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Tone Curve Compensation of Multiple Color Halftoning Screen Printing for Heterogeneous Fabrics

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Abstract. *For mass production, multiple color halftoning screen printing (MCHSP) can be considered as the alternative textile printing technology when vivid color gradation is needed and the cost of digital printing is a concern. Essentially, MCHSP utilizes the same equipment as traditional screen printing to print overlapping multiple color gradation under halftoning patterns by applying dedicated treatments on color separation and calibration. To ensure color quality, equipment calibration and tone curve compensation are required to compensate for the variables arising from equipment setup and heterogeneous fabrics. In this research, the authors present a procedure of tone curve compensation to eliminate the discrepancy from heterogeneous fabrics. The experimental results based on 55 samples of 44 different fabrics show the effectiveness of compensation and reveal the distribution of average compensation percentage across fabrics.* © *2020 Society for Imaging Science and Technology.*

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1. INTRODUCTION

Screen printing technology is one of the major fabric printing methods used in the textile printing industry. Based on the research report from Grand View Research [1], by 2018, more than 95% of the global printed textile market share arose from traditional printing technology including rotary screen textile printing, hand screen printing, dye-sublimation transfer printing, and automatic flat screen printing. In general, traditional spot color screen printing (SCSP), which uses a mesh to transfer one color ink on a fabric supported by the rotary or linear flat moving equipment, remains the major fabric printing technique for mass production.

Although SCSP dominates in the mass production process, it has limitations in the capability of color representation and business practice. First, due to the nature of discrete color printing, in mass production, SCSP needs a relatively larger space, which leads to the printing of a limited number of colors (plates). For example, considering a common automatic flat screen printing system, at the most, only 10–15 screens (colors) can be printed sequentially. Second, the thickness of the screen thread and the screen mesh count used in spot color screen printing are also physical limitations that result in low resolution. Consequently, the physical limitations of SCSP confine the contents of the design pattern to simple gradation or spot color designs; thus, the resulting patterns are not highly complex. Due to the above limitations, in business practice, when customers require multicolor gradation or the required number of colors exceeds the limit of the printing machine, using direct to garment (DTG) printing or discretizing multicolors by combining similar colors is a common solution.

In fact, multiple color halftoning screen printing (MCHSP) can provide an alternative solution, which enables the original screen printing equipment to provide multicolor gradation. According to [2], "halftoning is the reprographic technique which simulates continuous-tone imagery through the use of dots, varying either in size or in spacing, thus generating a gradient-like effect." In MCHSP, different inks or pigments are pressed through tiny holes on a screen mesh to create overlapping dot patterns for obtaining multicolor gradation. This also means that MCHSP needs more dedicated treatments on color separation and calibration. First, compared with spot (discrete) color separation, MCHSP needs to conduct color separation on primary color channels such as cyan, magenta, yellow, and black (CMYK) or extended combinations including gray, light gray, light cyan, and light magenta. Second, a finer screen is usually needed to create smaller dots to produce details with multiple colors. Third, to reproduce details precisely, MCHSP requires calibration and tone compensation to eliminate variables from heterogeneous fabrics, tension of screen, squeegee sharpness, viscosity of inks, and so on [3, 4].

Although tone curve compensation is a common procedure in digital printing technology, in the literature, few studies are available from the MCHSP domain. In this research, a tone curve compensation process for MCHSP was proposed to fill this gap. The focus is on creating a compensation curve to eliminate the discrepancy caused by fabrics. The experimental result based on 55 samples of 44 fabrics shows that the proposed tone curve compensation

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Table I. Comparison of traditional spot color screen printing, multiple color halftoning screen printing, and direct to garment printing on fabric in mass production [3, 5–7].

	Items	SCSP	MCHSP	DTG
Presentation	Detailed designs	Low	Digital-like	High
	Color matching	Good	Good	Medium
	Color consistency	Medium	Medium	High
	Color gradation	Simple, discrete	Digital-like	Fine and vivid
	Special effects[a]	Versatile	Versatile	Poor
Operation	Color separation	Simple	Dedicated	N/A
	Setup process	Time-consuming	Time-consuming	Fast
	Production cycle	Long	Medium	Short
	Production speed	Fast	Fast	Slow
	Fabric treatment	Needs pre- and post-processing	Needs pre- and post-processing	In development
Cost	Facility cost (for mass production)	Medium	Medium	High
	Ink cost	Low	Low	High
	Maintenance cost (cartridge[b])	Low	Low	High
	Inventory cost	High	Medium	Low
Business	For bulk prints	Good	Good	Poor
	On-demand customized	Low	Low	High
	Response speed to market	Low	Low	Fast

[a] Special effects are created by specialty inks and additives such as puff, fluorescent, metallic, glitter, shimmer, plasticharge products, and so on.

[b] Cartridge is only used for DTG technology.

method can achieve better color quality. For its use in the industry, the proposed procedure can provide a guideline for better reproduction of color by MCHSP.

