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© K. Chepurna, PhD, Associate professor, O. Khmiliarchuk,
PhD, Associate professor, M. Ehorchenko, master,
Igor Sikorsky KPI, Kyiv, Ukraine

EFFECT OF FABRIC PROPERTIES ON OPTICAL PARAMETERS OF PIGMENT-BASED INKJET PRINTS

The article presents the results of an experimental study on the influence of the physical properties of natural fabrics on the optical characteristics of prints produced by direct inkjet printing with pigment inks. In response to the growing demand for personalized textile products, the study analyzes image reproduction on cotton fabrics with varying characteristics, including color, thickness, weave type, and surface roughness.

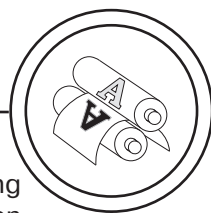
Keywords: inkjet printing; natural fabrics; pigment inks; color difference; lightness; optical density; white underlayer.

Introduction

The growing demand for applying various types of images to textile products has become a significant vector in the development of the textile industry, as it adds both economic and emotional value to the final product. Direct-to-fabric digital printing is currently one of the most efficient solutions in modern printing technologies due to its numerous advantages, including speed, personalization, and the ability to produce complex designs [1–3]. The use of fabrics with different weave structures, colors, and textures necessitates the development of technical and technological solutions to ensure graphic, tonal, and color accuracy in reproducing digital layouts. It is essential to consider that the physico-optical properties of the printed substrates particularly porosity

and color directly influence the visual perception of printed images, including their colorimetric and optical characteristics. In turn, the surface texture and weave structure of textile materials affect the graphical accuracy and sharpness of image reproduction.

Research on the quality of prints produced by direct digital textile printing is conducted in several directions, including the study of physico-mechanical fabric properties; evaluation of the effectiveness of surface treatments; implementation of intelligent methods and algorithms for color management in textile printing; and improvement of ink formulations for inkjet textile applications [4–10]. For example, in [4], the influence of structural characteristics of polyester fabrics on graphical and color accuracy was examined. It was found that



ink diffusion depends on fiber porosity, while surface pretreatment helps reduce edge blurring in printed elements. In [6], it was established that weave structure, fiber type, surface fuzziness, and pretreatment significantly affect the quality of pigment-based digital printing, particularly in terms of color saturation and image durability. Pretreatment reduces ink spreading and migration into the fiber bulk, which enhances the color intensity of the print layer; however, additional synthetic coatings may reduce ink-to-fiber adhesion. Furthermore, using yarns made from short fibers increases color intensity due to a larger pigment deposition area but negatively affects rub resistance, thereby reducing the functional durability of prints.

The effectiveness of surface treatment of cotton fabrics with cationic nanoparticles for improving inkjet print quality on textiles with different weaves was demonstrated in [5]. The treatment reduced fabric porosity and surface roughness, increased hydrophobicity, and enhanced dye interaction, resulting in high image sharpness, improved color saturation, and sufficient ink fixation without significantly affecting the tactile properties of the fabric.

To eliminate color differences between the original digital design and the print on textile substrates caused by both the physical properties of the substrate and the characteristics of the output device [7] proposed the use of ICC profiles generated based on material data and printer parameters. A comparative analysis was conducted between manually created profiles and those produced using a regression-based neural network model.

Various algorithms are being tested for optimizing production processes and predicting product quality [8]. The application of artificial neural networks, fuzzy logic, clustering, and optimization algorithms significantly enhances the precision and efficiency of processes such as color management. Nevertheless, challenges related to data complexity and variability in experimental conditions remain, opening new directions for further research [9].

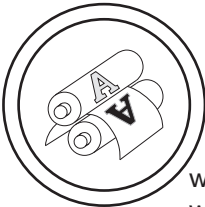
The development of innovative colorant formulations is addressed in [10], where an improved reactive ink formulation for cotton inkjet printing was proposed using polymer components. Specifically, the incorporation of polyethylene glycol reduced satellite droplet formation, limited ink spreading and penetration into the fabric, and increased dye fixation. These findings confirm the potential of polymer structures in the creation of high-quality and cost-effective next-generation inks.

