Measuring Print Quality of Digitally Printed Textiles

Ming-Kai Tse and John C. Briggs
QEA, Inc.
99 South Bedford Street #4, Burlington, MA 01803 USA
Tel: (781) 221-0080 · Fax: (781) 221-7107
e-mail: info@qea.com
URL: www.qea.com

Yong K. Kim, and Armand F. Lewis
Textile Sciences Department, University of Massachusetts-Dartmouth
Dartmouth, MA

Paper presented at the IS&T's NIP14
International Conference on Digital Printing Technologies
October 18-23, 1998, Toronto, Ontario, Canada

Measuring Print Quality of Digitally Printed Textiles

Ming-Kai Tse and John C. Briggs
QEA, Inc.
Burlington, Massachusetts/USA

Yong K. Kim and Armand F. Lewis
Textile Sciences Department
University of Massachusetts-Dartmouth
Dartmouth, MA/USA

Abstract

This paper aims to develop an understanding of the factors affecting print quality in inkjet printed textiles and discusses tools for quantifying print quality in these textiles. Cotton fabrics with different fabric structures, yarn sizes, yarn types, and surface treatments were printed on a commercial desktop inkjet printer. Print quality (PQ) analyses were performed using an automated print quality analysis system to quantify quality attributes including line width, image noise, optical density, tone reproduction and CIELab color. Wicking tests were also conducted to elucidate the correlation between the observed print quality and the wicking behavior of the fabric structure. An image processing technique was developed to enhance the accuracy and reliability of print quality measurements and minimize the "noise" introduced by the structure of the fabric. The results of this study provide some insight into the relationship between structure and printability in inkjet printing of textile fabrics. The efficacy of the automated PQ analysis instrument used is also demonstrated.

Introduction

Digital printing on textiles is viewed by many as key to reviving the competitive edge of the textile printing industry in the United States and many other industrialized countries. Digital printing has the potential to shorten the lead time from design to production, speed up production of samples, and reduce production lot size and hence inventory cost.

Digital printing technology on paper for office and graphic arts applications is very advanced – the fruits of many years of investment and R&D. Unfortunately, the same cannot be said for digital printing on textiles. Although several proprietary systems have been successfully developed and reported in the literature[1-6], it is fair to say that in general the technology of digital textile printing is still in its infancy. To maximize the potential of digital printing technology for textiles, much R&D is needed to improve print engines, marking materials, and the manufacturing infrastructure.

The leading digital printing technology for textiles today is inkjet printing, and the most notable applications are in proofing and sample production. Clearly, to realize the full potential of digital printing, and inkjet printing in particular, we must extend applications beyond proofing and sample production and into full production. To achieve this objective, significant improvements are needed in production speed, equipment and operating costs, and print quality.

Print quality in inkjet printing is strongly dependent on the interactions between the ink and the media. In inkjet printing on paper, the significance of ink-media interactions is well recognized and has been extensively researched. Inkjet printing on textiles, however, is a different matter. While the impact on print quality of the fibrous structure of textiles is no surprise, a true understanding of ink-fabric interactions and their effects on print quality remains a wide open field for both academic and industrial research.

As in any R&D activity, an essential first step is to acquire or develop analytical tools for tracking progress and quantifying improvements. When the technology moves out of the laboratory and onto the production floor, these tools will continue to serve, accelerating product development, providing objective specifications, and helping to establish quality control standards. Among the tools needed for textile printing R&D, print quality analysis tools are unquestionably at the top of the list.

Objective print quality analysis is now in use for digital printing on paper and paper-like media, though the number of commercially-available systems is still quite limited.

Automated print quality analysis systems have been used in a variety of applications including print engine and marking material development and production quality control. While there is no fundamental reason why such systems should not be applied to textile printing, the complexity of textile structures and the diversity of textile applications call for a new methodology specific to textiles. This paper discusses the application of a commercial automated print quality analysis of digitally printed textiles. Our objectives are to explore the issues involved in developing a systematic approach to print quality analysis on textiles and to demonstrate the efficacy of this methodology for quantifying the effects on print quality of fabric structure, finish and physical properties.

