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Influence of Gloss and Surface Roughness of Coated Ink Jet Papers on Print Uniformity

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Abstract:

The final print quality depends on the quality of the digital image as well as the properties of the printing system, the inks and the paper used. One of the most widely used digital printing technologies is ink jet, where ink is ejected directly onto a substrate from a jet device driven by an electronic signal. Most ink jet inks have low viscosity and low surface tension, which pose high demands upon the surface properties of the paper. The aim of this study was to investigate the influence of paper properties of commercially available papers suitable for ink jet printing on print mottle, non-uniformity. We used two high glossy, one glossy, one semi-glossy and two matte papers. For the assessment of the surface properties, we measured surface roughness with the portable Roughness Tester TR 200. We also measured surface gloss with QIP Glossmaster. To characterise the print mottle we used the image analysis method – Gray level co-occurrence matrix (GLCM). Print mottle was estimated according to five GLCM parameters: Contrast, Correlation, Entropy, Energy and Homogeneity. Results obtained in this paper showed that the surface properties of paper are not in any direct relation with print uniformity.

Keywords:

Surface Roughness, Paper Gloss, Print Mottle, GLCM

1. Introduction

Printing is described as the process of transferring ink onto paper (or another substrate) via a printing plate. One of the most important printing technologies is ink jet printing. In the inkjet process, the ink is transferred directly onto the paper, without the printing plate. The ink jet print quality is dependent on several parameters such as inks, printers, paper (media) and software. The paper properties influence the image transfer and image appearance in all colour reproduction processes. In predicting and reproducing colour, paper has a significant impact on the print quality, such as print contrast, density, colour, tonal range and surface uniformity. The interaction between paper and ink, its porosity and roughness, together with optical properties, such as whiteness, opacity, light scattering and gloss, must be considered in the printing process (Kandi, 2013).

Inexpensive plain papers e.g. ordinary uncoated copy papers can be used if the print quality demand is moderate or if only text is to be reproduced. Ink jet printing can yield very high print quality, in the same range as photographs, but this requires special photo quality paper. Ink jet has a unique potential for high print quality since the intensity of an ink spot on the paper can be varied by adding several ink droplets on top of each other. With 'printability' we refer to the paper ability to facilitate ink drying and yield a high print quality.

When high quality ink jet printing is wanted, papers with special coatings are required. The structure of those papers is presented in *Fig. 1*. These coatings may contain several specific layers, for instance a dye fixation layer and an ink-sorbent layer. The dye fixation layer contains chemicals that interact with dye molecules and anchor the dye at the surface. This improves print density, colour saturation and water fastness. The ink-sorbent layer may consist of porous particles with high specific area such as silica gels, or of a swellable polymer e.g. gelatine. Ink absorption into the micro porous layer is fast and governed by capillary forces (capillary absorption) while the absorption into the swellable layer is slow and controlled by molecular diffusion. Glossy photo quality ink jet papers most often have a swellable layer and print quality is extremely high although the drying time is long (Ek et al., 2009).

Very important aspects for digital printing are structure and composition together with the electrical and thermal properties of paper. These paper properties have a direct influence upon the runnabilty and performance of digital printing systems. The printability of paper surface is influenced by surface properties such as smoothness (roughness), uniformity and the absorption of ink (Wilson, 1997 cited in Wu et al., 2007). In general, high print quality is associated with good formation and with smooth, compressible paper (Thompson, 1998 cited in Wu et al., 2007). The most important surface properties of the paper include roughness, formation, porosity and permeability. On the other hand, optical paper properties (whiteness, brightness, opacity, gloss, etc.) have no bearing upon the runnability and performance, but do have a significant impact upon the print quality. In this paper we attempted to analyse the print quality on different specially coated ink jet papers. We characterized these papers by measuring two very important paper properties: surface roughness and gloss.

Many researchers have studied the effect of paper properties on the final print quality. They have taken into account different parameters of paper, and their conclusions about the print quality were based on different print attributes, but mostly on colour reproduction (colour gamut, colourimetric values, optical density, print contrast, etc). In addition to the colour reproduction, some of them have introduced new secondary print quality attributes, such as print sharpness and print mottling. Lundberg et al.

