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Influence of the surface roughness of coated and uncoated papers on the digital print mottle

ABSTRACT

Many factors influence the occurrence of print mottle in prints. In printing process three main components are involved: printing press, substrate and toner. They can be considered as separate components, but in most cases their interaction influences the quality of the print.
The goal of this work was to examine the influence of surface roughness of different types of paper (coated and uncoated on print mottle of electrophotographic digital prints. We set up a hypothesis that print mottle will be more apparent on rougher surfaces. In the experimental part we printed four different substrates with different surface properties on electrophotographic printing press. Morphology of the papers surface was analysed using atomic force microscopy (AFM) from which surface properties were calculated. For print mottle characterization Gray level co-occurrence matrix (GLCM) method was used. Based on the measurements and results we can conclude, contrary to the initial hypothesis, that uncoated papers with rougher surfaces produce smaller print mottle values.

KEY WORDS

surface roughness, print mottle, print uniformity, electrophotography, AFM, GLCM

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Introduction

The perception of paper and print quality is often linked to subtle phenomena such as the visual evenness of the paper and print surface. Any unevenness in gloss, brightness and print density will have a strong negative impact on the perceived print quality, known as print mottle or print non-uniformity. In electrophotographic printing process, the print quality is formed by a combination of three factors: process, toner and paper. Non-ideal interactions of paper and toner in high-speed printing processes cause several undesired effects in prints, such as print mottle.

There are various factors which influence print mottle occurrence. This can involve coating formulation, coating structure and finishing process of paper. Press conditions, such as speed and toner type, also have an impact (Hudson, 2007). Kawasaki, Ishisaki and Yoshimoto (2009) reported that print mottle mainly occurs on coated paper for offset printing and that it deteriorates print quality. They also stated other causes of print mottle, such as non-uniformity of fountain solution absorption (in offset printing), non-uniformity of toner absorption, paper surface roughness, non-uniformity of toner transfer and non-uniformity of printing density. Of all mentioned factors, Plowman (1994) considers that non-uniformity of toner transfer is the main cause of print mottle.

Despite the fact that there are several components and interactions in the printing process that can cause print mottle, the crucial point is still when the toner is transferred from the press to the paper. This is because the paper is normally the most spatially inhomogeneous component in the process (Fahlcrantz, 2005). If we are speaking about the paper as a printing substrate, its large topographical variations could cause print non-uniformity. To improve paper properties, coating layer could be applied. The coating of paper is in fact nothing less than applying a base makeup that consists mainly of pigments and binders, to increase the light scattering of the surface and to fill in the macro-structure deficiencies. In addition to smoothening the surface, the coating typically should give a more homogeneous toner absorption that decreases mottle, a higher opacity that reduces the risk of print through, and an enhancement of the paper brightness and gloss level. Unfortunately coating is no guarantee that print mottle will be avoided (Fahlcrantz, 2005).

Different compositions of coating layer of paper can increase or decrease print mottle. To achieve a coating that has good coverage, good optical properties and good runnability, many different components are added to the coating. The connection between coating layer and print mottle has been pointed out by several researchers (Dappen, 1951; Ahrheilger, 1978; Tripathi et al., 2007, Ragnarsson, 2012). In general the coating porosity variations need to be minimized by good coverage of the base paper by the coating, in order to reduce print mottle (Preston et al, 2008).

Ragnarsson (2012) investigated the influence of starch as binder in paper coating, to the print mottle. Hiorns (2010) found that a lot of money can be saved by replacing latex with a starch, but Ragnarsson (2012) concluded that the implementation of starch degrades quality of prints, it increases print mottle. Coatings consisting of starch as binder have a tendency to suffer more from print mottle than comparable coatings using other binder systems. Nevertheless, many researchers report that mottling and the inhomogeneity in the coating layer that are believed to cause mottling can be controlled by proper drying profiles. Dappen (1951) and Ahrheilger (1978) indicated that in order to prevent print mottle, the coatings should be dried slowly.

