The effect of dot gain linearization as a printer calibration criteria on color matching accuracy

by Fred Hsu

Keywords

calibration, ICC profile, color matching accuracy

Abstract

Two ICC profiles were generated from an Epson ink jet printer under two printer conditions, default and 0% dot gain. Color matching experiments were performed by means of the "B-to-A" analysis with a set of CIELAB values which are reproducible by the ink jet printer. CIE-based color difference, CIEDE2000, between the initial LAB values and its derived values was analyzed and compared between the two conditions. The results show that calibrating the printer to 0% dot gain before doing characterization did not improve its color matching accuracy. The color matching accuracy of an ICC profile cannot be improved by applying device calibration alone. Color gamut of a output device needs to be optimized before device calibration in order to improve B-to-A transformation of an ICC output profile.

Introduction

To improve color matching accuracy between digital proofer and press sheet, the strategy to build a reliable color management system becomes a critical issue. The objective of this research is to investigate whether a digital output device using a color management system (CMS) can be enhanced via a specific calibration method, dot area curve linearization. The research question is: will 0% dot gain calibration improve B-to-A color matching performance?

Literature review

ICC color management system (CMS) is a major tool for color reproduction in the printing and publishing industry. Through a well-organized CMS, accurate image rendering and color matching can be achieved. (Chan, Chung, and Cheung, 2000)

ICC provides us a standard profile format and basic workflow for color transform. However, it is the vendor's responsibility to pursue transformation accuracy by both the profile creation and CMM implementation. (Zeng, 2002)

Calibration brings an output device into a standard condition, for which a predefined tonal response is ensured. There are distinct advantages to linearity, e.g. device stability and optimal use of available levels. (Livens and Mahy, 2002)

The typical purpose of the linearization curves in conventional four-ink printing is to compensate for dot overlapping and dot size variations and therefore accommodate the non-linearity of the printing process. (Noyes, Hardeberg, and Moskalev, 2000)

Color matching accuracy and a profile may be assessed by B2A1 (device to LAB, colorimetric tag) and A2B1 (LAB to device, colorimetric tag) are used to assess ICC output profiles. The accuracy of the B2A1 part of the output profile can be measured by calculating the color difference between the source LAB values sent to a printer and the measured LAB values printed by the printers. (Sharma, 2005)

CIEDE2000 is the most accurate tool at present to predict visually perceived color difference among the last three CIE-recommended formulas. (Melgosa, Huertas, and Berns, 2004) CIEDE2000 color difference formula predicts visual color differences of high chroma colors better than the CIELAB color difference formula. (Chung, 2005) Thus, CIEDE2000 was chosen to assess color matching ability in this study.

Equipment & materials

Variation during the processes can impact the color management performance. The result can vary if different printer, different paper, or different color management profiling software is used. The experiment was tested under the following conditions:

- Operation System: Mac OS X
- CMS: Profiling Software: GretagMacbeth ProfileMaker 4.1.5
- API: Adobe Photoshop CS
- RIP: Harlequin RIP Eclipse Release SP4
- Printer: Epson Stylus Pro 4000 Print Engine with UltraChrome Ink. The same ink cartridges were used through the entire study. Only cyan, magenta, yellow, and photo black were used in this study.
- Paper: Epson proofing paper commercial semimatte (S041744)
- Measurement and analysis Instrument: GretagMacbeth Spectrolino; Spectroscan system
- Test targets: ECI 2002R CMYK profiling target; IT8.7/3 basic target (page 60): CIELAB test target; ISO color chart S7A; spatial uniformity target (ISO 12640, 1997); printer calibration target
- Excel spreadsheet: Calibration.xle; Transfer.xle. Process.xle

Only colorimetric matching ability based on CIELAB

(D50, 2 degree) was evaluated and color differences are displayed as CIEDE2000 (ΔE_{00}) in this study. All measurements were collected under standard white backing. (ANSI CGATS.5., 2004)

Methodology

Calibration adjusts a device's output to correlate with a requested value. In the case of a color printer, calibration ensures that the correct amount of cyan, magenta, yellow, and black colorants are printed. "Linearization is the process of adjust values on output so that the result is proportional to the values request." (Global Graphic, 2004) There are many approaches in achieving printer calibration, and dot curve linearization is one of them. In this study, the methodology focuses on calibrating the printer linear to dot area.

Fig. 1 is a flowchart explaining the testing process. Part A is the device qualification stage. Part B is the experimental stage that includes printer calibration, building ICC profiles, and the color matching analysis.