The rest of the paper is organized as follows. Section 2 compares MCHSP with SCSP and DTG with different aspects. Then, the past literature on the calibration process and tone curve compensation is reviewed. Section 3 presents the proposed calibration and compensation procedures for MCHSP. Section 4 provides the experimental result obtained by applying the compensation. Section 5 concludes the study and proposes future work.

2. LITERATURE REVIEW

2.1 *Business Opportunity for halftoning screen printing*

Essentially, MCHSP shares the same characteristics with SCSP but involves additional processes on color separation and compensation. Table I lists a comparison among traditional SCSP, MCHSP, and DTG based on four categories: presentation, operation, cost, and business perspective, particularly under mass production conditions.

From the presentation perspective, DTG has better capabilities on detailed designs, color consistency, and fine color gradation except that it is limited in special effects. The DTG procedure also involves a simple operation process and fast setup time although the production speed is relatively slow in mass production. For cost-sensitive mass production, the DTG technique is costly. Although DTG can save the use of screens, the cost of color inks and maintenance, including the cartridge head, which needs replacement after certain printing processes, is high for mass production. Without doubt, DTG outperforms other methods in on-demand customization and response time.

When comparing SCSP with MCHSP, the operation and cost structure are similar. However, MCHSP has more capability for providing better detailed designs and color gradation. For some applications, MCHSP can provide digital-like color gradation and vivid presentation if more primary colors are installed. Note that the operating cost considered here includes overhead (water, electricity, and so on), labor, and inventory but not the cost of following environment-friendly and social-influence practices.

2.2 *Color calibration*

Color calibration aims to measure color reproduction and adjust the controlling variables of a device to maintain the performance state. In the digital textile or digital printing industry, color calibration is used to create a color profile with a color gamut that presents a range of printable colors specifically for a specific substrate and ink combination [6]. In the textile industry, it is used to create a color profile that presents a range of printable colors specifically for a specific substrate and ink combination. In general, color calibration is a requirement for all printing equipment involving color correction as part of a color-managed workflow.

For an electrophotographic printer, the so-called laser printer system, Yang et al. and Kuo et al. analyzed the sensor readings from densitometers and temperature, humidity, and tone level to create an online tone prediction model to reduce the sensor mapping discrepancy between the measurements on real media and sensor reading on substitute media such as transfer belts [8, 9]. In their work, the tone reproduction curves for each of the primary colors—cyan, magenta, yellow, and black—were constructed to represent the colorimetric values of halftone levels. This tone reproduction curves were used to calibrate the printer's control system by compensating the density on different halftone levels for improving color consistency.

In the screen printing industry, there are multiple factors that affect screen printing detail [3, 10]. These factors include screen tension, squeegee sharpness, pressure of squeegee, speed of ink transfer, surface properties of the fabric being printed, viscosity of the ink, and so on. Some of these factors are correlated with the equipment setup such as screen tension, squeegee sharpness, pressure of squeegee, and speed of ink transfer. Others are related to the properties of materials such as ink and substrate.

Among those variables influencing print quality, the structural properties of a fabric have an impact on the way the ink interacts with the fabric to reproduce images [11, 12]. For polyester fabric, Park et al. studied the image quality on inkjet printed fabrics with different values of line width, edge blurriness, and edge raggedness [13]. Their work found that the printing direction, weave structure, and the finishing process of the fabric affected the final image quality. For cotton fabric, Jihyung investigated the correlation between the surface texture characteristics and color appearance of the DTG printed fabric [14]. His work found that there is a high correlation between the instrumental measurement of fabrics and the visual assessment of color lightness printed by DTG (inkjet printer). Moreover, geometric and surface texture parameters such as thickness, weight, crimp, and fabric densities are correlated with each other.

Regarding the calibration process or method, essentially, color patches are printed to capture the performance characteristics of the printing machine. For example, a patent [15] was obtained for the invention of a method to generate a calibration file from the measured color values of the printed patches, mapping a color space for the printed patches to a color space for a printer used to print the patches. The patent [16] also included an efficient procedure to characterize a printing device response for the halftoning screen. Basically, the tone response curve (TRC) is generated to perform the calibration to compensate for the disturbance.

However, to the best of our knowledge (from the literature), few studies can be found related to TRC compensation in screen printing for multiple color halftoning application. Although the basic concept of printing patches and measurement in digital printing is simple and can be applied to screen printing, in particular for MCHSP mass production, research regarding the compensation procedure and its effectiveness is scarce. More importantly, in the textile printing industry, knowing how to use the compensation technique to eliminate the discrepancy due to different fabric properties for improving color quality is critical to applying MCHSP on the existing screen printing equipment. Therefore, in this research, the procedure regarding tone curve compensation in MCHSP and the associated compensation result are provided for advancing the screen printing industry.

