Color Matching Capability of Digital Printers

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Abstract

In the printing process, color proofing is done for the purpose of checking the color to ensure that it is as desired, before proceeding to the plate-making process. Proofing with digital printers has grown remarkably, because of its advantages of high speed, wide color gamut, and affordable prices for a device. The accuracy of proof-press color matching is affected by the printer, software and substrate involved in digital proofing processes. Therefore, the combination of the right equipment, software and print media is the key to obtaining good proof-press color matching. The main purpose of this experimental study is to examine the color matching capability of digital printers. The color matching capability was evaluated in terms of color difference and process consistency.

Introduction

Color-proofing has experienced enormous technological changes over the past few years. Traditional imaging businesses such as printers, service bureaus, and in-plant operations are struggling to determine which color-proofing solution will best meet their digital imaging requirements. Digital proofing is produced directly from digital data by printing on color thermal transfer, inkjet, or electrophotographic printers. At present, the most dominant digital proofing technology is inkjet printing, representing more than 60% of the market on a worldwide basis, and it is still growing [1]. Inkjet printers have the capability to print high-quality fine art black-and-white and color images on a variety of substrates. Furthermore, inkjet printers, combined with advanced color-matching software, can offer a better color match.

The accuracy of proof-press color matching is affected by the printer, software and substrate involved in the digital proofing processes. Different types of printers utilize different ink technologies, which affect the print result. Print media is a significant variable in predicting and reproducing color. The interaction between paper and ink, its porosity, roughness, coating structure, together with paper properties such as whiteness, light scattering, and gloss must be considered in the digital proofing process [2-4]. Generally, proofing is done using the substrate that will be used for actual product printing. Proofing on the actual production stock more closely predicts print outcome. However, working with different inks and devices, the same actual production printing substrate can have a very different color gamut and behave differently in the digital proofing process, which in turn affects the proof-press color matching result. Indeed, digital proofing on the actual production printing substrates does not reproduce well the colors from the printing press [5]. Good proof-press color matching also needs the aid of color management, which integrates with an effective raster image processor (RIP) configuration and profiling techniques and relies on profiles to do the conversion work [6-8].

When the printing workflow enters the digital era, a suitable and reliable digital color-proofing solution should be investigated to meet the needs of color printing. The main purpose of this study is to examine the color matching capability of digital printers. The color matching capability was evaluated in terms of color difference (ΔE^*_{2000}) and process consistency. The former is a valuable tool to determine color accuracy in the proofing systems and does a better job to determine a ΔE that more accurately reflects how the eye sees color, compared to the ΔE^*_{ab} method [6, 9]. The latter uses statistical techniques to measure and analyze the variation in processes and provides a process capability ratio to identify how capable a process is of meeting specifications.

Experimental

Three gravure publication printing substrates- free sheet coated paper (FS), light weight coated paper (LWC), and newsprint (News)- were selected as the color matching targets. These papers were printed on a four-color rotogravure web press Model 118 from Cerutti Group (Italy), located at the Western Michigan University (WMU) Printing Pilot Plant. Thirty samples of each substrates were collected and measured with an X-Rite DTP70 spectrophotometer, and the average L*a*b* value was computed as original data.

Three types of manufacturer recommended proofing papers- Semimatte Photo Paper (PSPP), Pearl Proof Paper (Pearl), and Selected Proof Paper (Selected) were tested and compared. **Table 1** provides basic paper properties of selected proofing paper used in this study. Semimatte Photo Paper tends to have a smoother and more uniform surface. Selected Proof Paper has smaller average pore size and porosity, compared to other proofing papers. For the three proofing papers, Semimatte Photo Paper and Selected Proof Paper contain optical whitener. The highest CIE whiteness was found in Semimatte Photo Paper with whiteness of 105.93, followed by Selected Proof Paper (97.3), and Pearl Proof Paper (88.86). The opacity readings for all tested proof papers are in the range of 90% to 97%. Pearl Proof Paper has highest paper gloss of 63.13%, while Semimatte Photo Paper has lowest paper gloss of 47.46%.