Besides, composition of coating layer and type of coating process used also influences on print mottle appearance. Tripathi et al. (2007) concluded that there is difference in print quality between curtain and blade coated papers. They found that print mottle on the curtain coated paper is significantly higher than the blade coated paper, although the difference in optical density is negligible. Higher roughness of curtain coated paper resulted in a less uniform transfer of the toner, resulting in higher print mottle (Tripathiet al., 2007).

Based on a review of current literature it can be concluded that there are plenty of factors that influence the occurrence of print mottle on prints. The goal of this work was to extract one of the crucial influential factors (paper surface roughness) which depends on coating of layer and examine its effect on print mottle of digital prints. There are several different methods to quantify print mottle (Sadavnikov, et al., 2005; ImageJ, 2008; Hladnik, et al., 2010; Kraushaar, 2011), but in the research (Jurič, et al., nd) it has been proven that the GLCM method in the best way correlates print mottle with visual perception of print uniformity. Therefore, this method was implemented in our work.

Methods and Materials

This paper was set on hypothesis that higher surface roughness will enhance print non-uniformity. In order to evaluate this hypothesis we used four different commercially available papers: two uncoated and two coated papers. In Table 1 are presented optical paper properties (whiteness, brightness and opacity) and grammage.

Table 1

Optical paper properties and grammage of papers used in experiment

Samples		Grammage [g/m²]	Optical paper properties		
			Whiteness	Brightness [%]	Opacity [%]
A (uncoated)	Univerzal-Masterprint	250	116,53	94,60	99,73
B (uncoated)	Radeče Bristol	250	118,67	96,87	99,93
C (coated)	Radeče Nextra SC1	250	86,37	85,87	99,93
D (coated)	MultiArt Silk	250	98,07	89,01	99,60

Papers were characterized by their surface properties (topography, surface roughness). For evaluation of the paper surface roughness we used NTEGRA prima atomic force microscope (AFM) (NT-MDT, Moscow, Russia). Measurements were performed in air using intermittent-contact AFM mode and NT-MDT NSGO1 silicon cantilevers (N-type, Antimony doped, Au reflective coating). The used cantilevers have nominal force constant of 5.1 N/m and resonance frequency in the range 87-230 kHz. During the measurements, scan size was chosen to be equal 5 square microns, driving frequency was 148 kHz, while line scanning frequency was 1 Hz. For the investigated samples both topography and "error signal" AFM images were taken and analysed using the software Image Analysis 2.2.0 (NT-MDT, Moscow, Russia). The same software was applied for roughness evaluation.

Test chart used for the experiment consisted of one square 16 x 16cm (C: 65, M:50, Y:50 and K:50%) for obtaining print mottle (Krausshar, 2010; Rasmussen, et al., 2005). It was printed using electrophotographic printing machine, Xerox DocuColour252 with standard printing settings. Print mottle was evaluated using GLCM image analysis method. For assessing print mottle with image analysis method, printed samples need to be digitized. Therefore, after printing, samples were scanned by scanner Canon CanoScan5600F at 1200 spi. This resolution is recommended by standard ISO 24790:2009. Calculations of GLCM parameters were performed for all 4 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 and Shen, 2003; Milić, Slavuj and Milosavljević, 2010). As well, the importance of L* channel is mentioned in the new announced standard ISO 15311, which will be published in 2016 (Liensberger and Kraushaar, 2014).

GLCM calculations were performed in MATLAB software with a code proposed by Uppuluri (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 was examined, was selected to 1 pixel. For the orientation (θ) the average of the possible four (0^o, 90^o, -45^o and 45^o) was taken into account. With this code it is possible to obtain 22 parameters. From those, as parameters of importance for print mottle we take into account contrast, correlation, entropy, energy and homogeneity for further analysis. In the studies (Chen, 1998; Hladnik, et al., 2010; Gebeješ, et al., 2012) it was found that low contrast, low correlation, low entropy, high energy and high homogeneity correspond to uniform gray level distribution, i.e., indicate a uniform, smooth paper surface. It was also found that parameter entropy correlates the best with human texture perception (Gebeješ, et al., 2012).

