Factors Impacting the Evaluation of Printer Profile Accuracy

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Abstract

The evaluation of printer profile accuracy is affected by many factors and the printing device represents only one such factor. This paper examines the effect of profiling target layout and patch size on printer profile accuracy. Two digital color printing devices were evaluated using a single color measurement system. The evaluation avoids temporal variation associated with the color printing device on purpose. It was found out that (1) the spatial color uniformity of the device bears a larger impact on its colorimetric accuracy than factors such as target layout and patch size; (2) the use of the random target over the visual target helps minimize spatial non-uniformity in the shadow region of the color gamut; and (3) there is no significant difference in colorimetric accuracy when reducing the patch size of the random target from 6mm to 4mm using the color measurement instrument in this experiment.

Keywords: ICC, profile, accuracy, colorimetry

1 Introduction

Many people in North America live in the world of eight-and-half-by-eleven. The notepad is 8.5 by 11; the magazine is 8.5 by 11; and the most popular paper size for desktop printers is “Letter Size,” and that is 8.5 by 11 inches. Having the same dimension helps to keep documents in a neat pile.

There is finite area in an 8.5 by 11 inch space. If one takes one inch out as margins, the printable area of an 8.5 by 11 page is 6.5 x 9 inches or 58.5 in². This translates into 37,741 mm² (one inch is equal to 25.4mm). You may question what’s all the fuss!

When the first CGATS-endorsed profiling target, IT8.7/3, came out in mid-1990s, it contained 928 6mm patches and the entire target would fit into an 8.5 by 11 page with 6mm patch size nicely. As a matter of fact, the “Letter Size” page with one-inch margin can accommodate 1,048 6mm patches.

When CGATS introduced the IT8.7/4 profiling target with 1,617 6mm patches [1], the magic world of 8.5 by 11 no longer could cope with the addition of patches that were deemed necessary by the color management communities. The only recourse without changing the paper size while keeping the target intact is to reduce the patch size. For example, if one reduces the patch size from 6mm to 4mm, it can accommodate up to 2,358 patches. Incidentally, neither IT8.7/3 nor IT8.7/4 specifies the patch size as the normative part of the specification. The default patch size of 6mm came from the days of IT8.7/3 and constraints in color measurement instrumentation. In other words, the patch size of 6 mm is not a part of the standard, but the user will confront the issue of target size when implementing color management.
In addition to the increase in number of patches, CGATS also introduced a random layout of the target along with the visual layout in the informative part of the standard. Figure 1a is a reduced size of the IT8.7/4 random target and Figure 1b is a reduced size of the IT8.7/4 visual target.

![Figure 1: Two default layouts of the IT8.7/4 target](image)

1.1 Problem Statements

Printer profile accuracy depends on the following immediate factors: the profiling target, the color printing device, the color measurement instrument, the profile-making software, the CMM, etc. Depending how printer profile accuracy is tested, spatial uniformity of the printing device becomes a factor if it involves comparison of colorimetric measurements from more than one location within the sheet. If it involves comparison of colorimetric measurements between the press run that generates the press profile and the press run that applies the press profile, color repeatability of the printing device then becomes a factor. Thus, it is important to ask, “Which testing condition is suitable for testing printer profile accuracy?”

There are two default target layouts, i.e., random vs. visual, mentioned in the IT8.7/4 specifications. The concept of randomizing patches is believed to minimize the effect of inherent device noises associated with inking evenness, ink starvation, etc. The question of interest becomes, “To what extent is the random target more effective in minimizing printer noise than the visual target?”

The dimension of IT8.7/4 with a patch size of 6mm no longer fits within the letter size. A question of equal interest becomes, “Is there an adverse effect in color measurement accuracy when patch sizes are reduced?”

These questions regarding target orientation, patch size, and measurement noise were initially explored by Chung [2] and are now more fully examined. The researcher recognizes that the experimental findings will not be absolute, but relative to the variables compared, e.g., visual layout vs. random layout, 6mm patch size vs. 4mm patch size. Furthermore, specific findings depend on the testing conditions, e.g., printing devices tested and color measurement instrument used.

