Improvement of Color Matching Accuracy with an Inkjet Proofer

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Abstract

We have conducted an evaluation of the characteristics of inkjet printers that have lately attracted considerable attention as an output device of DDCP (Direct Digital Color Proofing). We confirmed that inkjet printers have a color gamut that covers almost all colors possible with a press, high repeatability, and uniformity. In particular, it was found that inkjet printers with pigment inks are more suitable for DDCP because of their high stabilities over time.

In general, however, there are many cases where the color matching accuracy is inadequate when using a commercial profiling tool for default settings. Although it is likely that different factors affect this issue, we concentrated on the accuracy of the BtoA1 table in a printer profile, the closeness to press in spectral characteristics, and the effect of fluorescent brighteners contained in papers. We have examined the issues related to these factors and found a method to achieve enough color matching accuracy for practical use.

Introduction

Printing processes have been more and more digitized in recent years. DDCP has come into wide use for proofing. Although different kinds of printing methods are used in output devices of DDCP, drop-on-demand inkjet printers, in particular, have being widely noticed owing to the recent remarkable improvements in their quality, speed and cost.

When using an inkjet printer as DDCP, a process of color conversion is required for matching its color reproduction to that of a printing press. In general, however, it is difficult to achieve high accurate color matching when using a commercial profiling tool for default settings. Consequently, there are many cases where profile editing is performed in order to improve the color matching accuracy. This is related not only to the problem of the lack of proper color matching technology understanding, but also different factors. Furthermore, profile editing tends to spoil the smoothness of tone due to selective color corrections and deteriorate overall accuracy due to color corrections with tone curves, therefore it does not necessarily produce good results.

Therefore, we have aimed to evaluate the limitation of color matching accuracy with inkjet printer and establish a profiling method that enables high accuracy in color matching without editing profiles. For this purpose we have evaluated the characteristics of inkjet printers and explored different factors that affect the color matching accuracy.

This paper discusses the issues and remedies related to the accuracy of the BtoA1 table in a printer profile, the closeness to press in spectral characteristics, and the effect of fluorescent brighteners contained in papers.

Characteristics of Inkjet Printers

We evaluated the characteristics of two types typical of inkjet printers: a pigment-based printer and a dye-based printer. We used BESTColor4.2J as a printer driver.

Color Gamut

BESTColor has the features to set the maximum density of each colorant and total ink limit. We evaluated the color gamuts of two printers after optimizing output conditions using these features. Figures 1 and 2 show a comparison of each printer's gamut with that of Japan Color2001, which indicates a typical sheet-fed offset printing press in Japan.

As shown in Figure 1, yellow ink and magenta ink of the pigment printer are not as red as those of a press. Therefore, although its gamut does not cover a slight portion of that of the press from yellow to red, it covers almost all of it.

As shown in Figure 2, yellow ink of the dye printer is much redder than that of a press. Therefore, the gamut from yellow to green is narrow, the solid green color of the press is badly out of the printer's gamut. The printer covers almost all other colors of that of the press.

We see from the above results that the color gamut of the pigment printer is superior to the dye printer.

