Color Reproduction of Digitally Printed Textiles

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Abstract

Short-run sampling and customized production with digital textile printing is an attractive option for creative professionals to market their designs in a cost-effective way. The accuracy of color reproduction on the digitally printed textile is crucial for designers. The main objective of this study is to evaluate color reproduction capability of digitally printed silk fabrics based on color gamut and optical density. In addition, color management with ICC profiles was used to investigate the color matching capability of specific spot colors, which were selected from the Pantone® Fashion + Home digital color library. The accuracy of color matching of digitally printed silk fabrics was evaluated in terms of color difference ($\Delta E_{CMC\ 2:1}$). Three different silk fabrics - silk chiffon, silk crepe de chine, and spun silk taffeta, were tested and compared. The choice of textile substrate significantly influences image quality. It was found that Crepe De Chine is capable of yielding a wider color gamut and higher optical densities, resulting in better color reproduction capability and color matching. Chiffon has a relatively small color gamut and only can reproduce lighter colors.

Introduction

The benefits and beauty of printing on textile are apparent. With developments in digital large format printing technologies, digital textile printing usage continues to grow. I.T. Strategies' Research on Emerging Print Markets predicts that the value of the printed output from digital textile printers will grow from $1.9 billion in 2007 to $6.1 billion in 2012[1]. A projection for the digital wide-format printing market also predicts that the inkjet printing will expand its share of textile printing market[2].

Digital textile printing, based on inkjet technology, empowers designers and retailers with digital design. Today, the majority of digital textile printing technologies operates with water-based dye based on the paper ink-jet print systems. The color reproduction of digitally printed textile highly depends on the range of colors and tonal ranges that digital printers can reproduce and also how accurately these color numbers can be manipulated in comparison to printing characteristics. The former is determined by ink-fabric interaction of a digital printer and the latter needs the aid of color management. Before performing color matching, the color gamut of print combination of digital textile printing system must be well defined.

The color gamut is the range of colors that a particular combination of printer, ink, and fabric can achieve. Color gamut of a given printing system is evaluated in terms of gamut volume, which can be interpreted as the number of independent colors that can be printed on the designated substrate within a ΔE tolerance of $\sqrt{3}$ (i.e. the diagonal of a unit cube). Volume is then expressed per cubic CIELAB units (cCu). Higher volumes indicate the possibility of making more color combinations. Therefore, color gamut is treated as an indicator predicting color reproduction capability of a device[3]. In this study, gamut volume with a given printing combination has been proposed as a measure of color reproduction capability. Optical density is used as another measure, which is determined by colorant concentration and dot coverage on the fabrics.

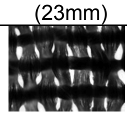
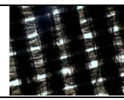
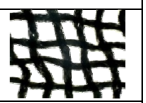
The color reproduction capability of a digital textile printing system in turn affects accuracy of color matching. The printer control software used in a digital textile printing system governs the color matching functions, which usually apply color management to control color numbers. Functionally, there are two kinds of software to control a printer. The first one is the print driver (inkjet printer manufacturer's software); the other one is the third-party raster imaging processor (RIP) software[4]. Print driver software drives printer to print data files in RGB mode. A third-party RIP software interprets raster and vector data files for a specific postscript printer in either RGB or CMYK mode. By controlling CMYK inks directly, RIP software can provide better control for accurate digital color reproduction. The application of an RGB or CMYK device will depend on the user's workflow[5, 6]. For most users, Adobe Photoshop probably is the most useful tool to integrate the basic color management techniques to their workflow[7]. This study employed Photoshop to implement ICC-based color management and perform color conversion.

Today, ink jet printing technology is penetrating into textile printing and serving as a sampling/short-run production tool. The accuracy of color reproduction on the digitally printed textile and the ability to consistently control output are essential. This study evaluated color reproduction of digitally printed silk fabrics in terms of color gamut and color matching.

Methodology

In this study, an Epson Stylus Pro 9800 printer was used with acid dye inks (Huntsman Lanaset® SI HS acid inks). Three silk fabrics, silk chiffon, silk crepe de chine, and spun silk taffeta, were tested and compared. These pretreated fabrics were paper-backed for digital textile printing. Table 1 shows characteristics of tested silk fabrics. As shown in Table 1, the tested silk fabrics are all made with plain weave, however, their texture and porosity differ a great deal one from another. Chiffon is the most porous and thin fabric, while Crepe De Chine is a less porous and heavier fabric.

