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Quality Analysis in Digital Printing Based on Color Management System

Maohai LIN, Shisheng ZHOU, Fuqiang CHU

Abstract—**Managing and controlling color is a major concern for the imaging industry. The aim of the investigation was to identify the color difference that exists in the color patches in a typical color reproduction workflow. After the Calibration, Characterization and Conversion of the devices (Philips CRT Monitor, Microtek scanmaker 9600 and Xerox DC 2060) using GretagMacbeth ProfileMaker software and X-Rite Eye-one spectrophotometer, the color gamut of the devices were inspected with ColorThink software for profile accuracy. Based on the results obtained by spectrophotometer measurements, the reproduction quality of specific color patches was evaluated in terms of the ΔE in CIEL*a*b* color space. The analysis shows the color difference exists in digital printing and the results can be significant to acquire flexible control over colors in reproducing images.**

Index Terms—**color difference, color gamut, digital printing, Color Management System**

I. INTRODUCTION

In today's graphic reproduction, the market sets new demands every day and expects realization of reproductions with maximal quantities of information about color and their compatibility with the original. At the same time we have to operate a series of input devices such as scanners and digital cameras, output devices such as monitors and printers [1]. The chromatic performance of devices was depending on their own color capabilities thus resulting in a number of possible color conversions when color was transferred. Accurate color control from beginning to end in a printing or imaging process is important for quality output (display or printed).

Color management is the use of software to automatically reproduce accurate and consistent color in every stage of the reproduction process. It is transformation of color between different devices so that an optimal match is achieved. Color management is not about image enhancement but about minimizing color changes when transferring image data from one device to another. A Color Management System (CMS) transforms the image data from a device color space to a device independent reference color space or profile connection space (PCS) such as CIELAB. The CMS then transforms the data to the color space of another device. The CMS knows the shape of the color gamut of each device involved in the reproduction process. The CMS is capable of doing the conversion of image data from one device to another. The conversion is done by a calculation engine known as a color management module (CMM) [2]-[4].

The first step in color management is to calibrate the devices-collecting data about the reproduction characteristics of the device. Calibration is the setting up of a device so that it gives repeatable and accurate results. Input and output device manufacturers provide instructions for calibration procedures. Monitor calibration is normally done by standalone calibration software or a CMS.

The second step in color management is device characterization, collecting data about the reproduction characteristics of the device. The data is saved in a file called device profile and can later be used by the CMM when converting images. The profile is valid for use only in the same conditions and for the same settings that were used when the profile was created (type of paper, inks, rendering quality, gamma, viewing illuminant, etc.) For instance, two different kinds of paper for the same printer require two profiles: one for coated special paper and one for normal uncoated paper. The device profile should include tags for all the settings used. Device manufacturers provide generic profiles of their device models, but a custom profile is more accurate. The profiles should be updated when device performance changes or when the device is calibrated or needs calibration.

The third and final step in color management is color conversion, using the profiles for converting images between devices for optimal reproduction. Color conversion is done by the CMM. The workflow of a typical color management system is shown in Fig. 1.

In color management workflow the settings for each device in the production chain are independent of the other devices. There are various combinations of matches in open-system color: screen to print, proof to press, original to print, screen to screen, print to print, and so on. A sequence of color space transformations using the profiles can be linked into one composite profile in order to reduce computation upon color conversion. However, the linking of the device profiles makes the link profile device-dependent. The profiles can be used to simulate one device on another, such as creating a soft proof of a print on the monitor. Device profiles also help in getting consistent color between different applications on the same device [5]-[6].

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M. H. Lin is a Ph.D candidate with the Xi'an University of Technology, Xi'an, 710048, China, and at the same time he is a lecturer of Shandong Institute of Light Industry, Jinan, 250353, China (phone: 86-531-89887701; fax: 86-531-89631163).