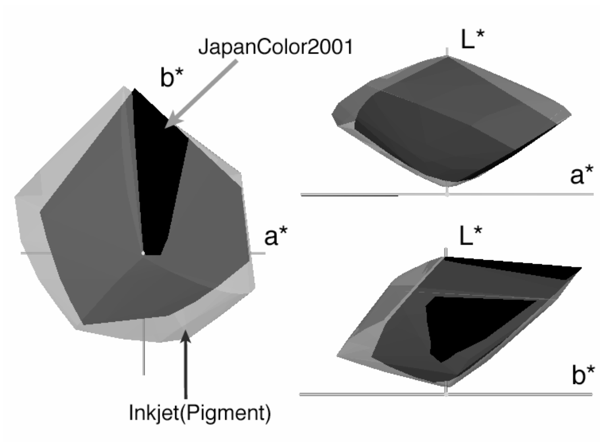

Figure 1. Color gamut of the pigment inkjet printer

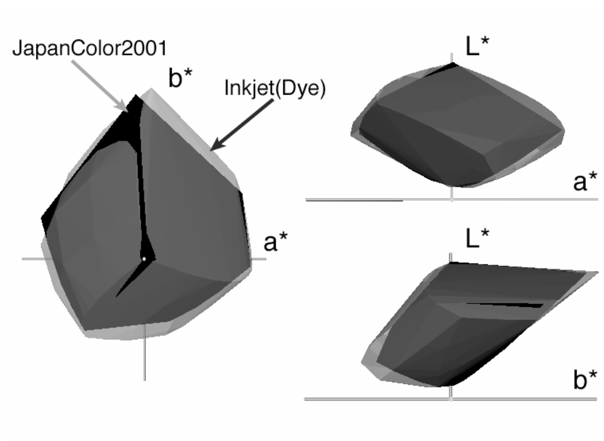

Figure 2. Color gamut of the dye inkjet printer

Repeatability

We printed a color chart five times every three hours, measured them, and calculated the average and maximum color differences using the following formulae. The color chart consists of eight steps (2%, 5%, 10%, 25%, 50%, 75%, 100%) of seven colors such as cyan, magenta, yellow, black, red, green, and blue. We conducted the same evaluations for a laser thermal transfer type DDCP and a silver halide photography type DDCP in order to compare results with high-end DDCPs.

As shown in Table 1, both printers have enough repeatability for practical use though they are inferior to the laser thermal transfer type, but superior to the silver halide photography type.

L^*_{ijk} , a^*_{ijk} , b^*_{ijk} : measured L*a*b* value of i-th step in j-th color of k-th chart

$$\overline{L^*_{ij}} = \frac{1}{5}\sum_{k=1}^{5} L^*_{ijk} \tag{1}$$

$$\overline{a^*_{ij}} = \frac{1}{5}\sum_{k=1}^{5} a^*_{ijk} \tag{2}$$

$$\overline{b^*_{ij}} = \frac{1}{5}\sum_{k=1}^{5} b^*_{ijk} \tag{3}$$

$$\Delta E_{ijk} = \sqrt{(\overline{L^*_{ij}} - L^*_{ijk})^2 + (\overline{a^*_{ij}} - a^*_{ijk})^2 + (\overline{b^*_{ij}} - b^*_{ijk})^2} \tag{4}$$

$$\Delta E_{ave} = \frac{1}{8 \cdot 7 \cdot 5}\sum_{i,j,k} \Delta E_{ijk} \tag{5}$$

$$\Delta E_{max} = \max_{i,j,k} \Delta E_{ijk} \tag{6}$$

Table 1. Repeatability

Device Type	Average ΔE	Max ΔE
Laser Thermal Transfer	0.30	1.12
Silver Halide Photography	0.68	2.46
Pigment-based Inkjet	0.51	3.14
Dye-based Inkjet	0.42	5.37

Uniformity

We printed a tint that consists of equal values of C, M, and Y and its L* value was around 70 in the whole print area, and measured L*a*b* values at four millimeters intervals in two directions of paper width and paper length. We evaluated the uniformity by calculating the color differences of the average L*a*b* values of the whole measurements in each direction and the measured L*a*b* value in each measurement point. Figure 3 shows the variation of color differences in paper width direction and Figure 4 shows that of paper length direction. We also conducted the same evaluations for the laser thermal transfer type DDCP and the silver halide photography type.