Part A. Device qualification

Stable and repeatable devices are the key requirements within an experiment. Before the color matching performance test, substrate spatial uniformity, printer spatial uniformity, temporal consistency, and printer gamut were verified.

Substrate spatial uniformity

A random sheet of Epson ink jet proofing paper commercial semi-matte was measured using the same template for IT8.7/3 basic target (5.5″ x 6″) on a GretagMacbeth SpectroScan with GretagMacbeth MeasureTool software. Following Chung and Shimamura (2001), total of 182 measurement samples were collected for substrate spatial uniformity. Substrate uniformity was estimated by (a) the average ΔE_{00} between the average L*, a*, and b* values of all samples and the individual CIELAB values, and (b) the cumulative relative distribution of all ΔE_{00}s (CRF). (Eqs. 1-5)

$$\overline{L^*} = \frac{\sum_{i=1}^{n} L^*_i}{n} \quad \text{Eq (1)}, \qquad \overline{a^*} = \frac{\sum_{i=1}^{n} a^*_i}{n} \quad \text{Eq (2)}, \qquad \overline{b^*} = \frac{\sum_{i=1}^{n} b^*_i}{n} \quad \text{Eq (3)}$$

$$\Delta E_i = \sqrt{(\overline{L^*} - L^*_i)^2 + (\overline{a^*} - a^*_i)^2 + (\overline{b^*} - b^*_i)^2} \quad \text{Eq (4)}, \qquad \overline{\Delta E} = \frac{\sum_{i=1}^{n} \Delta E_i}{n} \quad \text{Eq (5)}$$

The average ΔE_{00} of substrate spatial variation is 0.07. The CRF curve shows (1) 50 percent of the ΔE_{00}s are 0.06 or less, and (2) 90 percent of the ΔE_{00}s are 0.12 or less (Fig. 2). The substrate spatial variance is very small, and therefore this substrate is qualified for the testing.

