Spot Color Matching for Digital Package Prototyping Using UV Ink-jet Printer

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Abstract

Digital printing technology is dramatically changing the packaging/prototyping market. Packaging work is among the most color critical in the industry. Matching corporate and brand colors is essential, as is the ability to accurately reproduce spot colors. The main purposes of this experimental study are to (1) examine the quality of spot color reproduction using UV wide-format inkjet printer for digital package prototyping, and (2) establish printing workflows for digital package production. In order to examine the spot color matching capability and establish a digital printing workflow for digital package prototyping, sets of test samples were prepared. Spot colors from the Pantone color guide were used to design the spot color test chart for this study. CIE $L^*a^*b^*$ *values of Pantone color swatches were used as target values. Adobe Photoshop CC 2014 was employed to generate the spot color test chart in digital form. The designed test target was printed on different grade of paperboards and corrugated board on an EFI Vutek PV 200 UV inkjet printer. Color management with ICC profiles was used to investigate the reproduction of specific spot colors. These profiles were used to compare the device gamut and to investigate reproduction of specific spot colors. The quality of spot color matching was evaluated in terms of the* ΔE_{2000} *in CIE L*a*b* color space.*

Introduction

The rapid innovation trends in digital printing in terms of cost-effective productivity and remarkable quality impacts the continuous growing market over offset printing, which set to reach to $187.7 billion by 2018[1].

In terms of Packaging industry, digital printing technology has been employed in different long and short-run applications. For instance, "Share a Coke With." Coca Cola's Campaign that started in 2013 used variable data printing technology and HP Indigo digital press to personalize their 378ml and 500ml bottles and produced more than 750 millions packs[2]. While some Screen-printing companies turn to inkjet for their economical short-run projects[3].

In addition, the innovations of packaging design and proofing solutions by many leading companies such as Esko-Graphics along with the continuous technology shifts for inkjet and electrophotography allows many packaging companies to be more open to employ digital printing to produce package proofs and prototypes, which increases customer engagements with the designed products[4, 5].

However, despite the continuous market growing for both inkjet and electrophotography technologies, Experts anticipated increasing adaptation of inkjet technology over electrophotography. This adaptation was driven by the fact that many companies are turning to high-speed color inkjet due to high-quality printing matching with laser printing and for their flexibility of using roughly any substrates and ink sets with reasonable prices to produce various applications, which fit the demands of many printing and packaging companies with different sizes[6, 7]. And thus, experts anticipated that the use of inkjet in packaging would keep growing by 15.9% from 2014 to 2019[3].

Moreover, the environmental impact of inkjet technology was another major reason behind these fast emergent rates, especially with the introduction of the UV LED inkjet printing technology. The UV inks that are use in this technology have rabid cure rates using UV light, they do not dry and their opacity can be very transparent[8]. This technology becomes the interest of many researchers[9-11] and packaging companies as the UV-curable ink can be printed on almost any materials such as plastic, wood and glass and are suitable to use under high-speed production rates.

In general, one of the major challenges that Packaging industries are facing is accurately reproducing spot colors of a product. This is essential as a brand's colors not only identify the product but also has its major effect on consumers' interaction with it. Spot colors should be the identical during all production process phases. It also essential to control the cost of using spot colors which could be added to the packaging products[12].

The employment of digital printing in packaging permits achieving high-quality color matching proofs and prototypes on virtually any substrate with substantial cost and time saving. In conjunction with digital printers, third-party Raster Image Processors (RIP) is typically used to convert digital vector image files into a raster or bitmap files that a printer can understand. Most RIP software control colors through ICC workflow system with additional enhancing tools that can be added to for accurate interpreting extend gamut colors. It also supports Pantone library for better reproduction results when converting spot colors to matching CMYK inks[13].

Typically, the selection of the printing media, output device and color control or matching software will significantly affect the reproduction results. Considering the fact that interests are increasing on using UV wide-format inkjet printers in Packaging industry due to their high quality proofing and prototyping results on many substrates, this research is conducted to investigate the spot color reproduction quality of UV inkjet printer for digital packaging prototype. A digital printing workflow for digital packaging production was established.

Experimental

In order to examine the spot color matching capability and establish a printing workflow for UV inkjet digital package prototyping, sets of test samples were prepared.