Results and discussion

For the quantification of the surface roughness we have chosen the root mean square roughness factor Sq and other parameters such as Max, Min, Sy, Sssk and Ska. Results are summarized in Tables 2 and 3. As we can see from the results presented in Table 2, the root mean square roughness of plain paper is higher than the one of the printed paper. Application of toner decreased roughness for all samples. Also, it is noticeable that the coating layer affects the surface roughness of papers. Higher values were obtained for uncoated papers. The highest Sq value (503,04nm) was obtained for uncoated paper (sample A). On this sample Sq value decreased after printing, but it was still the highest (202,73nm). Sample D (coated paper) is the smoothest, with smallest Sq value before (132,11nm) and after (80nm) printing. Other parameters of surface roughness (Max, Min, Sy, Sssk and Ska) are not consistent. There is no same relation between the samples of plain paper and samples after printing. For example, parameters Max and Sy decreased after printing for samples A, C and D, while in the case of the sample B values increased after printing.

Table 2

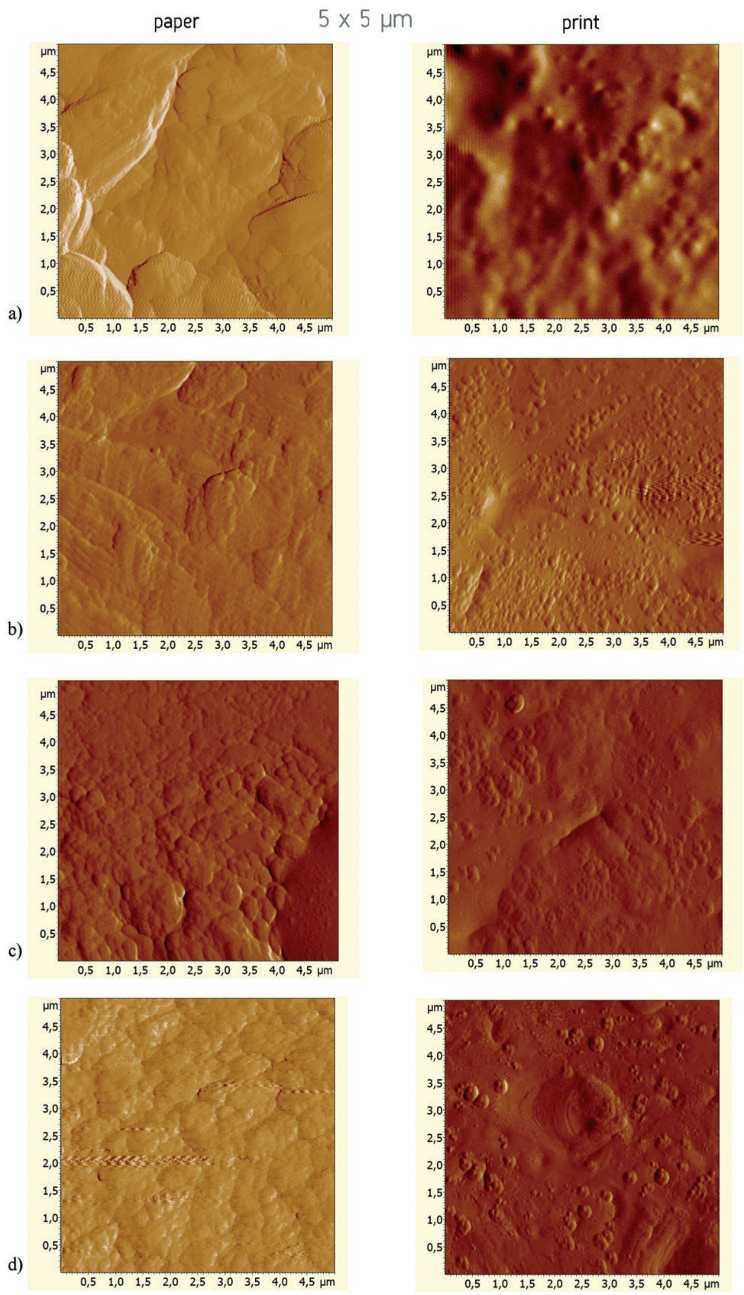
The root mean square, Sq, surface roughness values of the measured samples obtained from scan areas of 5x5µm