2 Literature Review and Pilot Study

A printer profile contains Look-up Tables (LUTs) between CMYK and CIELAB. It assumes that there is no variability within a device so that each combination of CMYK is mapped to a unique CIELAB values, and vice versa. In fact, a printer can vary both spatially and temporally
By understanding the magnitude of the variations, one can begin to have a handle on the estimation of printer profile accuracy.

Variability is the degree of repeatability or precision of the measured outcome. When a person measures anything only once, he knows nothing about its variability. If one measures a printed color chart more than once, he can assess the variability associated with a color measurement system or a printing device.

2.1 Instrument Repeatability
Researchers at Rochester Institute of Technology devised a method to estimate color measurement instrument repeatability [4]. The Committee for Graphic Arts Technology Standards also recommends the method whereby cumulative probability plot of ΔE distribution from a multi-patch color chart is used for evaluation [5]. The procedures are to (1) measure a printed IT8.7/3 (basic) target twice using one color measurement instrument; (2) calculate colorimetric difference between any one of the two colorimetric measurements and its average; and (3) arrange the ΔE distribution of all 182 patches in the form of relative frequency (better known as a pie chart) or as a cumulative relative frequency (CRF). The CRF of ΔE becomes a graphic depiction of the instrument repeatability. A Spectrolino/Spectroscan was used in this study. Measuring a printed color chart twice is the minimum number of times to assess repeatability of a measurement system.

The repeatability of this instrument, as shown in Figure 2, shows that one-half of the time, the uncertainty of a color measurement is 0.2 ΔE or less; and 90% of the time, the uncertainty of a color measurement is 0.4 ΔE or less. For purpose of comparing variations induced by different factors, the scaling of the CRF curve is normalized from 0 to 10 ΔE in the x-axis.

![Figure 2: Instrument repeatability of Spectrolino/Spectroscan](image)

2.2 Spatial Uniformity of the Printing Device
Spatial uniformity of a CMYK printing device can be estimated similarly with the use of a minimum of two identical IT8.7/3 (basic) color blocks printed on the same sheet (Figure 3). Colorimetric difference between any one of the two colorimetric measurements and its average are calculated. The ΔE distribution of all 182 patches in the form of cumulative relative frequency (CRF) becomes a graphic depiction of the spatial uniformity of the output device [6].
Figure 3: Two IT8.7/3 (basic) color blocks with one rotated

Figure 4 shows an example of spatial uniformity of a digital press using the analysis method outlined above. By comparing with the instrument repeatability, one can see that one-half of the time, the uncertainty of spatial uniformity is 0.6 $\Delta E$ or less; and 90% of the time, the uncertainty of a spatial uniformity is 1.5 $\Delta E$ or less.

Figure 4: Spatial uniformity of a digital press

2.3 **Temporal Consistency of the Printing Device**

Temporal consistency of a CMYK printing device can be estimated similarly with the use of two IT8.7/3 (basic) color blocks printed at different times. Here, spatial uniformity (the average of the sample measurements) is differentiated from temporal consistency (the difference between the sample value and its target value).

Figure 5 shows the CRF curve between two digital press runs. One can see that one-half of the time, the uncertainty of temporal consistency of the digital press is 2.6 $\Delta E$ or less; and 90% of the time, the uncertainty of temporal consistency is 5.7 $\Delta E$ or less. Multiple CRF curves may be generated between sampled press sheets and the target to reflect temporal consistency of the press run.
Instrument repeatability, spatial uniformity, and temporal consistency are independent factors that impact the repeatability of color measurement data. When evaluating printer profile accuracy, one has to live with the uncertainty of a color measurement instrument and the spatial uniformity of the printing device.