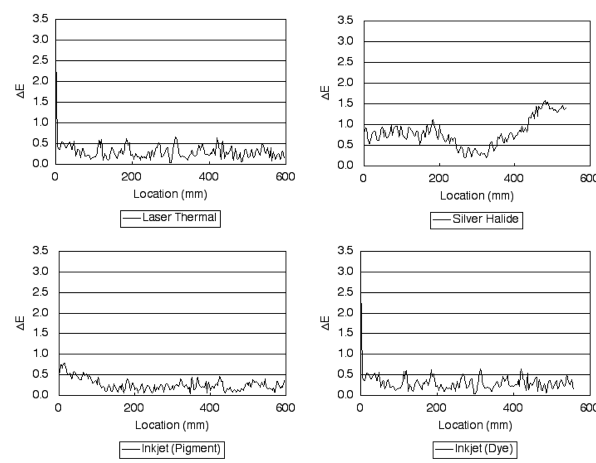

Figure 3. Uniformity in paper width direction

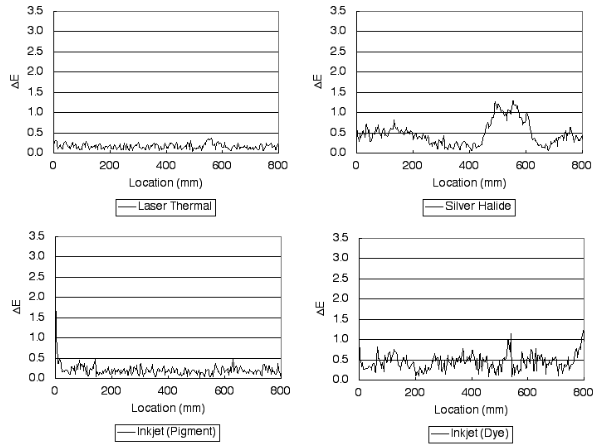

Figure 4. Uniformity in paper length direction

Inkjet printers are unstable when starting print, as shown in Figures 3 and 4. The pigment printer has a uniformity equivalent to a laser thermal transfer DDCP. On the other hand, the dye printer is inferior to the pigment printer, however, superior to the silver halide photography DDCP.

Color Drift over Time

We printed a color chart, which consists of nine steps (0%, 2%, 5%, 10%, 25%, 50%, 75%, 90%, 100%) of nine colors such as cyan, magenta, yellow, black, red, green, blue, 3-color gray and 4-color gray, and measured them at 30-minute intervals, just after printing. We evaluated the color drift over time by calculating color differences on the basis of the measured value obtained just after printing. We also conducted the same evaluations for the laser thermal transfer type DDCP and the silver halide photography type.

As shown in Figure 5, the color drift of the dye printer is extremely large and continues without settling. On the other hand, the color drift of the pigment printer is less than that of the silver halide photography DDCP, and almost stabilizes after around twelve hours from printing.

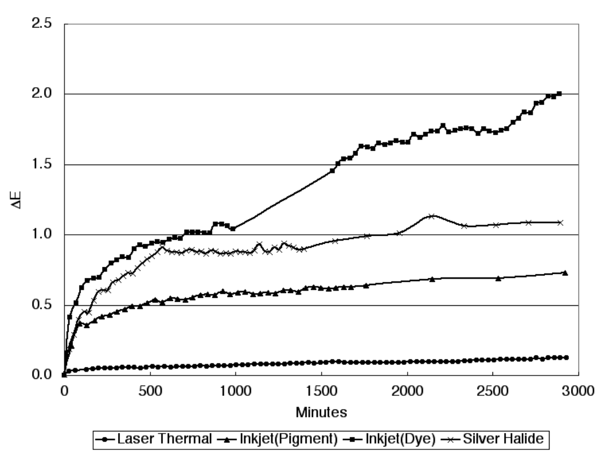

Figure 5. Color drift over time

We see from the above results that inkjet printers are inferior to the laser thermal transfer DDCP, but superior to the silver halide photography DDCP regarding the stability. Therefore, inkjet printers are suitable for the output device of DDCP.

Color Matching Accuracy under a Default Condition

We examined the color matching accuracy using a commercial profiling tool for default settings. We used GretagMacbeth's ProfileMaker Pro 3.1.5 as a profiling tool and made a printer profile according to the following settings.

Our final target of color matching is the color reproduction produced by a press. However, the uniformity of a press is worse than that of a DDCP, therefore color matching accuracy is affected. For this reason we created a color matching target using the laser thermal transfer DDCP, which is the closest to the color reproduction of the press and highly stable.

The settings of ProfileMaker Pro 3.1.5 when building printer profiles:

Profiling Target: IT8.7/3 chart
Profile Size: Default
Black Start: 40%
Black Max: 100%
CMYK Max: 400%
Separation: GCR3

The above settings are a default condition for inkjet printers.