Equipment and Materials

An EFI Vutek PV 200 UV inkjet printer with UV-curable inks was employed in this study. This printer uses UV-A spectrum. Printing process was controlled by using the EFI Fiery XF RIP. Five commercially available paperboard and corrugated board were tested, which included 12-pt, 18-pt, 30-pt of solid bleached sulfate (SBS) paperboards, 18-point coated recycled board (CRB), and B-flute corrugated board. The colorimetric values of tested paperboards and corrugated board are illustrated in Figure 1. Tested paperboards and corrugated board have natural shades of paper white, with the exception of 12-pt SBS paperboard, which contains optical brightener agent (OBA).

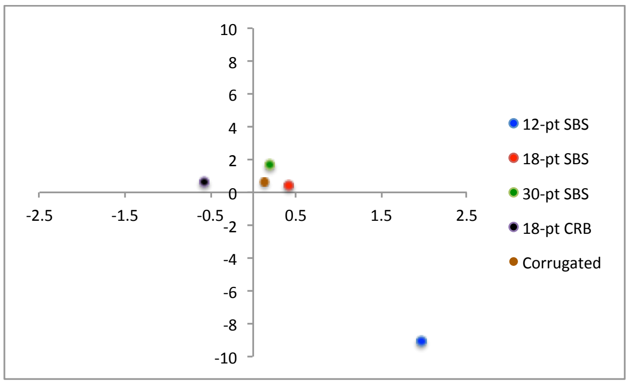

Figure 1: The colorimetric values (a and b*) of tested paperboards and corrugated board*

Test Target Design

Spot colors from the Pantone color guide were used to design the spot color test chart (Figure 2) for this study. L*a*b* values of Pantone color swatches were used as target values. Adobe PhotoShop CC 2014 was employed to generate the spot color test chart in digital form.

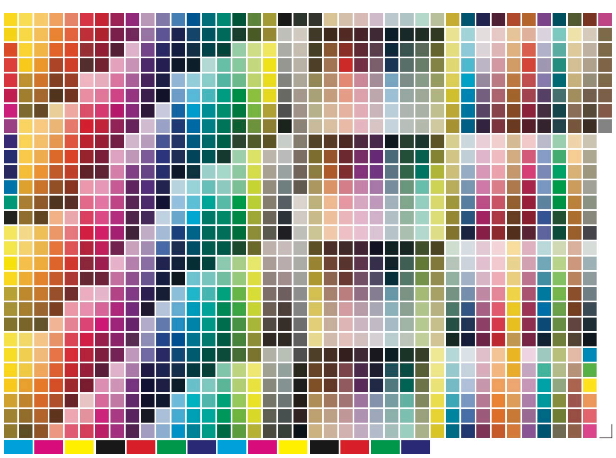

Figure 2: Spot Color Test Chart

Creating and Optimizing Profiles

Fiery XF RIP provides a set of tools for improving the color reproduction of output device. For each tested paperboards and corrugated board, the following procedures were applied. The tested charts were printed and measured with a X-Rite i1iO Spectrophotometer.

- Create a new base linearization file: a base linearization file forms the basis for a media profile, which contains details of the quantities of ink that are necessary to achieve the maximum density of color for a specific combination of output device and media type.
- Create a media profile, which characterizes the tested paperboard/corrugated board.
- Load Pantone spot color library so that spot colors can be automatically detected in Fiery XF RIP.

Print Modes

The following print settings were kept consistent throughout the test runs.

- Shutter mode: double cure
- Lamp cure setting: medium
- Speed: standard
- Smoothing: heavy
- Printer output resolution: 360*600 dpi

Spot Color Matching Capability Analysis

The spot color test chart was measured by an X-Rite eXact spectrodensitometer at illuminant D50 and 2° observer. The quality of spot color matching was evaluated in terms of the color difference (ΔE_{2000}) in L*a*b* color space. The color gamuts of the tested paperboards and corrugated board were compared using ColorThink Pro 3.0.3 software.