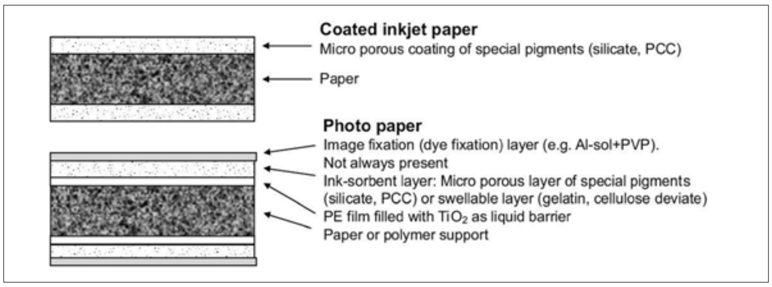

Figure 1. Structure of high-quality ink jet papers

(2004) studied the print quality in terms of 12 different quality attributes. According to study (Lindberg et. Al, 2004), the important perceptual print parameters are: colour gamut, sharpness, contrast, tone quality, detail highlights, detail shadows, gloss levels, gloss variation, colour shift, patchiness, mottle and ordered noise. As it is preferable to use all parameters in determining the print quality, the use of a limited number of quality parameters is more suitable for evaluating prints in industrial environment. Lindberg found that print mottle and colour gamut strongly affect the perception of the quality of printed samples, and that colour shift and sharpness also had influence on perceived quality (Lindberg et. Al, 2004). Lindberg reduced the number of quality attributes to this four and that is close to the statement by Engeldrum (Torrey Pines Research, 2003) that observers would not perceive more than five quality attributes simultaneously. Petersson (2005) also concluded that print mottle plays a significant role in the print quality. In addition, colour gamut, colour shift and sharpness are also important for the evaluation of print quality.

The goal of our study was to investigate the effect of surface roughness and gloss of different specially coated papers on the print mottle and print uniformity in ink jet printing. A simple definition of print mottle is a variation in print density, unevenness in density (Madstedt, 2008). Print mottle can be also explained as a term describing optical heterogeneity, unevenness in optical density and print gloss. It appears in solid tones or smooth image regions. Several methods have been developed over years to evaluate mottle instrumentally. To quantify print mottle in this study, texture analysis method was used – Gray level co-occurrence matrix (GLCM).

1.1 Gray level co-occurrence matrix (GLCM)

GLCM is one of the most frequently used statistical surface analyses. GLCM – also known as the grey level spatial dependence matrix – is a matrix that keeps track of how often different combinations – pairs – of pixel intensity (grey level) values in a specific spatial relationship and distance occur in an image (Hladnik et al, 2010). For the software ImageJ, Julio Cabrera developed a GLCM Texture Analyzer plugin (Cabrera, 2003). The plugin has a somewhat limited functionality; it is therefore better to use MATLAB software with code proposed by Uppuluri (2008). MATLAB code provides more features in comparison to ImageJ. With this code it is possible to obtain even 22 parameters, but for the print mottle evaluation we do not need all of them. Parameters of importance (contrast, correlation, entropy, energy and homogeneity) are highlighted in different papers (Chen, 1998; Hladnik et al, 2010; Hladnik and Lazar, 2011, Gebeješ et al, 2012). Hladnik (2011) and his colleagues concluded that contrast, correlation, energy and homogeneity should be used for print mottle assessment. They found that low contrast, low correlation, high energy and high homogeneity correspond to uniform grey level distribution, i.e., indicate a uniform, smooth paper surface. They also found that energy, entropy and inverse difference moment correlate very well with the visual ranking of the cyan and black printed samples so they, according to these initial experiments, have a good potential to be used as predictors of print non-uniformity (Hladnik, 2011). It is also known that high energy, low contrast and low entropy correspond to uniform grey level distribution, low print mottle (Chen, 1998). It was also found that entropy parameter correlates the best with human texture perception (Gebeješ et al, 2012).