Table 2 shows the color matching accuracy of each printer for the IT8 target. Both color differences were over 2 and confirmed that even visual appearance lacked accuracy, for example, more vivid reproduction and yellowish gray. That is, we could not achieve a color matching accuracy suitable for practical use.

Table 2. Color Matching Accuracy under a Default Condition

Printer	Average ΔE	Max ΔE
Pigment-based Inkjet	2.08	15.42
Dye-based Inkjet	2.83	9.28

Improvement of Color Matching Accuracy

We see from the above evaluations of the gamut, the color drift over time, and the color matching accuracy that the pigment printer is more suitable for DDCP than the dye printer. However, even in the case of the pigment printer, we could not achieve an accurate color matching suitable for practical use. Therefore, we have addressed the improvement of the color matching accuracy.

To reduce the effect of printer's drift to a minimum and to confirm the effects of each remedies precisely, we evaluated the color matching accuracy under a default condition by experiment whenever we examined the effects of each remedy.

Improvement of Accuracy of the BtoA1Table

In case of colorimetric rendering, color conversion is determined by the AtoB1 table in a press profile set as a source profile, the BtoA1 table in a printer profile set as a destination profile, and a color conversion engine. Therefore enhancement of the accuracy of a printer profile means enhancement of the accuracy of the BtoA1 table.

The BtoA1 table describes CMYK values corresponding to L*a*b grid points. Therefore, all CMYK values are basically calculated by interpolation from the measured values of a profiling target, thus in general, increase of the number of color patches results in reduction of the error of interpolation and improvement of the accuracy of the BtoA1 table. However, since increasing the number of patches causes an increase in measurement load, it is important to add patches which effectively contribute to the improvement of accuracy. We have invented a 2-step profile building method for this purpose.

Figure 6 shows the algorithm. Firstly, an initial profile is built from the measurements of the IT8 target. Secondly, the BtoA1 table is extracted from the profile. In this case it is necessary to extract only in-gamut data because the BtoA1 table also includes out-of-gamut data. Then a color chart, which consists of CMYK values extracted from the BtoA1 table, is created. We call this BtoA1 chart. Then the BtoA1 chart is printed and measured. Finally, a second profile is built from the measurements of the IT8 target and the BtoA1 chart.

The aim of this algorithm is to improve the accuracy of interpolation when calculating the BtoA1 table by adding the measured values close to L*a*b* grid points.

We have verified the effectiveness of this algorithm using ProfileMaker Pro's feature, which enables users to build profiles from any user-defined target.

Firstly, we made a BtoA1 chart that consists of 1,222 patches according to this algorithm. Then we evaluated the accuracy of the BtoA1 table by comparing the L*a*b* values of the grid points with the measured values of the printed BtoA1 chart.

By adding the BtoA1 chart, the accuracy of the BtoA1 table was improved as Table 3 shows.

Then we examined how the improvement of the accuracy of the BtoA1 table affects the color matching accuracy. We printed test images and the IT8 target using the built printer profile and evaluated the color matching accuracy.

As shown in Table 4, the color matching accuracy was definitely improved by adding the BtoA1 chart. We also confirmed that the color matching accuracy was visually improved.

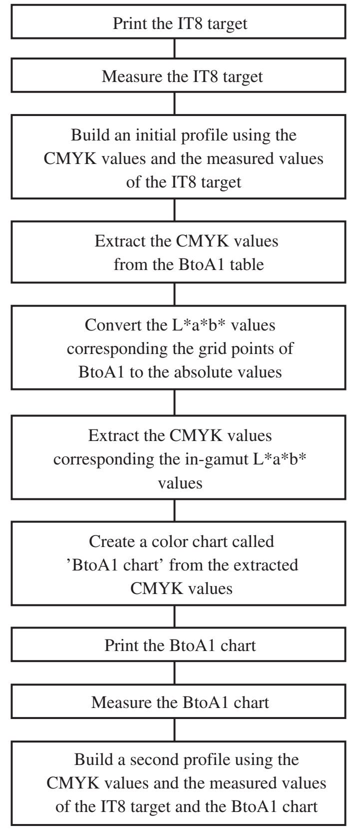

Figure 6. The algorithm of a 2-step profile building method

Table 3. Improvement of the BtoA1 Table

Profiling Target	Average ΔE
IT8	2.98
IT8+B2A1	2.29

Table 4. Effectiveness of the BtoA1 Chart

Profiling Target	Average ΔE
IT8	2.62
IT8+B2A1	1.65
Effectiveness	0.97

Optimization of Black Generation

Although the ICC color management is based on the principle of metamerism, it is more desirable to also match the spectral characteristics as closely as possible. The setting of black generation in a profiling tool causes the CMYK values to change, which therefore also affects the closeness to press in spectral characteristics.