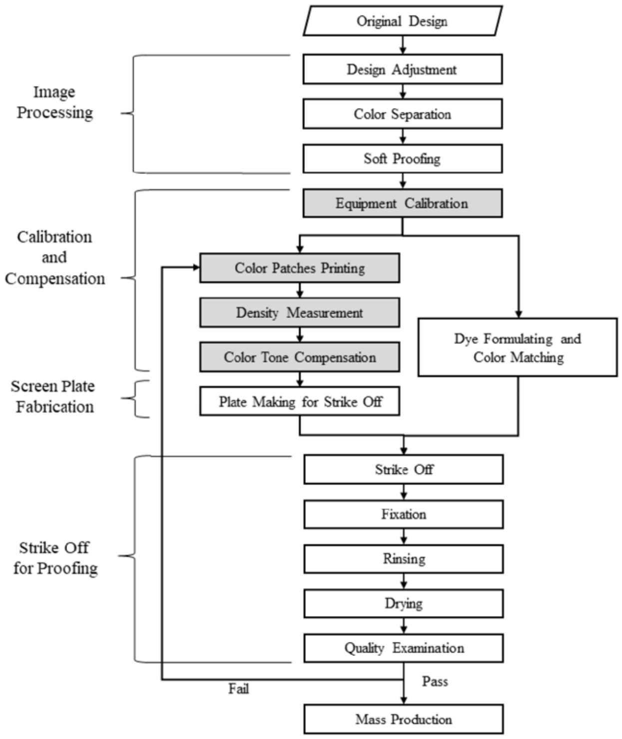


Figure 1. Pre-processing of MCHSP before mass production. The gray color indicates the calibration and tone compensation processes.

3. CALIBRATION OF MCHSP

In this section, the pre-processing stage prior to the mass production of MCHSP is presented. In particular, the calibration details for compensating different variables are provided.

3.1 *Overview of pre-processing of MCHSP*

As mentioned earlier, MCHSP basically utilizes the same procedures of SCSP, which are (1) image processing, (2) calibration and compensation, (3) screen plate fabrication, and (4) strike-off (Figure 1), prior to mass production.

The image processing step basically considers the characteristics of an image to determine the number of colors for color separation. After the color separation, a calibration and tone compensation process (indicated by gray in Fig. 1) is needed to ensure the quality of production by compensating for the variables from the equipment setup and fabric properties. The equipment calibration aims to compensate for the disturbance caused by the equipment or tool difference, while the tone curve compensation

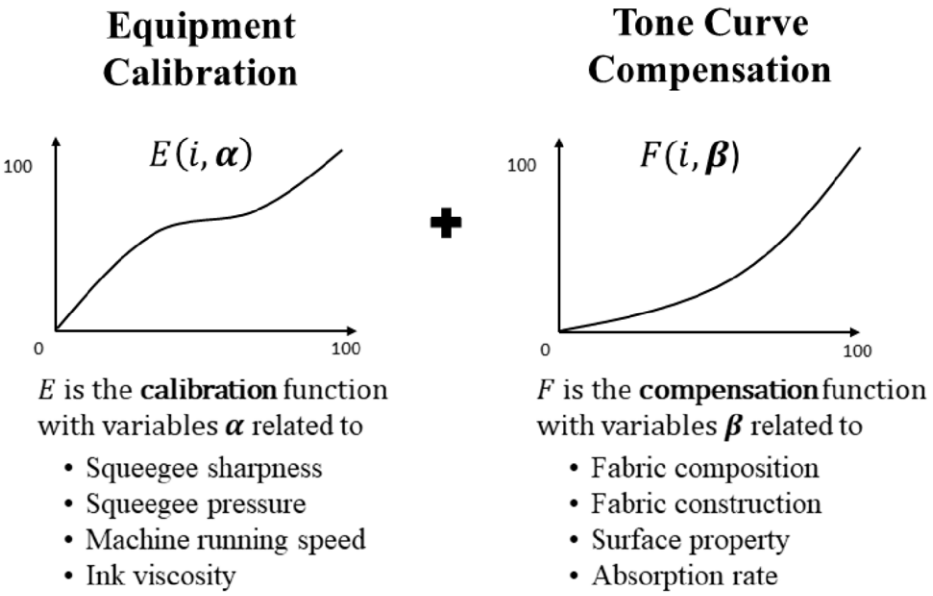


Figure 2. Illustration of equipment calibration and tone curve compensation processes.

procedure, the focus of this research, aims to compensate for the discrepancy caused by the surface properties of the material being printed. The assumptions and the detailed steps are described in the following subsections.