Table 1. Paper properties of selected proofing paper

Paper Properties	Semimatte Photo Paper	Pearl Proof Paper	Selected Proof Paper
Roughness, µm	1.06	0.78	1.13
Formation Index	318.33	212.06	259.31
Ave. pore diameter, nm	47.40	36.1	28.60
Porosity, %	36.66	37.25	26.39
TAPPI Brightness, %	95.73	95.73	92.98
CIE Whiteness	105.93	88.86	97.30
TAPPI Opacity, %	96.68	94.55	90.05
Paper Gloss at 75°, %	47.46	63.13	56.96

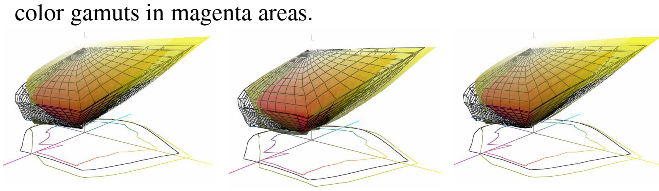
Two commercially available inkjet digital printers, an Epson Stylus Pro 4000 printer with UltraChrome pigmented inks and an Epson Stylus Pro 9800 printer with UltraChrome K3 inks, were combined with the commercially available GMG ColorProof RIP and tested for selected proofing substrates. ICC profiles were generated for the digital printers by using MonacoPROFILER 4.8. The device was profiled as a CMYK device. The ECI2002R CMYK test target designed for DTP 70 spectrophotometer was employed for this study. The target L*a*b* values generated from the gravure publication printing substrates were loaded into the RIP's color matching function. The GMG ColorProof RIP then performs proof-press color matching by controlling CMYK ink amounts to match L*a*b* values between digital printer (proof) and target (press). Once the good color matching result was achieved (the smallest average ΔE value of color patches of ECI2002R chart was obtained), 15 ECI2002R charts were printed out for each tested print combination. Those charts were measured with DTP 70 spectrophotometer and the color difference (ΔE^*_{2000}) values between proof and press were recorded and collected to examine the color matching capability and process consistency.

Results and Discussion

In this study, six digital proofing systems (print combinations) were tested to match gravure publication printing. The color-matching paper targets included free sheet (FS), light weight coated (LWC), and newsprint (News). The color gamut, color matching capability and process consistency of digital proofing systems for gravure publication substrates were tested and compared. The color gamuts of print combinations were compared using ColorThink Pro 3.0 software, while color differences (ΔE^*_{2000}) were determined by using GretagMacbeth MeasureTool (now X-Rite) software. Minitab 14, a statistical software package, was used for process consistency analyses.

Gamut Comparison

Before performing proof-press color matching, the color gamut of print combination of digital proofing systems must be well defined. **Figure 1** to **Figure 3** illustrate the proof-press color gamut comparison for the Free Sheet, Light Weight Coated paper, and newsprint, respectively. As expected, the color gamuts of proofing papers were wider than those of gravure publication substrates that was printed via the Cerutti rotogravure web press. It also shows that proofing papers printed via the Epson Stylus Pro 9800 printer (yellow color) tend to yield wider color gamuts in yellow and red regions. Printing via Epson Stylus Pro 4000 printer (black wireframe), however, these proofing papers have wider color gamuts in magenta areas.

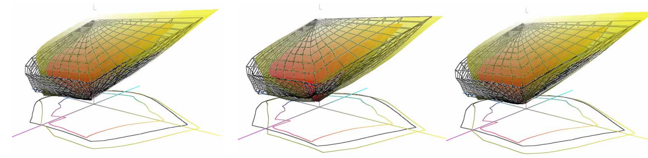


(a) Free sheet (press, true color) vs. Pearl proof paper (EP4000: black wireframe; EP9800: yellow)

(b) Free sheet (press, true color) vs. Semimatte photo paper (EP4000: black wireframe; EP9800: yellow)

(c) Free sheet (press, true color) vs. Selected proof paper (EP4000: black wireframe; EP9800: yellow)

Figure 1. Proof-press color gamut comparison for the Free Sheet paper.

