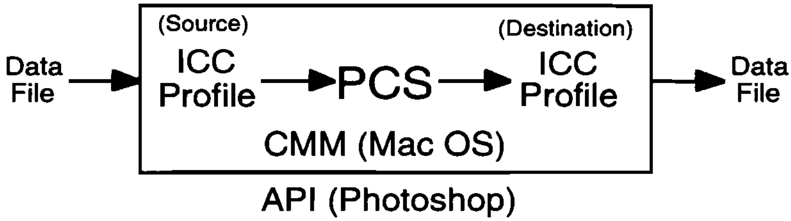

Figure 1. ICC-based color management system model.

ICC specifies three color rendering intents, i.e., perceptual, colorimetric, and saturation. Perceptual rendering is suitable for pictorial image rendering of scanned images. Colorimetric rendering is suitable for color matching between devices, e.g., digital proofing. Saturation rendering is meant for business graphics applications.

There are three types of devices that can be profiled: scanner, monitor, and printer. The performance of the color management system depends not only on the quality of the device profile (Plaisted and Chung, 1997), but also on the device calibration and process control. Device calibration precedes the profiling which includes linearization and adjustment of the device to known parameters. Process control follows the profiling stage which involves the use of test targets and color measurement tools to control and ensure that the device is operated at the calibrated state at all time.

Research Objectives

Many experiments have been conducted, including those which were performed by the authors, to test the performance of color management systems. Yet, there have been little definitive findings. One of the difficulties has to do with not knowing how to separate the color error, introduced by the inconsistency of the device, from that resulted from the use of the CMM and device profiles.

When testing the quality of a device profile, our major interests are in the performance of printer profiles. When testing a printer profile, it's easier to test its color matching performance than its perceptual rendering performance. This is because color matching can be studied quantitatively by colorimetry, and perceptual rendering cannot.

The most common use of a color proof is to provide a visual verification that the prepress has being done correctly, and its appearance simulates a "standard" press sheet. Currently, two types of color proof are in use: film-based analog proof and filmless digital proof.

As the computer-to- ... technology becomes more and more prevalent, the demand for digital proof increases drastically while the film-based proof market dwindles. In the digital proofing market, there is a small segment of the industry uses dot-based digital proof, e.g., Kodak Approval. But the majority of the industry is leaning towards less expensive contone digital proof, e.g., Imation Rainbow dye sublimation. Thus, the question, "Is contone digital proof good enough in matching the color of the press sheet?" despite the fact that it has lower addressability than imagesetters, and it uses different colorants and substrate.

With the aforementioned introduction, the objective of the research is to test two aspects of the color management performance: (1) the consistency of a printing press, i.e., how to measure color consistency between press runs; (2) whether ICC-based CMS improve the color matching between proofs and press sheets.

Experimental Procedures and Data Collection

Proofs and press sheets

ColorBlind, an ICC-compliant profiling software, was used to generate a scanner profile and three printer profiles. Monitor profiles were not needed in the experiment.

Three contone pictorial images were scanned as RGB files initially. They were converted to CMYK images using the ColorSync Export (RGB-to-CMYK) procedures (Figure 2). Briefly, Linotype/Hell's Saphir scanner was the source profile; the Heidelberg sheetfed press was the output profile; and the rendering intent was perceptual. These images were output to film, plated, and printed by the Heidelberg 72 SP+L sheetfed offset press. The three printed images are known as the reference images.

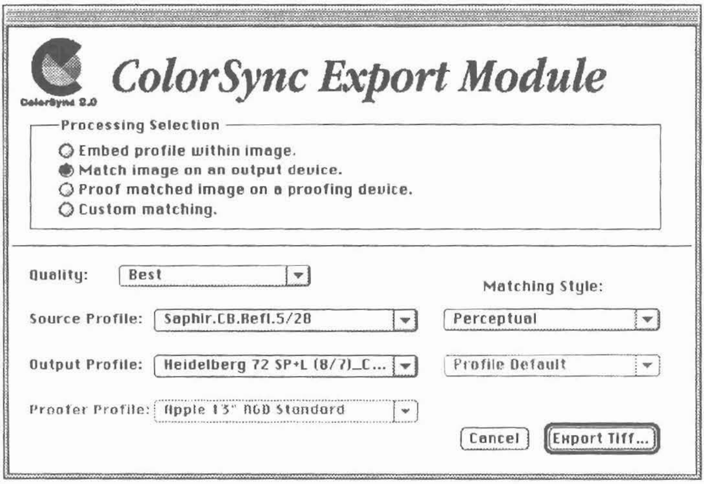

Figure 2. ColorSync Export (RGB-to-CMYK) procedures.

