



QUANTITATIVE EVALUATION OF DOT PATTERN TRANSFER QUALITY ON THE FACE AND BACK SIDES OF PRINTED TEXTILE FABRICS

Scientific paper
DOI: 10.5937/CT_ITI26134T

Emilija Toshikj¹

¹Ss. Cyril and Methodius University in Skopje, Faculty of Technology and Metallurgy,
Department of Textile, Skopje, North Macedonia,
E-mail: tosic_emilija@tmf.ukim.edu.mk, ORCID ID: 0000-0001-6685-4795

ABSTRACT: The quality of printed textile structures is commonly evaluated visually, although objective image analysis provides more reliable and reproducible results. This study presents a quantitative assessment of circular dot patterns printed on textile fabric by comparing the face and back sides using digital image processing. Twelve printed dots were analyzed on each side, and several geometrical and quality parameters were calculated, including dot area, circularity, aspect ratio, roundness, solidity, pattern transfer ratio (PTR), dot fidelity index (DFI), contrast loss index (CLI), and pattern fidelity performance index (PFPI). The results indicate complete pattern detection on both fabric surfaces; however, significant degradation occurred after ink penetration through the fabric. The mean dot area decreased by 21.6%, circularity by 51.2%, and DFI by 51.2%, while CLI increased to 0.307, indicating moderate contrast degradation. According to the proposed grading system, the face side achieved Grade A, whereas the back side received Grade C. The proposed methodology provides an objective approach for evaluating print transfer quality and can support optimization of textile printing processes.

Keywords: textile printing, image analysis, digital image processing, pattern transfer, dot fidelity, print quality

KVANTITATIVNA PROCENA KVALITETA PRENOSA TAČKASTOG UZORKA NA LICU I NALIČJU ŠTAMPANIH TEKSTILNIH MATERIJALA

APSTRAKT: Kvalitet štampanih tekstilnih struktura najčešće se ocenjuje vizuelno, iako objektivna analiza slike pruža pouzdanije i reproduktivnije rezultate. U ovom radu predstavljena je kvantitativna procena kružnih tačkastih uzoraka odštampanih na tekstilnom materijalu poređenjem lica i naličja primenom digitalne obrade slike. Na svakoj strani analizirano je dvanaest odštampanih tačaka, pri čemu su izračunati različiti geometrijski i kvalitativni parametri, uključujući površinu tačke, kružnost, odnos osa, zaobljenost, punoću (solidity), odnos prenosa uzorka (Pattern Transfer Ratio – PTR), Indeks geometrijske očuvanosti oblika tačke (Dot Fidelity Index – DFI), indeks gubitka



9. Međunarodna naučna konferencija
„Savremeni trendovi i inovacije u tekstilnoj industriji“
17-18. septembar 2026. Beograd, Srbija

kontrasta (Contrast Loss Index – CLI) i indeks performansi vernosti uzorka (Pattern Fidelity Performance Index – PFPI). Rezultati ukazuju na potpunu detekciju uzorka na obe površine tkanine; međutim, nakon penetracije boje kroz tekstilni materijal uočena je značajna degradacija kvaliteta. Prosečna površina tačke smanjena je za 21,6%, kružnost za 51,2%, a geometrijska očuvanosti oblika tačke (DFI) za 51,2%, dok je indeks gubitka kontrasta (CLI) povećan na 0,307, što ukazuje na umerenu degradaciju kontrasta. Prema predloženom sistemu ocenjivanja, lice materijala svrstano je u kvalitetnu klasu A, dok je naličje ocenjeno klasom C. Predložena metodologija omogućava objektivan pristup oceni kvaliteta prenosa štampe i može doprineti optimizaciji procesa štampanja tekstilnih materijala.

Ključne reči: Štampanje tekstila, analiza slike, digitalna obrada slike, prenos uzorka, indeks očuvanosti oblika tačke (DFI), kvalitet štampe.

1. INTRODUCTION

The quality of textile printing is determined not only by accurate color reproduction but also by the geometric fidelity of printed motifs. During the printing process, pigments or dyes penetrate the textile structure, where fiber morphology, yarn configuration, and fabric porosity influence ink spreading, edge sharpness, and dimensional stability of the printed pattern [1,2]. Similar structural characteristics have also been shown to influence laundering behavior, dimensional stability, and the performance of functional textile materials, including antimicrobial chitosan-treated cotton yarns [3-8]. The effects of ink penetration are particularly evident on the reverse side of the fabric, where deformation of printed elements and reduction of image contrast may occur.