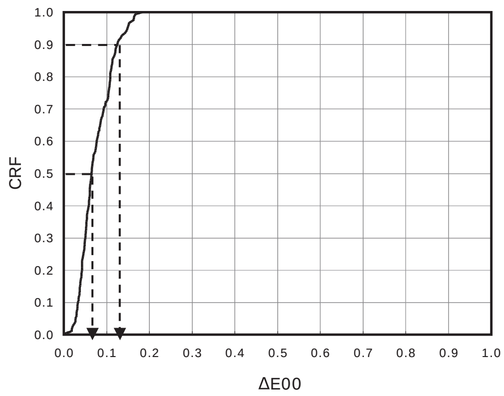

Fig. 2: CRF curve of substrate spatial uniformity

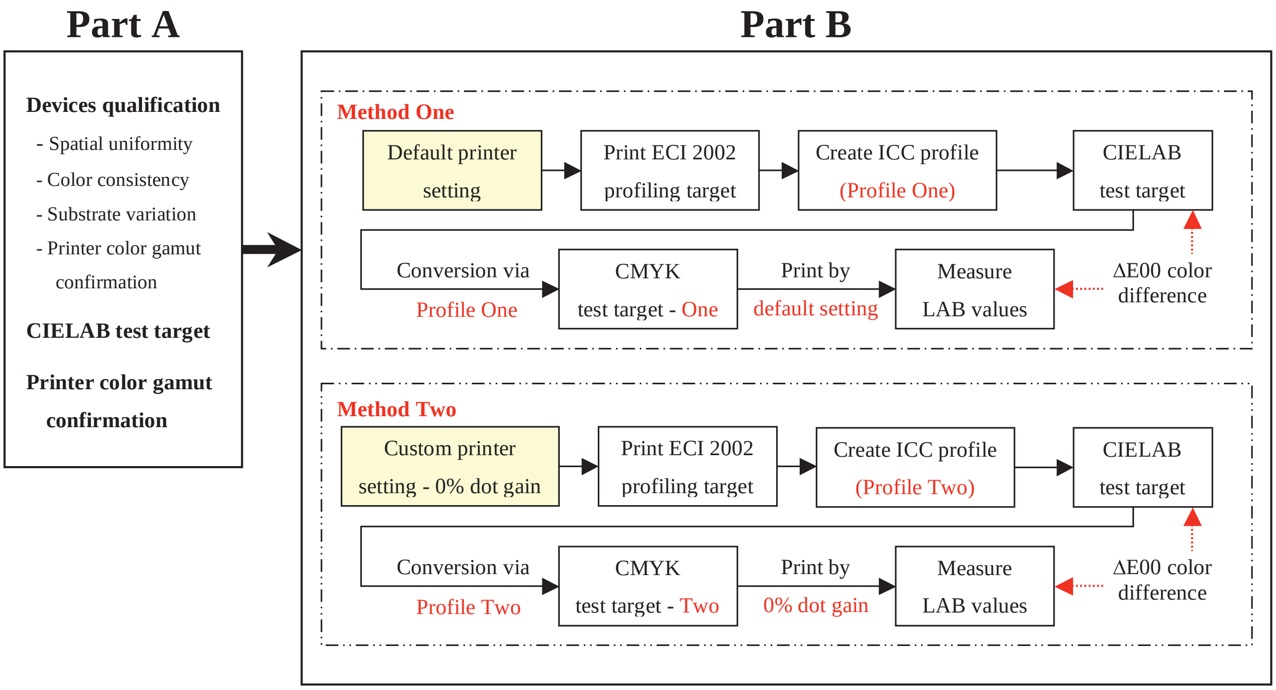

Fig. 1: Testing workflow

Printer spatial uniformity

Printer spatial uniformity is defined as the degree of ink uniformity within a single print and it is assessed colorimetrically. Four solid color strips, cyan, magenta, yellow, and black across a single sheet were printed by Epson Stylus Pro 4000 (Epson SP4000). Each trip is 8 x 0.25 inch and this target is printed twice in two orientations, horizontal and vertical.

30 CIELAB measurement samples were collected width wise from each strip. Spatial uniformity is estimated by (a) the average ΔE_{00}, i.e., the average of each L*, a*, and b* value between the individual CIELAB values. The sum of CIELAB was then divided by the number of measurements. (b) The cumulative relative distribution of all ΔE_{00}s (CRF).

Fig. 3 shows the CRF curves of horizontal (top) and vertical (bottom) printer spatial uniformity. The horizontal print presents a result that 90% of the all CMYK ΔE_{00}s are equal or less than 0.16. The vertical print shows 90% of the all CMYK ΔE_{00} are equal or less than 0.39, but the largest ΔE_{00}, 0.74, is much higher than the largest ΔE_{00}, 0.17, of the horizontal print. The average ΔE_{00} of spatial uniformity is 0.11 ΔE_{00}. (horizontal 0.07 ΔE_{00} and vertical 0.14 ΔE_{00})

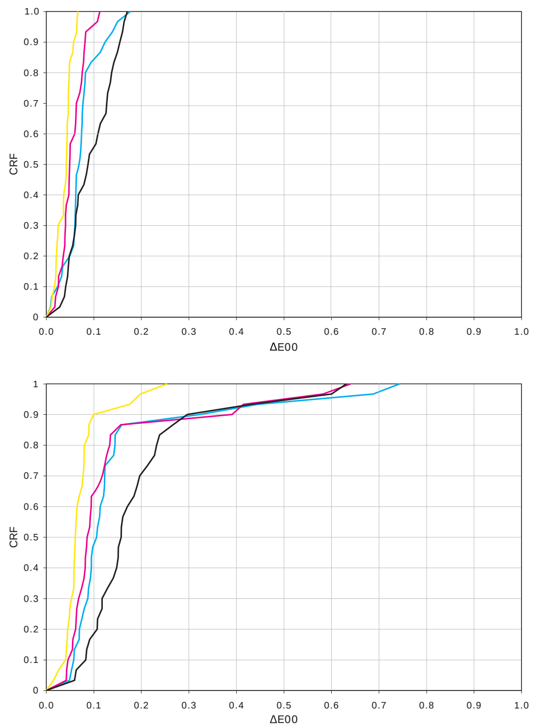

Fig. 3: CRF curves of printer spatial uniformity, horizontal (top) and vertical (bottom)

Sources of variability in spatial uniformity can be assignable or random. Assignable variation can be differentiated from random variation by observing patterns from individual ΔE_{00}s as a function of width wise. In brief, any assignable caused variation can be identified by the non-randomness in a distance dependent plot. The horizontal print shows random variation and good uniformity. However, it is obviously that the vertical print shows assignable variations in the head and the tail of the test strips with the largest ΔE00 0.74 (cyan).

Printer color consistency

A 78-patch ISO color chart, S7A.tif (ISO, 1997), is printed by Epson SP4000 each day for one week and followed by once a week for a month. The first print was treated as a reference. ΔE_{00}s of each patch between reference and samples were calculated and recorded in an Excel spreadsheet for color consistency analysis.

Fig. 4 shows the time plot of printer color consistency. It shows no assignable caused variation in the plot. The average of all prints is 0.25 ΔE_{00} and the maximum ΔE_{00} is 0.33.