Table 1: Characteristics of tested silk fabrics

Silk Fabrics	Crepe De Chine (23mm)	Taffeta	Chiffon (8mm)
Microscope images (@100X magnification)			
Characteristics	A fine, lightweight, plain weave silk fabric wove. The fabric has a fine crepe effect and is very soft to touch.	Fabrics made with plain weave. The fabric usually has a fine cross rib produced by employing a heavier filling yarn than wrap.	Extremely thin flat plain weave. The fabric is delicate but relatively strong.

Color Test Targets

The TC 9.18 RGB test target (Figure 1) designed for i1iO spectrophotometer was selected for ICC profiling. These ICC profiles were used to compare the color gamuts – the defined color range a print combination can reproduce.

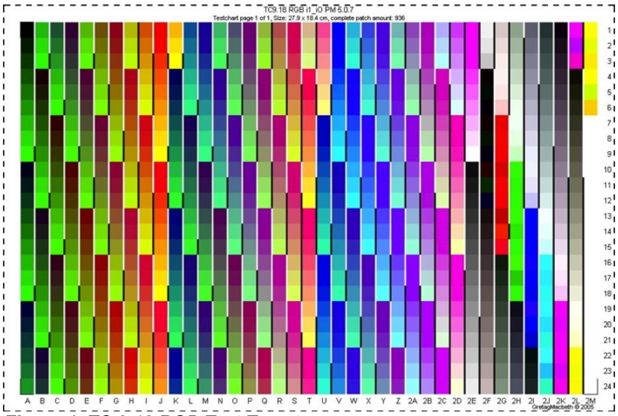


Figure 1. *TC 9.18 RGB Test Target*

A spot color target containing a set of specific Pantone® Fashion + Home digital colors was created to evaluate color matching capability of digital textile printing. In order to evaluate the ability of color matching, these spot colors are chosen across the color wheel of high saturation, with the exception of the black color. Adobe Photoshop CS3 was employed to generate the spot color test chart in digital form. The L*a*b* values associated with the spot color target are listed in Table 2.

Table 2: L*a*b* Values of selected Pantone® spot colors

PANTONE Color Name		L*	a*	b*
	19-5708	17	-3	1
	12-0643	92	-5	88
	17-1350	66	49	71
	18-1664	46	67	49
	17-2624	48	56	-12
	19-1650	28	39	15
	18-3949	35	12	-48
	16-4535	66	-30	-28
	18-5424	38	-28	-2
	19-5513	31	-15	5
	16-6340	61	-48	41
	17-0145	51	-34	32

Color Reproduction Capability Assessment

In the first stage, three silk fabrics were tested and characterized by generating ICC profiles. The TC 9.18 target was printed without color management via Epson Stylus Pro 9800 print driver. Once the silk fabrics have been printed and dried, steaming was used to fix printed textiles. Acid dyes were steamed under atmospheric pressure at around 100°C for one hour, followed by washing and drying to ensure removal of unfixed dye. The washing-off process occurs in several stages, including hand wash with cold water, washing with Inkjet Fabrics Acid Wash agent, and a couple of cold rinse cycles. After wash, the silk fabrics were patted dry with towels. When dry, printed silk fabrics were then measured with an X-Rite i1iO spectrophotometer (D65/10° measuring geometry), operated by GretagMacbeth Measure Tool 5.0.9 software. The measurement files were used to generate profiles using GretagMacbeth ProfileMaker Pro 5.0.9. The color gamuts of tested silk fabrics were compared using ColorThink Pro 3.0 software.

Color Matching Evaluation

In the second stage, the digital spot color target was printed via the Epson Stylus Pro 9800 print driver, whereas the ICC profiles were assigned in relevant functions. The procedures were as follows:

- Place the ICC profiles established from the first stage in the system color folder.
- Launch Photoshop and convert the spot color test chart from Lab color space to destination RGB printer profiles using Edit > Convert to Profile. The conversion settings are Adobe ACE for color management module and absolute colorimetric for rendering intent.
- Print out the spot color target (same print settings when print out the TC 9.18 target).

Once the silk fabrics have been printed and dried, the post-treatment (steaming-washing-drying) was applied again to set the dye and remove the loose colorant. L*a*b* values for each color patch of the chart were measured using the X-Rite i1iO spectrophotometer. The quality of color reproduction was evaluated in terms of color difference ($\Delta E_{CMC\ 2:1}$), which has been adopted by the textiles industry since 1984.