S. S. Zhou is a Ph.D. supervisor with the Xi'an University of Technology. He is now the dean of the Faculty of Printing and Packaging Engineering, Xi'an University of Technology, Xi'an, 710048, China.

F. Q. Chu is an associate professor with the Shandong Institute of Light Industry, Jinan, 250353, China

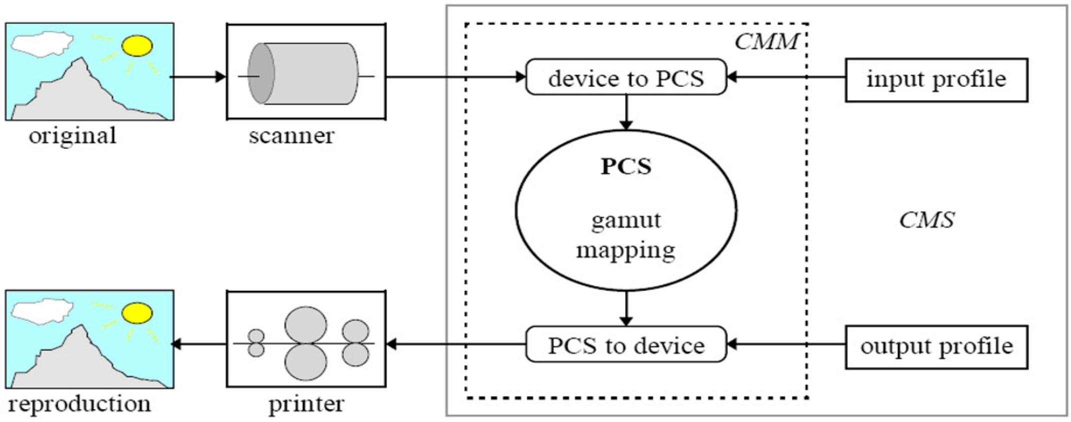

Fig. 1 The workflow for image reproduction in a typical color management system

II. Experiment

The investigation used quantitative techniques to collect and analyze the data. The aim was to identify the color difference that exists in the specific color patches in a typical color reproduction workflow. Prior to device profiling all devices used in the experiment were calibrated and characterized according to device manufacturer standards. The GretagMacbeth ProfileMaker5.05 software was used to profile or characterize the devices that were used in the experiment.

A. Monitor Profile

Monitor profiling consists of measuring a series of known color targets on a calibrated screen with a Colorimeter or Spectrophotometer. The resulting data is rendered by the profiling software into a profile that accurately describes how the monitor represents color in a color managed system.

A Philips CRT monitor was profiled by using the GretagMacbeth ProfileMaker 5.05 and X-Rite Eye-one spectrophotometer. Existing default profile of the monitor was disabled in the system prior to profiling the monitor. The contrast and brightness controls on the monitor were adjusted with the help of the software and were kept the same in the experiment. The desire temperature of 5000 Kelvin (D50), 2° standard observer and gamma value of 2.2 were set for the Monitor.

B. Scanner Profile

For input devices, characterization involves reproducing a test target. The test target for an input device was a combination of color patches, each of which has a pre-defined value in the reference color space. The reference values are included in a reference data file.

The standard reflective input target of the graphic arts industry is a photographic print called an IT8.7/2 target. The patches in the IT8 target that are reproducible by the most common photographic paper types are uniformly spaced in terms of CIELAB hue angle, lightness and chroma.

The device color space can be modeled by comparing the recorded RGB values with the reference CIELAB values. The RGB channels are linearized with tone reproduction curves created from the test patch data. The tone reproduction curves can be calculated by least-squares fitting polynomials. The linearization data is saved in the device profile. Other methods for scanner gamut modeling include nonlinear transformation algorithms, dye-modeling algorithms, and interpolation with lookup tables[7].

A Kodak ANSI/ISO IT8.7/2 scanner target (as shown in Fig.2) was scanned at 600dpi to create the profile for the Microtek scanmaker 9600. 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. The scanned IT8.7/2 target was cropped and run through the Profilemaker5.05 software. 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.