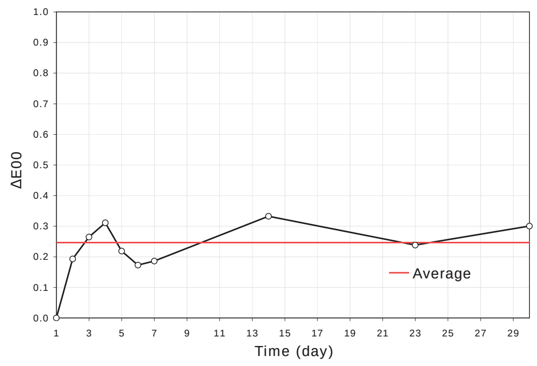

Fig. 4. Printer color consistency over a month

CIELAB test target & printer color gamut confirmation

A CIELAB test target is needed in this study to test the printer profiles in color matching ability from LAB color space to CMYK color space. Using Adobe Photoshop CS, an IT8.7/3 basic target was converted from CMYK to LAB color space via the standard ECI offset profile, ISOwebcoated.icc. It was converted under absolute colorimetric intent and Adobe CMM engine. The LAB IT8.7/3 basic target was saved as a TIFF file. Furthermore, the CIELAB values of 182 patches were recorded from Photoshop CS after the conversion and saved in an Excel spreadsheet for color gamut analysis.

To reproduce all of color patches in the LAB IT8.7/3 basic target, we need to confirm that: the Epson Stylus Pro 4000 with Epson UltraChrome Ink on Epson proofing paper commercial semi-matte can reproduce all the color patches on the LAB IT8.7/3 basic target. A CMYK IT8.7/3 basic target was printed via printer default setting, and its CIELAB colorimetric data was measured and compared to the gamut of the LAB IT8.7/3 basic target.

To assess whether the printable gamut of Epson SP4000 covers all the patches in the LAB IT8.7/3 basic target, a CMYK IT8 basic chart was printed and the colorimetric data was analyzed in the Excel template, Process.xls.

In the Excel template, the CIELAB data of the LAB IT8.7/3 basic target was treated as a reference in comparison to the sample, CIELAB values from the printed CMYK