Film-based proofs were made with the Imation Matchprint III, and contone digital proofs were made with the Imation Rainbow. The initial CMYK images (both digital files and films) that were used for the press run were used to make the Matchprint and the Rainbow proofs are known as *proofs without CMS.*

The CMYK digital files that were used for the press run were, then, further processed to make the Matchprint and the Rainbow with the ColorSync Export (CMYK-to-CMYK) procedure. Briefly, the TIFF (CMYK) file was opened in Photoshop; it was exported via the ColorSync Export Module with the Heidelberg sheetfed press as the source profile, and the Matchprint III and Rainbow as the output profile. The rendering intent was relative colorimetric. The Matchprint and the Rainbow proofs, made with the procedures, are known as *proofs with CMS.*

The three pictorial images provide a qualitative approach to color match between the sample proofs and the reference press sheets. To provide a quantitative analysis of the same, the IT8.7/3 target was also converted using the same Colorsync Export (CMYK-to-CMYK) procedure.

Test for printing consistency

Two press runs are necessary to test its consistency. The first press run was to print the IT8.7/3 target for press calibration , and to print the press characterization target for constructing press profiles. The second press run was to print the IT8.7/3 targets again for testing the press consistency, and to print reference color images for the color matching experiments. Both press runs used the same paper, ink, and printing conditions.

Test for color matching between proofs and press sheets

Friedman's ranking test was used to test the color match between proofs and press sheets. Seven observers were screened for their normal color vision by the FM-100 Hue Test. Under the standard viewing conditions, each observer was asked to rank the four color proofs in terms of their color appearance match to the reference press sheet. There were three independent tests for each of the three pictorial images.

Results and Discussion

Printing consistency

The goal was to have the two press runs print as close to each other as possible. The reality was that there are differences in solid ink density and % dot gain between them (Table 1). We noticed that solid ink densities of the magenta printer and the yellow printer were quite repeatable where the cyan and the black did not.

Table 1. Solid ink density & dot gain between press runs.

	C		M		Y		K	
Press run	1st	2nd	1st	2nd	1st	2nd	1st	2nd
SID	1.32	1.06	1.41	1.37	0.87	0.85	1.46	1.33
Δ SID	**0.26**		0.04		0.02		**0.13**	
% Dot Gain	32	29	32	32	31	31	30	29
Δ Dot Gain	3		0		0		1	

Density is a measure of the ink film thickness. Density differences between the two press runs only indicate the ink film thickness difference, and they do not imply the resulting color difference. To estimate the color difference due to printing inconsistency, all 182 patches of the IT8.7/3 target of the first press run and the second press runs were measured colorimetrically. The average ΔE between the two press runs was found to be 3.76. The paper patch where no ink was printed has the minimum ΔE. A dark purple patch with total area coverage of 270 (100C 100M 70Y 0K) has the largest ΔE of 10.8 units.

Previous investigation of the color consistency requirement of typical packaging printing suggested that a stable print production would produce colors within the color tolerance of 6 ΔE or less (Stamm, 1981). Using this finding as a reference and compared it to the average ΔE of 3.76 as derived from the experiment, we acknowledged that the experimental error was well within the acceptable limits for packaging printers. Thus, we conclude that the two press runs were consistent. The magnitude of 3.76 ΔE also suggests that this is the best that a color management system could perform under this particular printing conditions.

Color matching between proof & press sheet

The subjective judgment was carried out with the use of the Friedman's ranking test. Two out of three ranking tests showed there is no significant color appearance difference among the four color proofs. However, the ranking of a high-key image showed that there is significant difference among color proofs. Specifically, the Rainbow digital proof with CMS was the best match to the reference press sheet.

It was surprising to note that the black-only components, as seen in the original IT8.7/3 target, was not preserved as black-only components in the color-managed version of the image. This is because the CMYK-to-CMYK conversion is dictated by the GCR settings used in the output profile. Consequently, color cast in the neutrals is visually noticeable, and it challenges process control greatly.

CMS performance analysis

Average ΔE between proofs & press sheet, based on the IT8.7/3 target, range from 6.41~9.14. This is twice the magnitude of color consistency between press runs. Analyses of sources of the ΔE indicates that ΔC* is the major culprit (Table 2).

Table 2. ΔC* is the major contributor of ΔE.

	MatchPrint III		Rainbow	
	w/o CMS	w CMS	w/o CMS	w CMS
Average ΔE	7.34	9.14	6.41	7.72
Average ΔC*	4.39	5.61	3.85	4.96
Average ΔL*	3.56	4.94	3.02	3.55
Average ΔH*	2.60	3.09	2.47	2.74

ΔE only provides only the magnitude of the color difference, and not the direction. Therefore, it makes sense that we examine the gamut of these output devices in the a* b* diagram.

The single-color solids (CMY) and their 2-color overprints (RGB) of the original IT8.7/3 target were compared between the printing and the proofing devices. By comparing color gamut of the two proofs with the press sheet in the a* b* diagram, we can see that, in general, both Matchprint and Rainbow have larger color gamut than the press sheet (Figure3).