The conducted literature review confirms the relevance of further research in the field of branded textile product manufacturing, particularly in applications such as eco-bags, drawstring backpacks, T-shirts, and hoodies, aimed at achieving predictable print quality.

The aim of this study is to investigate the influence of the properties of natural fabrics on the optical characteristics of inkjet-printed images using pigment-based inks.

Methods

For the experimental study, an Epson SureColor F200 inkjet printer was used. This device is equipped



with piezoelectric printheads and water-based pigment inks that are free from harmful volatile organic compounds, making the printing process environmentally safe. This aspect is especially relevant when printing on natural fabrics such as cotton. Pigment inks are well-suited for textile substrates, providing high durability and print fastness.

The test prints were applied to three types of natural cotton fabrics differing in thickness, surface roughness, and weave structure:

Sample 1: Ultra-soft, white, lightweight plain weave cotton fabric; yarn thickness — 0.17 mm; yarns consist of twisted fibers; surface is relatively rough.

Sample 2: Zweigart Edinburgh 35 ct. 3217/309 Light Mocha; light mocha-colored plain weave cotton fabric; yarn thickness — 0.41 mm; twisted yarns with a rough surface texture.

Sample 3: Beige denim twill ribbed fabric; 100 % cotton; twill weave; yarn thickness — 0.33 mm; tightly twisted yarns; the surface exhibits pronounced texture.

Photographs of the studied materials are presented in Table 1.

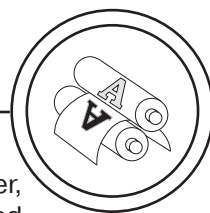
To evaluate the color reproduction accuracy and optical performance of the prints, a test chart was developed featuring standardized control elements intended for assessing tone and optical properties of printed images on textile substrates (see Fig. 1).

The test chart was prepared in the CMYK color space using Adobe Illustrator. To ensure consistent print conditions across all fabric samples, the standard CMYK profile 'Standard SLOW' embedded in the printer's RIP software was applied. The output resolution was set to 1440×720 dpi.

Table 1

Photographs of investigated textile materials

Fabric name	Photo of fabric weave	Photo of fabric fiber
Sample 1		
Sample 2		
Sample 3		



Studies [11, 12] have demonstrated that the inherent shade of the substrate material can cause distortion in the colorimetric properties of printed images. To evaluate the influence of the substrate's color on the optical and colorimetric characteristics of the prints, fabrics with varying inherent color shades were selected for analysis. Table 2 presents the lightness (L^*) and chromaticity (a^* , b^*) values of the investigated fabric samples. For comparative purposes, the CIELAB coordinates of a white underlayer and standard office paper used as reference measurement backgrounds were also determined.

Printing was conducted using two approaches. Sample 1 (white fabric) was printed without a white underlayer. Samples 2 and 3 were

printed with a white underlayer, which is technologically required to ensure accurate color reproduction. Additionally, Sample 3 was printed without an underlayer to isolate and assess the influence of the fabric's inherent color on the optical and colorimetric attributes of the resulting prints.

To study the optical and colorimetric properties of the printed samples, an X-Rite SpectroEye spectrophotometer was used (0/45° measurement geometry, 2° observer angle, D65 light source). Measurements were performed on top of a white office paper stack for both backed and unbacked samples. The evaluated parameters included: optical density (D), Lightness (L^*), color coordinates (a^* , b^*) in the CIELAB color space, color difference (ΔE^*).