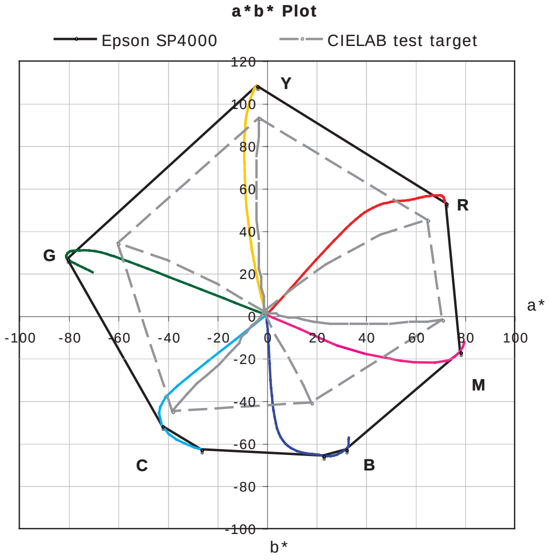

Fig. 5: a*b* diagram of the Epson SP4000 and the CIELAB test target

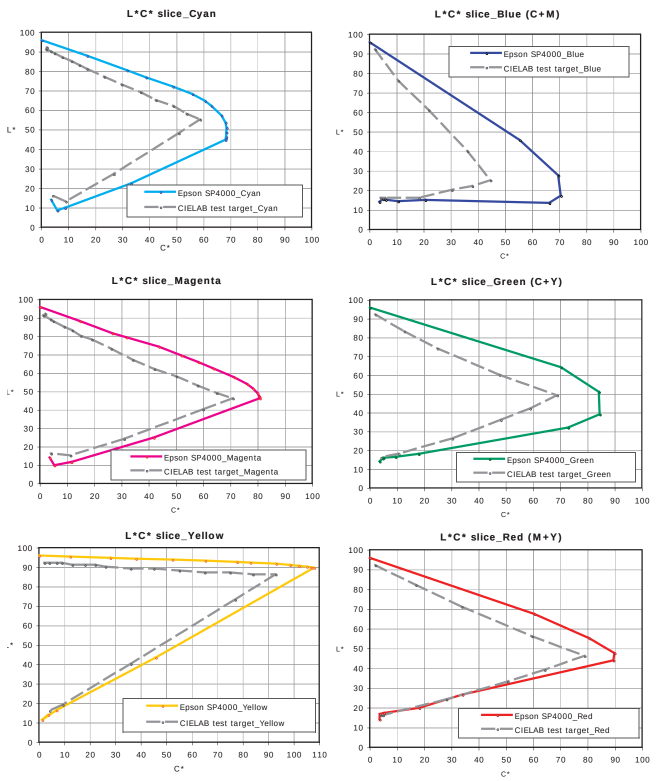

Fig. 6: L*C* charts of the Epson SP4000 and the CIELAB test target

IT8 basic target. Fig. 5 shows a*b* hexagon diagram to illustrate that the CIELAB test target is in the gamut of the printer with the paper. The L*C* slices of CMY and RGB were investigated in another aspect to tell the same result. (Fig. 6)

According to the above analysis, the Epson SP4000 is a very stable and consistent device. All the test patches on the CIELAB target are within the printer's color gamut. Therefore, the Epson SP4000 is qualified for the test.

Part B. Printer calibration & color matching analysis

After the device qualification, the printer is calibrated per 0% dot gain. Two printer settings, default and 0% dot gain, were used for ICC printer profiling and color matching analysis.

Printer per default and 0% dot gain calibration

When printing per default, no ink tonal adjustment was applied to the printer. To calibrate the printer to 0% dot gain, Harlequin RIP Eclipse Release SP4 was used to control the printer. A printer tonal calibration target was printed via Harlequin RIP. Density data of the printed target was measured by Spectrolino and recorded in Excel templates, Calibration.xle and Tansfer.xle. Transfer curves were calculated to calibrate the printer to 0% dot gain. The transfer curves were then loaded into the Harlequin RIP for color profiling. Fig. 7 shows the CMYK dot gain curves of default and 0% dot gain printer setting.

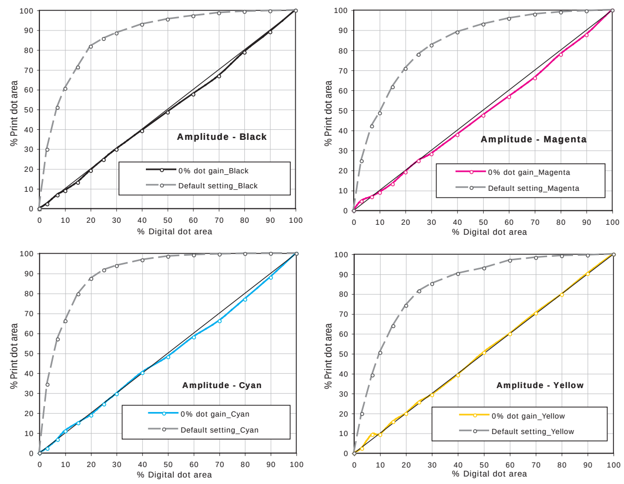

Fig. 7: Dot gain curves of default setting and 0% dot gain

Printer profiling and color matching analysis

An ECI2002R CMYK profiling target was printed under default (Method One) and 0% dog gain (Method Two) printer conditions. The profiling targets were measured and profiles were generated using GretagMacbeth ProfileMaker 4.1.5 under the GretagMacbeth predefined separation setting, Inkjet 400. (400TAC, black start: 40, GCR3) Both ICC profiles, Profile One (default) and Profile Two (0% dot gain) were used to convert the CIELAB test target to CMYK mode in Adobe Photoshop CS. The Adobe CMM was used, the intent was Absolute Colorimetric, and Dither was not selected. These two converted test targets were then printed by the printer under default and 0% dot gain settings separately.

The printed test targets were measured by GretagMacbeth Specroscan for CIELAB values under the condition of CIE illuminant D50 and 2-degree standard observer (ANSI CGATS .5-1993) on a white standard backing. These values were then compared to the reference values of the CIELAB test target.

Experimental results

Table 1 provides a descriptive statistical summary of the color matching experiment (SAS, 1990). A number of conclusions can be stated: (1) the average color matching performance under the default setting is 3.1 ΔE_{00} as opposed to 2.8 ΔE_{00} under the 0% dot gain setting; (2) the variance in ΔE_{00} distribution under the default setting is smaller (1.6) than that under the 0% dot gain setting (5.5); and (3) there is less skewness in the ΔE_{00} distribution (0.7) under the default setting than that under the 0% dot gain setting (1.5).

