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EVALUATION OF PRINT MOTTLE IN TEXTILE PRINTING: IMPACT OF PRINTING METHODS ON MACRO NON-UNIFORMITIES

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Abstract*: Besides the quality of colour reproduction itself, there are other secondary print quality attributes. Secondary print quality evaluation is very important and is influenced primarily by the print method and type of substrate. For textile printers, there is an additional challenge related to macro non-uniformities due to the nature of the substrate. One of these secondary quality attributes is print mottle, which is influenced by macro non-uniformities that remain at the top layer of the print after the ink is fixed on the substrate.*
Print mottle values primarily consist of an analysis of macro non-uniformities and can be analysed using the Gray Level Co-occurrence Matrix (GLCM) method, among others. In this study, the GLCM method was used as well as the macro non-uniformity index or NU value verification method performed by ImageJ software. Four different textile printing methods and one cotton fabric substrate are used. The objective is to examine print mottle and the impact of printing method on macro non-uniformities. The printing methods include DTF, DTG, screen printing, and screen transfer printing. The aim is to compare the results of different printing methods and to determine their relation to perceived non-uniformity as assessed visually.

Key words*:* print mottle, textile printing, macro non-uniformities, printing methods, substrate

1. INTRODUCTION

Colour plays a crucial role in creating a strong visual impression, influencing decisions in nearly every aspect of life. For textile products, colour is often the initial factor that captures the consumer's attention and significantly impacts their purchasing decision (JiHyun, 2007). Clothing must now go beyond fulfilling basic functions like protection and utility; it must also satisfy aesthetic and fashion criteria to effectively express an individual's personal character and lifestyle (Grujić, 2010). Textile printing is both an art and a science, involving the decoration of fabric with vibrant patterns or designs. While screen printing is the most common method used for textile materials, other techniques such as digital printing and thermal transfer are also employed. Today, there are numerous methods for embellishing clothes, each employing different technologies and materials (Prybeha et al., 2021).
According to Prybeha et al. (2021), a popular technique for enhancing textiles in the fashion industry is printing directly on garments. Despite the extensive history of fabric printing, manufacturers still encounter challenges in applying high-quality images to textiles. Specifically, there is a lack of guidance on selecting the appropriate image application method, as well as on determining the optimal parameters of the technological process-such as temperature, time, and pressure-based on the material's chemical composition. Currently, modern manufacturers utilize various methods for printing images on textiles. The choice of printing technology is influenced by several factors, including the quantity of products, the size of the image, the number of colours in the image, the fabric's raw material composition, and the fabric's colour. Each method has its own set of advantages and drawbacks that must be evaluated before application. It is important to recognize that no single technology is superior in all cases, as each type of product necessitates a specific method.
A numerical evaluation of colour reproduction alone isn't sufficient to determine the overall quality of a print. It has been shown that print quality doesn't simply correlate in a straightforward manner with hue, saturation, and value (Fedorovskaya et al., 1997; Pedersen et al., 2009). Quality attributes such as contrast, sharpness, and macro-uniformity are not related to colour reproduction, but they do impact print quality. These attributes are directly associated with line and dot quality, which are essential components of any image (Dhopade, 2010).
According to Lindberg (2004), while using all quality attributes is ideal for assessing print quality, a selection of specific attributes is often more practical in industrial settings. Lindberg found that print mottle and colour gamut significantly influence image quality perception. Additionally, colour shift and sharpness also play a crucial role in perceived quality (Petterson, 2005). Based on Lindberg's findings, it is possible to narrow down the number of quality attributes to these four, aligning with Engeldrum's observation that observers generally perceive no more than five quality attributes simultaneously (Rilovski et al., 2012).