2.4 Profiling Target Layout

Different target layout and the profile-making software react to spatial non-uniformity differently. There was a curiosity to learn if target layout influences the color measurement accuracy of the profiling target that, in turn, impacts the printer profile accuracy. If the spatial uniformity of an output device is good, patch layout of the profiling target should have little impact on the colorimetric accuracy of the resulting profile. On the other hand, if the spatial uniformity of an output device is poor, patch layout of the profiling target and the profile-making software may have a significant impact on the colorimetric accuracy of the resulting profile. Thus, to determine the effect of target layout on printer profile accuracy remains as an objective of the study.

2.5 Measurement Error due to Patch Size

Spooner discusses the effect of color measurement error due to patch size [7]. When the light of the measuring instrument that illuminates in all directions of a translucent substrate such as paper, some of the light that diffuses laterally out of the lighted area diffuses back to the lighted area. If the measured area is equal to the patch size, then some laterally diffused light will exit through the sample edges and back, and thus the measurement is influenced by adjacent colors. He called such an effect, lateral diffusion error (LDE). To avoid this type of measurement error, ISO 5/4 [8] specifies that the patch size should be 2mm larger on all sides from the measured area.

The default width of a color patch in the IT8.7/4 target is 6mm wide. The diameter of the Spectrolino/Spectroscan’s hold-down aperture, used in the experiment, is 5mm. The measured area is about 4mm (Figure 6). In this case, there was a concern regarding the measurement error when reducing the patch size from 6mm to 4mm.
3 Methodology

In this research, the IT8.7/4 (full or 1,617 patches) targets were used to build printer ICC profiles. The IT8.7/3 (basic block with 182 patches) target was used as input to the evaluation process. These targets were printed to a KPG Approval color proofer and a Xerox DocuColor 6060 digital printer. The GMB Spectrolino/Spectroscan was used to measure all color patches (CIELAB, D50, 2 degree). In other words, one set of color measurement was made from one KPG Approval print and one Xerox Docucolor 6060 print containing the targets as described. In addition, the GMB ProfileMaker 5.0 was used for ICC profile construction and CHROMIX ColorThink 3.0 Pro for data extraction from ICC profiles. ∆Eab was used to express the color difference as opposed to using other ∆E formulas because it is recommended by CGATS and ISO 12647.

3.1 Testing the Effect of Target Layout

To test if there is a significant difference in colorimetric accuracy between the visual target and the random target, two devices, KPG Approval and Xerox 6060 and the standard 6mm target were chosen for the experiment. It is hypothesized that the 2,540 spots/in (spi) with dye diffusion thermo transfer based KPG Approval is a spatially uniform output device. Thus, the difference in target layout will have less impact on colorimetric accuracy than that of the 600 spi dry toner based Xerox 6060. Below is the experimental procedure for testing the effect of target layout.

   a) Determine spatial uniformity of the devices by printing two IT8.7/3 (basic) color blocks within an A3 sheet. The ∆E distribution (CRF curve) between individual measurements and their averages is an indication of the spatial uniformity of the output device. More importantly, the average CIELAB values between the two corresponding patches of the two IT8.7/3 (basic) targets represent the reference values when assessing colorimetric accuracy of ICC profiles made from different layouts and from different patch sizes.

   b) Print the IT8.7/4 visual target and the IT8.7/4 random target to KPG Approval and Xerox 6060. Construct ICC profiles, with the same CMYK constraints using GMB ProfileMaker 5.0.

   c) Test colorimetric accuracy of these ICC profiles by means of output simulation. This is done using the Worksheet feature of ColorThink 3.0 Pro to perform A-to-B or device-to-PCS color conversion. Briefly, a CIELAB list can be generated from a CMYK list via a specific ICC profile and the absolute colorimetric rendering intent. The CIELAB list is the simulated outcome of printing the CMYK target. Because no physical printing device is used, there is no process variation involved.
d) Compute colorimetric difference (CRF curve) between the simulated output and the reference value established in Step (3.1a). The CRF curve is a measure of the printer profile accuracy.

3.2 Testing the Effect of Patch Size
To test if there is a significant difference in colorimetric accuracy due to patch sizes, KPG Approval with both the 6mm (visual and random) and the 4mm (visual and random) targets were chosen as the testing conditions. It is hypothesized that if patch size is a significant factor, larger colorimetric errors will be detected in the ICC profiles built from reduced patch sizes. The testing procedure is similar to Testing the Effect of Target Layout.