Traditionally, print quality has been evaluated by visual inspection or subjective comparison with reference samples. Although these methods are simple to perform, they are strongly dependent on the observer and environmental conditions, resulting in limited repeatability and reproducibility [9]. Consequently, objective evaluation techniques based on digital image processing have attracted considerable attention in textile quality control. Recent advances in digital image analysis have enabled accurate characterization of printed structures through quantitative morphological descriptors extracted from high-resolution images. Image-processing techniques have been successfully applied for evaluating textile print quality, print mottle, and the influence of printing parameters on print performance [10–12]. Furthermore, digital image analysis has proven to be an effective tool for objective characterization of other textile properties, including fabric drape behavior [13-15], as well as for quantitative evaluation and optimization of yarn-related parameters using hybrid image-based and statistical approaches [16]. Parameters such as area, circularity, aspect ratio, roundness, and solidity provide objective measures of geometric accuracy, dimensional stability, and deformation of printed patterns, thereby supporting quantitative assessment and optimization of textile printing processes.



Despite these advances, relatively little attention has been devoted to quantitative comparison of identical printed motifs on the face and back sides of textile materials. Objective evaluation of the morphological changes occurring during ink penetration can provide valuable information regarding print transfer behavior, geometric fidelity, and the influence of textile structure on print quality.

Therefore, the objective of this study was to quantitatively compare the geometry and transfer quality of circular printed dot patterns on the face and back sides of a textile fabric using digital image analysis. In addition to conventional morphological descriptors, the pattern transfer ratio (PTR), dot fidelity index (DFI), contrast loss index (CLI), and pattern fidelity performance Index (PFPI) were employed to objectively evaluate the preservation of print quality following ink penetration through the textile structure.

2. EXPERIMENTAL PART

2.1. Materials

The experimental investigation was carried out using a commercially available women's dress fabric purchased from the local retail market. The material was selected because it represents a typical lightweight apparel fabric commonly used in the garment industry. A regular polka-dot print consisting of dark-blue circular dots uniformly distributed on a white background was used as the test pattern for image analysis.

Based on visual inspection, the fabric exhibited a plain, smooth surface with a low-relief texture suitable for digital image acquisition. The circular printed dots were characterized by high color contrast with respect to the white background, facilitating accurate segmentation and quantitative evaluation. The regular spacing and nearly uniform diameter of the printed dots enabled direct comparison of their geometrical characteristics on the face and back sides of the fabric after print penetration.

The face side of the fabric, corresponding to the directly printed surface, and the back side, representing the reverse surface after ink penetration through the textile structure, were analysed separately. Digital photographs of both sides were acquired under identical illumination and imaging conditions using the same camera settings. A transparent metric ruler was included in each image to provide dimensional calibration for the conversion of pixel measurements into metric units (cm²) during image processing.

2.2. Procedure

The printed textile sample was placed on a flat, uniform background and photographed under controlled lighting conditions. Images of the face and back sides were captured separately using the same camera position, distance, resolution, and illumination setup. Special attention was paid to avoiding shadows, reflections, and fabric distortion during image acquisition.

After image acquisition, the images were imported into image-analysis software. The circular printed dots were segmented from the background using threshold-based digital image processing. Each detected dot was labelled as an individual object, and objects not corresponding to printed dots were removed from the analysis.



For both fabric sides, the same segmentation procedure was applied in order to ensure comparable results. The number of detected dots, their surface area, and shape descriptors were calculated automatically from the segmented images.

2.3. Testing methods

The total number of detected dots was recorded as the number of successfully segmented circular printed dots within the selected region of interest. The mean dot area (cm^2) was calculated as the average projected area of the detected printed dots after calibration of the images from pixels to square centimetres. The coefficient of variation of the dot area (CV, %) was determined to evaluate the uniformity of the printed dots within the analysed region.