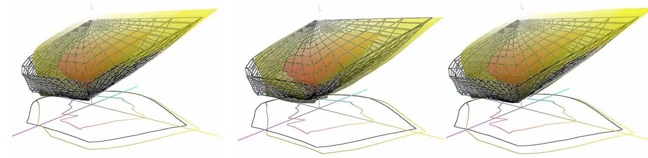


(a) LWC (press, true color) vs. Pearl proof paper (EP4000: black wireframe; EP9800: yellow)

(b) LWC (press, true color) vs. Semimatte photo paper (EP4000: black wireframe; EP9800: yellow)

(c) LWC (press, true color) vs. Selected proof paper (EP4000: black wireframe; EP9800: yellow)

Figure 2. Proof-press color gamut comparison for the LWC paper.



(a) Newspaper (press, true color) vs. Pearl proof paper (EP4000: black wireframe; EP9800: yellow)

(b) Newspaper (press, true color) vs. Semimatte photo paper (EP4000: black wireframe; EP9800: yellow)

(c) Newspaper (press, true color) vs. Selected proof paper (EP4000: black wireframe; EP9800: yellow)

Figure 3. Proof-press color gamut comparison for the Newspaper.

Table 2 displays gamut volumes comparison for printing and proofing papers. The color gamut of proofing paper is larger than that of the gravure publication substrates in terms of gamut volume. It shows that the gamut volume of Epson Stylus Pro 9800 printer is larger than that of Epson Stylus Pro 4000 printer. Printing via the Epson Stylus Pro 4000 printer, the color gamut of three proofing papers are similar to each other. The gamut volumes are in the range of 615,000 to 631,000. Printing via the Epson Stylus Pro 9800 printer, semimatte photo paper has a larger color gamut, compared to other two proofing papers. The gamut volumes are in the range of 650,000 to 710,000.

Table 2. Gamut volumes comparison for printing and proofing papers

Printing paper (Cerutti Rotogravure Web Press)		
Free Sheet	331,854	
Light Weight Coated	317,645	
Newsprint	149,459	
Proofing Paper	Epson 4000	Epson 9800
Pearl Proof Paper	630,203	657,396
Semimatte Photo Paper	616,790	702,352
Selected Proof Paper	630,282	685,689

Proof-Press Color Matching Capability

The quality of proof-press color matching was evaluated in terms of the color difference (ΔE_{2000}). The proof-press color matching results for the Free Sheet are listed in **Table 3**. As shown in **Table 3**, the smallest average ΔE_{2000} value was found in the Epson Stylus Pro 4000 printer/Selected Proof Paper combination with ΔE_{2000} value of 0.79. Compared to other print combinations, the Epson Stylus Pro 9800 printer/Semimatte Photo combination tends to have a larger ΔE_{2000} value and a larger standard deviation. The calculated differences in paper white for target (press) and proof $L^*a^*b^*$ values are in the range of 4.0-4.6. In other words, six print combinations didn't have very good paper white simulation ability to match paper white. The maximum ΔE_{2000} values of six print combinations are in the range of 5.1-13.1, while the minimum ΔE_{2000} values are in the range of 0.01-0.05.

Table 3. Proof-press color matching results for Free Sheet (FS)

Print Combination	Ave. ΔE	Std	Paper white	Std	Max. ΔE	Min. ΔE
EP4000/Pearl	0.84	0.01	4.18	0.14	5.55	0.05
EP4000/PSPP	0.99	0.04	4.10	0.08	13.02	0.04
EP4000/Selected	0.79	0.02	4.03	0.09	6.03	0.04
EP9800/Pearl	0.80	0.01	4.53	0.11	5.75	0.01
EP9800/PSPP	1.01	0.05	4.39	0.13	7.92	0.02
EP9800/Selected	0.84	0.01	4.16	0.27	5.10	0.04