Sample		Root mean square roughness, Sq[nm]
A (uncoated)	Print	202,73
	Paper	530,04
B (uncoated)	Print	128,48
	Paper	233,99
C (coated)	Print	72,04
	Paper	168,18
D (coated)	Print	80,53
	Paper	132,11

Table 3

Other surface roughness parameters Max, Min, Sy, Sssk and Ska

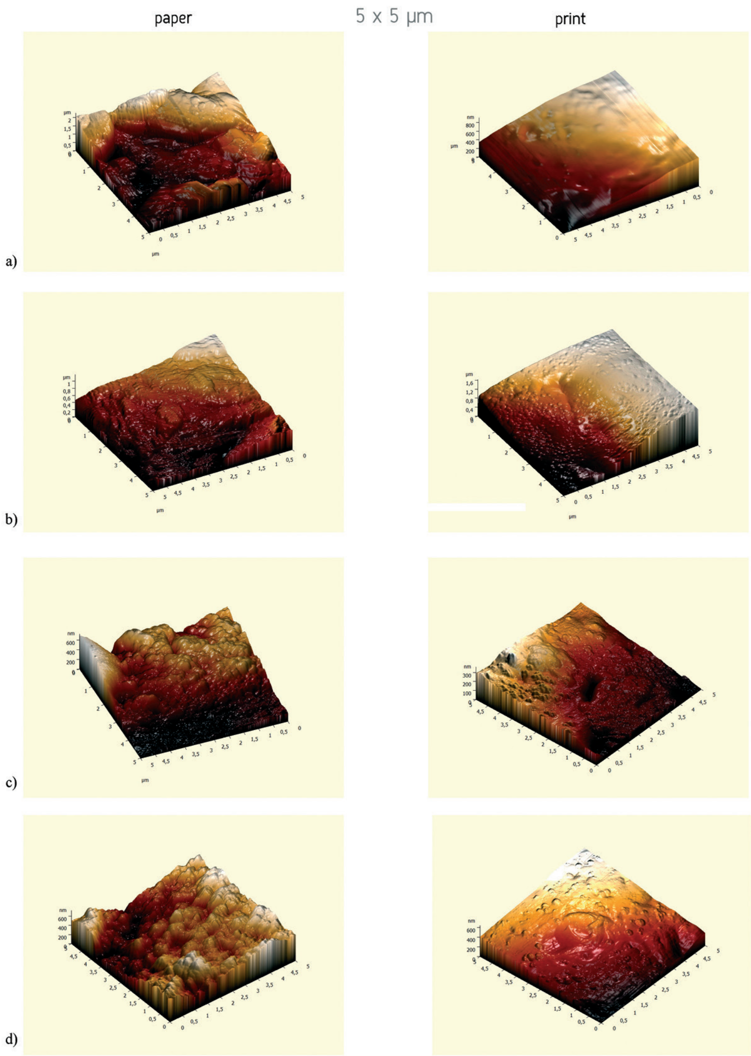
Samples/ Parameters	A (uncoated)		B (uncoated)		C (coated)		D (coated)	
	Print	Paper	Print	Paper	Print	Paper	Print	Paper
Max [nm]	918,67	2296,61	1640,47	1193,51	365,122	733,339	646,135	730,759
Min [nm]	0	0	0	0	0	0	0	0
Peak to peak, Sy [nm]	918,67	2296,61	1640,47	1193,51	365,12	733,339	646,135	730,759
Surface skewness, Sssk	-0,368	0,478	-0,364	0,471	0,273	0,0109	0,101	-0,355
Coefficient of kurtosis, Ska	-0,680	-0,913	-1,126	-0,376	-0,812	-1,029	-0,545	-0,322