3.2 *Calibration and Compensation Processes of MCHSP*

Essentially, multiple variables should be considered simultaneously during calibration to reduce the disturbances caused by the interaction among variables. Ideally, this calibration model can be described as in Eq. (1), where ∇y_i is the compensated density value at the i density level and φ is a calibration model that describes the relationship between the density values with two sets of influential variables such as α and $\boldsymbol{\beta}$ for equipment and fabric variations:

$$\nabla y_i = \varphi(i, \boldsymbol{\alpha}, \boldsymbol{\beta}). \tag{1}$$

However, developing a single φ function to compensate for all variables is difficult in practice due to the complexity of linear or nonlinear relationships among variables. Instead, in this research, the equipment calibration and fabric tone compensation are assumed to be independent of each other and can be described as in Eq. (2), where the compensated density values at the i density level for each calibration are summed up:

$$\nabla y_i' = E(i, \boldsymbol{\alpha}) + F(i, \boldsymbol{\beta}). \tag{2}$$

Based on the aforementioned pre-processing of MCHSP, it is reasonable to assume the independence between equipment calibration and tone compensation. First, for mass production, the equipment is usually set up for printing a certain type of fabric to avoid frequent setups. Therefore, the equipment calibration can be considered as tuning the operating parameters correlated with the aging issue of the equipment to maintain consistent operation such as controlling squeegee sharpness or controlling the printing speed. Variables arising from different fabric properties can be restricted by controlling the variations in each type of fabric composition. For example, for 100% cotton fabric, we can assume that the same equipment was utilized for mass production. Then, the tone curve compensation only aims to compensate for the variations among different cotton constructions such as 108 × 58/20 × 20 or 133 × 72/40 × 40.

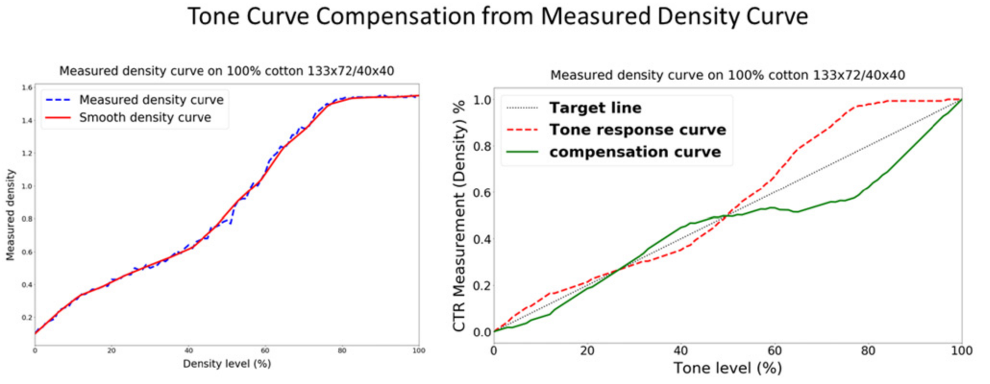
Figure 2 illustrates the correlation of the above-mentioned equipment calibration and tone curve compensation, where the independence between them is assumed. Note that in this research, developing a compensation function F to compensate for fabric discrepancy within the same fabric composition was proposed. More detailed information is presented in the next subsection.

3.3 *Tone Curve Compensation*

In this subsection, the procedures for conducting the tone curve compensation—(1) construct the measured density curve, (2) smooth the density curve, (3) rescale the density level, and (4) construct the compensation curve—are presented.

(1) Construct measured density curve

The density value of each color patch can be measured by a spectrophotometer to construct the measured density curve. Note that the measured density value usually ranges from 0 to 1.6 depending on the fabric. In addition, to improve the reliability of the measurement, it is common to take multiple measurements on the same patch or measure multiple patches with the same density level located at different positions on the fabric. The average of multiple measurements at one density level can be calculated. To



(a) Measured density curve

(b) Rescaled tone response curve and compensation curve

Figure 3. Illustration of the procedures for generating tone compensation curve. In (a), the solid red line is the smooth measured density curve. In (b), the dashed red line is the scaled density curve from 0 to 1, called the tone response curve. The solid green curve in (b) shows the associated compensation curve.

simplify the notation, “measured density values” are used in this article to represent the average values.

(2) Smooth the density curve for interpolation

This step aims to smooth the measured density curve and generate the interpolated values for density levels that are not printed. Usually, fewer than 100 patches are really printed for one color. The curve smoothing method such as linear interpolation can be applied to construct a smooth density curve and estimate the missing density values. The goal is to fill 100 density values from 1% to 100 %. A variety of smoothing methods can be applied here. More detailed information can be found in [17].

(3) Rescale the density level

After the smooth measured density curve is constructed, it can be rescaled to the 0–1 level. Figure 3(a) shows an example of the measured density curve for cotton. Here, the measured density values are rescaled as the colorimetric tone reproduction (CTR) measurement. $CTR_{i,j}$ indicates the CTR value for a specific tone level i, $i \in [1, \ldots, 100]$ of fabric j. The rescaling of measurable density ranges from 0 to 1 (0%–100%) is suggested for the construction of a tone response curve.