Table 4 displays the proof-press color matching results for the Light Weight Coated paper. Print combinations of Epson Stylus Pro 4000 printer/Selected Proof Paper and Epson Stylus Pro 9800 printer/Pearl Proof Paper have smaller average ΔE_{2000} values. Compared to other print combinations, the Epson Stylus Pro 4000 printer/Semimatte Photo combination tends to have a larger ΔE_{2000} value and a larger standard deviation value. Among six print combinations, Epson Stylus Pro 4000 printer/Selected Proof Paper has better paper white simulation ability in terms of lower paper white color difference between proof and press. The maximum ΔE_{2000} values of six print combinations are in the range of 3.6-14.0, while the minimum ΔE_{2000} values are in the range of 0.02-0.07.

Table 4. Proof-press color matching results for Light Weight Coated (LWC)

Print Combination	Ave. ΔE	Std	Paper white	Std	Max. ΔE	Min. ΔE
EP4000/Pearl	0.79	0.05	2.59	0.11	3.66	0.07
EP4000/PSPP	0.94	0.01	1.97	0.04	13.91	0.04
EP4000/Selected	0.71	0.03	1.71	0.16	8.22	0.03
EP9800/Pearl	0.71	0.01	3.58	0.09	6.09	0.04
EP9800/PSPP	0.85	0.05	2.51	0.15	10.94	0.02
EP9800/Selected	0.77	0.02	2.26	0.11	4.97	0.04

The proof-press color matching results for the Newsprint is exhibited in **Table 5**. Print combinations of the Epson Stylus Pro 4000 printer/Semimatte Photo Paper and the Epson Stylus Pro 9800 printer/ Semimatte Photo Paper have smaller average ΔE_{2000} values, while the print combinations of Epson Stylus Pro 4000 printer/Pearl Proof Paper and Epson Stylus Pro 9800 printer/Selected Proof Paper have larger average ΔE_{2000} values. Among six print combinations, Epson Stylus Pro 4000 printer/Semimatte Photo Paper has better paper white simulation ability in terms of lower paper white color difference between proof and press. The maximum ΔE_{2000} values of six print combinations are in the range of 3.0-11.0, while the minimum ΔE_{2000} values are in the range of 0.02-0.04.

Table 5. Proof-press color matching results for Newsprint

Print Combination	Ave ΔE	Std	Paper white	Std	Max. ΔE	Min. ΔE
EP4000/Pearl	0.74	0.07	2.91	0.21	3.21	0.03
EP4000/PSPP	0.64	0.01	2.52	0.09	8.33	0.03
EP4000/Selected	0.66	0.06	2.17	0.08	2.97	0.02
EP9800/Pearl	0.65	0.03	5.50	0.10	10.88	0.03
EP9800/PSPP	0.64	0.03	2.90	0.13	5.23	0.04
EP9800/Selected	0.74	0.03	3.09	0.12	6.28	0.04

Figure 4 summaries the proof-press color matching results (average ΔE_{2000}) for gravure publication printing substrates. As shown in **Figure 4**, print combinations of Epson Stylus Pro 4000 printer/Selected Proof Paper (blue-triangle dot) and Epson Stylus Pro 9800 printer/Pearl Proof Paper (cyan-square dot) have smaller average ΔE_{2000} values for Free Sheet, Light Weight Coated, and Newsprint. The Epson Stylus Pro 4000 printer/Semimatte Photo Paper (green-circle dot) yielded smallest ΔE_{2000} value for Newsprint. Among three gravure publication substrates, Free Sheet is the hardest substrate to match, while Newsprint is the easiest one to match. Overall, with the aid of color management software, the average ΔE_{2000} values are all controlled less than 1.0.

