Paper Topography and Its Influence on Print Quality

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Keywords:

Abstract

The topography or details of the paper surface have a great influence on the final printed result. This research paper evaluated the influence of the paper topography on the quality of the printed dot reproduction and therefore the overall print quality.

The paper topography was measured using the Verity IA Image Analysis software, which uses a modified flatbed scanner to acquire an image of the paper surface. This analysis provided information on the roughness of the papers. The roughnesses of the tested sheets were studied by taking microscopic images of paper at approximately 60x magnification and analyzed using also ImageJ software. The results from software applications were compared and a correlation between the results from both applications found.

In the second part of the study test coated and uncoated papers from both ends of the roughness scale were chosen for printing of a specially designed test form.

The test form was printed on a Xerox Docucolor 7000 and also on a Heidelberg Printmaster 74 offset press. Both printing systems have different requirements in regard to paper quality. The VerityIA software was used to evaluate the quality of the printed dot structure (shape, circularity and diameter of the dot) and how the paper directly influences it. The printed results from both printing technologies were compared in order to correlate the influence paper roughness has on the quality of dot reproduction.

Introduction

The topography (microscopic analysis) of the paper surface has a great influence on the final printed result. This paper evaluates the influence of the paper topography on the quality of the printed dot reproduction and therefore the overall print quality in offset and digital printing. Earlier works done by Rosenberger (Rosenberger 2003, Rosenberger 2006) analyzed paper topography

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in relation to gloss mottle and print mottle. Other researchers have used white-light interferometry(Sprycha et al., 2006)to determine the surface characteristics of paper using interference fringes of visible light.

The topic of studying the topography of paper surfaces in relation to printability is not a new topic. The approach taken in this research paper is of a different kind of nature and involves the study of print properties of the same papers used for sheetfed offset print technology and for digital toner-based print technology. A study done by Du (2008) determined the surface characteristics of the studied papers through topography, structure, and surface tension. Du states that it is important that the method for the measuring the paper topography does not apply pressure to the paper specimen, since it can influence the result.

Dickson and Chinga (2008) investigated the influence of a certain fibrous raw material on the paper quality and the resulting print quality. They tried to find a relation between ink coverage and variations in sheet grammage and topography and found that grammage variability had a greater influence on ink coverage than did the topography variability.

Loffler, Dusting, and Vanderhoek looked at the relationship between inkjet print quality and paper formation and roughness (Loffler et al., 2007). Their investigation varied the type of inkjet printer as well as the type of uncoated fine paper. The combination of inkjet printer and one of the eleven uncoated papers were tested for colour density, gamut, mottle, grain, dot gain, line width, and inter-colour bleed. Correlation between some of the individual print parameters has been found and some dependence of the print result on the paper surface and formation.

In 2003 Sirvö conducted a study on paper properties for modern dry toner presses (Sirviö, 2003). His study emphasizes that surface evenness and good uniformity is more important to print quality than electrical properties on the macroscale.

Hannsson and Johannsson (2000) describe in their article stereophotometric method to study reflectance and topography at the same time.

From this literature review it can be seen that many different attempts have been made to assess the topography of the surface that will be printed on and relate it to the achievable print quality.

Experimental

For this study test prints were done on a PrintMaster PM74 press and Xerox Docucolor 7000 digital press. For some of the analysis done, images of the test prints were taken with a digital SLR through a microscope at 10 times magnification. Most of the results obtained using the Verity IA software were done at 1200 ppi. The topography analysis was done at 2400 ppi in a 2.5 by 2.5 cm large area.

The Verity IA software can analyze images taken either by a digital camera or a modified high-resolution flatbed scanner. The measurement algorithms used in this software are based on Stochastic Frequency Distribution Analysis (SFDA).