4 Results and Analysis
If there are colorimetric differences due to target layout or patch size, the difference has to be relative to the inherent spatial variation of the device. The researcher will use the results of the spatial uniformity that includes color measurement system error as the starting point to discuss the effect of target layout and patch size on printer profile accuracy.

4.1 Spatial Uniformity of Output Device
The spatial uniformity of KPG Approval is shown in Figure 7. Colorimetric differences were between individual measurements and their averages. The ΔE statistics shows that the median ΔE is 0.3 and the 90-percentile ΔE is 0.5. The maximum ΔE of 4 was from the color patch ID 92 with %dot area value of 70C, 100M, 20Y, and 0K. This purplish color patch has the largest spatial color difference. Color patch ID 92 with a coordinate of H1 is located at the bottom center of the IT8.7/3 (basic) target. There was no physical flaw associated the patch and the cause of the color difference was unknown.

![CRF Curves](image)

*Figure 7: Spatial uniformity of KPG Approval*

The spatial uniformity of Xerox 6060 is shown in Figure 8. The ΔE statistics shows that the median ΔE is 0.5 and the 90-percentile ΔE is 1.2 with a maximum ΔE of 2.4. Figure 7 and 8 help verify that KPG Approval is more spatially uniform than Xerox 6060 digital printer.
4.2 Colorimetric Differences Due to Target Layout

To test the colorimetric accuracy of ICC profiles by means of output simulation, a CMYK list of the IT8.7/3 (basic) target was set up in ColorThink 3.0 Pro as a Worksheet. By specifying an ICC profile and absolute colorimetric rendering intent, the software transforms the CMYK list into a CIELAB list via the A-to-B look-up table (LUT). The researcher realizes that the accuracy of the color conversion depends on the CMM and algorithms used in the transform. This is how one would simulate the output device without temporal variability of the printing device.

The CIELAB list derived from the above simulation is known as the sample. The sample CIELAB list and the reference CIELAB list, derived from Step (3.1a) of the methodology, are used to calculate ∆E between them.

The comparison of colorimetric accuracy between target layouts of KPG Approval is shown in Figure 9. Curve A is the spatial uniformity of KPG Approval, as described in Figure 7. Curve B is the colorimetric difference associated with the profile built from the IT8.7/4 6mm version of the visual target. Curve C is the colorimetric difference associated with the profile built from the IT8.7/4 6mm version of the random target.

Figure 9 shows that the colorimetric error, via output simulation, is around 0.7 ΔE at the 50 percentile. This value is almost three times greater than the spatial uniformity of the Approval or 0.25 ΔE. This means that KPG Approval can match a colorimetric specified color with any possible combination of CMYK values with an average ΔE error of 0.7. In this instance, the error comes from the color measurement device, profile-making software, and CMM used in the ColorThink 3.0 Pro software.

Figure 9 also reveals printer profile accuracy between the two target layouts. While the median ΔE from the visual target is slightly smaller than that of the random target, it was uncertain if such a difference is significant. As stated earlier, KPG Approval is a uniform color output...
device. Profiles made with different target layouts may have little effect on their colorimetric accuracy.

More importantly, Figure 9 shows that there are more occurrences of large $\Delta E$ (greater than 4) values in the visual target than in the random target. Upon further analysis with the use of $\Delta E$ sorting feature in the ColorThink 3.0 Pro (Figure 10), these color patches were found to be all 4-color black tints with patch ID from 129-134 in the IT8.7/3 (basic) target. The significance of larger errors in 4-color black tints is that the use of gray component replacement (GCR) may help reduce printing variation.

![Figure 10: Color patches with $\Delta E$ values greater than 4 found in KPG Approval visual target](image)

There was only one color patch with ID 92, as shown in Figure 11, having a $\Delta E$ larger than 4 in the random target and the patch is made up of 70C, 100M, 20Y, and 0K, the same color patch that was found to have the largest color difference due to spatial non-uniformity. Given that there are choices, the use of the random target over the visual target, couple with the profile-making software, can help minimize color measurement errors in the shadow region of the color gamut.