2. Materials and Methods

The investigation was performed using six different coated papers specially designed for ink jet printing: A – *Premium high glossy paper*, B – *Photo matte paper*, C – *Glossy paper*, D – *Matte paper*, E – *Semi-gloss paper* and F – *Glossy paper*. Samples were marked with letters in order to facilitate the presentation of results.

Papers were characterized by measuring surface roughness and optical paper property (gloss). Surface roughness was evaluated by contact stylus roughness meter Roughness Tester TR 200 and surface roughness parameter (Ra) of samples was obtained. For all samples cut-off length was adjusted at 0.25 mm and evaluation length was set up at 5. Gloss was obtained using the QIS Glossmaster glossmeter. Measurements were made with 85° geometry.

Printed test form contained four solid squares of primary colours (cyan, magenta, yellow and black), dimensions 10 x 10 cm. The chosen printer was Epson StylusPro 7800 which uses eight high-density pigments based ink system. After printing, samples were scanned by scanner Canon CanoScan5600F at 1200spi. This resolution is recommended by standard ISO 24790:2012.

Calculations of GLCM parameters was performed for all samples in the CIELAB colour space on the L^* channel. The L^* channel was selected because several works stated that the majority of texture information (which is also important for print mottle) is located on this channel (Xin et al., 2005; Milic et al., 2010).

GLCM calculations were performed in MATLAB software with a code proposed by Uppuluri in 2008. When building the GLCM, parameters like number of grey levels, distance between two pixels of the GLCM (*d*) and orientation (θ) should be taken into account. In this experiment a 256 grey level image (L* channel) was used. The distance (*d*) between two pixels whose repetition is examined, was selected to 1 pixel. For the orientation (θ) the average of the possible four (0°, 90°, -45° and 45°) was taken into account. From those, as parameters of importance for print mottle we take into account contrast, correlation, entropy, energy and homogeneity for further analysis. In *Table 1* all the parameters used in the experiment are described, as well as the meaning of each one of them. In all formulas $p(i, j)$ stands for $(i, j)^{th}$ entry or value in a normalized GLCM.

Table 1. GLCM parameters for evaluation of print mottle

$Contrast = \sum_{i,j} \lvert i - j \rvert^2 p(i,j)$	Measures the intensity contrast between a pixel and its neighbour over the whole image
$Correlation = \sum_{i,j} \frac{(i - \mu i)(j - \mu j)\, p(i,j)}{\sigma_i \sigma_j}$	Correlation is a measure of how correlated a pixel is to its neighbour over the whole image.
$Entropy = - \sum_{i,j} p(i,j) \log (p(i,j))$	Entropy in any system represents disorder, where in the case of texture analysis entropy is a measure of spatial disorder in an image.
$Energy = \sum_{i,j} p(i,j)^2$	Energy is a measure of local homogeneity. Basically this feature will tell us how uniform the texture is.
$Homogeneity = \sum_{i,j} \frac{p(i,j)}{1 + \lvert i - j \rvert}$	Measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal.

3. Results and Discussion

Paper properties of selected papers are presented in *Table 2*. Papers with glossy coating have the smallest surface roughness (0.033-0.242μm) and the largest gloss (79.6-90.6), while the results on matte papers are the complete opposite. The largest surface roughness has sample 2 (2.623 μm), but this samples does not have the smallest gloss. Slightly smaller surface roughness has sample 4 (2.102 μm), and that sample has the smallest gloss (3.6).

The correlation between paper properties is presented in *Fig. 2*. On the basis of the correlation coefficient of (ρ = - 0.977), it can be concluded that paper properties (surface roughness and gloss) are directly related to each other. When gloss increases, the surface roughness decreases. Gloss is associated with high surface smoothness (low surface roughness).