Textile Print Quality

Print quality issues in digital printing of textiles fall into several main categories: 1) appearance-related issues including line definition, text quality, resolution, image noise, optical density, tone reproduction and (to a lesser extent) gloss; 2) color-related issues including color gamut, color matching and color registration; 3) permanence issues including light fastness and water fastness; and 4) usability issues including the presence of defects and “hand”. Not surprisingly, many print quality issues are common to both conventional and digital printing techniques. However, digital printing introduces a number of problems of its own, for example, jaggies (digital artifacts in edges), banding (lines of missing color), and satellites (extra drops of ink). Clearly, for digital printing of textiles to advance, significant improvements in print quality must be achieved.

Experimental Method

Materials

The most common printed fabrics are made of cotton and cotton blends. For this reason, this exploratory study focuses on cotton fabrics. The fabrics used were obtained from Testfabrics, Inc.[7] A description of them is presented in Table 1. All are woven fabrics except 437, a cotton “T shirt” knit. The fabrics were chosen to illustrate how print quality is affected by the following fabric attributes:

1) Fabric structure (plain weave, twill, sateen and knit)
2) Yarn fineness and thread count
3) Yarn type (combed vs. carded)
4) Fabric treatment (bleached vs. mercerized)

In this set of samples, 400M (print), 407 (poplin), and 419 (broad) are plain weave or its variations. The plain weave samples will be compared with 423 (twill), 428 (sateen) and 437 (knit) to explore the effect of fabric structure on print quality. 407 and 419 will be compared to study the effect of yarn fineness: both are mercerized plain weaves but of different yarn sizes. Samples 407, 419 and 437 (all combed), will be analyzed as a group and compared with 400M, 423 and 428 (all carded). Finally, to investigate the effect of pre-printing preparation, 400M, 407, 419 and 423 (mercerized) will be considered as a group and compared to 428 and 437 (bleached).

Table 1. Description of cotton fabrics studied.

Style	Treatment	Thread count (epi × ppi)*	Yarn size(count)
400M(print)	mercerized	78x76	40/1 × 32/1 (carded)
407 (poplin)	mercerized	100x50	20/1 × 17/1 (combed)
419 (broad)	mercerized	132x72	40/1 × 40/1 (combed)
423 (twill)	mercerized	108x52	14/1 × 14/1 (carded)
428 (sateen)	bleached	96x56	20/1 × 14/1 (carded)
437 (knit)	bleached	38 x 44**	30/1 (combed) ***

**epi = ends per inch, ppi = picks per inch*
*** wales per inch x courses per inch*
**** yarn size in cotton count for the knit*

Preparation and Printing of Test Samples

Printing the samples was performed with an Epson Stylus Color 1520 desktop inkjet printer and the OEM ink set. This printer and its ink set are not specifically designed for textile printing. However, after some experimentation, we decided to stay with this printer since our preliminary results persuaded us that it would teach us a great deal about the inkjet printing of textiles. A minor problem early on was that the sheet feeder was unable to feed the flexible textile samples. To overcome this problem, the fabrics were ironed, cut into rectangles of 216 mm x 280 mm (8.5" x 11"), and taped on three edges to pieces of card stock paper 280 mm x 432 mm (11" x 17") to provide the needed stiffness. After setting the printer's head-to-media spacing to the maximum, the mounted samples went through the normal paper path and were printed without problems. In general, the visual quality of fine detail and color quality in the printed samples was good.

Automated Image Analysis and Test Target Design

For quantitative analysis, a specially designed target was printed. The analysis was performed with an automated image analysis system (QEA IAS-1000). A schematic diagram of the system architecture is shown in Figure 1. Detailed descriptions of the system design and examples of applications can be found in previous publications.[8]

The test target designed for this study contained several sets of lines (1/8, 1/4, 1/2 and 1 pt) in both horizontal and vertical orientations for determining line width, edge raggedness, sharpness, modulation and ink bleed. The test target also contained large solid fill areas of increasing optical density (0 to 100% gray levels in 10% steps) for measuring optical density, tone reproduction, color gamut and image noise. A variety of colors (CMYK and RGB) was included.

In addition to the standard technique of using a diffuse, reflective light source, we developed a new technique for examining the fabric structure using a transmissive illumination table. The fabric was illuminated from below and analyzed with a CCD camera positioned above. The results, presented below, are very revealing of fabric structure and invaluable for differentiating structural characteristics from the topical or reflective qualities of the fabrics.