The Stochastic Frequency Distribution Analysis (SFDA) is usually employed in the measurement of surface patterns such as, topography, visible solid tone print mottle, half-tone print mottle, and paper formation. SFDA is a digital algorithm that operates only on digital images that can be acquired by any means. The original image may be poly-chromatic but must be processed to produce a mono-chromatic image for analysis. Its pixel (picture elements) luminance values (PLV) must vary from zero (0) for black to any number equal to or greater than 255 for white. The image content must be intended to be spatially uniform as the algorithm will measure the degree of spatial dispersion within the image PLV on a scale where zero (0) represents a perfectly smooth or uniformly dispersed subject matter lacking any features or texture in which case the PLV all have the same value.

SFDA employs square targets (often referred to as tiles) that can be a range of different sizes to measure the uniformity of a random pattern's PLV spatial distribution. When measuring visible phenomenon such as print mottle, the targets, if they were actual, would usually visible at normal viewing distance. When measuring sub-visible features such as topography and half-tone mottle, the SFDA targets would not visible under normal viewing conditions.

The resolution of the original image to be analyzed must be high enough to record the features of the mottle or pattern to be measured. With visible print mottle this is the texture or minute disturbance reproduced only with resolutions equal to or greater than 236 pixels per centimeter (ppc), or 600 pixels per inch (ppi). Because the eye detects but averages together sub-visible feature luminance, higher resolution than normally expected is required to resolve print mottle.

Paper formation does not have visible texture as such but does have wire marks that can obscure the formation measurement. In this case low resolution will minimize the impact of wire marks. The 60 ppc (150 ppi) is the recommended resolution for formation measurement. When measuring the sub-visible features in optical surface topography and the dots that make up half-tone print mottle, SFDA measurements require image resolutions of at least 472 ppc (1200 ppi).

The SFDA measurement employs square targets. These square targets are moved through the entire image following a regular traversing pattern. Typically starting at the upper right corner of the image, the target is moved one half its width to the right, stops, makes a measurement and then moves another half width, measures and moves, repeating the move-measure pattern until the edge of the image is reached. Another line of measurements is begun that is one half its height below the first or preceding line. This movement pattern continues until the bottom of the image is reached.

Like the resolution, the size of the target depends upon the pattern to be analyzed; usually multiple target sizes are employed depending upon the surface being analyzed. When a series of sizes is employed the first target size used determines the progression of target sizes that will be used. The target physical dimensions follow a binary progression, i.e., 2, 4, 8 … 1024 (maximum), as multiples on the first target. When only one target is used there is no size progression.

The target physical size progression used for print mottle measurement in an image with a resolution of 236 ppc (600 ppi) includes the target widths: 0.677 mm, 1.355 mm, and 2.709 mm. Similarly, formation measurements use a resolution of 59 ppc (150 ppi) and target widths of 1.355 mm and 2.709 mm. In these two examples the targets of 0.677 mm and 1.355 are visible; the observed pattern is visible.

Topography is sub-visible; its features cannot be seen with the naked eye. When measuring topography a resolution of 472 ppc (1200 ppi) required and the range of targets used in the evaluation starts with 0.338 mm which is below the visible limit.

Up to this point the SFDA measurement resembles others that measure the variation spatial distribution, but there is a difference: SFDA measures the Internal Rate of Change (IROC) within the image in addition to the variation in spatial distribution.

In the analysis, the target used is always a square, dimensioned 2 elements x 2 elements as shown in Figure 1 below. As described above, the target dimensions are determined by the measurement to be made, e.g., visible print mottle, topography, roughness, formation, etc. At the initiation of a SFDA measurement, the physical size (length and width) of this primary target square and the four (4) equal contiguous squares elements within it (see Figure 1) are rationalized to the resolution of the image to be analyzed. The primary target length and width measurements are always in integral pixels dimensions.

After the primary square physical dimensions are rationalized, the Luminance Values of the Pixels (LVP) within each smaller square are averaged. The average is recorded in a two-dimensional data base at a location corresponding to the physical location of the smaller square. The new data base elements will be the equivalent of a new image containing the average of the LVPs in the smaller squares within the primary target.