(4) Construct the compensation curve

After obtaining the tone response curve with the rescaled $CTR_{i,j}$ values, the compensation curve can be generated. Here, CTR_i^T is used to denote the target CTR value for the tone level i, $i \in [1, \ldots, 100]$. Basically, CTR_i^T, whose value is defined in Eq. (3), represents the ideal curve for color gradation:

$$CTR_i^T = \frac{i}{100}, \quad i \in [1, \ldots, 100]. \tag{3}$$

The compensation curve is constructed by using $\widehat{CTR}_i$, which can be calculated based on Eq. (4). Fig. 3 (b) shows the associated compensation curve, which is indicated by a solid green curve:

$$\widehat{CTR}_i = CTR_i^T - (CTR_{i,j} - CTR_i^T), \quad i \in [1, \ldots, 100]. \tag{4}$$

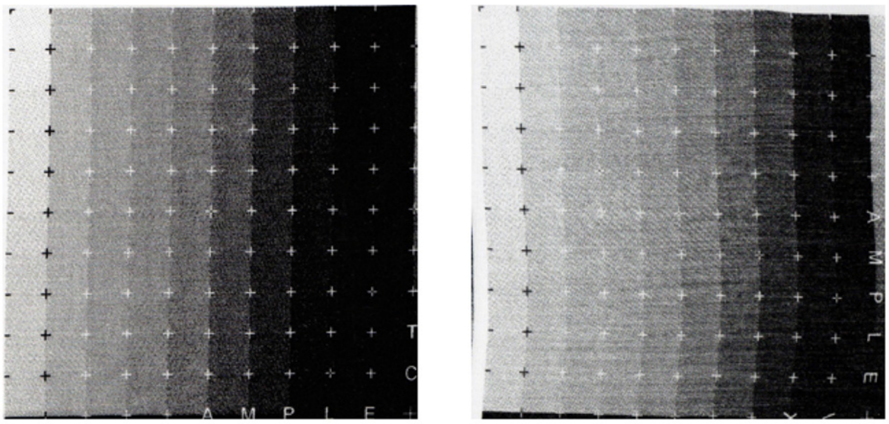
After these four steps, the tone compensation curve can be generated to adjust the density level for each color. In the next section, an evaluation of the compensation curve for 44 different fabrics using 55 samples is presented.

4. EXPERIMENT

4.1 *Data Collection*

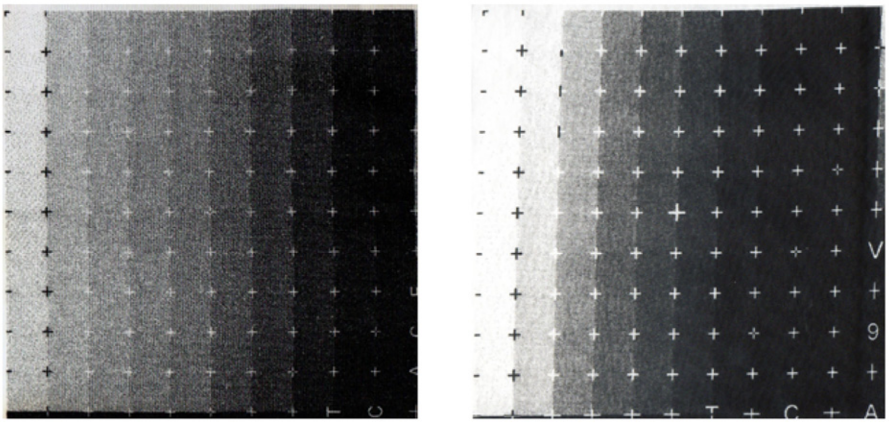
In this research, multiple testing patches are printed on a fabric to obtain CTR measurements. One hundred test patches with 1%–100% tone gradients as a 10 × 10 patch matrix for one primary color are printed on the fabric. Note that these patches are printed without any compensation for the tone level (calibration). This also means that we consider this printing as the initial trial without any treatment of the tone curve. Furthermore, for one primary color, four sets of test patches with different orientation angles (0°, 90°, 180°, and 270°) are printed on the fabric, and the average density values are computed to improve reliability. In this work, X-Rite® Ci64UV spectrophotometer [18] is used to measure L*a*b* values of 100 patches under D65 at a 10-degree viewing angle. The measured L*a*b* values are converted to density values using the PatchTool software [19].

Figure 4 shows examples of test patches that are printed on different fabrics. As can be seen in Fig. 4, the textile characteristics of the fabric significantly influence tone reproduction. By visual inspection of the scanned samples, we can easily see that the measured density values of cotton and nylon are saturated around 80% and 70% tone levels, respectively, when compared with those of rayon and polyester. Moreover, it seems that nylon is relatively lighter at the low tone level, while polyester is slightly darker in the same region. Rayon seems too light in the middle tone range. Obviously, the compensation for tone curves is needed in all these cases.



(a) Cotton

(b) Rayon



(c) Polyester Spandex

(d) Nylon

Figure 4. Black test patches printed on fabric: (a) cotton (100% cotton 133 × 72/40 × 40), (b) rayon (100% rayon 90 × 90/60 × 75D), (c) polyester spandex (86% polyester/14% spandex 120 × 98/75D × 75D), and (d) nylon (100% nylon 151 × 72/70D × 160D). All of them were printed using a 150 mesh count screen. Note that the slight distortion of the scanned image is due to the fabric elasticity when scanning.

