Digital Textile Printing with Laser Engraving: Surface Contour Modification and Color Properties

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Introduction This research combines two digital technologies for customizing textile substrates: carbon dioxide CO2 laser treatment and digital textile printing. With laser treatment and digital printing technology, various textures and patterns can be created on fabrics. One of the most important aesthetic effects of applying these technologies is the modification of the color properties of the textile materials. The objective of this research was to assess the color quality of inkjet-printed colors on cotton velvet fabric with pile height variance created by treatment with different laser intensities. Because color yield depends on the texture in contact with the dye (Endo et al., 2013; Kan et al., 2011; Kitaguchi et al., 2005; Shao et al., 2006; Xin et al., 2005), it was anticipated that variation in the pile height of a pile fabric would influence colorimetric attributes of the substrate.

Significance of the Research The precedent studies focused on inkjet printing quality and color attributes on woven, knitted and nonwoven fabric constructions and their surface characteristics (Bae et al., 2015; Carr et al., 2006; Choudhury, 2014; Janssen, 2017; Luo et al., 2015; Mhetre et al., 2010; Park et al., 2006). However, limited studies have concentrated on inkjet printing on pile fabric. In this research, the influence of the textured surface of a pile fabric on its instrumental color measurements will be investigated. Moreover, this study will provide a fundamental proof of concept demonstrating the effectiveness of combining these two technologies for creating multiple variations in texture and color on a given substrate. This is a key step toward developing an integrated laser treatment and digital inkjet printing manufacturing approach for the apparel and textile design industry. Customization systems are valuable tools for addressing sustainability and consumer demands. Moreover, instrumental color measurement data can be used to predict the color quality of the substrate, determining settings for specific surface design effects, and for practitioner use in mass customization approaches.

Background Pile fabrics are distinguished from other textiles by their surface, where an almost infinite number of fibers stand erect from the foundation structure of the cloth (Gladstone, 1970). Pile surfaces are suitable for sculpture with lasers through partial and controlled removal of portions of fibers and creating variations in fiber height. In addition, in digital inkjet printing, most of the ink reacts with the surface of the fibers instead of penetrating into the core; thus fabric surface topology and structure can affect the amount of ink that reacts with the fiber and hence its resulting colorimetric properties (Bae et al., 2015; Lim & Chapman, 2019). Researchers have previously indicated the possibility of creating certain design effects by controlling the intensity of the laser and removing the colorant present on the surface of the fabric and by altering the coloration properties and the dyeability of substrates (Bahtiyari, 2011; Kan, 2014; Shahidi et al., 2013).

Methodology To develop samples, a 40W Universal VLS6.60 laser was used for engraving the surface of 100% cotton velvet fabric and creating pile height variance. The laser generates a beam with a wavelength of 10.6 µm, and the settings were kept constant at 100% speed and 55% power with a resolution of 400 dots per inch. Laser intensity was controlled by using 0%, 50%, 75%, and 100% grayscale patterns to modify pile height and surface contour of velvet fabric. Higher grayscale intensities result in the removal of a larger portion of the surface pile because the laser machine engraves at the power set for the pure black graphics and uses less power for different levels of the gray. After exposure to the laser treatment and a subsequent wash, the substrate was pretreated for printing with reactive dyes. Following pretreatment, seven solid colors: cyan, magenta, yellow, black, red, green, and blue were printed in stripes on the surface of the treated fabric with a Mutoh 1938TX 60" roll to roll printer. The resolution was 180 dpi, the number of passes, and ink droplet size was held constant. Following printing, samples were post-treated in an SSM100 steamer and washed out. After sample development was completed, the colorimetric properties of the fabrics were measured with a Datacolor 800 spectrophotometer using D65 illuminant and 10° standard observer functions. UV was included and specular light was excluded and an average of four readings was obtained. Reflectance curves, CIE L*a*b*, C* and K/S values were obtained and interpreted to compare colorimetric properties of the treated substrates based on laser intensity for different hues and the results were analyzed.