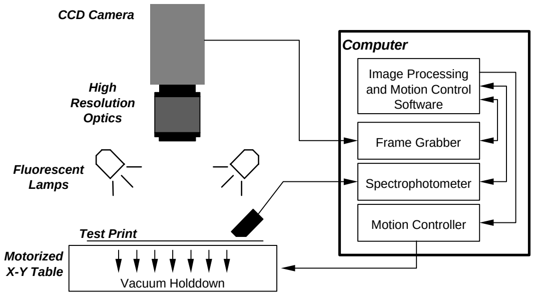

Figure 1: IAS-1000 Automated Print Quality Analysis System (Can also be illuminated from below the samples for transmission measurements.)

Wicking Properties of Fabrics

Wicking and absorption of ink by the fibrous structure of paper media are well known to have a significant influence on print quality, and we expected to see similar effects in fabrics. To quantify the relationship between wicking and print quality in fabrics, we used a simple test method defined in INDA IST 10.0-70 Method 10.3 for non-woven fabrics. Two sets of fabric samples 25 mm wide and 305 mm long were prepared. One set of samples was cut in the warp fiber direction and the other in the weft direction. During the test, each fabric strip was positioned vertically over a glass beaker containing one of several fluids, and the end of the fabric was immersed in the fluid. The wicking rate was measured in terms of the height the fluid achieved in the fabric after 5 minutes. The tests were conducted in both distilled water (W) and 2-octanol (O). The water was chosen to measure the hydrophilic nature of the fabrics. The 2-octanol was chosen to measure the oleophilic nature of the fabric. The ratio of these two measurements, the wicking ratio (W/O), was used as an indicator of the hydrophilic vs. hydrophobic (oleophilic) nature of the fabrics.

Results and Discussion

Visual Quality of the Prints

The visual quality of the textile prints we generated was quite good, considering that neither the printer nor the ink set was optimized for printing on fabrics. The fineness and sharpness of detail, the fineness of text, and the saturation and the quality of the color were all quite acceptable.

As an illustration, Figure 2 compares 6 pt. text images on a textile fabric sample, a "plain" (uncoated) inkjet paper; a matte coated paper and a glossy coated paper. Although the 6 pt. text and the fabric's weave structure are of the same order of magnitude, the text on the fabric sample is quite legible and in fact may be more so than the text in the plain paper image.

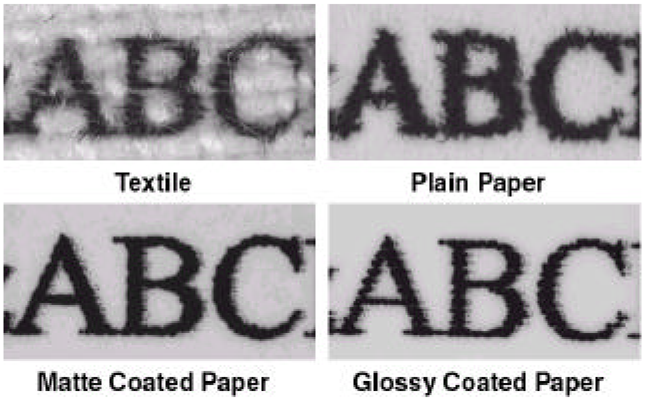
Textile
Plain Paper
Matte Coated Paper
Glossy Coated Paper

Figure 2. 6 pt. text on a plain-weave fabric, a plain paper, a matte coated paper and a glossy coated paper.

Figure 3 reports the color gamut of the same textile and plain paper samples. In both cases, the print quality of the textile sample compares favorably with that of the plain paper sample.

Structural (Transmissive) and Topical (Reflective) Images of the Fabrics

Figure 4 shows both transmissive and reflective images of the fabrics. In this analysis, the camera and optics were set at a pixel size of 8.5 µm, and the field of view of the captured images was approximately 4.1 mm x 5.4 mm. The pixel size and field of view were chosen to provide adequate resolution and a sufficiently large field of view for meaningful comparison of the results of the objective analysis with those of subjective evaluations.

In Figure 4, samples 400 to 428 are woven fabrics, where 400, 407 and 419 are plain-weaves, 423 is a twill woven fabric, and 428 is a sateen woven fabric. Sample 437 is a knitted fabric.