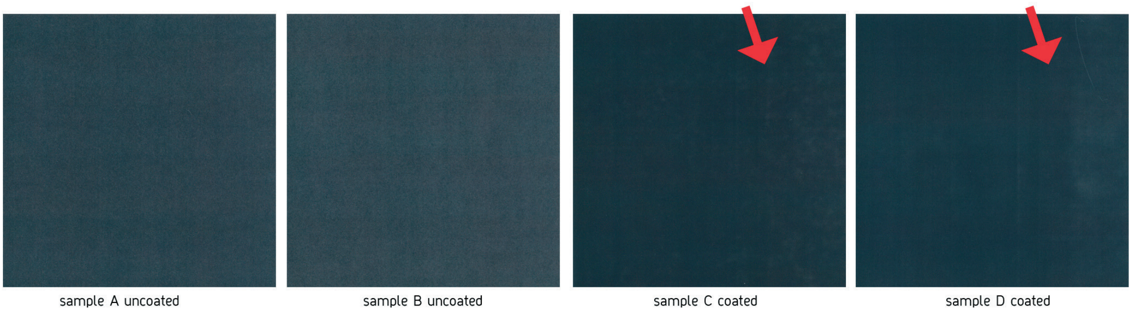
» **Figure 1:** *The surface topography illustrated by 2D error signal AFM images of (5 μm x 5 μm) scan areas of samples before and after printing: a) A, uncoated; b) B, uncoated; c) C, coated and d) D, coated*

In order to obtain more information about samples morphology, we have generated 2D and 3D AFM images. The Figures 1 and 2 show the typical topography of the studied samples. It can be clearly seen that the surface after printing is smoother comparing it with the surface of the paper without printing.

For quantification of print mottle (print non-uniformity), we used GLCM image analysis method. GLCM method was performed on scanned patches presented in Figure 3. Results are presented in Table 4, and to facilitate analysis, results are shown graphically in Figure 4. According to findings mentioned in studies (Chen, 1998; Hladnik, et al., 2010; Gebeješ, et al., 2012) and based on the results shown in Figure 4. we can say that samples A and B (uncoated papers) have uniform surface and that samples C and D (coated papers) have larger non-uniformity, print mottle. Sample B has the smallest contrast (0,001), correlation (0,125) and entropy (0,010), and the largest energy (0,998) and homogeneity (0,999), therefore it can be regarded as the sample with the highest print quality. Sample A has similar values as sample B, only value of the correlation is higher for sample A (0,223). Therefore, print is more uniform on sample B than on sample A. The largest nonuniformity was obtained for sample D. Sample D has the largest contrast (0,232) and entropy (1,123), and smallest energy (0,406) and homogeneity (0,884), only sample C has larger value of correlation parameter (0,592 for sample C and 0,446 for sample D).
This can also be concluded if we examine these scanned samples (Figure 3). If we only observe uncoated or coated papers, difference between them is negligible.



» **Figure 2:** *The surface topography (3D) of samples before and after printing obtained on (5 µm x 5 µm) scan areas: a) A, uncoated; b) B, uncoated; c) C, coated and d) D, coated*



» **Figure 3:** *Scanned samples*

Table 4

GLCM parameters of printed samples

GLCM parameter/samples	contrast	correlation	entropy	energy	homogeneity
A (uncoated paper)	0,001	0,223	0,0111	0,997	0,999
B (uncoated paper)	0,001	0,125	0,010	0,998	0,999
C (coated paper)	0,133	0,592	0,862	0,561	0,934
D (coated paper)	0,232	0,446	1,123	0,406	0,884