Table 1: Summary of color matching performance comparisons

	Method one Default setting	Method Two 0% dot gain
Total Patches	182	182
Average ΔE00	3.1	2.8
Standard Deviation	1.3	2.4
Variance	1.6	5.5
Skewness	0.7	1.5
T-test (Unequal variances)		
t Value	1.35	
Pr > |t|	0.18	

A T-test (unequal variances) was performed to test the hypothesis whether the two population means are the same or not. The result shows that the P-value, is 0.18. P-value is the probability of stating that the two means are significantly different. Thus, it is concluded that there is no significant difference between the two population means at the alpha risk of 0.05. In other words, there is no significant color matching improvement using 0% dot gain as the criterion for device calibration.

Discussion

The ΔE_{00} distribution, expressed as a cumulative relative frequency (CRF), for each of the two calibration methods is shown in Fig. 8. The key point of interest to find out is whether these color differences are randomly distributed throughout the lightness range or not.

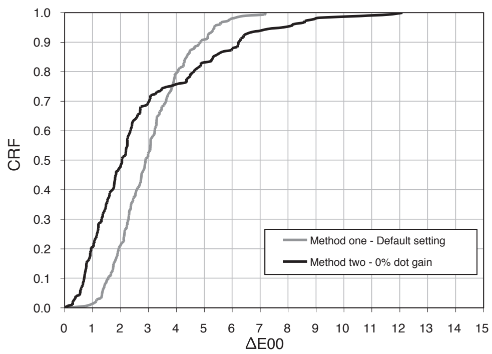

Fig. 8. CRF curves of color matching ability, default setting and 0% dot gain

Fig. 9 plots color difference as a function of L* for all color patches. The distribution of color differences (left-hand side) appears to be random in the default setting, but not random in the 0% dot gain setting. Specifically, larger ΔE_{00}s tend to fall between 20 L* and 30 L* in the 0% dot gain setting. The finding suggests that the ICC profile built under the default setting performed color matching equally throughout the tonal region and the ICC profile built under the 0% dot gain did not.

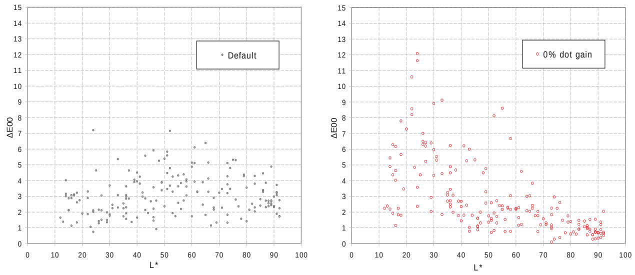

Fig. 9. ΔE_{00} vs. L* of the input CIELAB, default setting (left) and and 0% dot gain (right)

Table 2a & 2b: Worst 10% color patches. 2a (left), default setting. 2b (right), 0% dot gain

Patch ID	ΔE00	L*	a*	b*	C*	h
J2	7.20	24	2	-7	7	286
H1	7.15	30	30	-22	37	324
I5	6.39	65	15	15	21	45
L6	6.12	61	-1	-1	1	225
I2	5.92	46	27	3	27	6
H5	5.83	51	37	29	47	38
H3	5.60	51	38	11	40	16
G12	5.57	43	-17	-44	47	249
H6	5.39	51	38	11	40	52
H12	5.37	33	-4	-31	31	263
I9	5.32	75	2	4	4	63
B2	5.30	76	4	-10	11	292
M3	5.26	48	-34	-38	51	228
F6	5.14	66	-1	0	1	180
K9	5.13	60	-3	-1	3	198
A11	5.12	61	9	-20	22	294
I8	5.12	73	1	20	20	87
M2	4.89	89	-1	1	1	135

Patch ID	ΔE00	L*	a*	b*	C*	h
J2	12.1	24	2	-7	7	286
G13	11.6	24	7	-21	22	288
J10	10.6	22	-3	1	3	162
H12	9.1	33	-4	-31	31	263
N11	8.9	30	5	-9	10	299
A1	8.6	55	-38	-45	59	230
M6	8.6	22	15	-35	38	293
J13	8.2	22	-1	1	1	135
G10	8.1	52	-52	-13	54	194
J7	7.8	18	-5	2	5	158
M12	7.3	20	12	-28	30	293
N9	7.0	26	-27	14	30	153
C1	6.7	58	-35	-41	54	230
L9	6.5	26	-8	3	9	159
J11	6.4	27	-4	2	4	153
K1	6.4	29	-1	1	1	135
K5	6.3	26	-1	0	1	180
B9	6.3	15	-10	4	11	158

The other point of interest is whether the patches having large color differences in the 0% dot gain setting are distributed in a specific region of the color space or not. Tables 2a and 2b list the worst 10% color patches with their colorimetric properties (L*, a*, b*, C*, and h). By observation, many of the color patches are in the shadow area of the color space and hue angle is between 135 to 300 degree.