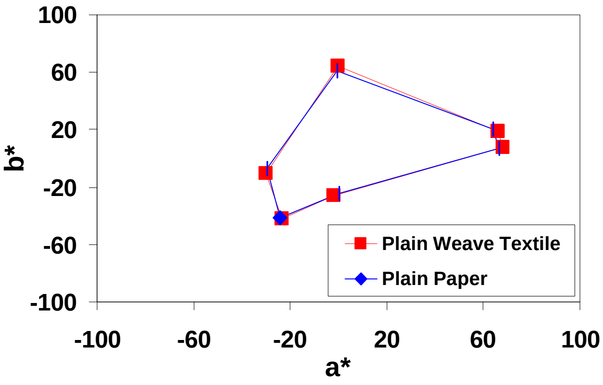

Figure 3 Color gamuts of plain weave textile and plain paper

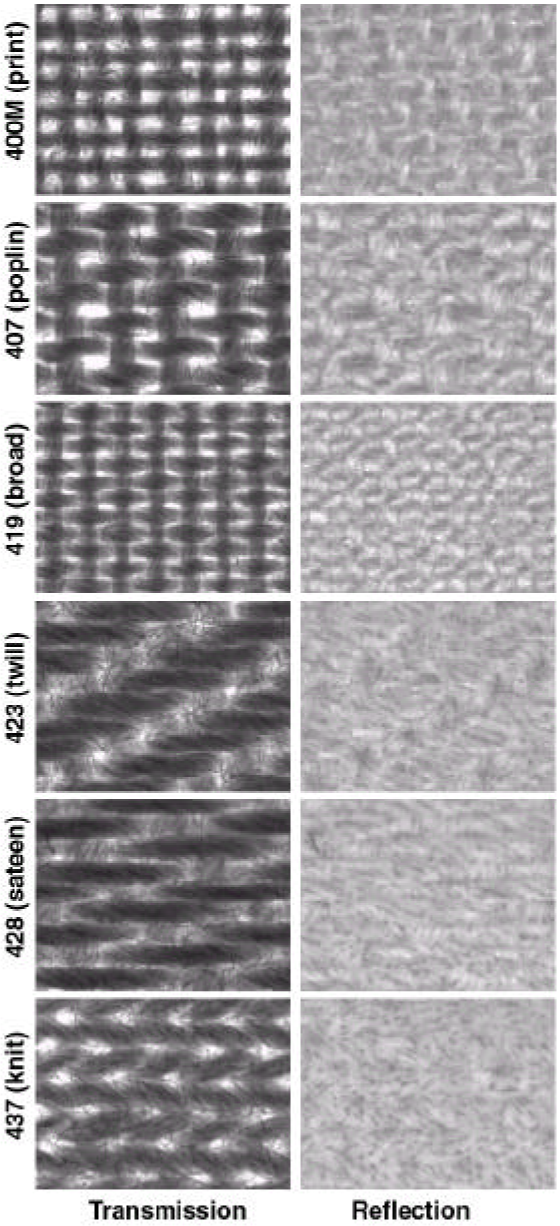

Figure 4. Tranmissive and reflective images of the cotton fabric samples studied.

The differences in fabric structure are very evident in the transmissive images obtained with the CCD camera with illumination from below. Distinct differences are evident between the plain-weave (400, 407 and 419), twill (423), and sateen (428) groups of samples. It should be noted that quantitative information readily obtainable from the transmissive images is an estimate of the number of threads per inch and pore sizes.

The reflective images were obtained using a CCD camera and diffuse, reflective lighting from above the sample. Comparing the reflective images with the transmissive images, it can be seen that the structure of the fabrics shows up quite differently depending on the lighting geometry Among the reflective images, the structure can be seen most clearly in the plain-weave samples (400, 407, and 419). In contrast, the fabric structure is barely detectable in the sateen woven fabric (428). This is expected because the sateen fabric has the smoothest surface structure. The significance of this observation is twofold. First, the fabric structure in the reflective images appears as "noise" in the quantitative analysis and must be treated accordingly. Secondly, the lesser impact of fabric structure in the reflective images suggests the possibility of minimizing the effect of structure in textile print quality analysis by optimizing the lighting conditions.

The issue of minimizing the effect of structure on PQ analysis will be addressed below. Optimizing the lighting conditions for more effective PQ analysis is currently being investigated and will be reported in a future publication.