Table 2. Paper properties

Samples	A	B	C	D	E	F
Surface roughness Ra [µm]	0.033	2.623	0.061	2.102	0.572	0.242
Gloss	90.6	5.6	79.6	3.6	51.7	87.8

So as to determine print unifomity, we analyzed five GLCM parameters: contrast, correlation, entropy, energy and homogeneity. *Fig. 3-6* show results of print mottle evaluation for four primary colours (cyan, magenta, yellow and black) respectively. In the *Introduction* section we mentioned previous studies which had concluded that low contrast, low correlation, high energy and high homogeneity corresponded to the uniform grey level distribution, i.e. indicated a uniform, smooth surface (Hladnik and Lazar, 2011). In other studies was also concluded that lower value of entropy corresponded to the low print mottle (Chen, 1998; Gebeješ, 2012). Gebeješ et al. (2012) found that entropy parameter is in the strongest correlation with visual ranking.

Based on the results presented in *Fig. 3-6*, it is obvious that we didn't find the same trend of print mottle for four primary colours. Each colour behaves and generates print uniformity differently. We cannot make any general statements and say that, for example, sample A has the best or worst print mottle.

Fig. 3 shows that sample B has uniform surface, because it has the smallest value of contrast, correlation and entropy, and the largest value of energy and homogeneity. But the same cannot be said for magenta (*Fig. 4*), yellow (*Fig. 5*) or black (*Fig. 6*). For magenta and yellow, sample A has a more uniform surface. On the other hand, sample F has the smallest print mottle for black. It is also evident that the largest variations are for black colour.

Variations in the grey level intensity for each colour are different. In *Fig. 7* the L* channels of the sample A for primary colours are presented. We can see that the non-uniformity is most noticeable for black, which is obtained numerically, as shown in *Fig. 6*. Other colours have uniform print surface. It is therefore better to define a patch that will contain a proportion of all primary colours as the basis for controlling print mottle.

While comparing the results obtained by measuring paper properties (surface roughness and gloss) and print mottle, we did not find direct correlation. Correlation coefficinets are small (not higher than 0.6).

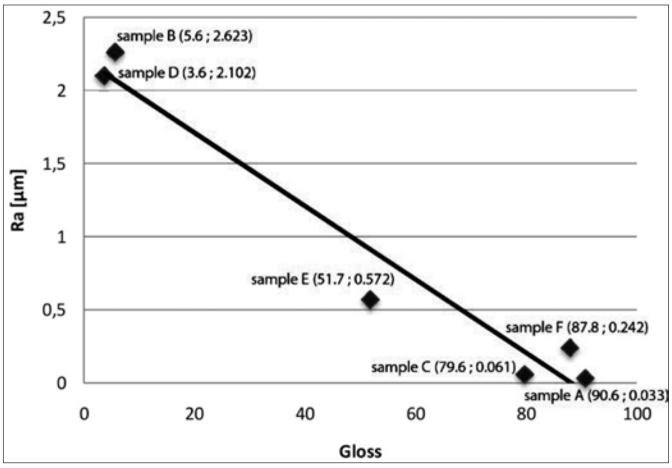

Figure 2: Correlation between surface roughness (Ra) and surface gloss

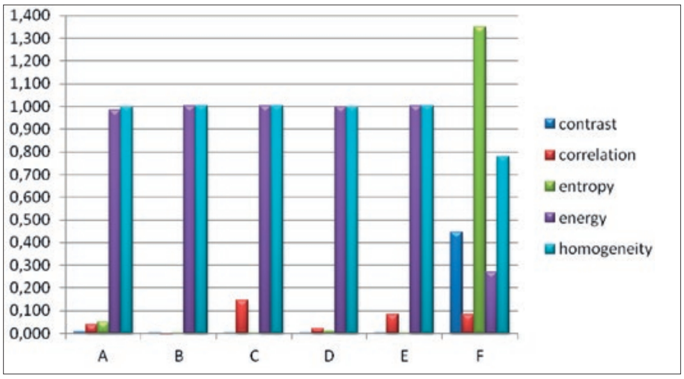

Figure 3: GLCM parameters (Contrast, Correlation, Entropy, Energy and Homogeneity); cyan