The geometrical characteristics of the printed dots were further evaluated using shape descriptors. Mean circularity was calculated as a dimensionless parameter describing the degree of similarity between the detected dot and a perfect circle, where a value of 1.0 corresponds to an ideal circular shape. Mean aspect ratio was calculated as the average ratio between the major and minor axes of the fitted ellipse for each printed dot and was used to evaluate possible directional deformation. Mean roundness was determined as an indicator of the smoothness and compactness of the printed dot contour, whereas mean solidity was calculated as the average ratio between the projected dot area and the corresponding convex hull area to quantify edge regularity and boundary integrity.

The efficiency of pattern transfer through the textile structure was evaluated using the pattern transfer ratio (PTR), calculated as the ratio between the mean dot area measured on the back side of the fabric and the corresponding mean dot area measured on the face side. The preservation of the original dot geometry after penetration through the textile material was assessed by the dot fidelity index (DFI), calculated as the ratio between the mean circularity values obtained from the back and face sides of the fabric.

The contrast loss index (CLI) was calculated as a normalized indicator describing the reduction in image contrast between the face and back sides caused by ink penetration through the textile structure. Furthermore, the pattern fidelity performance index (PFPI) was determined as a composite quality indicator integrating the effects of dot area preservation, geometric fidelity, and contrast retention, thereby providing an overall assessment of print quality after transfer through the textile material.

Finally, the calculated geometrical parameters and performance indices were used to assign an overall quality grade to the printed pattern. The grading system was established according to the level of preservation of the original printed geometry, where Grade A indicated excellent pattern preservation and progressively lower grades corresponded to increasing degradation of the printed pattern after transfer through the fabric.

3. RESULTS AND DISCUSSION

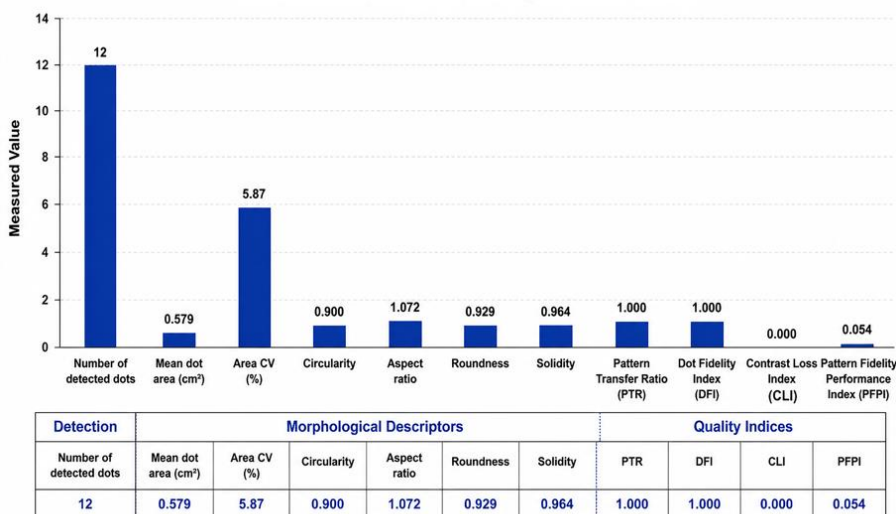
3.1. Evaluation of the face side

The quantitative image analysis of the face side demonstrated excellent print quality and served as the reference for evaluating pattern transfer through the textile structure (Figure 1). All twelve printed dots were successfully detected, indicating complete pattern

recognition without missing or merged objects. The mean projected dot area was 0.579 cm², reflecting the original dimensions of the printed motifs.

The geometrical descriptors confirmed a high degree of shape preservation. The mean circularity reached 0.900, indicating that the printed dots closely approximated an ideal circular geometry. Similarly, the mean roundness (0.929) and mean solidity (0.964) demonstrated smooth boundaries and compact dot morphology with minimal edge irregularities. The aspect ratio of 1.072 showed that the dots remained nearly circular with only negligible elongation.

As expected for the reference surface, the pattern transfer ratio (PTR) and dot fidelity index (DFI) were both equal to 1.000, indicating complete preservation of the original printed geometry. Furthermore, the contrast loss index (CLI) was equal to zero, confirming the absence of contrast degradation on the directly printed surface. Consequently, the face side achieved the highest pattern fidelity performance index (PFPI = 0.054) and was classified as Grade A, representing excellent print quality.



Notes: Area in cm²; CV = Coefficient of Variation; PTR = Pattern Transfer Ratio;
 DFI = Dot Fidelity Index; CLI = Contrast Loss Index; PFPI = Pattern Fidelity Performance Index.