![Figure 11: Color patches with $\Delta E$ values greater than 4 found in KPG Approval random target](image)

The colorimetric accuracy comparison between target layouts of Xerox 6060 is shown in Figure 12. Curve A is the spatial uniformity of Xerox 6060, as described earlier. Curve B is the colorimetric difference associated with the profile built from the IT8.7/4 6mm version of the visual target. Curve C is the colorimetric difference associated with the profile built from the IT8.7/4 6mm version of the random target.

![Figure 12: Printer profile performances between two target layouts of Xerox 6060](image)
Figure 12 shows that colorimetric errors, via the Xerox 6060 output simulation, are greater than 1.5 ΔE at the 50 percentile. This value is, again, three times greater than the spatial uniformity of Xerox 6060 or 0.5 ΔE. Without further testing if the difference between spatial uniformity and temporal consistency are significant, Table 1 reconfirms that colorimetric accuracy of a printer profile begins with spatial uniformity that is inherent in the output device.

Table 1: Comparison of colorimetric errors by output simulation

<table>
<thead>
<tr>
<th>Spatial non-uniformity</th>
<th>Visual target</th>
<th>Randomized target</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPG Approval</td>
<td>0.25</td>
<td>0.7</td>
</tr>
<tr>
<td>Xerox 6060</td>
<td>0.5</td>
<td>1.7</td>
</tr>
</tbody>
</table>

In term of the effect of target layout on colorimetric accuracy of Xerox 6060 printer profiles, Figure 12 suggests that the median ΔE from the visual target is slightly larger than that of the random target. It is uncertain if such a difference is significant.

Figure 12 also shows that there are more occurrences of large ΔE (greater than 4) values in the visual target than in the random target. Using the ΔE sorting feature in the ColorThink 3.0 Pro, it was found out that the same group of color patches with patch ID from 129-134 in the IT8.7/3 target yielded larger ΔE values from the visual target as discussed in the Approval case. Both the magnitude and the occurrence of larger ΔE (greater than 4) were reduced in the random target.

4.3 Colorimetric Differences Due to Patch Size
Colorimetric accuracy of two KPG Approval profiles, i.e., Visual_6 and Visual_4, is shown in Figure 13. Curve A is the spatial uniformity of the Approval, as described in Figure 7. Curve B is the colorimetric difference associated with the profile built from the IT8.7/4 6mm version of the visual target and the curve C is that of the IT8.7/4 4mm version of the same target.

Figure 13 shows that (1) the median ΔE between the visual 6mm and the visual 4mm KPG Approval targets is the same; (2) there are larger ΔE values associated with the reduced patch size. For example, ΔE at the 90 percentile increased from 1.9 ΔE to 2.6 ΔE as the patch size reduced from 6mm to 4mm. Spooner’s lateral diffusion error (LDE) may very well explain why this had occurred. But the effect of lateral diffusion error did not support the two random targets (Figure 14). As shown in Figure 14, colorimetric differences are relatively small between the random 6mm and the random 4mm targets.
By stepping back and examining both Figure 13 and 14 together, it became evident that (1) the random target tends to yield better profile accuracy than the visual target by reducing the occurrence of larger \( \Delta E \), and (2) the random target is less affected by the effect of reduced patch size.

5 Discussion

This research work was initially motivated by curiosity of the causal relation between the profiling target variations and the printer profile accuracy. Although measurements can also be affected by ambient illumination entering the instrument, it was realized that printer profile accuracy is the response of a system, and not a single element alone.

Figure 15 summarizes the factors that may influence printer profile accuracy. Major factors that contribute to the evaluation of printer profile accuracy include printer repeatability, color management, color measuring instrument, and the evaluation method used. In this research, the researcher paid special attention to the effect of profiling target and the type of printer on printer profile accuracy. He held a number of factors, e.g., color measuring instrument, profile-making software, as constants in the experiment.