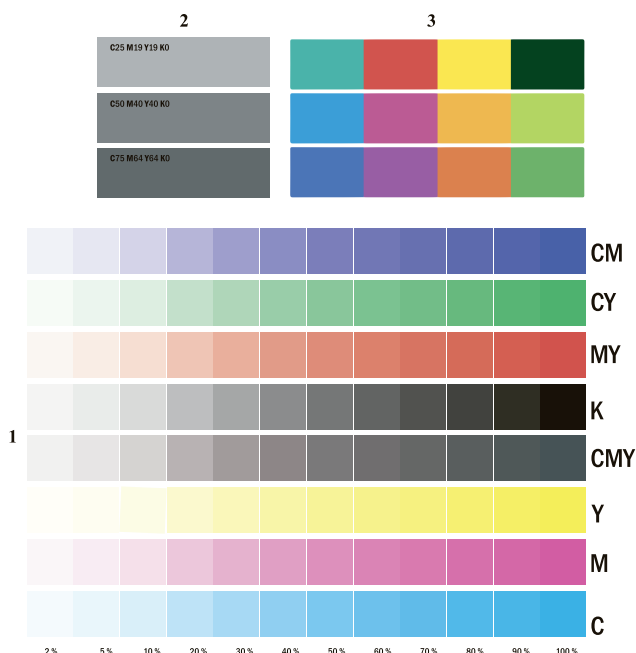


Fig. 1. The test chart for experimental printing: 1 — CMYK tone scales and their binary gradients; 2 — neutral gray balance patches (25 %, 50 %, 75 %); 3 — color memory patches (reference hues)

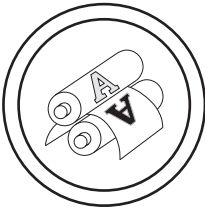


Table 2

Colorimetric parameters of investigated fabric samples

Samples of materials	L*	a*	b*	Color simulation of samples using Lab coordinates
Fabric sample 1	90,99	2,49	-10,28	
Fabric sample 2	81,52	0,91	10,96	
Fabric sample 3	78,18	2,9	16,05	
White underlayer	89,87	0,11	-0,51	
Office paper	93,76	3,07	-8,13	

The color coordinates of the test patches in the digital reference file were used as the target values for evaluating the color difference metric, as presented in Table 3. A visual assessment of the uniformity and solidity of the printed color layers was conducted using a Si-geta Biogenic 40x–2000x microscope.

Results and Discussion

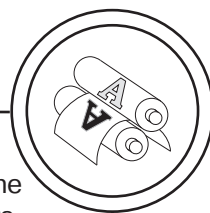
The visual perception of the studied textile substrates correlates with

the measured color coordinates, confirming the consistency of their chromatic tones. Samples 2 and 3 are characterized by warm beige hues, whereas Sample 1 and the office paper exhibit a cooler tone, shifted toward the blue-violet spectrum, as indicated by the negative values of the b* coordinate. Additionally, Samples 2 and 3 display lower lightness (L*) values (Table 2), which may further contribute to the reduction in the perceived brightness and color saturation of printed images.

Table 3

CIELAB color coordinates of the 100 % coverage patches in the digital test file

Control patch	L*	a*	b*	Control patch	L*	a*	b*
C	58	-25	-50	CMY	14	-2	17
M	50	74	-4	MY	48	66	54
Y	94	-13	101	CY	49	-77	41
K	0	0	0	CM	20	36	-49



Measurement results showed that the lightness values of the prints were generally higher, indicating that the images appeared lighter and less saturated (Fig. 2). An exception is the yellow control patch, where the results are influenced by the high transparency of the yellow pigment and the underlying substrate color. In Samples 2 and 3 with a white underlayer, the yellow control patch shows a loss of lightness due to the presence of additional colorant components, which is a known feature of inkjet printing technology [13]. For substrates with a white underlayer, the lightness values remain nearly identical, as the image is formed on the underlayer itself, serving as a uniform optical background, regardless of the textile base color. In Sample 3 without an underlayer, the lightness values of the CMY triadic patches are slightly lower, confirming the influence of the fabric structure. Both composite black (CMY) and process black (K) were reproduced with lighter tones compared to the corresponding values in the

digital file, which is attributed to the optical transparency of pigments, light scattering on the textile surface, and insufficient ink absorption by the fibers.

Fig. 3 demonstrates the impact of the fabric on the rendering of 25 %, 50 %, and 75 % gray balance patches. Samples 2 and 3 (with white underlayer) show Lab coordinates closest to the digital reference, due to the optical neutrality of the white base. In contrast, Sample 1 exhibits a noticeable blue hue in grayscale patches due to the fabric's inherent color; similarly, Sample 3 (without underlayer) reflects a warm yellowish hue from the textile. It is evident that fabric influence is more pronounced in low-saturation patches (25 %, 50 %) than in darker areas (75 %).