Method of Data Reduction

In the next sections, the data are analyzed in four groups by fabric type to explore the relationship between fabric properties and print quality:

1) Plain weave vs. twill, sateen and knit
2) Size 20 (407) vs. size 40 (400) yarns
3) Combed (407, 419 & 437) vs. carded (400, 423 & 428)
4) Mercerized (400, 407, 419 & 423) vs. bleached (428 & 437)

The print quality attributes analyzed quantitatively include:

1) Line quality: width, edge raggedness and sharpness
2) Image noise (graininess)
3) Optical density and tone reproduction
4) Color gamut and color accuracy

Line Quality Analysis

Our results show that different fabric properties affect line quality quite differently. Of the properties studied, one of the most significant is fabric structure. The results of our structure comparisons are shown in Figure 5. As the figure shows, the plain weave fabrics have the highest line width gain, followed by the twill and sateen woven fabrics. The knitted fabric has the lowest gain. However, in the case of the knitted fabric, another important factor may come into play, namely, the hydrophobic character of the fabric as demonstrated by wicking tests. The results of these tests are shown in Figure 6. Here, the average line width gain is plotted against the water/alcohol wicking ratio, which is a good indicator of the hydrophilic/hydrophobic nature of the material. From these data, it is clear that the knitted fabric is hydrophobic, whereas the other fabrics are hydrophilic. The correlation suggests that in addition to the effects of structure shown in Figure 5, the hydrophilic/hydrophobic nature of the fabric (or the finish on the fabric) strongly influences the ink-fabric interaction.

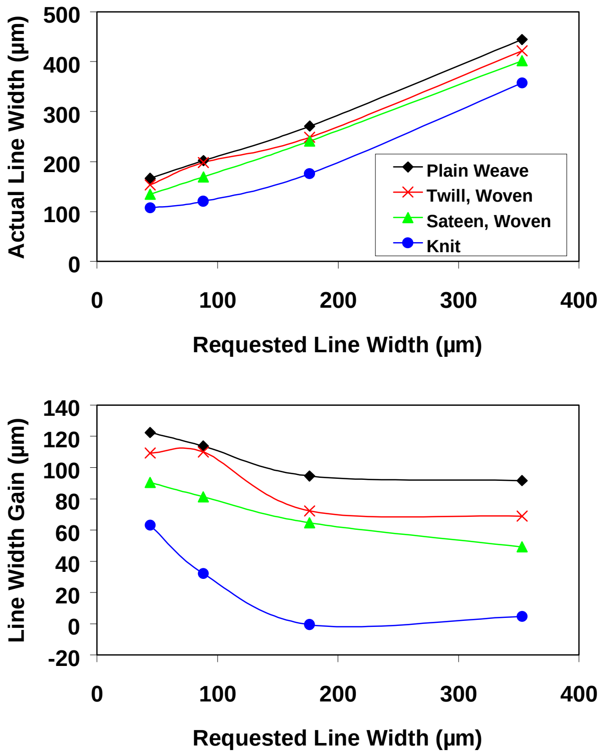

Figure 5. Effect of fabric structure on line width and line width gain

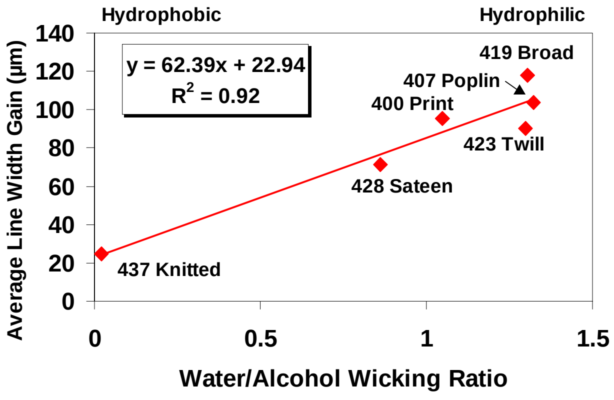

Figure 6. Correlation between avg. line width gain and water/alcohol wicking ratio.

In examining the role of yarn size (20 vs. 40) and type (combed vs. carded) in print quality, we found neither to have a significant effect on line quality. This is expected because these fabrics have similar structures and their physical yarn diameters are not that far from each other. As for the effect of treatment, the bleached samples (sateen and knit) showed substantially smaller line width gain than the mercerized samples (print, poplin, bond, and twill), but this finding could have been biased by the strong effect of the hydrophobic knitted fabric.

The dependence of edge raggedness and sharpness on fabric properties was found to be similar to the dependence of line width on these properties.

Graininess (Image Noise) Analysis

The effect of fabric structure on graininess (image noise) was noticeable, and the fabric variable with the greatest impact on image graininess was found to be yarn size. The results are shown in Figure 7. Yarn type was also considered, but was found to have no significant impact on graininess. Generally, as gray level increases from 10 to 100%, graininess decreases. In other words, noise is most noticeable in the highlight and mid-tones regions; it is affected mostly by the size of the yarn and to a lesser degree by the fabric structure.