Results and Discussion

Table 3 lists color-related attributes of tested silk fabrics, including optical densities and color gamut. Among three tested silk fabrics, Crepe De Chine yielded higher optical densities and produced a wider color gamut. The overall average of optical densities of Crepe De Chine were 1.60 for cyan, 1.58 for magenta, 1.09 for yellow, and 1.59 for black. Compared to Crepe De Chine, Taffeta produced lower optical densities and a smaller gamut volume. The optical densities of cyan, magenta, and black for Taffeta were in the range of 1.34 to 1.39. Chiffon has a quite open textile structure, resulting in poorer ink holdout. The overall averages of optical density of Chiffon were 0.74 for cyan, 0.73 for magenta, 0.57 for yellow, and 0.71 for black. The color gamut of Chiffon was in the range of 51,000 to 61,000, which corresponds to the density measurements.

Table 3: Color-related attributes of tested silk fabrics

Silk Fabrics	Optical Density				Color Gamut
	Cyan	Magenta	Yellow	Black	
Crepe De Chine	1.59-1.61	1.57-1.59	1.08-1.11	1.59-1.60	242,000-245,000
Taffeta	1.38-1.39	1.35-1.36	0.95-0.96	1.34-1.39	211,000-221,000
Chiffon	0.73-0.77	0.72-0.75	0.56-0.58	0.70-0.72	51,000-61,000

The gamut comparison for the tested silk fabrics is shown in Figure 2 (with L*a*b* values of target data for reference). The largest color gamut was found in Crepe De Chine, followed by the silk Taffeta. Chiffon yielded the smallest color gamut. The color gamut of Crepe De Chine (wire frame) is slightly larger than that of Taffeta (red color). However, the silk Taffeta yielded a wider color gamut in magenta and purple regions. The gamut of silk Crepe De Chine is larger in the lower L* values area, while the gamut of Taffeta is larger in the higher L* values area. The silk Chiffon has a relatively small color gamut and only can reproduce lighter colors. Some spot colors trajectory traversing out of color gamut of test printer (as shown in Figure 2) contributing to higher $\Delta E_{CMC\ (2:1)}$ values.

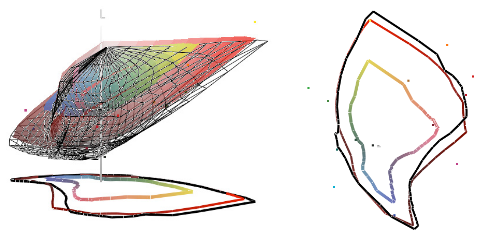


Figure 2. Gamut comparison for the tested silk fabrics (Crepe De Chine: wire frame; Taffeta: red; Chiffon: true color)

The color matching ability of reproduction was evaluated in terms of the $\Delta E_{CMC\ (2:1)}$ for selected Pantone spot colors. In general, a $\Delta E_{CMC\ (2:1)}$ of 1 or less represents a good degree of color matching for a dyed fabric, while a $\Delta E_{CMC\ (2:1)}$ of up to 3 might be acceptable in a textile print[8]. The measured L*a*b* values for each silk fabric and calculated $\Delta E_{CMC\ (2:1)}$ for each color are shown in Table 4, 5, and 6. Overall, Crepe De Chin and Taffeta have smaller $\Delta E_{CMC\ (2:1)}$ values, while the $\Delta E_{CMC\ (2:1)}$ values of Chiffon are above 9. In other words, Chiffon is less capable of reproducing selected spot colors, primarily due to gamut limitation. The averages $\Delta E_{CMC\ (2:1)}$ for Crepe De Chine, Taffeta, and Chiffon are 5.09, 6.17, and 14.47, respectively. For most spot colors, chroma differences (ΔC*) contribute more to $\Delta E_{CMC\ (2:1)}$ than lightness/darkness differences (ΔL*).

Table 4: Color matching results for silk fabric Crepe De Chin

PANTONE Color Name	Target			Digital Printing on Crepe De Chin			Color Difference		
	L*	a*	b*	L*	a*	b*	ΔL*	ΔC*	$\Delta E_{CMC\ 2:1}$
19-5708	17	-3	1	18.54	-2.19	0.81	1.54	0.83	1.75
12-0643	92	-5	88	81.02	2.39	80.67	10.98	10.41	5.71
17-1350	66	49	71	60.07	38.61	52.78	5.93	20.97	7.10
18-1664	46	67	49	44.40	54.96	39.15	1.6	15.56	4.98
17-2624	48	56	-12	47.66	31.44	-13.08	0.34	24.58	9.40
19-1650	28	39	15	28.85	33.96	12.45	0.85	5.65	2.48
18-3949	35	12	-48	35.82	2.83	-46.78	0.82	9.25	6.23
16-4535	66	-30	-28	60.75	-21.46	-13.67	5.25	16.68	7.80
18-5424	38	-28	-2	38.29	-27.83	1.43	0.29	3.43	2.33
19-5513	31	-15	5	30.34	-17.49	6.32	0.66	2.82	1.97
16-6340	61	-48	41	56.64	-28.00	27.61	4.36	24.07	8.72
17-0145	51	-34	32	50.01	-28.40	30.18	0.99	5.89	2.57