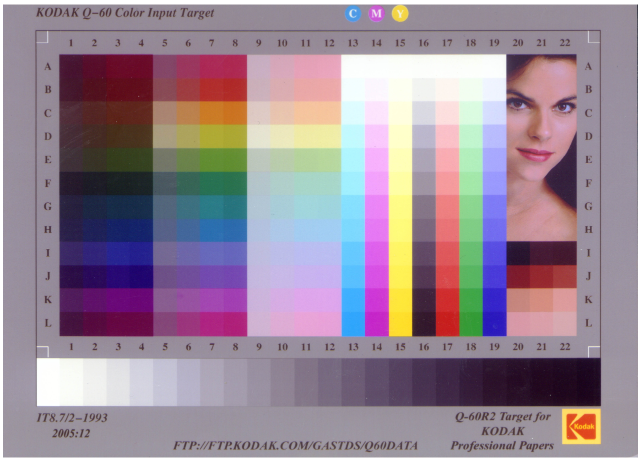

Fig. 2 A Kodak ANSI/ISO IT8.7/2 Target for Scanner Profile

C. Printer Profile

Characterization for output devices such as printers is similar to scanner characterization in that it involves reproducing a test target. The reference data values for the test patches are device color space values. A common test target design has the color patches uniformly spaced in the device color space. The printed test target values are measured with a spectrophotometer. The profile maker sends known RGB or CMYK values to the printers and then measures the printed output. Again, it builds a profile that correlates the stimulus and the response, so that the CMS can tell from the profile what actual color will result from specific RGB or CMYK values, and what RGB or CMYK values are needed to print a specific color [8]-[11].

An ANSI/ISO IT8.7/3 printer target with 928 patches (as shown in Fig.3) was printed on the Xerox DC 2060 printer. Prior to printing the patches, the printer was calibrated 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 X-rite Eye-One spectrophotometer and the data was run through the Profilemaker 5.05 to create the printer profile.

The CMYKRGB tone scales of A Kodak professional Q-60 were selected for evaluation. It consisted of patches with different gray levels, generating a chart with a variety of shades for the color (as shown in Fig.4).

The color patches were scanned and opened with Adobe PhotoShop-CS and displayed onto the CRT monitor. The scanner device profile was assigned to the image. The CIE L*a*b* data of the colors on the monitor were recorded using X-Rite Eye-one in emission mode.

Printed proof was analyzed by using a Gretagmacbeth Spectrophotometer and CIE L* a* b* values of CMYKRGB color patches were measured on the printed proof. Each patch was measured for L*a*b* values three times to reduce the measuring error. Color difference (ΔE) was calculated to see the noticeable color differences exist among the CIE L* a* b* values of original, monitor and printed proof.