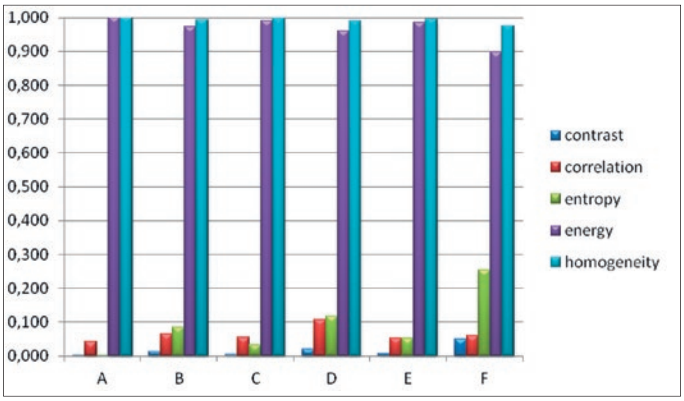

Figure 4: GLCM parameters (Contrast, Correlation, Entropy, Energy and Homogeneity); magenta

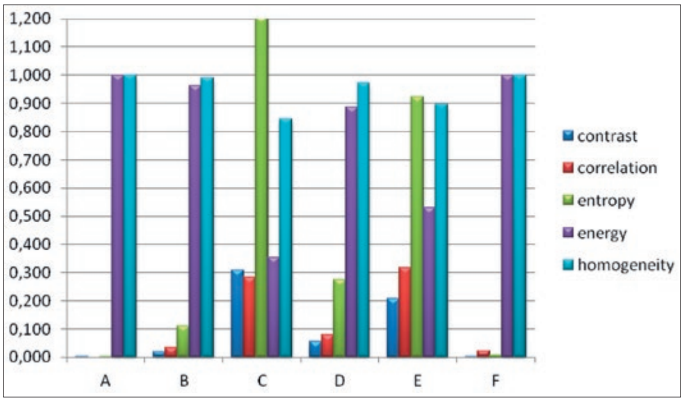

Figure 5: GLCM parameters (Contrast, Correlation, Entropy, Energy and Homogeneity); yellow

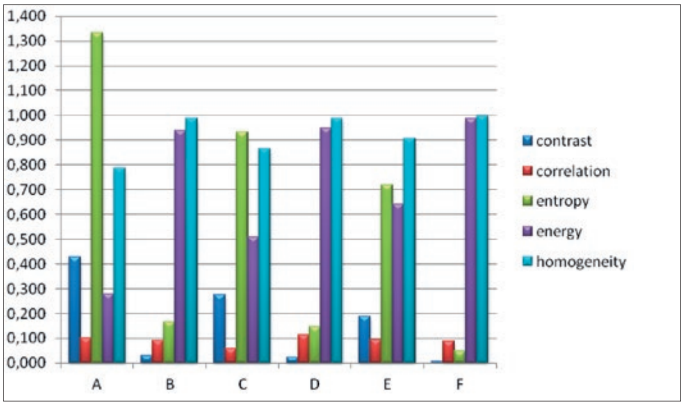

Figure 6: GLCM parameters (Contrast, Correlation, Entropy, Energy and Homogeneity); black