The idea behind the 0% dot gain calibration is to see if the increased slope in the shadow region of the tonal scale can improve the color matching performance of the ICC profile (Fig. 10). What we have learned in this study is the opposite of what we envisioned.

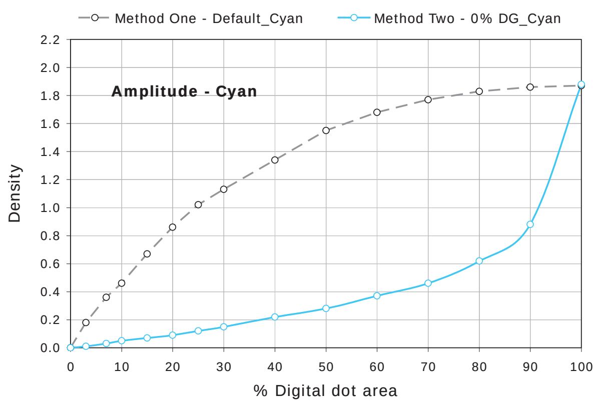

Fig. 10: Density curve comparison

Fig. 11 plots the hue progression of primary (CMY) and overprint (RGB) colors between default and 0% dot gain settings on an a*b* diagram. Most of the data points were shifted to low chroma area, and not enough data points were used to model the color behaviors in high chroma area. It explains why highlight patches show much better result in color matching ability than shadow patches via the 0% dot gain setting.

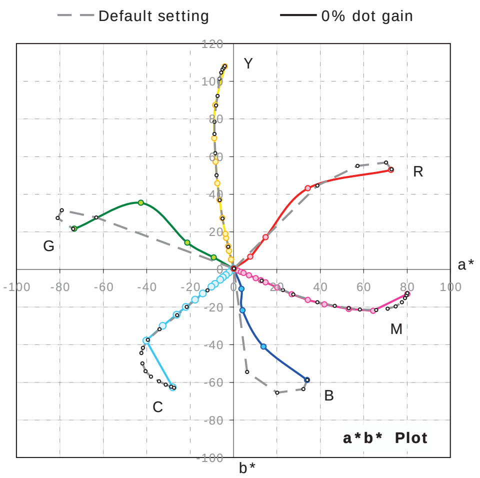

Fig. 11: Hue progression comparison

Suggestions for further study

In this study, only calibrating a printer linear per dot area was researched. The result showed that there is no improvement in color matching performance. There are other approaches that may be examined for printer calibration, such as linear to L* or C* (Fig. 12).

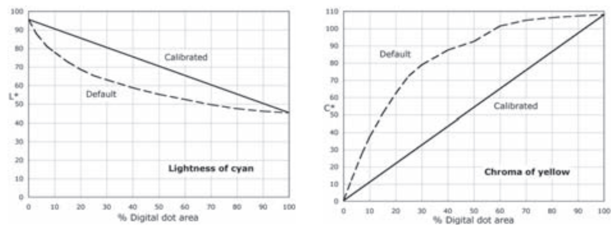

Fig. 12: Calibration per lightness (left) and chroma (right)

Using ΔE formulas to express color difference of synthetic targets does not provide concrete evidence whether two pictorial images match or not. A full-scale color management study involving proofer calibration, profiling, color managed press run, and digital proofing is recommended to provide an opportunity to test color matching performance in both quantitative and visual assessment between press sheets and digital proofs.

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References

ANSI CGATS.5, (2004). Spectral measurement and colorimetric computation for graphic arts images.

Chan, J., Chung, R. and Cheung, W., (2000). Digital proofing with ICC CMS. 2001 TAGA Proceedings, pp. 143-159.

Chung, R., (2005). Color repeatability of spot color printing. 2005 TAGA Proceedings.

Chung, R. and Shimamura Y., (2001). Quantitative analysis of pictorial color image difference. 2001 TAGA Proceedings. pp. 333-345.

Global Graphic Software Ltd., (2004). Harlequin RIP for Mac OS X OEM Manual. Harlequin Eclipse Release SP4.

ISO 12640:1997(E), (1997). Graphic technology - Prepress digital data exchange - CMYK standard colour image data (CMYK/SCID). International Organization for Standardization

Livens, S. and Mahy, M., (2002). Quality managed proofing: The road to visual consistency. Presented at the 29th International IARIGAI Research Conference, Sept. 8-11, 2002, Switzerland.