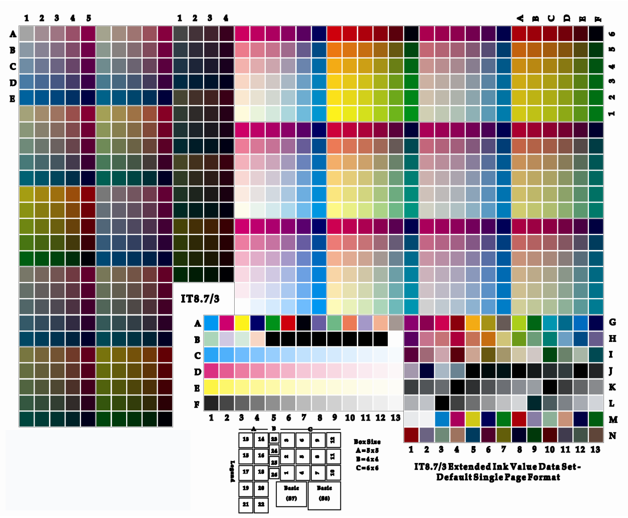

Fig. 3 ANSI/ISO IT8.7/3 Target for Printer Profile

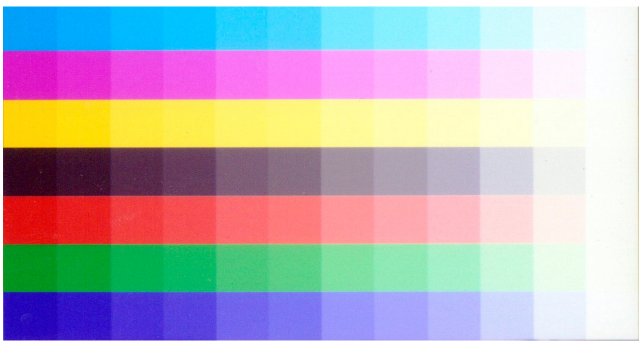

Fig. 4 Test chart for output

III. Results and Discussion

The color gamut of all these devices was inspected with ColorThink software. Visual examinations of all the device profiles indicated that they have different color capabilities because they came from different manufacturers. Fig.5 illustrated color gamut comparison for the Microtek Scanmaker9600 and the Philips CRT. The color gamut of them was similar in shape but it was important to note that many colors were out of the other's gamut especially in yellow and blue area. Fig.6 illustrated color gamut comparison for the Microtek Scanmaker9600 and the Xerox DC2060. The shape of them were distinct different.

Obviously, there will be unavoidable color difference when color in the edge area was transferred. The ΔE values for the original and actual output CIEL*a*b* values (display and printed) were shown in Table.I The first ΔE value indicated the minimum ΔE value for each color chart. The second ΔE value was the maximum ΔE value, the third value showed the average ΔE value for each color, while the last value showed the average ΔE value for the best 80% color patches.

The Philips CRT provided good color reproduction for Green color (the average ΔE value were lower than 6), but failed to saturated Yellow, Cyan, Magenta and Black colors (the maximum ΔE value were far bigger than 6). As shown in Fig.7, the ΔE values increased significantly in highly saturated areas for almost every color except for Green.

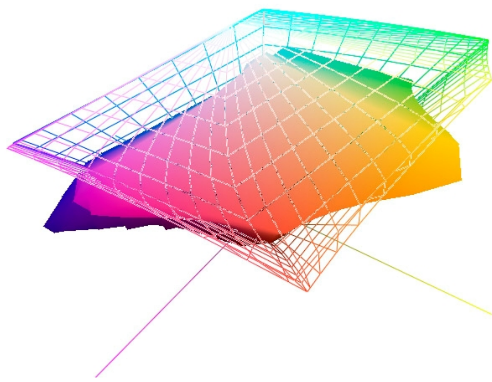

Fig. 5 Color gamut comparison in 3D CIE L* a* b* space：Scanner （wireframe）vs. CRT（true color）

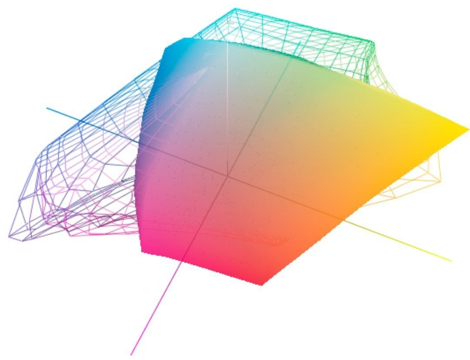

Fig. 6 Color gamut comparison in 3D CIE L* a* b* space：Scanner （wireframe）vs. printer（true color）