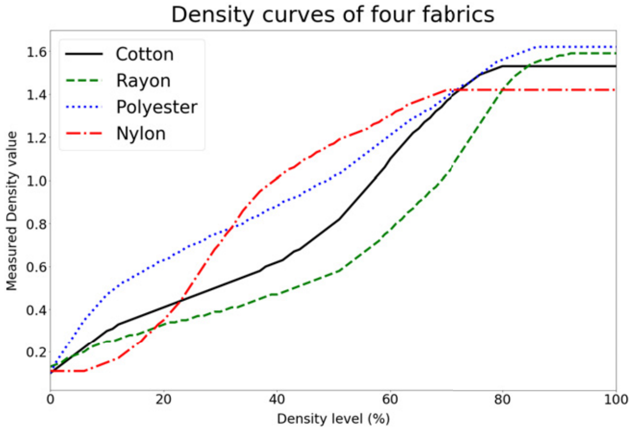
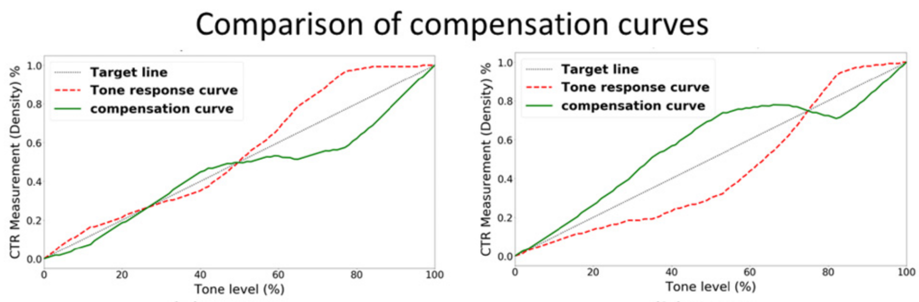


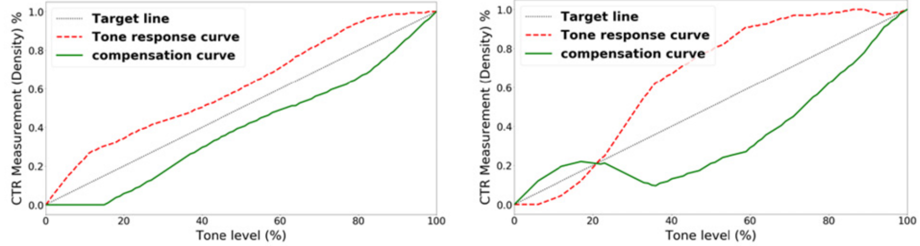
Figure 5. Density curves of four fabrics: (a) cotton (100% cotton 133 × 72/40 × 40), (b) rayon (100% rayon 90 × 90/60 × 75D), (c) polyester spandex (86% polyester/14% spandex 120 × 98/75D × 75D), and (d) nylon (100% nylon 151 × 72/70D × 160D) with no compensation. All of them were printed using a 150 mesh count screen.

Figure 5 presents the density curves of the above-mentioned fabrics. First, consistent with what can been seen in Fig. 4, we can note that the fabrics have different saturated densities. For example, polyester can reach a measured density of 1.6, while nylon can only approach approximately 1.4. In addition, the pattern of each gradient curve is different. Cotton and rayon are more convex, while cotton is more concave. The different curve characteristics, such as convex, concave, and mixed, of the fabrics influence the linearity of tone reproduction. Therefore, calibration is needed to compensate for “oversaturation” or “undersaturation” due to the surface property of each fabric.

In this research, 55 samples of measured density values for 44 different fabrics are used to evaluate the compensation curves. The information about the composition and construction of 55 samples is listed in Table A.1 in Appendix. By following the procedure mentioned in Section 3.3, the density values are rescaled to CTR measurements with a 0–1 scale and the tone response curve can be constructed. Then, the compensation curves denoted by $\widehat{CTR}_{i,j}$ are calculated



(a) Cotton (b) Rayon



(c) Polyester Spandex (d) Nylon

Figure 6. Comparison of compensation curves for four fabrics: (a) cotton (100% cotton 133 × 72/40 × 40), (b) rayon (100% rayon 90 × 90/60 × 75D), (c) polyester spandex (86% polyester/14% spandex 120 × 98/75D × 75D), and (d) nylon (100% nylon 151 × 72/70D × 160D). Solid green curves indicate compensation curves; dashed red lines indicate tone response curves.