Color Attributes

One-way Analysis of Variance (ANOVA) statistical procedure was employed to determine whether the differences in optical density and color gamut of tested paperboards and corrugated board were significant (Table 1 to Table 5). The significant level (α) was set at 0.05 for all tests. The significant value of p is 0.000 < 0.05 (α) for all observed optical densities and color gamut, in other words, at least one pair of the mean optical densities/color gamut values is significantly different at 0.05 levels.

Table 1: One-way ANOVA test on the cyan optical density

Source	DF	SS	MS	F	P
Factor	4	0.9072	0.226798	90.37	0.000
Error	115	0.2886	0.002510		
Total	119	1.1958			

Table 2: One-way ANOVA test on the magenta optical density

Source	DF	SS	MS	F	P
Factor	4	0.06653	0.016631	22.95	0.000
Error	115	0.08333	0.000725		
Total	119	0.14985			

Table 3: One-way ANOVA test on the yellow optical density

Source	DF	SS	MS	F	P
Factor	4	0.09973	0.024932	168.04	0.000
Error	115	0.01706	0.000148		
Total	119	0.11679			

Table 4: One-way ANOVA test on the black optical density

Source	DF	SS	MS	F	P
Factor	4	1.37712	0.344280	603.73	0.000
Error	115	0.06558	0.000570		
Total	119	1.44270			

Table 5: One-way ANOVA test on the color gamut

Source	DF	SS	MS	F	P
Factor	4	13010010728	3252502682	15.70	0.000
Error	115	14503072388	207186748		
Total	119	27513083117			

Figures 3 to 7 illustrate Interval Plots on the color-related attributes among the paperboards and corrugated board. The optical densities of tested paperboards and corrugated board range from 1.54 to 1.70 for cyan, 1.22 to 1.30 for magenta, 0.75 to 0.84 for yellow, and 1.55 to 1.77 for black. Among the tested paperboards and corrugated board, 18-pt SBS paperboard has higher optical densities for colors cyan and black, while corrugated board has lower optical densities for colors cyan and yellow. 30-pt SBS paperboard tends to have larger color reproduction variability. Figure 7 shows that the 12-pt SBS paperboard produces a wider color gamut, while 18-pt CRB yields a smaller color gamut. Overall, tested SBS paperboards produce wider color gamut volumes, compared to CRB or corrugated board. However, 18-pt CRB paperboard has smaller color reproduction variability.