The question might be asked: “Would using a lower resolution to acquire the original image suffice instead of this averaging technique?” Empiric testing has shown that the human eye discerns the small variations that are sub-visible, and, although the image may appear correct, the digital camera, when asked to operate a lower resolution, does not reproduce important details necessary to do a good analysis.

After the creation of this new image data base containing the LVP averages within the smaller square elements, the primary target is now moved one data base element horizontally. When the traverse is complete, the target is indexed down one target element and traversed one element at a time through the entire data base. This is the equivalent of moving through the original image one half (½) its physical width horizontally and one half (½) its physical height vertically through out the entire image.

At each stop in the element-by-element traverse of the data base, the SFDA algorithm calculates:

1. The Internal Rate of Change (IROC) as the cross absolute differences in average luminance within the small squares in the primary target as shown in step five (5) in Figure 1. With this individual IROC, the algorithm updates the variables necessary to calculate:
   The Standard Deviation ($\boldsymbol{\sigma}_{\mathbf{IROC}}$)
   The Mean ($\mathbf{M}_{\mathbf{IROC}}$)

   for the primary target IROCs at the completion of the data base traverse

2. The mean luminance value ($\mathbf{Mean}_{\mathbf{Ave\ 1–4}}$) of the small squares average luminance values. With this individual mean value, the algorithm updates the variables necessary to calculate:
   The Standard Deviation ($\boldsymbol{\sigma}_{\mathbf{Mean}}$)

At the completion of the data base traverse, the SFDA Number is calculated:

$$\textbf{SFDA Number} = \textbf{Constant} \times \boldsymbol{\sigma}_{\mathbf{IROC}} \times \mathbf{M}_{\mathbf{IROC}} \times \boldsymbol{\sigma}_{\mathbf{Mean}}$$

An illustration of this procedure can be seen in Figure 1.

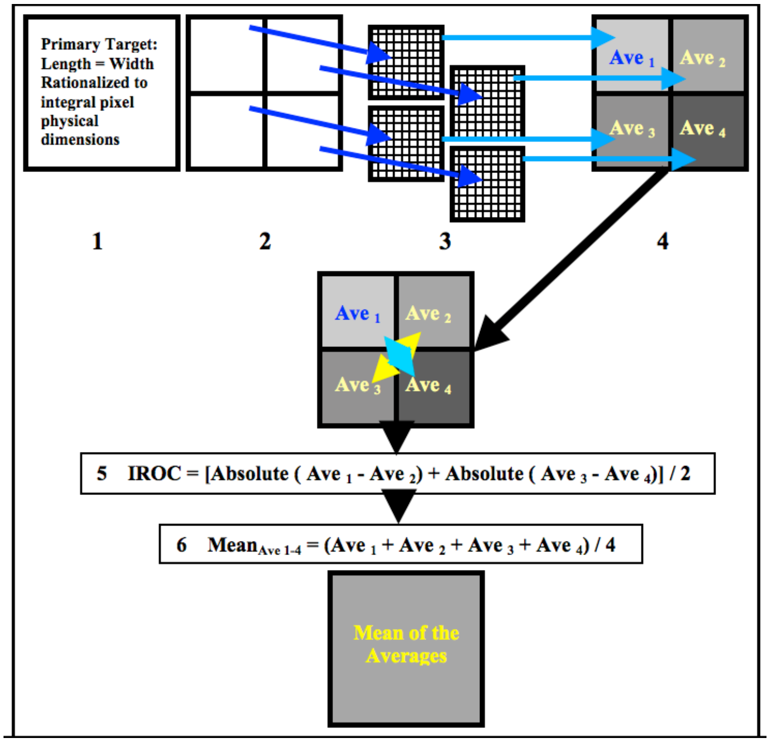

Figure 1: The first step (1) identifies the square dimensions of the smallest target to be used in the SFDA rationalized to integral pixel physical dimensions. This target is then sub-divided into four equal and contiguous squares (2). The pixel luminance values underlying these smaller squares are then averaged (3). These averages are then used to create another image (4) that is then used to calculate the absolute Internal Rate of Change (IROC) within the original target area (5). At the completion of the IROC calculation data for the final calculation of the standard deviation and the mean IROC are accumulated. At step six (6) the mean of the four smaller squares average luminance values is calculated and data is accumulated for the final calculation of the standard deviation of these means

The results of the SFDA measurement in each target size within the preset range are averaged together for the final SFDA number. An image with a SFDA Number of “0” is the ideal, which occurs when no pattern or texture is exists in the image.