In the color matching under a default condition, we confirmed that gray was reproduced with yellowishness. Therefore, we measured the L*a*b* values and the spectral reflectances of a gray area, which consists of C40%, M40%, Y40%, K10%, in the printed matter of the laser thermal transfer DDCP and the pigment printer. The color matching accuracy of both was 1.53, which is below the average color difference in the IT8 target. Figure 7 shows both spectral reflectances of the gray. As shown in Figure 7, the spectral curve of the pigment printer's gray has a peak around 500nm and widely differs from that of the laser thermal transfer DDCP.

Therefore, we changed the settings of black generation in ProfileMaker Pro and sought a condition in which both spectral curves of gray are close. As it turned out, we found that both spectral curves are closest when maximizing the setting of black generation. Figure 8 shows both spectral reflectances of gray in the case of maximizing the setting of black generation. Furthermore, the color matching accuracy of the gray in this case was 0.86, therefore improved regarding the L*a*b* color difference.

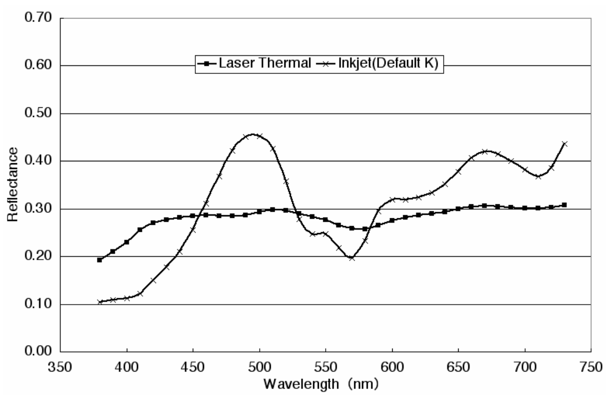

Figure 7. Spectral curve in gray (default K)

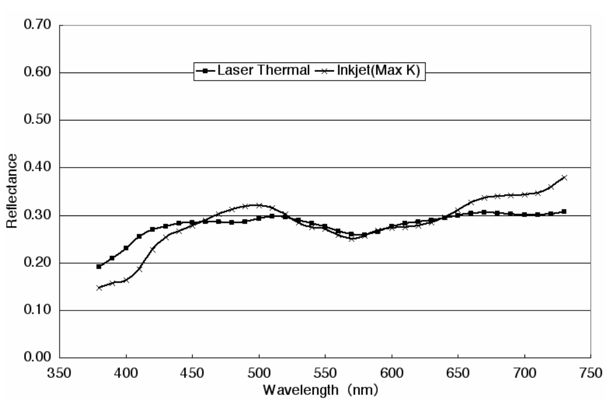

Figure 8. Spectral curve in gray (max K)

We printed test images and the IT8 target using the built printer profile and evaluated the color matching accuracy. In visual evaluation, the yellowish gray was definitely improved and the color matching accuracy was also improved as a whole. As shown in Table 5, the color matching accuracy was also improved in numerical evaluation by maximizing the setting of black generation.

Table 5. Effectiveness of Optimization of Black Generation

Black Generation	Average ΔE
Default	2.08
Maximum	1.58
Effectiveness	0.50

Use of the UV Filter

In general, papers for inkjet printers contain fluorescent brighteners. Therefore, ultraviolet light contained in a light source affects the measurements when measuring a profiling target. Figure 9 shows the characteristic of fluorescence of the inkjet paper used in our experiments in three dimensions. Figure 10 shows that of the press paper. We see from Figures 9 and 10 that the inkjet paper is more affected by ultraviolet light than the press paper.