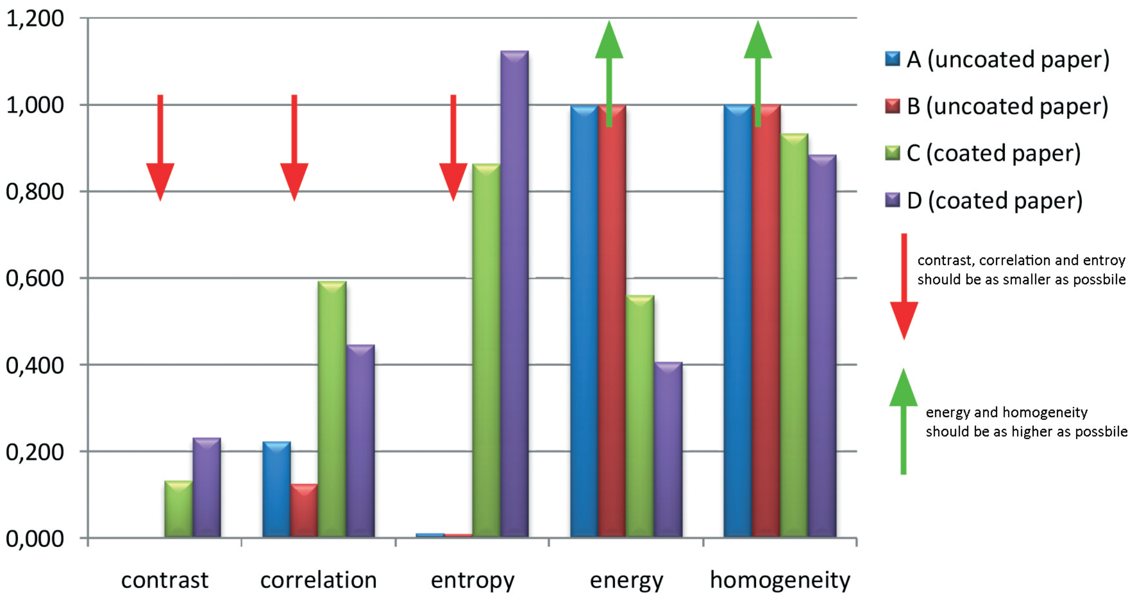


Figure 4: *GLCM parameters (contrast, correlation, entropy, energy and homogeneity) for assessing print mottle samples*

Coated samples C and D have larger non-uniformity, predominantly in the right part of the patch. On uncoated samples A and B, graininess is more apparent, but the uniformity of the macro-level (print mottle) is satisfactory. For assessing the possible relationship between surface roughness (root mean square Sq) and print uniformity, we calculated Pearson correlation coefficient for linear relation. Results of correlation coefficient between surface roughness of printed samples and GLCM parameters are presented in Table 5.

Table 5

Correlation coefficient between surface roughness of printed samples (Sq) and GLCM parameters

	Sq and contrast	Sq and correlation	Sq and entropy	Sq and energy	Sq and homogeneity
Correlation coefficient (ρ)	-0,782	-0,730	-0,835	0,829	0,780

Surface roughness (root mean square, Sq) is in negative linear correlation with contrast, correlation and entropy, and in positive linear correlation with energy and homogeneity. This result indicates that the more uniform print is achieved on rougher surfaces. As surface roughness increases, contrast, correlation and entropy decrease, while energy and homogeneity increase. Uncoated papers have higher surface roughness, but print on those papers is more uniform than on coated papers which are smoother.

Conclusions

Print mottle will physically always be present in a print, therefore it is good to know why it occurs and of course to try to remove it. During toner transfer to the paper, the amount of toner vary to some extent which causes inhomogeneities on prints. The variation may be low, but it will nevertheless always exist. Visually however it may be possible to eliminate it. If the print density variations are reduced below the threshold of detection, they will no longer be visually present.

In this paper we investigated the influence of coated and uncoated papers, which have different surface roughness, on print mottle. Print mottle can be quantify with several different methods. The results obtained by the various methods are not correlated, so that the choice of method certainly affects the results. We used five parameters (contrast, correlation, entropy, energy and homogeneity) from GLCM method for the assessment of print mottle. On the basis of the obtained experimental results, conclusions were made which are completely opposite to the primary hypothesis. We found that print non-uniformity is smaller on uncoated papers, which have larger roughness of surface. Coated papers are less rough, but on these papers print mottle was higher. This conclusion confirmed the fact by Fahlcrantz (2005), who stated that coating is not guarantee that print mottle will be avoided.

To investigate further the influence of coating of paper on print mottle, in addition to surface roughness other properties (structure of coating, porosity, absorbency and optical properties) should be examined, in order to make a more complete lock up.