Pedersen (2011) further refined the quality attributes from existing literature to six key categories: sharpness, colour, lightness, artifacts, contrast, and physical attributes.
Petterson also emphasized the significance of print mottle in print quality, alongside colour gamut, colour shift, and sharpness (Petterson, 2005). Print mottle, defined as the visual irregularities in print density affecting overall print quality, is considered one of the major issues in printing (Fahlcrantz, 2005; Kawasaki & Ishisaki, 2009). It refers to the optical inconsistency and unevenness in optical density and print gloss, which can manifest in solid tones or smooth image areas (Rilovski et al., 2012). Fahlcrantz defines mottle as perceived variations in lightness across the printed surface under uniform illumination (Fahlcrantz, 2005). Evaluating the overall product quality relies on the uniformity of homogeneous image regions (Lindberg, 2004).
Print mottle arises from uneven toner transfer and adhesion, influenced by substrate and toner properties, as well as printing press conditions, such as toner fixation (Rilovski et al., 2012). Consequently, print density and mottle issues occur when toner adhesion and colorant fixation are inconsistent across the paper surface (Petterson, 2005). The paper, toner, and printing process are identified as the three primary factors affecting toner adhesion and fixation (Rilovski et al., 2012).
Print quality in any printing process depends on the process, ink, and substrate. Imperfect interactions among these factors can lead to unwanted effects like print mottle. Print mottle appears as unevenness in solid areas and impacts the print's density and gloss, varying with the ink, substrate, and printing method used. Print mottle is a common printing defect, making it crucial to reduce or eliminate it as much as possible. Given the many factors that influence print mottle, controlling these variables is essential for minimizing its occurrence or selecting a printing process that produces the least amount of mottle.
This research concentrates on examining macro-level non-uniformities such as print mottle. The key print mottle parameters under investigation include contrast, correlation, entropy, energy, and homogeneity. The findings indicate that a uniform grey level distribution, which corresponds to low print mottle, is characterized by low contrast, low correlation, low entropy, high energy, and high homogeneity (Chen, 1998; Hladnik & Lazar, 2011; Ružičić et al., 2014).

2. METHODS AND MATERIALS

This study involves four different textile printing techniques.
Considering the printing techniques for clothing in small and medium runs, the following will be explained:

- The DTF method involves aqueous inkjet technology and transferring an image from a specialized film to the fabric using heat and pressure. The image is first printed onto a special film, which is then applied to the fabric. The image is transferred onto the fabric through the application of high temperature (Prybeha et al., 2021).
- DTG refers to the process of printing digitally on apparel or other assembled products, using an aqueous ink jet technology (Chandavarkar, 2013).
- Screen printing (also known as silkscreen printing) involves pushing ink through the open areas of a flexible mesh stencil onto the printing surface using a special tool called a squeegee. This technique can be used to print on a variety of materials, including paper, metal, glass, fabric, polyethylene, plastic, leather, and other sheet or roll materials and their products (Prybeha et al., 2021).
- Screen transfer printing is a process where an image is moved from a special film to fabric using heat and pressure. Initially, the image is printed onto a unique film via screen printing, and then this image is placed onto the fabric. The image is transferred to the fabric through the application of high temperatures.

The printing substrate used for all printing techniques in this study is identical. It is a cotton fabric from the same manufacturer and batch 155 gsm. The fabrics were cut to dimensions of 21 x 30 cm, and a patch was printed on each piece. Once dry, the samples were scanned using an Epson Perfection V600 Photo flatbed scanner. During scanning, all automatic image adjustment options are disabled. The scanning settings are identical for each sample.

The DTF printing technique was carried out using the Storm Jet printer, which employs inkjet printing technology. This printer uses the Epson I3200-A1 printhead CMYK+W. The DTG printing technique was performed on the Epson SureColor F2000 DTG printer, which also uses inkjet printing technology. This printer uses the Epson PrecisionCore printhead CMYK+W. Screen printing is conducted using a mesh with a count of 100 threads/cm for both direct printing and transfer printing within the research. The process uses Argon Texiplast inks.

To obtain results, the study utilized solid tone patches of 16 x 16 cm (refer to Figure 1). The test image for the study was created using Adobe Illustrator 2023. Previous research employed solid tone patches, specifically 2.54 x 2.54 cm, to evaluate print mottle (Stančić et al., 2013a; Stančić et al., 2013b; Ružičić et al., 2014; Jurič et al., 2015). Another study (Milošević et al., 2013) used 1 x 1 cm patches for similar assessments. Due to the variability in patch sizes in earlier studies, this research opted for the 16 x 16 cm patches, as suggested by Jurič (2018).