Table. I Summary of ΔE comparison in the workflow

Color	ΔE values	
	original vs. CRT	*original vs. printer*
Cyan	3.3, 18.6, 7.4, 5.9,	6.1, 14.1, 10.1， 8.7
Magenta	3.5, 13.2, 8.0, 6.9	2.1, 24, 13.7， 10.2
Yellow	4.8, 12.6, 7.1, 6.1	11, 23.6, 18.3， 17.4
Black	1.8, 18.1, 6.4, 4.7	2.7, 10.6, 6.0， 6.3
Red	3.8, 14.6, 6.4, 5.4	3.7, 27.7, 11.7， 8.1
Green	2.6, 8.9, 5.4, 5.0	10.9, 21.2, 15.7， 14.6
Blue	0.8, 8.0, 6.2, 5.6	0.2, 22.3, 10.3， 6.3
Mean	2.9, 13.4, 6.7, 5.7	5.2, 20.5, 12.3, 10.2

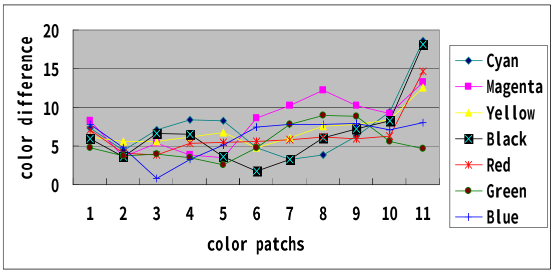

Fig.7 ΔE values between original and CRT

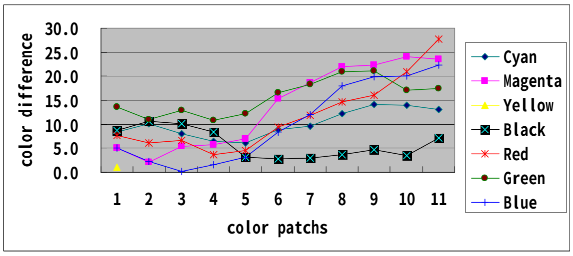

Fig. 8 ΔE values between original and printed proof

The Xerox DC2060 provided better color reproduction only in mid-tone of blue and black color, poor color reproduction for others almost in all the color areas (see Fig. 8). The mean ΔE values between original and printed proof were larger than 6 which means an obvious color difference in vision.

The CIE color system, however theoretically developed to concern with matching large uniform color areas, does not give satisfactory results in the cross-media system [12].

IV. Conclusions

In the conventional color management systems, most of the color transformations are performed independent of the image contents and a single transformation is conveniently applied to entire pixels. Application of CMS cannot match output (display or printed) with the original image.

The goal of image reproduction is to ensure that colors of the output are a close match to the original. This study was limited to digital electro-photographic printer only. Future study can be conducted by using other kinds of digital press. More efforts are needed to improve the conventional color management system with optimal PCS and image-dependent transformations for better color reproduction.

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Maohai LIN was born in Shandong Province of P.R. China in 1973. He received a Bachelor of Technology in Printing Engineering from Hunan University of Technology in 1997, a Master Degree in Business Management from Shandong University in 2004. He is now a Ph.D candidate in Printing Engineering at Xi'an University of Technology.

He is a lecturer of the Shandong Institute of Light Industry. His research interests are in digital printing and imaging, color management.

Mr. Lin is a member of the IACSIT. He was awarded for Academic production by Educational Department of Shandong Province in 2008.

Shisheng ZHOU was born in Shandong China in 1963. He received a Doctor degree in Biomedical Engineering from Xi'an Jiaotong University(Xi'an, P.R. China) in 1996. He is a professor at Xi'an University of Technology. His research interests are in color image reproduction.

Fuqiang CHU was born in Shandong Province of P.R. China in 1970. He received the Master degree and Doctor degree of pulp and papermaking engineering at Tianjin University of Science and Technology (Tianjin, P.R. China) in 2004 and 2007 respectively.

He is an associate professor of the Shandong Institute of Light Industry from 2004 to present. He was a lecture from 1997 to 2004 at the same unit. His research interests are focused on printing materials, printability and digital workflow of printing process.

Dr. CHU is a member of Pulp and Papermaking Association of China. He was awarded for Academic production by Educational Department of Shandong Province in 2008.