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References

1. Ahrheilger, D. (1978) Influence of coating drying on paper quality. Das Papier, Vol. 32, ISSN: 0031-1340 3.
2. Chen, Y. (1998) Image analysis methods for paper formation evaluation. M.A.Sc. thesis, University of Toronto, Canada, pp. 33
3. Dappen, J.W. (1951) Distribution of Starch in Clay Coatings. Tappi Journal, Vol .34, No. 7, ISSN: 0734-1415
4. Gebeješ, A., Tomić, I., Huertas, R. and 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
5. Fahlcrantz, C.M. (2005) On the Evaluation of Print Mottle. Doctorial Thesis in Computer Science, ISSN 0348-2952ISBN 91-7178-205-2, KTH School of Computer Science and Communication, Stockholm, Sweden
6. Hiorns, A. (2010) Can starch be used in topcoating?, Tappi 11th Advanced Fundamentals Symposium, Munich, Germany: Tappi Press, Atlanta, GA, USA.
7. Hladnik, A., Krumpak, G., Debeljak, M and Gregor-Svetec, D. (2010) Assessment of paper surface topography and print mottling by texture analysis. ImageJ Conference 2010, Centre de Recherche Public Henri Tudor, Luxemburg
8. Hudson, D. (2007) Technical guide: Print mottle. [Online] Available at: http://www.imerys-paper.com/pdf/Technical%20Guide%20Print%20Mottle.pdf, [Accessed: 15.5.2014.]
9. International Organization for Standardization (2009) ISO/IEC 24790: Information technology- Office equipment- Measurement of image quality attributes for hardcopy output - Monochrome text and graphic images
10. Jurič, I., Karlović, I., Novaković, D., and Tomić, I. (submitted) Comparative study of different methods for the assessment of print mottle
11. Kawasaki, M., Ishisaki, M. and Yoshimoto, Y. (2009) Investigation into the Cause of Print Mottle in Halftone Dots of Coated Paper: Effect of Optical Dot Gain Non-uniformity. Japan TAPPI journal, ISSN:0022-815X, Vol.63, No.11, pp.1362-1373
12. Kraushaar, A. (2010) Evaluation of ‘within sheet uniformity’ by means of the M-Score. [Online] Available at: http://www.fogra.org/dokumente/upload/dbd47_2010_en_mscorev1_ak.pdf, [Accessed: 25.5.2013.]
13. Liensberger, T. and Kraushaar, A. (2014) Evaluation of perceptual resolution of printed matter (Fogra L-Score evaluation).SPIE Proceedings, Vol. 9016, Image Quality and System Performance XI, DOI:10.1117/12.2037262, San Francisco, California, USA
14. Milić, N., Slavuj, R. and Milosavljević, 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
15. Plowman N. (1994) Predicting Print Mottle: A Method of Differentiating Between Three Types of Mottle. Tappi Journal, Vol.77, No.7, pp.173
16. Preston J., Hiorns A. G., Elton N., Ström G. (2008) Application of Imaging Reflectometry to Studies of Print Mottle on Commercially Printed Coated Papers, Tappi Journal, January
17. Ragnarsson, M. (2012) Variations Related to Print Mottle in Starch-Containing Paper Coatings. Dissertation, Karlstad University, Faculty of Technology and ScienceChemical Engineering, ISSN 1403-8099, Sweden
18. Rasmussen, D.R., Donohue, K.D., Ng, Y.S, Kress, W.C, Gaykema, F. and Zoltner, S. (2005) ISO 19751: Macro-uniformity, SPIE Proceedings, Vol. 6059, Image Quality and System Performance III, DOI:10.1117/12.648086, San Francisco, California, USA
19. Sadovnikov , A., Salmel, P., Lensu , L., Kamarainen , J.K. and Kälviäinen, H. (2005) Mottling Assessment of Solid Printed Areas and Its Correlation to Perceived Uniformity. Lecture Notes in Computer Science, Vol.3540, pp. 409-418
20. Tripathi, P.,Joyce, M., Lee,D.I., Fleming, P.D and Sugihara, M.(2007) Comparison of the Surface and Print Quality of Curtain and Blade Coated Papers. TAGA Journal, Vol. 3, ISSN 1748-0337, SWANSEA PRINTING TECHNOLOGY LIMITED, Swansea, United Kingdom
21. Uppuluri, A. (2008) GLCM texture features. [Online] Available at: http://www.mathworks.com/matlabcentral/fileexchange/22187-glcm-texture-features, [Accessed: 27.5.2013.]
22. Xin J.H.and 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