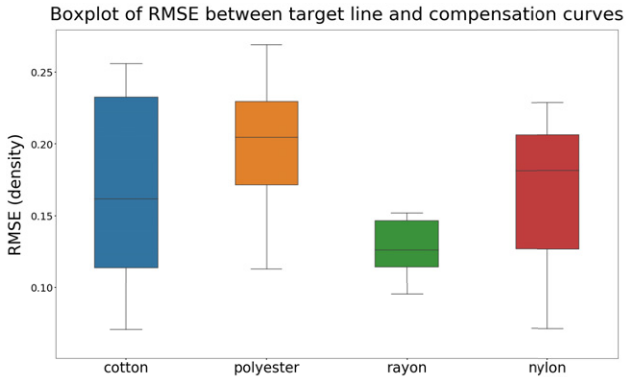


Figure 7. Box plot of RMSE between the target line and the compensation curves for four fabrics: cotton, polyester, rayon, and nylon.

by using Eq. (4). In the next section, the evaluation of compensation curves is presented.

4.2 *Experimental Result*

Figure 6 shows the comparison of compensation curves for the same fabrics shown in Figs. 4 and 5. As can be seen, the solid green curves represent the compensation curves, while the dashed red line indicates the tone response curves. In general, since cotton and nylon have a larger saturation zone at the high tone level, there exist steeper and longer compensation curves (farther from the target line) to reduce the density in that range to compensate for the saturation. Moreover, it seems that polyester tends to print darker in the whole tone level range; the compensation curve of polyester tries to reduce the density at all tone levels. Cotton seems to have more linear gradation at the low to middle tone levels, while rayon and nylon require more compensation at the middle tone level.

To measure the level of compensation for each fabric, the root mean square error (RMSE) defined in Eq. (5) is used to evaluate the difference between the compensation curve $\widehat{CTR}_{i,j}$ and the target line $\widehat{CTR}^{T}_{i,j}$. In Eq. (5), n denotes the number of density levels; $n = 100$ for tone levels i from 1% to 100%:

$$RMSE_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\widehat{CTR}_{i',j} - \widehat{CTR}^{T}_{i',j})^2}. \qquad (5)$$

In general, across four different fabric compositions, the average RMSE between two compensation curves is approximately 0.17 (17%) in terms of the density level. This means that the compensation curve can improve around 17% of density adjustment on average.

Figure 7 shows the box plot of RMSE between the compensation curve and the target line for four fabric compositions. Basically, for each fabric, the maximum, third quartile (Q3 or 75%), median (Q2 or 50%), first quartile (Q1 or 25%), and the minimum of RMSE between two curves are indicated from top to bottom. Note that the unit of RMSE is the scaled density level from 0 to 1, which means 0% to 100%. This also means that 0.1 RMSE indicates that 10 % of density values should be adjusted.

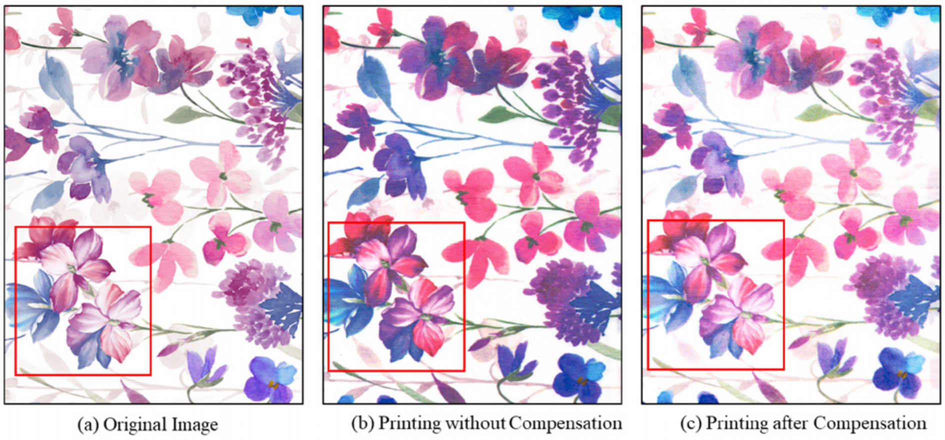

(a) Original Image (b) Printing without Compensation (c) Printing after Compensation

Figure 8. Printings without and with compensation. (a) is the original image for reference; (b) is the scanned image from the print without tone curve compensation; (c) is the scanned image from the print after compensation. Note that (b) and (c) are printed on 100% cotton 133 × 72/40 × 40 twill weave with ten colors (cyan, magenta, yellow, black, gray, light gray, light cyan, light magenta, orange, and green).

As can be seen in Fig. 7, polyester requires more compensation while rayon needs less on average. In addition, cotton and nylon have larger variations in the compensation percentage across different fabric compositions. This also implies that tone curve compensation for cotton and nylon is indispensable for MCHSP mass production. The creation of a compensation curve for each composition of cotton and nylon is suggested. Rayon has a relatively smaller amount of compensation percentage with a more stable variation. This means that rayon has a relatively consistent compensation percentage across different fabric constructions. For the mass production of MCHSP, one rayon compensation curve might be sufficient for different rayon compositions.