Figure 1: Solid patch

The print mottle parameters under investigation are conducted by GLCM image processing. The GLCM image processing technique was utilized on the scanned printed samples using MATLAB software and a plugin developed by Uppuluri (Uppuluri, 2008). This plugin offers data on 22 parameters, with the most pertinent ones used in both existing literature and this research being contrast, correlation, entropy, energy, and homogeneity. The macro non-uniformity of the surface is quantified also by the macro non-uniformity index, or NU value conducted by ImageJ software.
Table 1 outlines all the parameters used in the experiment and explains the significance of each one.

Table 1: GLCM parameters for evaluation of print mottle

CONTRAST	Measures the intensity contrast between a pixel and its neighbour over the whole image.
CORRELATION	Correlation is a measure of how correlated a pixel is to its neighbour over the whole image.
ENTROPY	Entropy in any system represents disorder, where in the case of texture analysis entropy is a measure of spatial disorder in an image.
ENERGY	Energy is a measure of local homogeneity. Basically, this feature will tell us how uniform the texture is.
HOMOGENEITY	Measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal.

In Table 2, the samples are listed in order along with their abbreviated names and a description of the printing technique used.

Table 2: Sample overview

Sample number	Sample label	Printing techniques
1	SD-WB	Direct screen printing. Black over White. Curing with hot air.
2	SD-B	Direct screen printing. Black only. Curing with hot air.
3	DTF-WB	Digital inkjet printing on film. Black over White. Transfer and drying with a heated press.
4	DTF-B	Digital inkjet printing on film. Black only. Transfer and drying with a heated press.
5	ST-WB	Screen printing on film. Black over white. Transfer and drying with a heated press.
6	ST-B	Screen printing on film. Black only. Transfer and drying with a heated press.
7	DTG-B	Direct digital inkjet printing. Black only. Drying with a heated press.

3. RESULTS

The results from GLCM image processing are obtained in charts in Figure 2.