The evaluation of the color difference metric (ΔE) enables a quantitative assessment of the color matching accuracy between the printed output and the digital reference file. The ΔE value serves as a critical parameter for ensuring accurate color reproduction and compliance

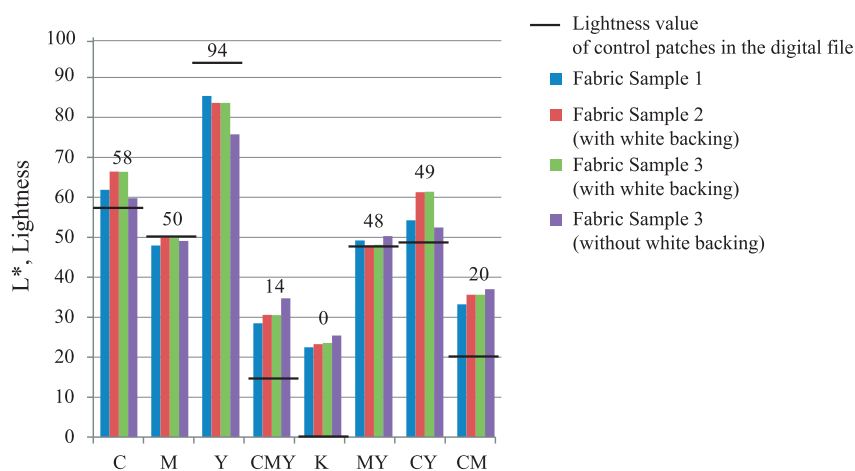
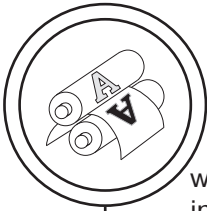


Fig. 2. Influence of textile material on lightness (L^*) for 100 % test patches



with customer specifications. According to the certified Fogra Process-Standard Digital (Fogra PSD) methodology [14], the permissible ΔE_{00} value depends on the selected level of color conformity and the intended application of the printed product. For the standard conformity level 'B', the ΔE_{00} tolerance is defined as less than 5.5, whereas for higher precision requirements (level 'A'), the ΔE_{00} must be below 4.5 [14].

Fogra PSD is based on a series of international standards, including ISO 15311-2 [15], which specifies a recommended tolerance range for ΔE_{00} in digitally printed textiles of 1.5 to 5.5.

To calculate the color difference, the $\Delta E_{1994(\text{Textiles})}$ formula was employed, as it accounts for the specific characteristics of textile substrates. Based on the calculated ΔE values, presented in Table 4, graphical dependencies were constructed to illustrate the influence

of fabric color properties on the reproduction accuracy of the control patches.

Based on the calculated ΔE^* values for grayscale patches (25 %, 50 %, 75 %) (Fig. 4, a), the influence of the fabric color is evident, particularly for light and midtone fields in Samples 1 and 3 (without underlayer). In contrast, Samples 2 and 3 (with white underlayer) demonstrated ΔE values within the acceptable range (≤ 5 units), which is reasonable, as the underlayer effectively isolates the image from fabric interference.

In analyzing ΔE for 100 % solid patches (Fig. 4, b), Sample 1 and Sample 3 (without underlayer) exhibited slightly higher deviations compared to underlayer-based prints. This highlights the role of substrate color and structure in color accuracy.

A comparative analysis of ΔE values across materials facilitates identification of the optimal sub-