Results Reflectance values represent the percentage of the amount of light leaving a surface divided by the amount of light that strikes it (Johnsen, 2016), and for white paper and textiles printed with colored inks are inversely proportional to the amount of colorant present on the surface. For fabrics printed with cyan, magenta, yellow, red, and green printed colors, the reflectance values decreased when the laser treatment was applied. As the surface area available for the coloration of fiber increases, the appearance of the colored fiber would become lighter for a given amount of colorant employed. This could be due to the increased scattering of light from larger surfaces. Accordingly, a reduction of pile length can result in a reduction of the sum of reflected light due to reduced scattering and increased absorption of light. However, printed fabrics with black and blue printed colors showed increased reflectances after laser treatments because in those cases, the removal of pile resulted in increased reflectance from the white background substrate. Besides, in the case of dark printed colors, the low signal to noise ratios can increase the effect of noise on readings.

Chroma, C* indicates the purity, colorfulness, or departure from gray for various hues. The value increases for increased amounts of colorants present on a fabric surface. Higher C* is described as more vivid, while lower C* is paler (Hunt & Pointer, 2011). As shown and expected C* of printed samples decreased as laser intensity increased which indicates that shorter pile heights exhibited lower color intensity (Figure 1). In other words, this implies decreased amounts of colorants are present on the shorter pile substrate. Note that black is an achromatic color. K/S values, shown in the plot, are obtained using the Kubelka-Munk function and denote the color yield of fabrics. The K/S values decreased based on an increased grayscale category associated with increased laser intensity similar to C* except for black printed color. In agreement with expectations, this indicates lower color strength at higher laser intensities due to increased removal of piles from the substrate.

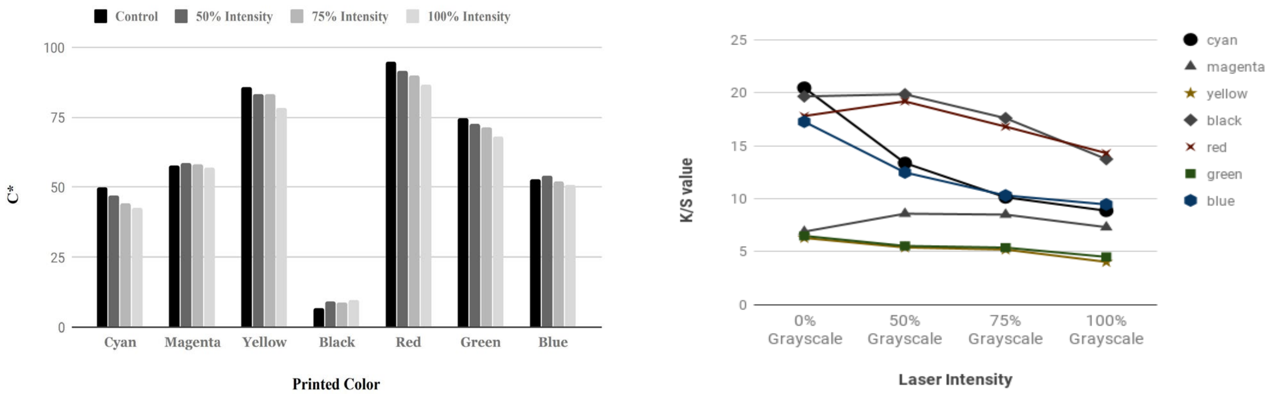

Figure 1. C* Value of All Printed Colors by Laser Intensity (Left), K/S value of All Printed Colors by Laser Intensity (Right)

The total color difference, represented by ΔE or DE, is the quantification of the perceptual difference between two colors. It indicates the difference or distance between two given colored stimuli in the CIE L*a*b* color space. For the total color difference, control fabric with no laser treatment was standard for each color. Interestingly, the ΔE_{cmc} mean rank decreased when the laser treatment was applied, similar to the color attributes C* and K/S. Moreover, the increment of laser intensity resulted in the smaller difference of ΔE_{cmc} score between colors.

Conclusion The experiments revealed that the changes in surface morphology of cotton velvet fabric printed by a digital printer with reactive dye achieved variable reflectance values, chroma, color strength, and total color difference. The increased removal of pile fibers after laser treatment reduced the surface available for colorant absorption as well as light loss in these regions. Furthermore, in this research, a controlled variation of pile height by adjusting the laser intensity resulted in instrumentally measurable differences in the color quality of inkjet-printed substrates. Future work will aim at demonstrating the relationship between instrumental color assessment and visual color perception of textured fabrics. Moreover, diverse types of fabrics, depending on structures and fiber content, will be studied.

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