Melgosa, M., Huertas, R., and Berns, R., (2004, December). Relative significance of the terms in the CIEDE2000 and CIE94 color-difference formulas. Journal of the Optical Society of America, Volume 21, Issue 12, pp. 2269-2275.

Noyes, Y., Hardeberg, J., and Moskalev, A., (2000). Linearization curve generation for CcMmYK printing. Eighth Color Imaging Conference: Color Science and Engineering Systems, Technologies, Applications, Volume 8, pp. 247-251.

SAS Institute Inc., (1990). SAS/STAT User's guide volume 2. GLM-VARCOMP, Version 6 (4th edition), pp.1633-1640.

Sharma, A., (2005, January). WMU profiling review 2005. Retrieved June 26, 2005, WMU Profiling Review Home Page, http://www.wmich.edu/ppse/staff/downloads/.

Zeng, H., (2002). Color accuracy in ICC color management system. IS&T's 2002 PICS Conference pp. 175-180.

Premedia color variability

by Michael Riordan, Associate Professor

Keywords

premedia, color variance, spot color, ICC profile

Abstract

The successful implementation of color management in any digital print environment is dependent on the ability to characterize and control the critical stages of production workflow. Even after quality practices have become established in the pressroom, the potential for color variance based on operator-defined actions during the course of normal prepress production operations remains significant. This variation may result in an unacceptable deviation from the expected or target outcome in print production scenarios where any level of operator intervention is considered general practice.

To quantify the potential variation resulting from specific operator-defined actions, a study was conducted in which several production workflows characteristic of digital print environments were replicated. Assuming different levels of color management understanding, a series of user-defined profile decisions were applied to a standardized target and a selected set of representative test images within the context of software applications customarily used in premedia production. The resulting test files were printed and color variance was determined via ΔE and paired comparison for a set of workflow combinations representative of those common in many premedia production environments.

Introduction

The premedia phases of the digital print production workflow extend from the initial creation of digital files through to the raster image processing of files at the print device. While print quality has continuously improved through the application of quality control measures for physical print reproduction, quality control measures are more difficult to implement due to the behavioral aspects inherent to the premedia production process.

Generally speaking, quality control in premedia production can be improved through the application of standard operation procedures (SOPs) during the creation of print-ready digital files. The creation of such SOPs for color management practices and PDF creation are commonplace in many professional environments, although they may not insure quality improvements based on both the variance in SOPs between different environments and the thoroughness to which operators implement already established SOPs. Further, even with established SOPs, the SOPs themselves may introduce variation (e.g. Failure to embed a color profile).

This potential for variation during premedia production has increased steadily as the affordability of software-based production tools has enabled the further decentralization of premedia services to creative professionals, advertising agencies and other imaging professionals. This dispersion of the production process has introduced a natural increase in the variation in both the quality and quality expectations of files submitted for print production. The range of skills, knowledge and general practices of the diverse professionals participating in components of the premedia production the fuel this variability and the lack of industry standards and specifications for most of the steps leading up to proofing due little to curtail this range in general practices.

To further illuminate the variance in trade practices and technical understanding, consider that the 2004 TrendWatch report on Color Management showed that, while 71% of printing companies reported that they used SOPs in premedia activities relating to color reproduction, the same report showed that the SOP usage for publishers and design firms was only at 33% overall. While the increasing trend in utilization of SOPs is still encouraging, there is little available data qualifying that the SOPs of printers, publishers and design firms are the same SOPs or produce the same results.

TrendWatch further reported that the implementation of color management followed suit with nearly 2/3 of printers reporting using some form of color management, but for "more than half of the firms that say they do use color management say that simply 'eye-balling' jobs is their primary means of color management." According to the same report, about 2/3 of design firms and publishers do not use color management technology overall. Magazine publishers are slightly above average at 40%.

To establish a benchmark for the actual trade practices being used by the creative and technical professionals participating in the premedia production cycle, interviews with and direct observation of these professionals were conducted over a span of several months. The exploratory study revealed several reoccurring differences in established SOPs, the most significant variable relating to premedia color reproduction being the differences in the definitions of clear and consistent use color preferences and/or color settings within software applications. When paired with the variations in subsequent procedures for the handling of color profiles assigned, embedded or missing from an image file, the potential for color variation was determined to be very high.

Independent of this, inconsistencies in the reproduction of spot colors (e.g. Pantone, etc.) were identified as a reoccurring problem, especially for those files destined for digital print production environments.