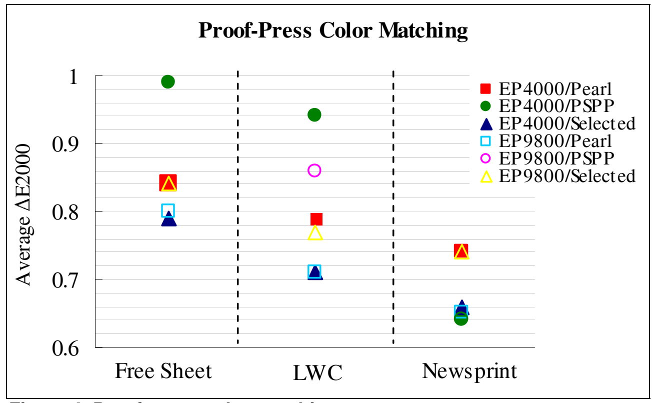


Figure 4. Proof-press color matching

It is well known that color appearance will be affected by the surrounding colors, especially when it comes to proof-press color matching. The paper color of Light Weight Coated and newsprint is yellowish, while paper color of the Free Sheet is bluish. Proofing papers, on the other hand, tend to have bluish paper white. The smaller the ΔE in paper white, the less influence by the paper color and better match to the reference press sheet by visual assessment. **Figure 5** shows that print combinations of Epson Stylus Pro 4000 printer/Selected Proof Paper (blue-triangle dot) has the smallest paper white ΔE values, while Epson Stylus Pro 9800 printer/Pearl Proof Paper (cyan-square dot) print combination has the largest paper white ΔE values for all gravure publication printing substrates. That is, the Epson Stylus Pro 4000 printer/Selected Proof Paper combination has better paper white simulation ability. Among three gravure publication substrates, Free Sheet is the hardest substrate to match, while Light Weight Coated paper is the easier one to match. The paper white ΔE values vary from 1.6 to 5.6.

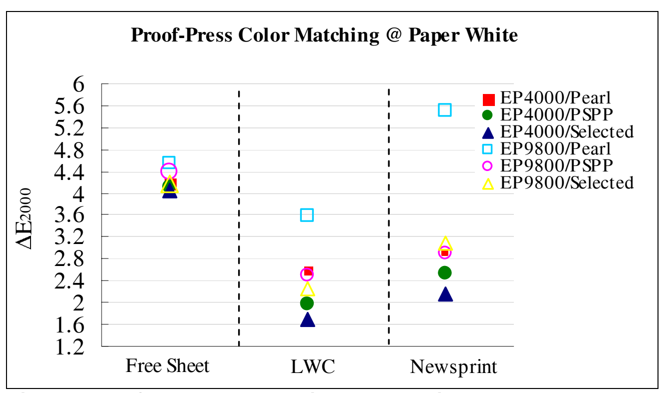


Figure 5. Proof-press color matching- Paper White

Process Capability Analyses

For the proof-press color matching, the repeatability and consistency of proofing systems need to be concerned. The color matching process consistency and capability of the digital printers are discussed. Individual Control Chart (I Chart) and Capability Analyses were used to analyze the consistency. Process capability ratio (PCR or Cp index) is the simplest indicator of process capability, which is defined as the ratio of the specification range to the process range. Cp ratio can be expressed as "(upper specification limit - lower specification limit)/(6*Sigma)." In other words, this ratio expresses the proportion of the range of the normal curve that falls within the specification limits. The higher the Cp index, the more capable or more consistency the process is.

In this study, the relative PCR were compared between different print combinations due to the lack of historical parameters of lower specification limit (LSL) and upper specification limit (USL) for the color differences. After eliminating all out-of-control points, the final LSL and USL (as shown in **Table 6**) are obtained by subtracting from and adding to the average 3*Sigma for each print combination (the average Sigma was computed from the Sigmas of six print combinations).