Figure 1: Morphological and print quality parameters of face side of the printed fabric

3.2. Evaluation of the back side

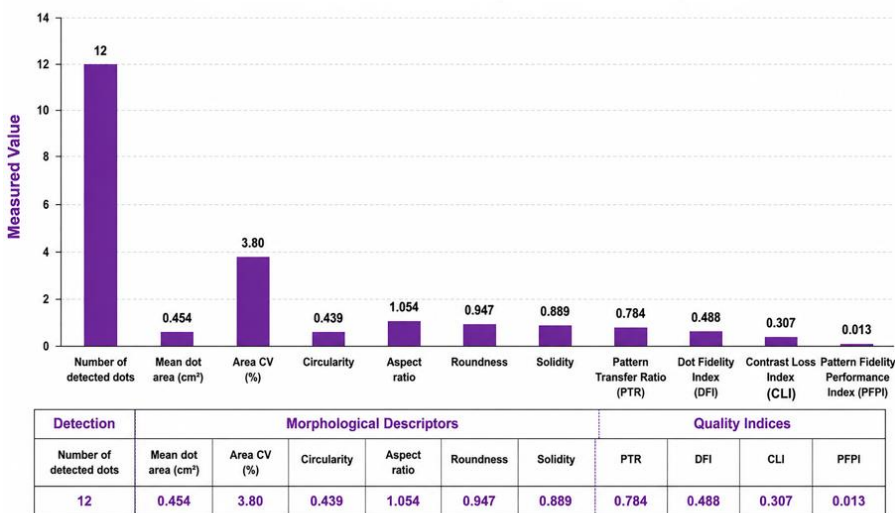
The image analysis of the back side revealed that all twelve printed dots remained detectable after penetration of the printing paste through the textile structure, confirming that complete pattern transfer had occurred (Figure 2). However, noticeable changes in both geometrical characteristics and print quality were observed.

The mean projected dot area decreased to 0.454 cm², indicating a reduction in the amount of transferred printed material. The coefficient of variation decreased from 5.87% to

3.80%, suggesting slightly improved size uniformity among the transferred dots despite the reduction in their average size.

More pronounced changes were observed in the shape descriptors. The mean circularity decreased to 0.439, indicating substantial deformation of the originally circular printed dots. Although the aspect ratio remained nearly unchanged (1.054), suggesting negligible directional elongation, the mean solidity decreased to 0.889, revealing increased edge irregularity after ink penetration through the textile structure. In contrast, the mean roundness slightly increased to 0.947, indicating that although the dots became smaller and less circular, their overall compactness remained relatively stable.

The calculated pattern transfer ratio (PTR = 0.784) indicated moderate transfer efficiency, whereas the dot fidelity index (DFI = 0.488) demonstrated that only approximately one-half of the original dot geometry was preserved after transfer. The contrast loss index increased to 0.307, confirming moderate deterioration of image contrast on the reverse side. Consequently, the pattern fidelity performance index decreased to 0.013, and the back side was classified as Grade C, indicating noticeable degradation of print quality.



Notes: Area in cm²; CV = Coefficient of Variation; PTR = Pattern Transfer Ratio;
 DFI = Dot Fidelity Index; CLI = Contrast Loss Index; PPFI = Pattern Fidelity Performance Index.

Figure 2: Morphological and print quality parameters of face side of the printed fabric

3.3. Comparative analysis between the face and back side

A comparative evaluation of the face and back sides of the printed textile fabric is presented in Figure 3. The comparative analysis demonstrated that penetration of the printing paste through the textile structure significantly influenced both the geometrical characteristics of the printed dots and the overall print quality. Although all twelve printed dots were successfully detected on both fabric surfaces, confirming complete pattern transfer,



substantial changes were observed in the morphological descriptors and quality indices after penetration.

The mean projected dot area decreased by 21.6%, indicating a reduction in the effective amount of transferred printing paste on the reverse side of the fabric. Simultaneously, the coefficient of variation of the dot area decreased by 35.3%, suggesting a slightly more uniform distribution of the transferred dot sizes despite the reduction in their average dimensions.