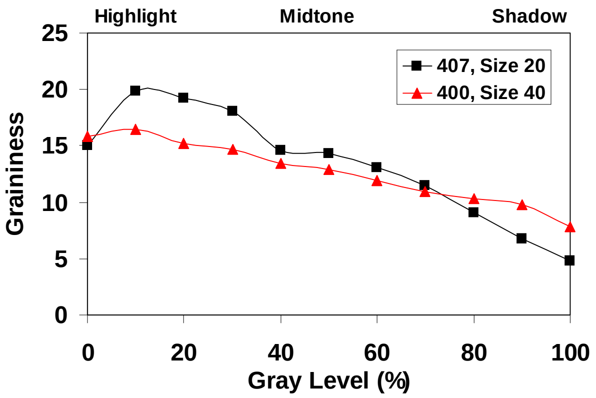

Figure 7. Effect of yarn size on graininess (image noise)

Optical Density and Tone Reproduction

Figure 8 compares the optical density and tone reproduction characteristics of different fabric structures. The most significant difference is found between woven and knitted structures, particularly at high gray levels.

Color Gamut and Color Accuracy

We were surprised to find that the color appearance of all samples tested was quite similar. Quantitatively, the color gamuts of all the samples were about equal. However, two observations (illustrated in Figure 9 and Table 3) are worth mentioning. The top graph in Figure 9 compares the color gamuts of the two fabrics (yarn sizes 20 and 40) listed in the top row of the table. It appears that the color gamut for the larger size yarn is larger than the smaller size yarn. The difference is 15.5%, as shown in Table 3. Secondly, although the numerical color gamuts for the plain weave samples and the knitted sample are very close, there is an apparent downshift in the a*-b* plane for the knitted sample, indicating a color shift between the two types of fabric structures.

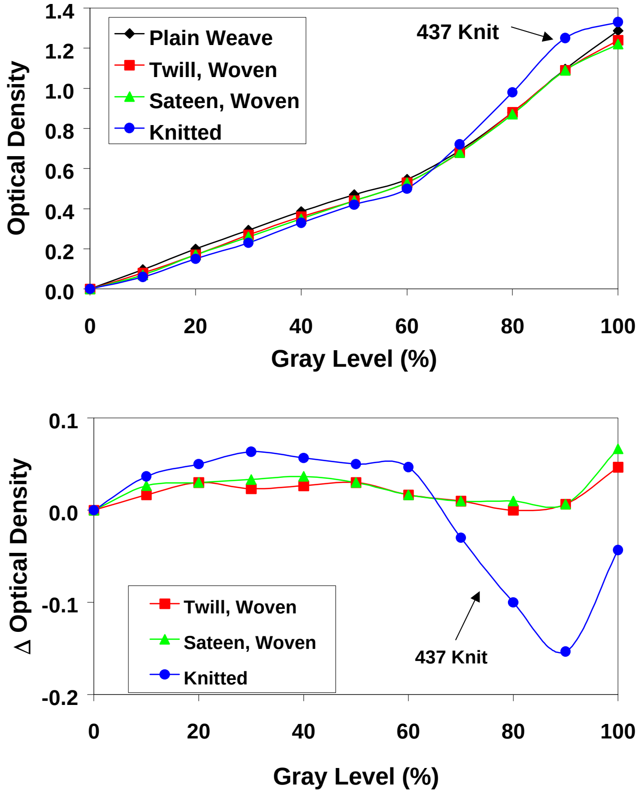

Figure 8. Effect of fabric structure on tone reproduction.