The SFDA measurement results from each size target are simply averaged:

$$\textbf{Final SFDA Number} = \textbf{Constant} \left(\sum\nolimits_{1 \text{ to } N} \textbf{SFDA} / \textbf{N} \right)$$

The uniqueness of this study is that the same set of printing papers will be printed on with offset and digital print technology. The test form for both printing processes contains the same main elements that allow that the same analysis will be carried out independently of the printing technology that was used.

We also utilized a free image processing software called ImageJ that had a plug-in installed for surface characterization. ImageJ is open-source software that originated with the National Institutes of Health (ImageJ, 2009). This software can be enhanced with its capabilities through plug-ins. Chinga (2007) wrote a plug-in for the determination of the surface roughness. Chinga et al. have described in detail how the plug-in works (Chinga et. al, 2007).

In the first stage of the study papers available at the School of Graphic Communications Management were analyzed for their roughness, so it was possible to determine which papers will be used for the press tests on the offset and digital press. Both software solutions were used for the evaluation of the paper roughness.

In the second stage of the study five coated and five uncoated papers were used for printing a test form. All papers were used on the offset and the digital press. The test forms were analyzed for topography, mottle, and halftone mottle and dot circularity. The dot circularity can also be described as dot fuzziness. The more round and well defined a printed dot is, the lower will be the dot circularity or the less fuzzy the printed do will be. It will be interesting to see the differences the dots printed on the offset and the digital press.

Results

Roughness results for both software packages

For this part of the study images of the tested papers were taken at 10 times magnification with a digital SLR camera and analyzed in both software solutions. The exposure times of the SLR camera were adjusted so that a paper structure was visible, but to avoid over- and underexposure.

The results of this analysis can be seen in Table 1.

	Verity IA	ImageJ
Coated #1	***4.87***	***12.04***
Coated #10	***11.18***	***14.93***
Coated #11	***5.955***	***13.05***
Coated #12	***2.805***	***8.88***
Coated #13	***2.715***	***11.35***
Coated #2	***3.415***	***11.85***
Coated #4	***2.97***	***13.90***
Coated #5	***4.3***	***12.00***
Coated #6	***4.18***	***12.62***
Coated #7	***4.55***	***11.87***
Coated #8	***0.885***	***7.87***
Uncoated #10	***10.61***	***13.90***
Uncoated #11	***12.27***	***14.53***
Uncoated #12	***12.18***	***14.18***
Uncoated #4	***39.65***	***17.46***
Uncoated #6	***15.95***	***15.38***
Uncoated #7	***16.285***	***15.27***
Uncoated #8	***9.645***	***14.83***
Uncoated #9	***13.99***	***14.97***

Table 1. *Comparison of roughness values obtained from both software solutions*
A visual presentation of the values listed in Table 1 can be seen in Figure 1.

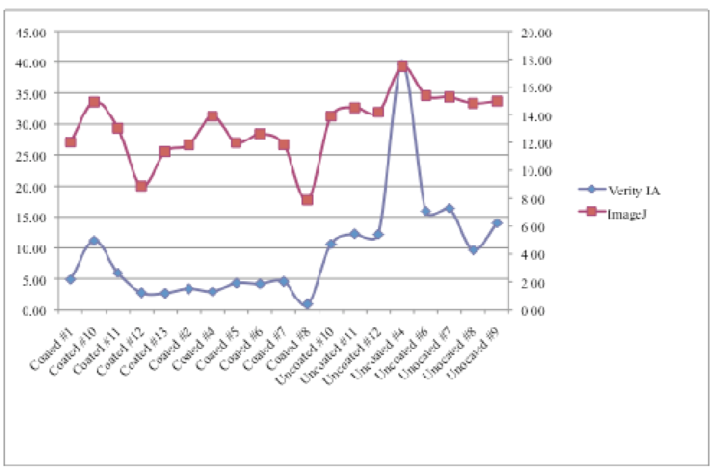

Figure 1. *Comparison of roughness values between the tested software packages. Values for a newsprint-type paper have been omitted for better comparison reasons.*