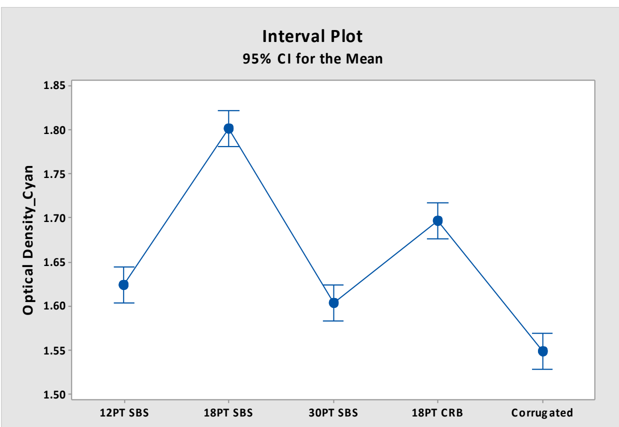

Figure 3: Interval Plot for the cyan optical density

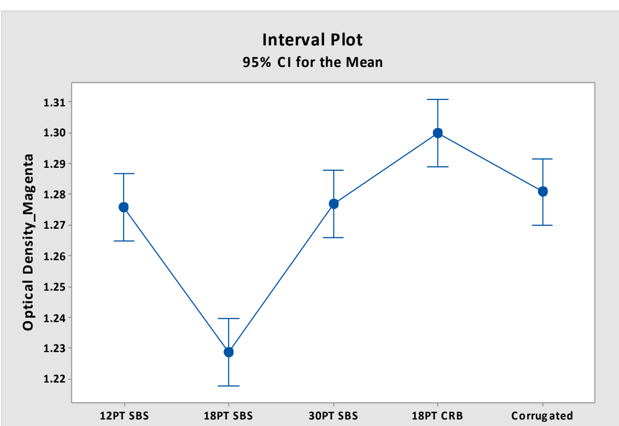

Figure 4: Interval Plot for the magenta optical density

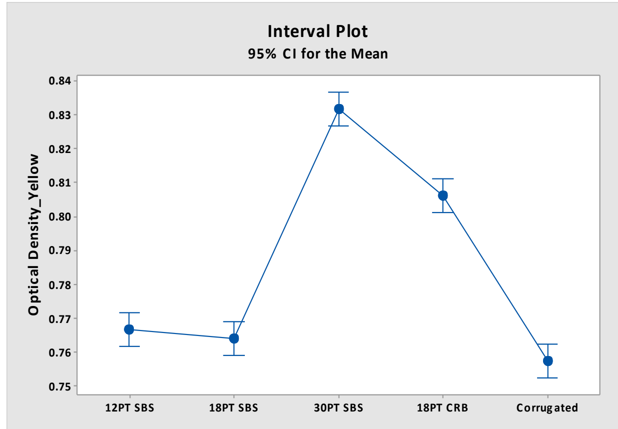

Figure 5: Interval Plot for the yellow optical density

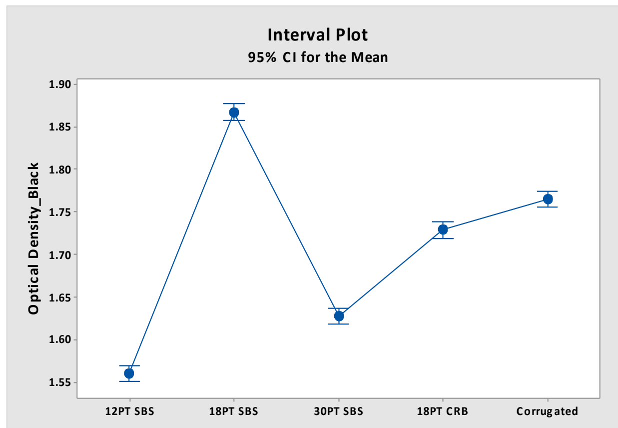

Figure 6: Interval Plot for the black optical density

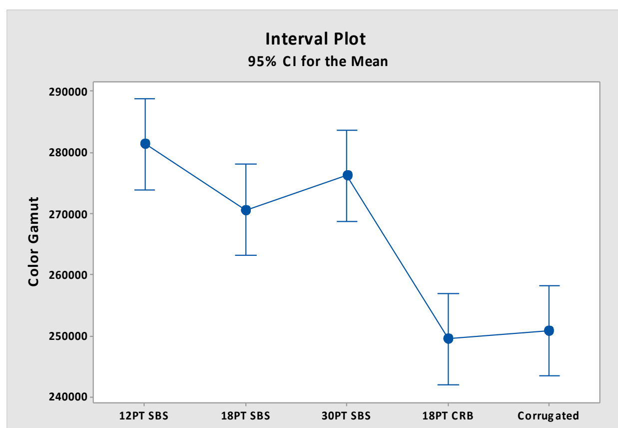

Figure 7: Interval Plot for the color gamut

Figure 8 illustrates the graphs of color gamut with L*a*b* values of target spot color data for tested paperboards and corrugated board. Around 44% of Pantone spot colors are located within the color gamut of tested paperboards and corrugated board. In other words, those high-saturated colors will be difficult to be reproduced on those paperboards and corrugated board.