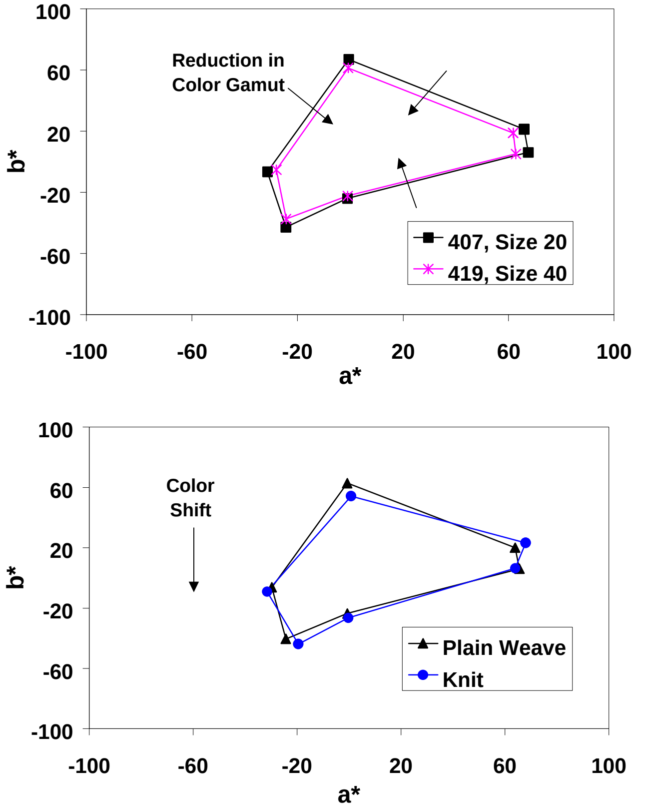

Figure 9. Effect of yarn size and fabric structure on color gamut.

Table 3. Effect of fabric properties on color gamut.

Variable	Gamut A	Gamut B	Δ (%)
Size 20 (A) vs. Size 40 (B)	5449	4607	15.5
Mercerized (A) vs. Bleached (B)	5039	4863	3.5
Others (A) vs. Knit (B)	4992	4923	1.4
Combed (A) vs. Carded (B)	4993	4968	0.5
Plain Weave (A) vs. Others (B)	4991	4969	0.4

Image Processing To Improve the Signal-to-Noise in Print Quality Analysis on Fabrics

As shown in Figure 10, the fabric structure clearly appears in the background in reflective images of 1/8 pt. lines. Not surprisingly, the structural background appears as "noise" in the captured images making it very difficult to make quantitative measurements accurately and reliably. This is particularly true for lighter colors such as magenta, as shown in Figure 10. To solve this problem, one approach we developed is to make use of the repetitive nature of the fabric structure, using averaging to isolate the signal (e.g. a printed line) from the noise (fabric structure).

Figure 11 illustrates how averaging enhances the signal-to-noise ratio for the magenta images. The top graph in Figure 11 shows a single-pixel-wide scan of the reflective magenta lines (lower right image in Figure 10) from left to right. In this graph, the "noisy" nature of the single-pixel-wide data is evident. The lower graph in Figure 11 shows the average of 200 single-pixel-wide scans, and a dramatic improvement in the line scan data is evident.

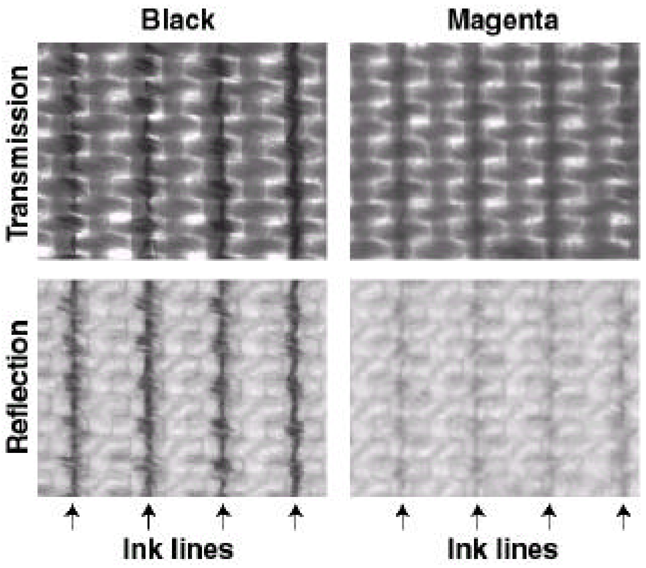

Figure 10. Transmissive and reflective images of fabric and printed lines.