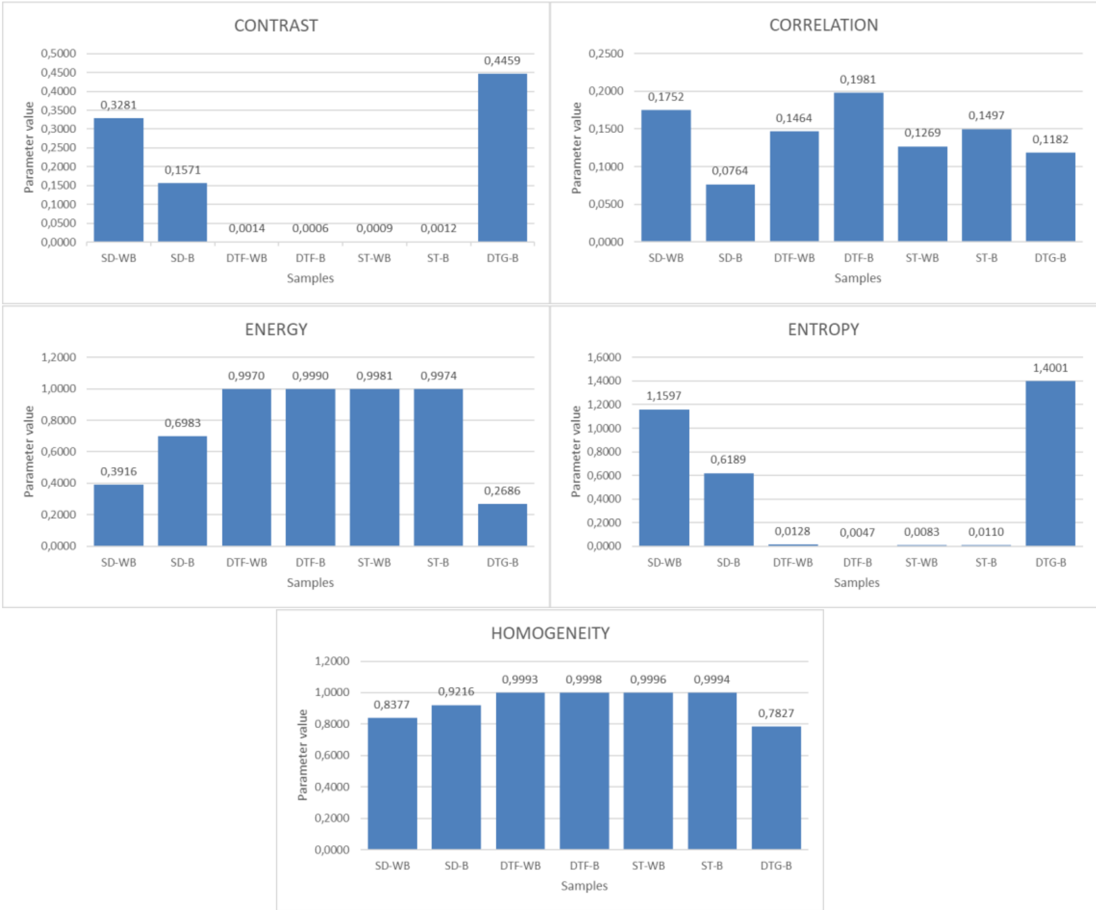

Figure 2: Macro non-uniformity parameters

The macro non-uniformity of the surface is quantified by the macro non-uniformity index, or NU value. Table 3 shows the macro non-uniformity results for the samples, as determined through image analysis with ImageJ software. The optimal macro non-uniformity value is zero; thus, results nearer to zero indicate less macro non-uniformity.

Table 3: Macro non-uniformity results conducted with ImageJ software.

Sample number	Sample label	NU mottle
1	SD-WB	15,6446
2	SD-B	8,5041
3	DTF-WB	1,8236
4	DTF-B	1,8941
5	ST-WB	1,2544
6	ST-B	1,3524
7	DTG-B	16,4383

Figure 3 shows scanned samples prepared for GLCM analysis using MATLAB and ImageJ software.