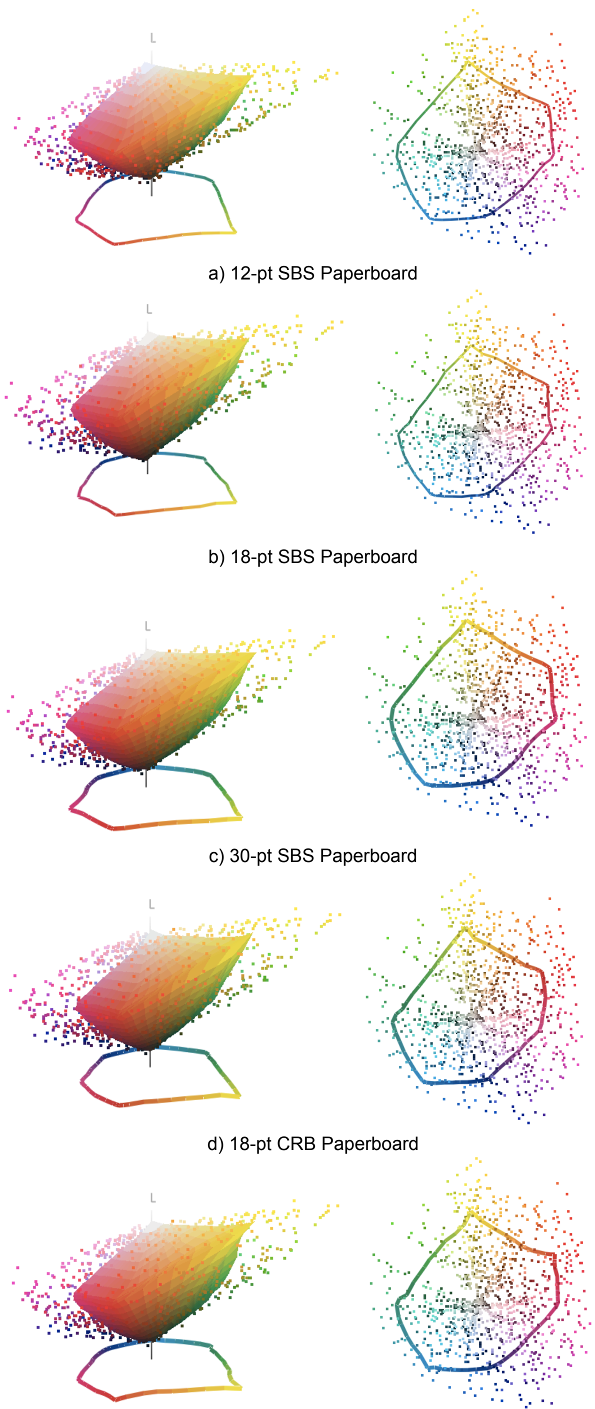

*Figure 8: Color Gamut of tested paperboard and corrugated board (with L*a*b* values of spot color original data for reference)*

Spot Color Matching Analysis

Table 6 summarizes ΔE_{2000} comparison for tested paperboards and corrugated board. For those inside-gamut spot colors, the average ΔE_{2000} value is 7.00 for 12-pt SBS, 8.91 for 18-pt SBS, 6.11 for 30-pt SBS, and 8.65 for both 18-pt CRB and corrugated board. Figure 9 shows spot color matching capability of tested paperboards and corrugated board. It shows that 30-pt SBS paperboard can reproduce about 12% of Pantone spot colors with ΔE_{2000} lower than 4.0, while the 18-pt SBS and 18-pt CRB paperboards can only reproduce around 3% to 4.5% of Pantone spot colors with ΔE_{2000} lower than 4.0. Around 31% of Pantone spot colors can be reproduced with ΔE_{2000} lower than 8.0 when the 30-pt SBS paperboard is used.

Table 6: Summary of ΔE_{2000} comparison for tested paperboards and corrugated board

	Average ΔE_{00}	$\Delta E_{00} < 2$	$\Delta E_{00} < 4$	$\Delta E_{00} < 8$	Min. ΔE_{00}	Max. ΔE_{00}
12-pt SBS	7.20	0.91%	7.27%	23.91%	0.92	14.02
18-pt SBS	8.91	0.27%	3.55%	16.27%	1.04	14.87
30-pt SBS	6.11	2.00%	11.82%	30.91%	0.70	13.56
18-pt CRB	8.65	0.18%	4.36%	15.55%	1.97	14.14
Corrugated	8.65	0.55%	7.36%	22.36%	1.57	12.60

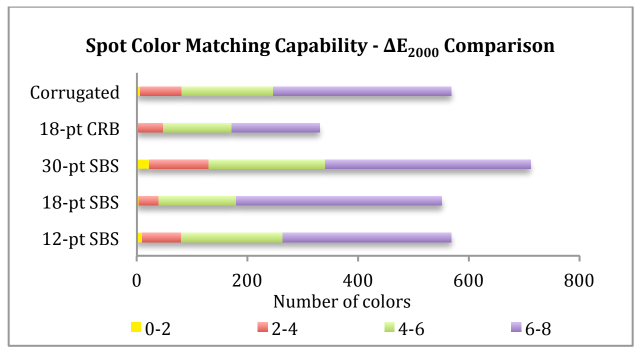

Figure 9: Spot color matching capability for tested paperboards and corrugated board

Figure 10 illustrates the graphs of color gamut with ΔE_{2000} lower than 4.0 for tested paperboards and corrugated board. It is interesting to note that spot colors with good matching capability tend to scatter in the lower portion of color gamut. Pantone spot color swatches with ΔE_{2000} less 4 for the tested paperboards and corrugated board are in Appendix I.