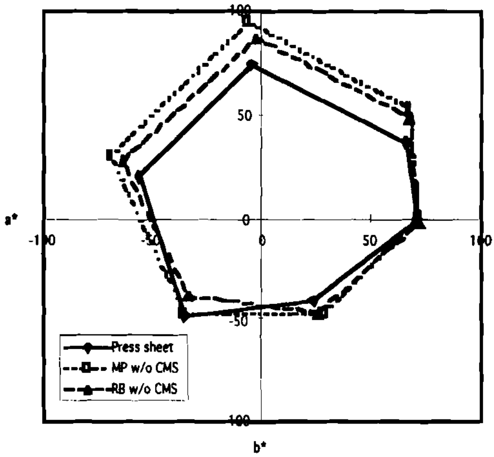

Figure 3. Color gamut comparison between press sheets and proofs without color management.

When we plotted the same six patches (CMYRGB) of the IT8.7/3 targets from the color-managed Matchprint and the Rainbow, we can see that both proofs with CMS align their gamuts closer to that of the press sheet (Figure 4). In addition, the gamut compression seems to be over-compensated.

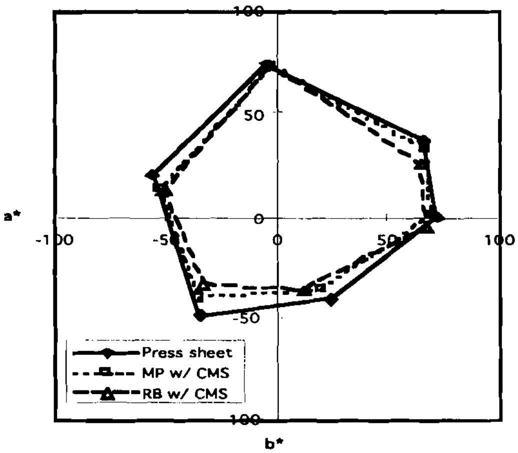

Figure 4. Color gamut comparison between press sheets and proofs with color management applied.

To verify this observation, chroma ratio was plotted against L* of the press sheet for all patches with C* greater than 40 in the IT8.7/3 target. Specifically, chroma ratio of a patch is obtained by dividing the C* of the proof from the C* of the press sheet (Pobboravsky, Pearson and Yule, 1971). This graphical analysis help verify our suspicion, i.e., proofs without CMS have more points plotted towards the right-hand-side of the center line, i.e. proofs are more saturated than the press sheet (Figure 5). A part of the color gamut in the proofs with CMS are over-compensated, i.e., proofs are less saturated than the press sheet (Figure 6).

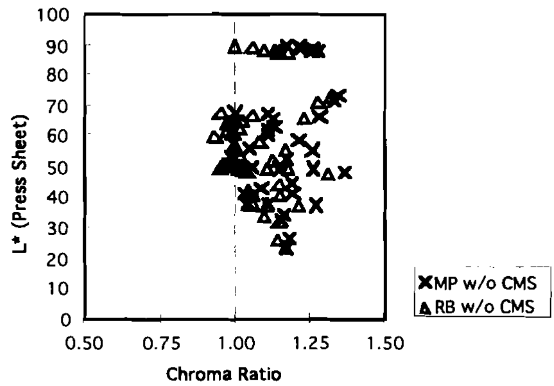

Figure 5. Chroma ratio vs. L* without CMS.

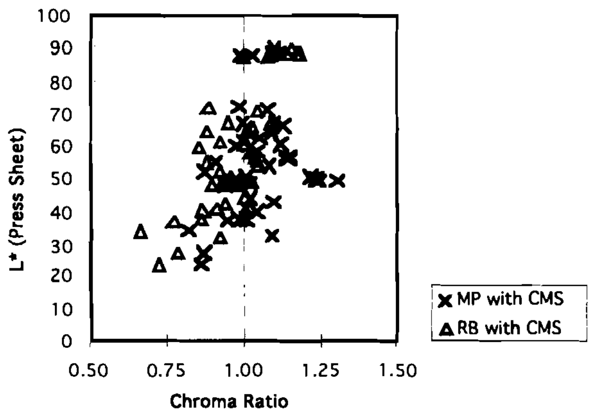

Figure 6. Chroma ratio vs. L* with CMS.

Summary

When study the performance of color management systems, it makes sense that we differentiate color consistency from printing consistency. Printing consistency can be measured by the degree of conformance to solid ink density and dot gain. Color consistency between press runs can be measured by the average ΔE based on the IT8.7/3 target. Typical color differences between two press runs is 2~4 ΔE. This quantity limits the color matching performance of any color management system.

Both the Matchprint and the Rainbow are well known color proofing systems in the graphic arts industry. By design, colorants and substrate used in the proofing process are well in line with the typical printing conditions. Thus, color matching using the ICC-based CMS is no better than a calibrated proofing system.

There are pluses & minuses in the digital proofing performance of color management systems. The pluses include (a) it aligns the color gamut of a proofing device to the that of the reference press sheet, and (b) the contone digital proof is as good as dot-based film proofs in simulating color appearance of the press sheet. The minuses include (a) ΔE between the proof and the press sheet is still considered large in comparison to the ΔE between two press runs. ΔC* is the major contributor to the ΔEs, (b) the black-only components are not preserved in CMYK-to-CMYK conversion. Future improvement in ICC-based CMS is needed to make the use of contone digital proofing in the computer-to-... technology more viable.

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