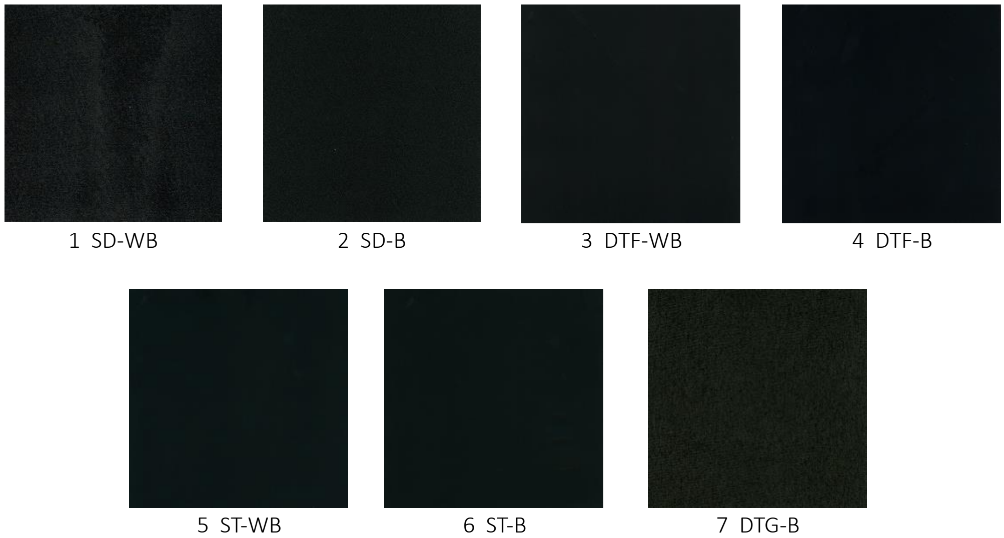

Figure 3: Scaned samples 500 x 500 px

4. DISCUSSION

Reviewing the results of GLCM analysis for different samples reveals clear differences in texture, which can help identify macro-uniformity. Sample 1 SD-WB (0.3281) and Sample 7 DTG-B (0.4459) have the highest contrast values, suggesting sharp transitions between dark and light areas. These samples may be uneven. Samples 3-6 have very low contrast values, indicating an almost uniform surface. All samples exhibit different, but relatively low correlation values. It is expected that there will be variations in correlation values between samples, with the greatest difference occurring between Sample 2 SD-B (0,00764) and Sample 4 DTF-B (0,1981), indicating greater variations in surface uniformity.
Energy is inversely proportional to entropy. Samples 3-6 have very high energy (close to 1), indicating that these samples are highly uniform. Sample 7 DTG-B (0.2686) and Sample 1 SD-WB (0.3916) have lower energy, suggesting fewer uniform textures. Sample 7 DTG-B (1.4001) and Sample 1 SD-WB (1.1597) have high entropy values, indicating a more complex and unpredictable texture. This is a classic sign of uneven surfaces. Samples 3-6 have very low entropy values, suggesting a very simple, uniform surface.
Samples 3-6 have nearly perfect homogeneity (close to 1), confirming that these surfaces are consistent. Sample 7 DTG-B (0.7827) and Sample 1 SD-WB (0.8377) have lower uniformity values, indicating some variation in texture.
Considering the NU values from Table 3, it is evident that Samples 1 SD-WB, 2 SD-B, and 7 DTG-B have very high surface non-uniformity values, which characterise them as having significant surface unevenness and texture complexity. In contrast, Samples 3 DTF-WB, 4 DTF-B, 5 ST-WB, and 6 ST-B have relatively low and uniform values, indicating that they are quite consistent and even.

5. CONCLUSION

Samples 1 SD-WB and 7 DTG-B show high values for both contrast and entropy, indicating unevenness and macro-nonuniformity. Samples 3-6 are very uniform, with low contrast, high energy, and low entropy, suggesting that their surfaces are quite consistent. Samples 3-6 have very low values for contrast and entropy, along with high values for energy and homogeneity, which indicates high macro-uniformity and simple textures. Sample 7 DTG-B has the highest entropy, the lowest homogeneity, and the highest contrast, indicating the greatest surface unevenness and texture complexity.
Summarising all of the above, the following conclusion can be drawn: Printing techniques that use transfer foil (such as screen transfer and DTF) in samples 3-6 yield consistent results in terms of macro non-uniformity parameters. It can be concluded that the method of transferring images and fixing the ink through temperature and pressure, which is common to both screen transfer and DTF techniques, plays a significant role in achieving favourable results regarding macro non-uniformity. In contrast, direct printing

techniques that use hot air drying or fix the ink through temperature and pressure tend to leave surface irregularities caused by the weaving of the cotton fabric. Consequently, the direct printing method exhibits poor macro non-uniformity results and leads to a pronounced print mottle effect, which can negatively impact colour reproduction quality.

7. REFERENCES

Chandavarkar, A. (2013) Digital textile printing offers creative and commercial opportunities. *Textile Magazine*. 55, 140-143.

Chen, Y. (1998) *Image Analysis Methods for Paper Formation Evaluation*. MSc thesis. University of Toronto.

Dhopade, A. (2010) Image quality assessemnet according to ISO 13660 and ISO 19751. In: *Test Targets 9.0.* Chun, E. (ed.) Rochester, New York, School of Print Media. pp. 43–50.

dst-digital.com. (n.d.) Available from: https://dst-digital.com/dtf-dtg-white-toner-dst-dsst/ [Accessed 2nd September 2024].

Fahlcrantz, C. (2005) *On the Evaluation of Print Mottle*. PhD thesis. KTH Royal Institute of Technology.

Fedorovskaya, E., A., De Ridder, H. & Blommaert, F. (1997) Chroma variations and perceived quality of colour images of natural scenes. *Color research and application*. 22 (2), 96- 110. Available from: doi: 10.1002/(SICI)1520-6378(199704)22:2<96::AID-COL5>3.0.CO;2-Z

Grujić, D. (2010) *The impact of material properties on the thermo physiological comfort of clothing*. PhD thesis. Fakulteta za strojništvo. Univerza v Mariboru.

Hladnik, A. & Lazar, M. (2011) Paper and board surface roughness characterization using laser profilometry and gray level cooccurrence matrix. *Nordic Pulp and Paper Research Journal.* 26 (1), 99-105. Available from: doi: 10.3183/npprj-2011-26-01-p099-105

JiHyun, B. (2007) *Color in Ink-Jet Printing: Influence of Structural and Optical Characteristics of Textiles*. PhD thesis. Textile Technology Management, North Carolina State University.