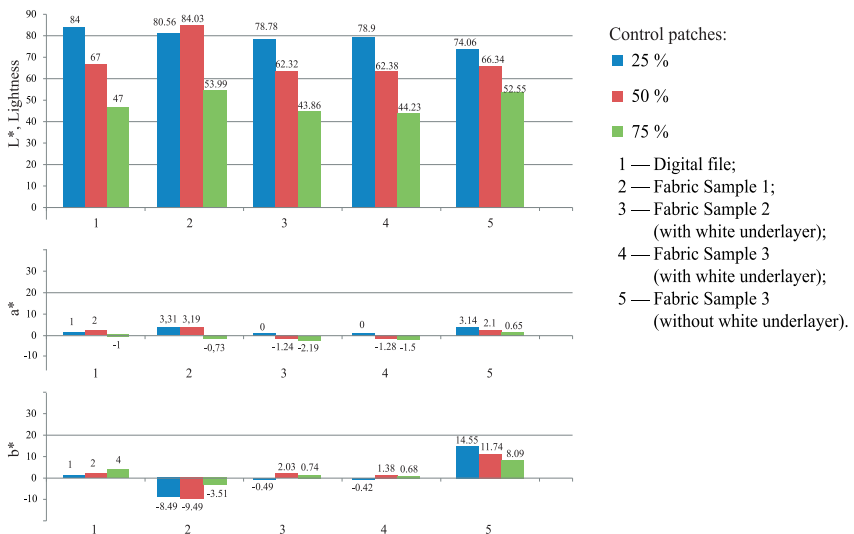


Fig. 3. Impact of fabric on color coordinates of grayscale control patches (25 %, 50 %, 75 %)

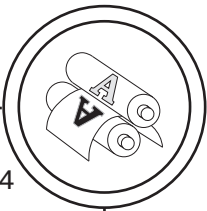


Table 4

Calculated color difference values for the investigated materials

Control patches	Color difference $\Delta E_{1994}(\text{Textiles})$			
	Fabric Sample 1	Fabric Sample 2	Fabric Sample 3 (with white underlayer)	Fabric Sample 3 (without white underlayer)
C	9,27	9,17	9,41	12,97
M	11,84	4,78	4,69	11,52
Y	6,27	7,95	7,68	11,58
CMY	11,53	12,13	12,04	12,87
K	11,32	11,7	11,85	13,03
MY	9,32	6,87	6,79	10,35
CY	11,37	11,34	11,62	11,78
CM	12,23	10,49	10,57	14,53
GS 25 %	9,46	3,1	3,05	13,79
GS 50 %	13,72	3,89	3,94	8,69
GS 75 %	7,91	3,55	3,28	4,68

strate for consistent color reproduction, ensuring high-quality prints aligned with digital proofs.

Fig. 5 presents the optical density (D) of 100 % patches. Sample 1 (without underlayer) exhibited higher optical density than Sample 3. This is due to the high reflectivity of light-colored (especially white) substrates, which enhances the ink's light absorption and perceived color saturation. Conversely,

dyed fabrics affect spectral absorption by contributing their own reflectance, thus reducing overall ink absorption and decreasing optical density and contrast.

High optical density is generally associated with greater color saturation, as more light is absorbed by the ink layer. To prevent saturation loss, print settings may be adjusted to increase ink density, tailored experimentally to the specific textile substrate.

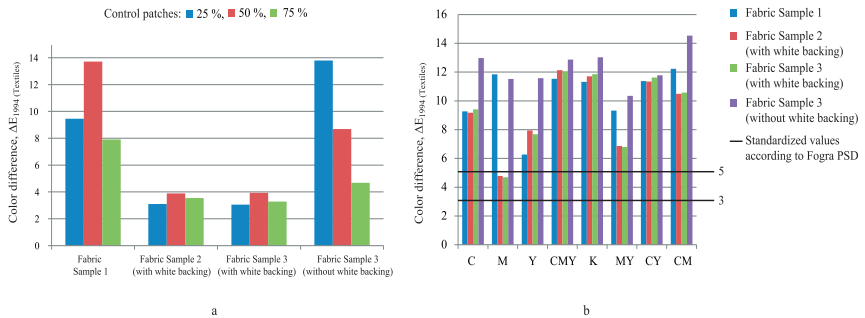


Fig. 4. Color difference (ΔE): (a) grayscale control patches 25 %, 50 %, 75 %; (b) 100 % control patches