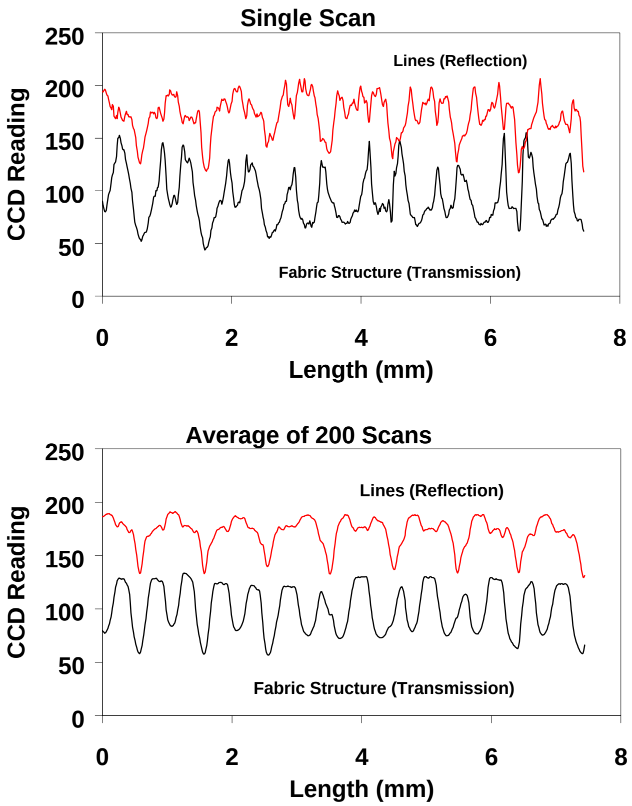

Figure 11. Use of averaging to improve signal-to-noise in fabric print quality analysis.

Conclusions

This study demonstrates the application of automated print quality analysis to research and development of digital printing of textile fabrics. The efficacy of the test system used is demonstrated in a study of the effects of fabric properties on print quality. The main observations in this study can be summarized as follows:

1) The subjective, visual quality of inkjet printed cotton fabrics was as good as printed plain paper.
2) A technique using a transmissive lighting arrangement was developed to observe the fabric structures more clearly. This technique was shown to allow the fabric structure to be distinguished from the printed image on the surface of the fabric.
3) Several important print quality attributes including line quality, image noise, optical density and color quality were measured using the automated print quality analysis system. The results clearly show the efficacy of using automated print quality analysis on textiles.
4) The effects on print quality of several key fabric properties were studied. These include fabric structure, yarn size, yarn type and pre-treatment. The test results suggest that the most significant fabric variables are fabric structure, yarn size and the hydrophilic/hydrophobic nature of the fabric.
5) An image processing technique to enhance the signal-to-noise ratio in textile print quality analysis has been demonstrated. The technique uses a simple averaging method and is found to be very effective for analyzing print quality in fabrics having a repetitive structure.

References

1 J. L. Crawford, C. D. Elzinga, and R. Yudico, “Print Quality Measurements for High-Speed Electrophotographic Printers,” *IBM Journal of Research and Development*, Vol. 28, No. 3, May, 1984.
2 J. Raymond Edinger, Jr., “The Image Analyzer – A Tool for the Evaluation of Electrophotographic Text Quality,” *Journal of Imaging Science*, Vol. 31, No. 4, July/August, 1987.
3 Yasuhiko Tanaka and Takao Abe, “Quantitative Analysis of Print Quality Features,” *Journal of Imaging Technology*, Vol. 13, No. 6, December, 1987.
4 Dirk Hertel, Karin Töpfer, and Horst Böttcher, “Image Quality Investigations by Means of Photodetector Arrays,” Journal of Imaging Science and Technology, Vol. 38, No. 1, January/February, 1994.
5 Pei-Lun Wang, “Print Image Quality Evaluation System,” *IS&T’s 10th International Congress on Advances in Non-Impact Printing Technologies*, 1994.
6 Paul Spencer and Duane Schwartzwald, “Automatic Print Quality Measurement Using a Scanner,” *IS&T’s 12th International Conference on Digital Printing Technologies*, 1996.
7 Testfabrics, Inc. 415 Delaware Ave., West Pittston, PA 18643
8 M.K. Tse, D. J. Forrest and J. C. Briggs, “Automated Print Quality Analysis for Digital Printing Technologies,” PPIC/JH ’98: The Society of Electrophotography of Japan, Pan-Pacific Imaging Conference/Japan Hardcopy ’98 (1998).

Biography

Dr. Ming-Kai Tse founded QEA, Inc. in 1987. The company designs and manufactures automated quality control test systems for manufacturing and R&D applications in digital printing. Dr. Tse was a professor of Mechanical Engineering at the Massachusetts Institute of Technology between 1982 and 1989. At MIT he specialized in the areas of manufacturing, non-destructive testing, and quality engineering. Dr. Tse received his BS degree in Mechanical Engineering from Cornell University and his MS and PhD degrees, both in Mechanical Engineering, from MIT.