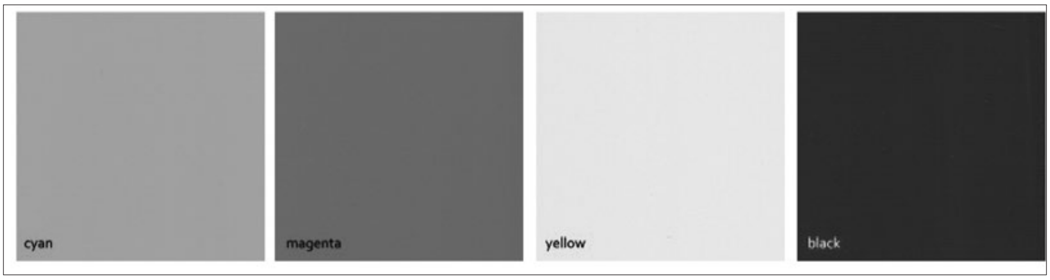

Figure 7: L channel of sample A*

4. Conclusions

Print mottle should be controlled and checked during printing in order to avoid mistakes and to get uniform print over solid areas. Ink jet printing is present in wide-format printing, where there are many large areas that need to be uniform. It is therefore very important to control print mottle. From the results of these investigations we concluded that print mottle is neither in a direct correlation with surface roughness of the substrate, nor with the gloss. In previous papers we found that print mottle is influenced by substrate properties, inequality absorption and fixation of colourants over the substrate surface and printing press conditions, so, in addition to the establishment of paper properties, absorption and fixation of colourants should be measured in order to obtain a more detailed analysis.

We also found that there is a difference between print mottle for primary colours on the same substrate and concluded that, if a patch with one colour has the largest value of non-uniformity, this does not necessarily imply that other patches with other colours would also have the highest value of non-uniformity for the same substrate. Maybe the GLCM method is not suitable for testing print mottle on individual primary colours. It is therefore necessary to assess the print mottle on the basis of a patch that will contain all the four primary colours in a certain ratio.

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References

CABRERA, J. (2003). GLCM Texture Analyzer. [Online] Available at: http://rsbweb.nih.gov/ij/plugins/texture.html, [Accessed: 27.6.2013.]

CHEN, Y. (1998): Image analysis methods for paper formation evaluation, M.A.Sc. thesis, University of Toronto, Canada, pp. 33

EK, M., GELLERSTEDT, G., HENRIKSSON, G. (2009): Pulp and Paper Chemistry and Technology. Volume 4, Paper Products Physics and Technology, ISBN 978-3-11-021345-4, Sweden

GEBEJEŠ, A., TOMIĆ, I., HUERTAS, R., STEPANIĆ, M. (2012): A preliminary perceptual scale for texture feature parameters. Proceedings of the 6th International Symposium on Graphic Engineering and Design, Faculty of Technical Science, ISBN 978-86-7892-294-7, pp. 195-202

HLADNIK, A., DEBELJAK, M., GREGOR-SVETEC, D. (2010): Assessment of paper surface topography and print mottling by texture analysis. ImageJ User and Developer Conference 2010, Archive of the ImageJ User and Developer Conference 2010.

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 Vol 26, No. 1/2011, ISSN: 0283-2631, pp. 99-105

KANDI, S.G. (2013): The Effect of Paper Appearance on Printed Color of Ink jet Printer. Color Research & Application, ISSN: 1520-6378, Vol. 38, Issue 4, pages 284–291, August 2013

LINDBERG, S. (2004): Perceptual determinants of print quality. PhD thesis, Stockholm University

MADSTEDT, S. (2008): The impact of coating composition on print mottle and print gloss variations in sheet-fed offset. Master of science thesis, KTH Computer Science and Communication, Stockholm, Sweden

MILIC N., SLAVUJ R., MILOSAVLJEVIC B. (2010): The colour mapping method based on the LCH colour space for simulating textile printed texture images. Proceedings of the 5th International Symposium on Graphic Engineering and Design, Faculty of Technical Science, ISBN 978-86-7892-294-7, pp. 167-172

PETERSSON, J. (2005): A Review of Perceptual Image Quality - a tool to predict perceived quality of a digital printed image. Department of Science and Technology, Linköpings Universitet, Sweden

TORREY PINES RESEARCH (2003): Ink jet Print Image Quality Considerations: PEARLSTM

UPPULURI, A. (2008). GLCM texture features. [Online] Available at: http://www.mathworks.com/matlabcentral/fileexchange/22187-glcm-texture-features, [Accessed: 27.6.2013.]

WU, Y. J., PEKAROVICOVA, A., FLEMING, P. D. (2007): How Paper Properties Influence Color Reproduction of Digital Proofs for Publication Gravure, Proceedings of the 59th TAGA Annual Technical Conference, pp. 527-544.

XIN J.-H., SHEN H.-L. (2003): Computational model for mapping on texture images. Journal of Electronic Imaging, ISSN: 1017-9909, Vol. 12, No. 4, pp. 697-704