Figure 8 displays the visual comparison between the printed images with and without tone curve compensation. In Fig. 8, (a) shows the original image for reference; (b) and (c) show the scanned images from the printed cotton with and without compensation. Note that both (b) and (c) are printed by using ten color channels (cyan, magenta, yellow, black, gray, light gray, light cyan, light magenta, orange, and green). As can be seen, after compensation, (c) exhibits lighter color compared with (b), which is obviously oversaturated. If we visually compare (c) against (a), the original image, it seems that (c) can retain acceptable details regarding the flower petals on the left bottom of this image, displayed in the red rectangle. In this case, the color presentation and print quality in that rectangular area demonstrate the business opportunity for MCHSP mass production.

5. CONCLUSION

For the mass production of MCHSP, machine calibration and tone curve compensation can be considered as separate operating procedures. Due to the requirement of compensating for printing variation caused by the textile characteristics of fabrics, this research proposes the implementation of tone curve compensation for each fabric composition before striking them off for proofing.

Although the concept of printing and measuring color patches to characterize printing is simple and has been utilized in the digital printing industry, in the literature, little information can be found regarding traditional screen printing especially for MCHSP. In this research, color patches printed on 55 samples with 44 different fabrics including cotton, rayon, polyester, and nylon were used to evaluate the compensation percentage in terms of the RMSE of the density level. Based on the experimental results, cotton and nylon tend to have a larger variation in the compensation percentage. This also implies that applying tone curve compensation for cotton and nylon is more critical if the MCHSP technique is used. This work also found that rayon has a relatively small amount of compensation percentage with a smaller variation.

In future work, to reduce the printing and measuring time, a model-based approach to predict the compensation percentage of a tone level for a specific fabric can be developed. More information regarding the fabric material such as plain weave and knitted fabric can be used as input variables of the model. Last but not least, in the application of MCHSP, the method of measuring color presentation and consistency for quality improvement is also required for industry use.

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APPENDIX.

Table A.1. List of fabrics used for experiments.

#	Fabric Type	Fabric Composition	Warp Count	Weft Count	Caliber Warp	Caliber Weft
1	Cotton	100% Cotton (1)[a]	173	113	60	60
2		100% Cotton (2)[a]	173	113	60	60
3		100% Cotton (1)[a]	140	104	80	80
4		100% Cotton (2)[a]	140	104	80	80
5		100% Cotton (1)[a]	150	80	50	50
6		100% Cotton (2)[a]	150	80	50	50
7		100% Cotton (1)[a]	133	72	40	40
8		100% Cotton (2)[a]	133	72	40	40
9		100% Cotton (3)[a]	133	72	40	40
10		100% Cotton	136	72	40	40
11		100% Cotton	180	58	20	20
12		98% Cotton, 2% Lycra	76	44	20 + 70D	20 + 70D
13		100% Cotton	173	130	60	60
14		78% Cotton, 20% polyester, 2% Opelon	133	58	20 + 150D	20 + 150D
15	Rayon	100% Rayon (1)[a]	90	84	60	60
16		100% Rayon (2)[a]	90	84	60	60
17		100% Rayon (3)[a]	90	84	60	60
18		100% Rayon (1)[a]	90	90	60	75D
19		100% Rayon (2)[a]	90	90	60	75D
20		100% Rayon (3)[a]	90	90	60	75D
21		100% Rayon (4)[a]	90	90	60	75D
22		100% Rayon (5)[a]	90	90	60	75D
23		100% Rayon	140	90	40	40
24		100% Rayon	90	100	40	40
25	Polyester	100% Polyester	238	108	50D	50D
26		100% Polyester	208	88	105D	150D
27		100% Polyester	233	91	50D	75D
28		100% Polyester	100	80	20D	150D
29		100% Polyester	220	170	20D	20D
30		100% Polyester	238	116	30D	150D
31		100% Polyester	270	103	50D	75D
32		100% Polyester	72	54	300D	300D
33		100% Polyester	112	94	75D	75D
34		100% Polyester	260	128	30D	30D
35		100% Polyester	133	52	75D	10D
36		40% Polyester, 60% rayon	89	87	85D	40D
37		100% Polyester	186	125	50D	50D
38		100% Polyester	137	138	75D	75D
39		100% Polyester	149	101	75D	75D
40		100% Polyester	159	79	150D	150D

Table A.1. Continued.

41		100% Polyester	119	108	150D	150D
42		100% Polyester	135	110	30D	50D
43		100% Polyester	103	89	75D	75D
44		100% Polyester	155	109	75D	150D
45		100% Polyester	255	133	75D	75D
46		100% Polyester	196	122	50D	50D
47		100% Polyester	106	74	75D	75D
48		86% Polyester, 14% spandex	120	98	75D	75D
49		100% Polyester	106	96	75D	75D
50		86% Polyester, 14% spandex	141	114	90D + 90D	90D + 90D
51	Nylon	100% Nylon	152	90	70D	70D
52		100% Nylon	124	77	80D	80D
53		100% Nylon	151	72	70D	160D
54		91% Nylon, 9% Opelon	128	112	70D + 40D	140D + 40D
55		100% Nylon	225	156	20D	20D

[a] Parentheses indicate the number of replications that are printed on the same fabric.

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