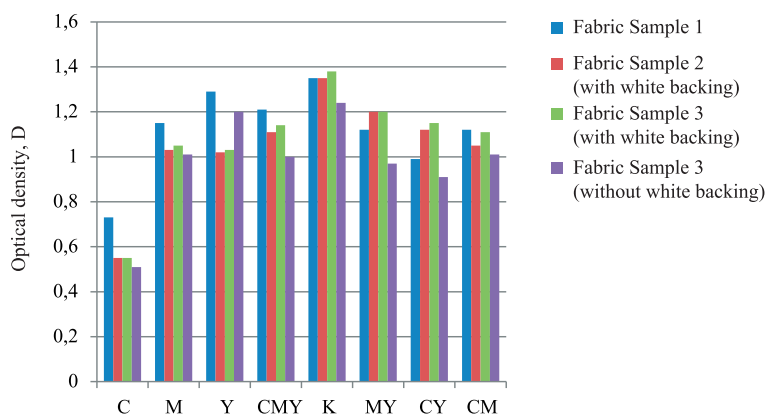
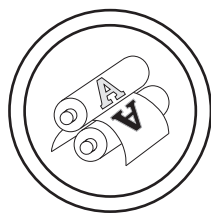


Fig. 5. Impact of fabric on the optical density (D) of 100 % control patches

Fig. 6 presents microphotographs of control patches from the investigated fabric samples, which were analyzed to assess the uniformity, continuity, and homogeneity of the printed image.

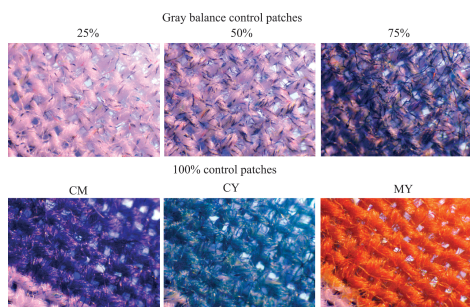
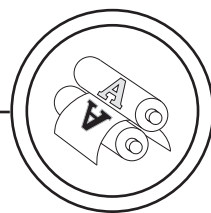
Sample 1 is characterized by a loose plain weave and a highly porous and open structure. On the one hand, this structure facilitates deep penetration of the dye into the fibers, while on the other hand, it promotes capillary spreading of the ink within the material, resulting in reduced image edge sharpness. In addition, the fabric contains a significant amount of surface fuzz and loosely twisted fibers protruding above the surface, forming a pronounced fluffy texture. This hinders the uniform application of ink, especially in light-toned areas of the image (Fig. 6, a).

Sample 3 features a twill weave (with a diagonal rib), typical of denim fabrics. This structure provides high mechanical strength and elasticity but creates a pronounced surface relief. The fibers in this sample exhibit a fuzzy morphology, which leads to uneven dye absorption: the ink may be trapped between

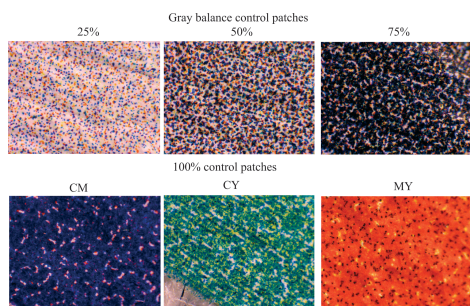
fibers or accumulate on the peaks of the texture, forming visual artifacts such as banding or mottling (Fig. 6, d).

Sample 2 also exhibits surface fuzziness but has a less pronounced texture due to a denser plain weave. To minimize the adverse effects of fuzziness on image quality and color accuracy in pigment inkjet printing, the application of a pretreatment coating is recommended. This coating reduces ink penetration depth and improves edge sharpness [4–6].

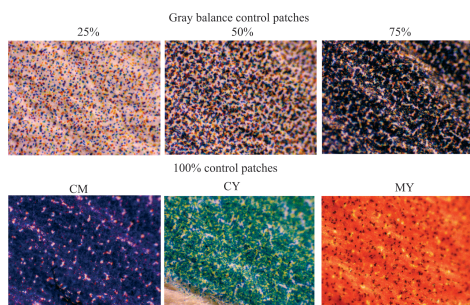
For pre-dyed fabrics, the application of a white underlayer is essential to ensure accurate color reproduction. However, printing with a white underlayer may enhance the visual prominence of the fabric's surface relief, which negatively affects the overall perception and integrity of the image (Fig. 6, b, c). To reduce the visual manifestation of the structural relief, a set of measures can be recommended: mechanical or chemical surface smoothing; the use of low-viscosity white pigment inks with high spreading ability to avoid ink buildup; and the application of