Table 6. Effectiveness of the Use of the UV Filter

Filter	Average ΔE
No	2.97
UV filter	2.44
Effectiveness	0.53

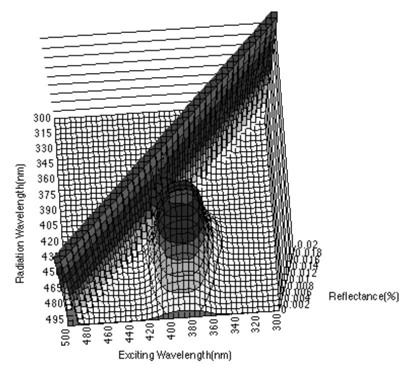

Figure 9. Characteristic of fluorescence of the inkjet paper

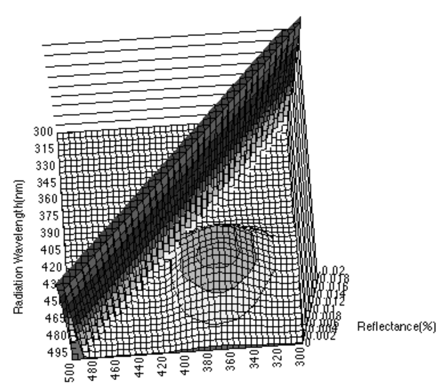

Figure 10. Characteristic of fluorescence of the press paper

The characteristic of fluorescence varies according to the strength of energy of ultraviolet light radiated. Therefore, it is necessary to eliminate the effects of ultraviolet lights when measuring and viewing when considering inkjet paper with greater fluorescent brightener. That is to say we presuppose the use of the UV filter and UV-cut fluorescent lamps.

To examine the effect of the UV filter, we conducted a color matching experiment attaching the UV filter to GretagMacbeth's SpectroScan. We printed test images and the IT8 target using the built printer profile and evaluated the color matching accuracy. Table 6 shows the color matching results. As shown in Table 6, the use of the UV filter caused a great deal of improvement of the color matching accuracy in numerical evaluation. As for visual evaluation, however, the improvement was imperceptible.

Effectiveness of the Combination

We confirmed from the above experiments that three remedies for the improvement of the color matching accuracy were all effective. Since it is likely that three remedies are basically not connected with each other, we examined the color matching accuracy in case of combining three remedies. We printed test images and the IT8 target using the built printer profile and evaluated the color matching accuracy. Table 7 shows the color matching results. As shown in Table 7, the color matching accuracy was greatly improved in numerical evaluation. In addition we obtained enough accuracy for practical use and visual evaluation.

Table 7. Effectiveness of the Combination

Condition	Average ΔE
General	2.48
Combinational	1.29
Effectiveness	1.19

Conclusion

We have evaluated the characteristics of inkjet printers as DDCP. Both the pigment printer and the dye printer indicated high repeatability and uniformity. Results related to the color drift over time, however, showed that the pigment printer was more stable than the dye printer and therefore, the pigment printer is more suitable for DDCP.

It was observed that the color matching accuracy was inadequate when using a commercial profiling tool for default settings, however, we have resolved this concern by applying three remedies: improving the BtoA1 table by using the BtoA1 chart, maximizing the amount of black, and using UV filters.

While we have obtained satisfactory results in color matching, the increase of the amount of black results in an increase in graininess. Furthermore, maximizing black generation caused the spectral characteristics of gray to become approximate, however, this is not necessarily applicable to other colors. Optimal black generation calls for further study.

References

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Biographies

Tsutomu Nakagawa received the B.E and M.E. degrees from Keio University (Japan) in 1983, 1985 respectively. Then he has worked as an engineer at Dai Nippon Printing Co., Ltd. He has developed digital proofing systems and researched algorithms of image processing and press process. He is a member of the Japanese Society of Printing Science and Technology.

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Shinya Kitaoka received a B.E. degree from Ehime University (Japan) in 2001. He is an engineer of Manufacturing Technology Integration Laboratory in Dai Nippon Printing Co., Ltd. Now he is researching a method of evaluation for DDCP.