Table 6. The LSL_{final} and USL_{final} of each print combination

Print Combination	Free Sheet		LWC		Newsprint	
	LSL	USL	LSL	USL	LSL	USL
EP4000/Pearl	0.82	0.87	0.78	0.82	0.75	0.82
EP4000/PSPP	0.94	1.00	0.92	0.96	0.60	0.67
EP4000/Selected	0.76	0.81	0.68	0.72	0.60	0.66
EP9800/Pearl	0.77	0.82	0.69	0.73	0.62	0.69
EP9800/PSPP	0.99	1.04	0.80	0.84	0.56	0.66
EP9800/Selected	0.81	0.86	0.74	0.78	0.70	0.76

The capability analyses of color matching for the print combinations are exhibited in **Table 7** and **Figure 6**. For the Free Sheet, as shown in **Table 7** and **Figure 6**, the pearl proof paper printed via the Epson Stylus Pro 9800 has the largest relative PCR (Cp = 3.46), that is, the pearl proof paper printed via the Epson Stylus Pro 9800 printer was the most capable print combination of producing consistent ΔE value among the six in terms of relative PCR. The relative PCR for all print combinations are over 1.00, with the exception of the Epson Stylus Pro 9800 printer/Semimatte Photo Paper (PSPP) combination. For the Light Weight Coated paper (LWC), the Selected Proof Paper printed via the Epson Stylus Pro 4000 printer has the largest relative PCR (Cp = 2.52), followed by the Epson Stylus Pro 9800 printer/Selected Proof Paper (Cp = 1.89), and Epson Stylus Pro 4000 printer/Pearl Proof Paper (Cp = 1.13). For the Newsprint, the largest relative PCR was found in Epson Stylus Pro 9800 printer/Semimatte Photo Paper (Cp = 2.13). The relative PCR for all print combinations are over 1.00, with exception of Epson Stylus Pro 4000 printer/Selected Proof Paper combination.

Table 7. Color matching process capability analyses

Print Combination	Free Sheet	LWC	Newsprint
EP4000/Pearl	1.75	1.13	1.02
EP4000/PSPP	1.18	0.96	1.83
EP4000/Selected	1.35	2.52	0.44
EP9800/Pearl	3.46	0.76	1.36
EP9800/PSPP	0.38	0.43	2.13
EP9800/Selected	1.11	1.89	1.03

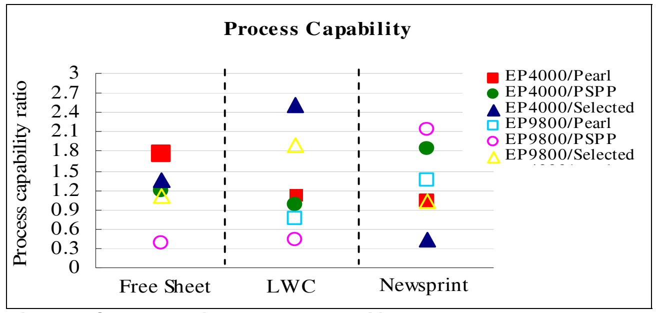


Figure 6. Color matching process capability

Conclusions

Generally, the color gamuts of the digital proofing systems are wider than for gravure publication printing. Therefore, the color space can be defined in software at RIPing stage to optimize the end result, helping ensure consistency from the proof to the final output. With the aid of color management software, the averageΔE_{2000} values of proof-press color matching are controlled less than 1.0. For the Free Sheet, print combinations of Epson Stylus Pro 4000 printer/Selected Proof Paper and Epson Stylus Pro 9800 printer/Pearl Proof Paper provide better proof-press color matching in terms of lower ΔE_{2000} values and a more stable reproduction process. The Epson Stylus Pro 4000 printer with Selected Proof Paper was the best match to the Light Weight Coated Paper (reference press sheet), but its process stability is not ideal. The Epson Stylus Pro 4000 printer/Semimatte Photo Paper and Epson Stylus Pro 9800 printer/Semimatte Photo Paper combinations, on the other hand, produce better proof-press color matching result for Newsprint in terms of lower ΔE_{2000} values, lower paper white ΔE values, and more stable reproduction processes. The Free Sheet is the hardest substrate to match, compared to other gravure publication printing substrates.

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