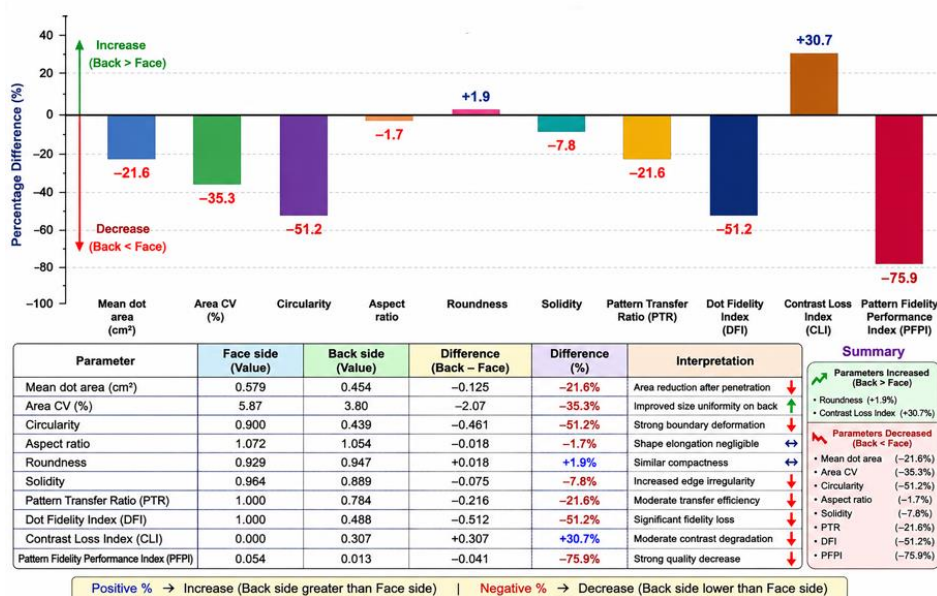


Figure 3: Comparison of the face and back sides of the printed textile fabric illustrating the influence of ink penetration on the geometrical characteristics and visual quality of the circular printed dots

The most pronounced geometrical degradation was observed for circularity, which decreased by 51.2%, indicating a considerable loss of the original circular geometry caused by interaction between the printing paste and the porous textile structure. A comparable reduction was obtained for the dot fidelity index (51.2%), confirming that the geometric fidelity of the printed motifs was significantly affected during penetration through the fabric. In contrast, the aspect ratio decreased by only 1.7%, demonstrating that the deformation occurred nearly isotropically without pronounced directional elongation.

Only minor changes were observed in roundness, which increased by 1.9%, indicating that the compactness of the transferred dots remained relatively stable. Conversely, solidity decreased by 7.8%, reflecting increased boundary irregularity and local edge deformation following ink penetration.

The pattern transfer ratio decreased from 1.000 to 0.784, indicating moderate transfer efficiency and confirming that approximately 78% of the original projected dot area was retained on the back side. Furthermore, the contrast loss index increased from 0.000 to 0.307, demonstrating moderate deterioration in image contrast and visual sharpness due to partial absorption and diffusion of the printing paste within the textile structure.

The cumulative effect of these morphological and optical changes was reflected by the pattern fidelity performance index, which decreased by 75.9%, representing the greatest relative reduction among all evaluated parameters. Consequently, the overall print quality classification decreased from Grade A for the face side to Grade C for the back side, indicating substantial deterioration of pattern fidelity after transfer through the textile material.

4. CONCLUSION

A digital image analysis methodology was developed for the objective evaluation of print quality on the face and back sides of printed textile fabrics. The proposed approach combined morphological descriptors with the pattern transfer ratio (PTR), dot fidelity index (DFI), contrast loss index (CLI), and pattern fidelity performance index (PFPI) to quantitatively characterize print quality and the effects of ink penetration through the textile structure. The face side exhibited excellent print quality, characterized by high circularity, regular dot morphology, and the highest overall quality grade (Grade A), confirming accurate reproduction of the printed pattern. In contrast, ink penetration through the textile structure resulted in reduced dot area, lower geometric fidelity, and increased contrast loss on the back side, leading to a decrease in print quality to Grade C. The proposed methodology provides a rapid, objective, and reproducible tool for evaluating print quality and the influence of ink penetration on printed textile fabrics. The approach can support quality control and optimization of textile printing processes by enabling quantitative assessment of both print fidelity on the face side and penetration effects on the reverse side.

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