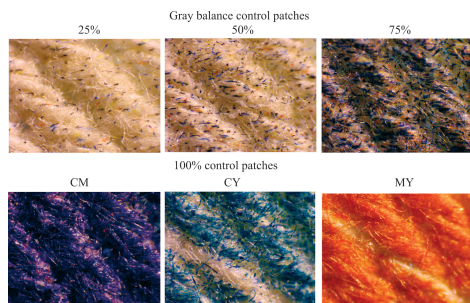
a



b

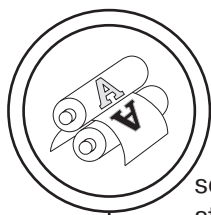


c



d

Fig. 6. Microscopic views of printed control patches: (a) fabric Sample 1 (without white underlayer); (b) fabric Sample 2 (with white underlayer); (c) Fabric Sample 3 (with white underlayer); (d) fabric Sample 3 (without white underlayer)



several thin layers of white ink instead of a single dense layer. This gradual build-up approach allows for smoother coverage of the fabric's microrelief without excessive texture enhancement.

Conclusions

Based on the results of the study, the following practical recommendations are proposed for inkjet printing with pigment-based inks on natural fabrics. These guidelines should be taken into account both during the preparation of digital artwork and in the printing process:

1. On white fabrics that do not require a white underlayer, solid triadic colors (C, M, Y, K) are rendered using single-channel inks, resulting in purer and cleaner color tones.

2. On colored fabrics, the use of a white underlayer is necessary to ensure accurate color reproduction and to eliminate the influence of the fabric's inherent color on the printed image.

3. It was found that when printing without a white underlayer, the resulting images acquire a color cast corresponding to the hue of the textile substrate. For instance, Sample 1, which has a noticeable blue tone, imparts a blue shift to the test patches. Similarly, Sample 3 (printed without an underlayer) results in test patches exhibiting a warm, yellowish tint originating from the base fabric.

4. The influence of fabric color is more pronounced in the lighter tonal ranges, particularly in the high-

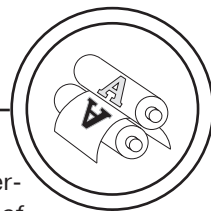
lights and midtones. The 25 % and 50 % grayscale control patches are more susceptible to color shift due to substrate color compared to darker 75 % patches.

5. The uniformity and evenness of ink coverage on fabric surfaces depend on the weave type and yarn structure. It was observed that yarns composed of loosely twisted fibers result in partial ink coverage, which affects the consistency of the printed image. In contrast, tight twill weaves, such as those in denim fabrics, produce a pronounced surface texture that causes visual unevenness in printed color layers. Ink settles more heavily in the depressions of the weave, leading to darker perceived areas. Consequently, printing on such fabrics without a white underlayer may result in a striped or banded appearance. The application of a white base layer is therefore recommended for relief-textured fabrics to reduce the impact of texture on image perception.

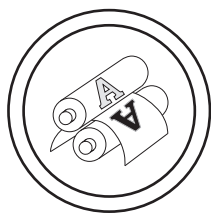
6. To ensure consistent color reproduction on dyed or non-white textiles, it is recommended to use a white underlayer. In cases where printing is performed on light-colored fabrics, the inherent hue of the fabric should be compensated through the use of an ICC color profile that accounts for chromatic shifts. Additionally, to prevent a loss of saturation in the final print, the print settings should be adjusted to a higher ink density or saturation level, which should be empirically determined based on the type of fabric used.

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У статті представлено результати експериментального дослідження впливу фізичних характеристик натуральних тканин на оптичні параметри відбитків, отриманих методом прямого струминного друку пігментними чорнилами. В умовах зростаючого попиту на персоналізовану текстильну продукцію проаналізовано якість відтворення зображень на бавовняних тканинах із різними характеристиками: кольором, товщиною, типом переплетення та шорсткістю поверхні.

Ключові слова: струминний друк; натуральні тканини; пігментні чорнила; колірна відмінність; світлота; оптична густина; білий підклад.

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