Based on our own research work, the magnitude of variation due to color measuring instrument is the smallest of all variations in the system. The smaller patch size of the profiling target can cause additional measurement error due to geometric precision of the positioning mechanism and the halftone structure of the print. It is recommended that more instruments with different measured areas be included as a follow-up study. Particularly, the alignment between the
instrument and the patch becomes critical as the measured area approaching to the size of the color patch. Lateral diffusion errors will be more severe for profiling target with small patch sizes in randomized layout than for profiling target in visual layout. This is because the magnitude of these errors varied with the size of the area being measured and the location of the adjacent colors [7].

Printing repeatability is a major factor in the evaluation of printer profile accuracy. Spatial uniformity of printing is adopted as a baseline when evaluating colorimetric accuracy of color printing devices. Temporal consistency and run-to-run variability associated with color printing devices were purposely avoided by means of output simulation with the Worksheet feature of the ColorThink 3.0 Pro.

Other than variations in profiling target layout and patch size, color management parameters, e.g., profile-making software, CMYK constraints, CMM, were held as constants in this experiment. As such, the researcher had to accept errors in profile predicted values via device simulation that was three times in ΔE magnitude in comparison to the spatial uniformity of the printing device. If the researcher were to experiment with the profile-making software settings, including the computational ability of the CMM, he would have reduced colorimetric errors in the simulation process.

Printer profile accuracy may be assessed by different evaluation methods. When a synthetic color target is used, it involves the A-to-B color conversion where the ‘A’ space is a CMYK color space. The use of a colorant-based synthetic target, such as the IT8.7/3 (basic), proved to be effective in the evaluation of color repeatability of printing devices in color-managed workflows. Other target, e.g., the ECI 2002 profiling target, with ECI published characterization data set as the reference was also used [9]. In this case, the device uniformity is excluded in the evaluation process.

There are two limitations with the use of a colorant-based synthetic target as experienced in this research: (1) only the A-to-B LUT of the printer profile is evaluated and the B-to-A LUT is not; (2) the findings do not necessarily predict visual responses of pictorial color image match. As suggested in Figure 15, it is useful to include pictorial color images with synthetic colors that are sampled from various pictorial scenes as the input target in the evaluation process. It is recommended that pictorial color images and an image-based synthetic target are included in the evaluation of printer profile accuracy in the context of digital proofing workflow as a follow-up study.

6 Conclusion

There was little research on conducting printer uniformity and temporal consistency when film-based proofs were the norm and pressmen were asked to print to visually match the supplied color proofs. ICC-based color management changed all that. In particular, color proofs are to match standard printing conditions. Color matching between two printing devices begins with accurate ICC profiles. This paper is an attempt to better understand factors that impact printer profile accuracy.

Colorimetric accuracy of a printer ICC profile can be affected by a number of factors. From the variables tested, device uniformity is the most important factor, i.e., the more uniform the device is, the more repeatable the color will be. Factors such as target layout and patch size are of secondary importance.

The use of the random layout over the visual layout of the profile target helps minimize spatial non-uniformity in the shadow region of the color gamut. This requires that the profile-making software have the data fitting and color space modeling capabilities.
Measurement noise is proportional to the spatial non-uniformity of the printing device. Measurement noise from the randomized target layout may be smoothed out by profile-making software. So, printer profile accuracy is a combination of target layout and data smoothing ability of the profile-making software.

Back to the world of 8.5 by 11. When reducing the IT8.7/4 profiling target from 6mm to 4mm, there are colorimetric differences between the two visual targets, i.e., there are more larger ΔE values associated with the reduced patch size. But this effect did not repeat in the random targets with different patch sizes. In this case, there were no significant colorimetric errors caused by the reduced patch size. For all practical purposes, there is no penalty to use the random target at the 4mm reduced patch size.

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References

1. CGATS IT8.7/4, Graphic technology – Input Data for Characterization of 4-Color Process Printing – Expanded Data Set, 2005
5. CGATS, Recommended Industry Practice, Color characterization data set development — Analysis and reporting, 2006