Jurič, I. (2018) *Print uniformity model for digital prints*. Novi Sad, Faculty of Technical Sciences. Available from: https://www.grid.uns.ac.rs/data/biblioteka/disertacije/Disertacija_Juric_GRID.pdf [Accessed 2nd September 2024].

Jurič, I., Kašiković, N., Stančić, M., Novaković, D., Vladić, G. & Majnarić, I. (2015) The influence of heat treatment on print mottle of screen printedtextile knitted fabrics. *Applied Thermal Engineering.* 90, 215-220. Available from: doi:10.1016/j.applthermaleng.2015.07.013

Kawasaki, M. & Ishisaki, M. (2009) Investigation into the Cause of Print Mottle in Halftone Dots of Coated Paper: Effect of Optical Dot Gain Non-uniformity. *Japan Tappi Journal*. 63, 1362-1373. Available from: https://www.tappi.org/content/06ipga/5-4%20kawasaki%20m%20ishisaki.pdf
[Accessed 2nd September 2024].

Lindberg, S. (2004) *Perceptual determinants of print quality*. PhD Thesis. Stockholm University: Department of Psychology.

Milošević, R., Kašiković, N., D., N., Stančić, M. & Adamović, S. (2013) Investigation of the Printing Pressure Level Application Influence on Sheet-fed Offset Print Quality. Machine Design, 4 (5), 171-176.

Pedersen, M. B. (2011) Image quality metrics for the evaluation of print quality. In: Famand, S. P. & Gaykema, F. (eds*.) IS&T/SPIE ELECTRONIC IMAGING: IS&T/SPIE ELECTRONIC IMAGING Proceedings volume 7867, Image quality and system performance VIII, IS&T/SPIE ELECTRONIC IMAGING, San Francisco, California. 23 -27 January 2011. Bellingham,* p.p. 1-19.

Pedersen, M., Bonnie, N., Hardeberg, J. & Albregtsen, F. (2009) Attributes of a new image quality model for color prints. *Proceedings of Color Imaging Conference, Albuquerque, New Mexico, USA.* pp. 204-209.

Petterson, J. (2005) *A Review of Perceptual Image Quality*. PhD thesis. Linköpings Universitet: Department of Science and Technology.

Prybeha, D., Koshevko, Y., Smutko, S., Onofriichu, V., Skyba, M., Synyuk, O. & Zlotenko, B. (2021) Analysis of methods of printing images on textile materials and evaluation of their quality. *Vlakna a textil (Fibres and Textiles).* 28 (2), 63-74. Available from: https://elar.khmnu.edu.ua/handle/123456789/11046 [Accessed 2nd September 2024].

Rilovski, I., Karlović, I., Novaković, D. & Tomić, I. (2012) Influence of Paper Surface Properties and Toner Type on Digital Print Mottle. *Celuloză şi Hârtie*. 61 (2), 4-9.

Ružičić, B., Stančić, M., Milošević, R. & Sadžakov, M. (2014) Influence of Substrate Thickness on the Reproduction Quality of Screen Printed Polymer Materials. In: D. Novaković (Ed.) *GRID 2014: International Symposium on Graphic Engineering and Design: Proceedings of the 7th International Symposium GRID 2014, 13-14 November 2014, Novi Sad, Serbia, Faculty of Technical Sciences*. pp. 239-245.

Stančić, M., Kašiković, N., Novaković, D., Milošević, R. & Grujić, D. (2013b) Thermal Load Effect on Print Quality of Ink Jet Printed Textile Materials. *Journal of Graphic Engineering and Design*. 2 (4), 27-33.

Stančić, M., Novaković, D., Kašiković, N., Vukmirović, V. & Ružičić, B. (2013a) Influence of material composition on print quality digitally printed textile substrates. *Tekstilna industrija*. 1, 37-43.

Stančić, M., Novaković, D., Tomić, I. & Karlović, I. (2012) Influence of Substrate and Screen Thread Count on Reproduction of Image Elements in Screenprinting. *Acta Graphica*. 23 (1-2), 1-12. Available from: https://actagraphica.hr/index.php/actagraphica/article/view/78. [Accessed 2nd September 2024].

Uppuluri, A. (2008) *GLCM texture features*. Available from: https://www.mathworks.com/matlabcentral/fileexchange/22187-glcm-texture-features. [Accessed 2nd September 2024].