Table 5: Color matching results for silk fabric Taffeta

PANTONE Color Name	Target			Digital Printing on Crepe De Chin			Color Difference		
	L*	a*	b*	L*	a*	b*	ΔL*	ΔC*	$\Delta E_{CMC\ 2:1}$
19-5708	17	-3	1	24.77	-1.66	0.06	7.77	1.64	7.52
12-0643	92	-5	88	84.12	1.79	74.50	7.88	15.11	5.95
17-1350	66	49	71	61.16	38.64	52.48	4.84	21.22	7.08
18-1664	46	67	49	47.83	48.80	35.40	1.83	22.72	7.21
17-2624	48	56	-12	48.45	32.30	-14.20	0.45	23.80	9.23
19-1650	28	39	15	35.40	31.22	9.92	7.40	9.29	6.34
18-3949	35	12	-48	37.77	1.15	-43.27	2.77	11.84	7.54
16-4535	66	-30	-28	62.66	-22.74	-13.97	3.34	15.80	7.37
18-5424	38	-28	-2	40.22	-26.10	-0.10	2.22	2.69	1.99
19-5513	31	-15	5	33.13	-16.91	6.15	2.13	2.23	2.01
16-6340	61	-48	41	58.74	-28.92	26.65	2.27	23.87	8.47
17-0145	51	-34	32	50.91	-27.69	26.79	0.09	8.18	3.30

Table 6: Color matching results for silk fabric Chiffon

PANTONE Color Name	Target			Digital Printing on Crepe De Chin			Color Difference		
	L*	a*	b*	L*	a*	b*	ΔL*	ΔC*	$\Delta E_{CMC\ 2:1}$
19-5708	17	-3	1	44.19	-1.24	-0.34	27.19	2.21	25.52
12-0643	92	-5	88	77.09	-1.14	48.85	14.91	39.34	13.20
17-1350	66	49	71	64.89	24.85	32.55	1.11	45.41	14.26
18-1664	46	67	49	56.09	23.60	17.80	10.09	53.45	17.52
17-2624	48	56	-12	53.03	19.60	-6.64	5.03	36.79	13.76
19-1650	28	39	15	49.20	15.48	5.39	21.2	25.41	17.51
18-3949	35	12	-48	50.45	-3.33	-26.45	15.45	26.45	15.53
16-4535	66	-30	-28	66.95	-14.91	-9.28	0.95	24.04	10.49
18-5424	38	-28	-2	52.19	-15.51	-0.79	14.19	12.55	9.98
19-5513	31	-15	5	50.95	-10.09	5.28	19.95	4.92	12.66
16-6340	61	-48	41	63.92	-18.58	16.12	2.92	38.53	13.61
17-0145	51	-34	32	58.98	-16.49	18.65	7.98	22.02	9.62

Conclusions

The ability to accurately reproduce a given color using digital inkjet textile printing is crucial for sampling as well as for mass customization. Understanding which colors are attainable within the limits of specific fabrics and ink sets is especially beneficial for designers. This study conducted color reproduction tests with basic ICC-based color management techniques on three different silk fabrics. It shows Crepe De Chine is capable of yielding a wider color gamut and higher optical densities, resulting in better color matching capability. Taffeta has a smaller color gamut, compared to Crepe De Chine. However, it yielded a wider color gamut in magenta and purple regions, as well as in the higher L* values area. Compared to Crepe De Chine and Taffeta, Chiffon has a quite open textile structure, resulting in poorer ink holdout. Therefore, ink control for Chiffon is very important to avoid bleeding. Chiffon has a relatively small color gamut and only can reproduce lighter colors. Therefore, Chiffon is less capable of reproducing selected spot colors (the $\Delta E_{CMC(2:1)}$ values of Chiffon are above 9).

Certainly, the ultimate goal of digital textile printing is to offer perfect color matching. The digital textile printing process is more complicated than the inkjet paper printing process. There are many variables that can have an impact on color quality. Fabric pre-treatment, steaming, and other finishing processes are all variables that affect color reproduction and add to color matching difficulties. Color management for digital textile printing must be able to overcome all variables and deliver exactly the same output color for a desired target color. Digital printers integrate with an effective RIP configuration and profiling techniques would take advantage of the whole gamut of the output device and offer a better color match. Further investigation will include process consistency tests and possible testing with RIP software to pursue a better color match.

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