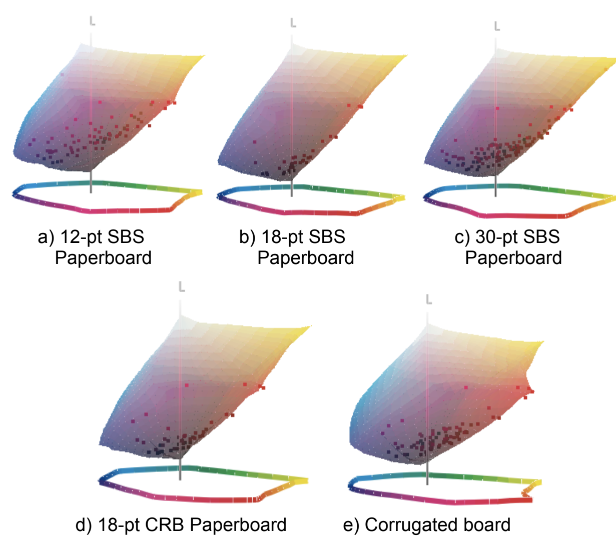

Figure 10: Color Gamut of tested paperboard and corrugated board (with ΔE_{2000} lower than 4.0)

Conclusions

Color consistency is a must in packaging. Color management is critical. Brand colors must match, spot on. The color gamut volumes of tested paperboard and corrugated board are in the range of 249,500 and 282,000. Around 44% of Pantone spot colors are located within the color gamut of tested paperboards and corrugated board. It was found that 30-pt SBS paperboard has better spot color matching capability (with 12% of spot colors having ΔE_{2000} lower than 4.0). Good matching spot colors can be found in the lower portion of the color gamut.

Acknowledgements

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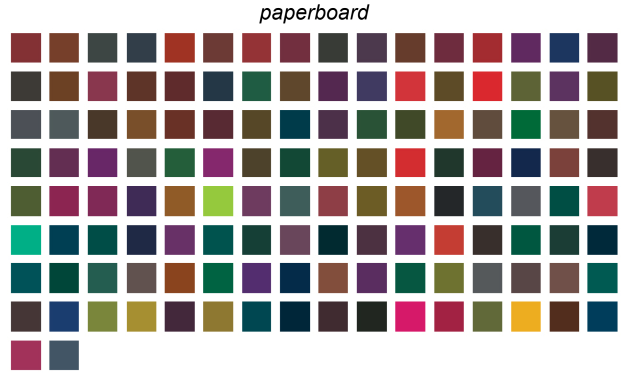
Appendix I

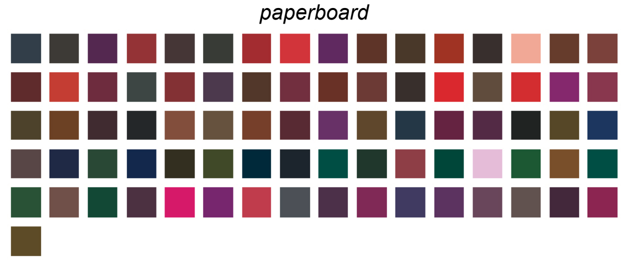
Spot color swatches with ΔE_{2000} less 4 for the 12-PT SBS paperboard

Spot color swatches with ΔE_{2000} less 4 for the 18-PT SBS paperboard



Spot color swatches with ΔE_{2000} less 4 for the 30-PT SBS paperboard

Spot color swatches with ΔE_{2000} less 4 for the 18-PT CRB paperboard



Spot color swatches with ΔE_{2000} less 4 for the corrugated board