From Figure 1 one can clearly see that there seems to be a correlation between the roughness values obtained from both software solutions. One needs to keep in mind that the values for newsprint-type paper have been omitted. In the following figure the roughness values obtained by both software solutions were plotted against each other.

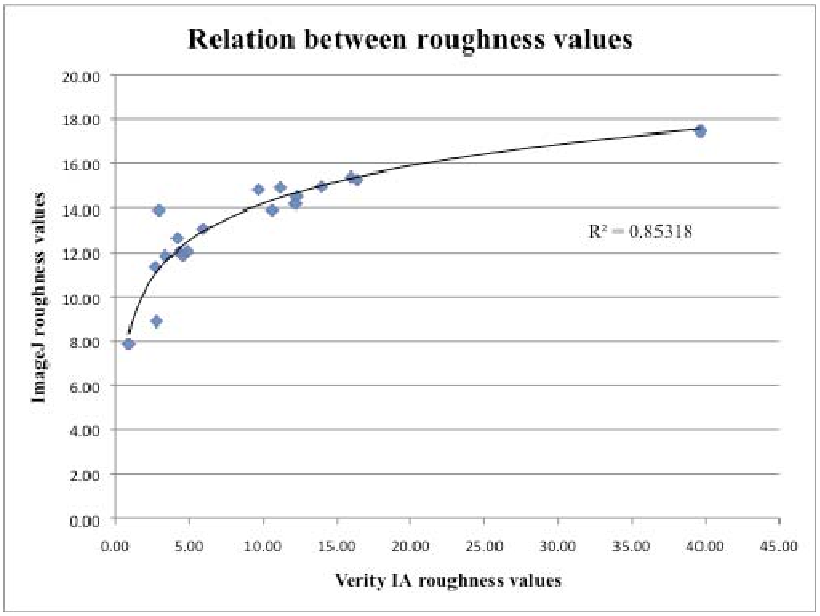

Figure 2. Comparison of roughness values obtained through both software solutions.

From Figure 2 it can be seen that a logarithmic correlation exists between the roughness values obtained through both software solutions. The r^2-value of 0.85 is not ideal but indicates at good correlation between the roughness values obtained with both software solutions. Based on this result it can be said that the roughness plug-in for ImageJ can be used for the most papers to determine the roughness values of paper surfaces. The roughness values obtained through ImageJ can be calculated into roughness values that will be obtained through the Verity IA software. The only exceptions are very rough paper surfaces like Newsprint and papers containing a high amount of post consumer fibers.

Press runs on an offset and digital print device

The press runs were conducted on a Heidelberg PrintMaster PM74 and Xerox 7000 Docucolor machine with an EFI digital front end. After the initial tests on various types of paper five different papers were chosen based on their topography values and availability in the desired sheet size for the offset press.

The selected papers still represent a variety of topography values. The list of papers can be seen in Table 2.

Coated Paper	Grammage [g/m^2]	Topography Value	Uncoated Paper	Grammage [g/m^2]	Topography Value
Coated #1	148	20.8	Uncoated #1	104	75.51
Coated #2	100	16.32	Uncoated #2	148	87.88
Coated #3	170	8.61	Uncoated #3	104	486.73*
Coated #4	90	8.48	Uncoated #4	148	21.73
Coated #5	100	21.14	Uncoated #5	104	153.08

Table 2. *List of papers used for the press runs, *Paper is made from 100% post consumer waste and contains many colored speckles.*

In the following images elements from both test forms are shown.

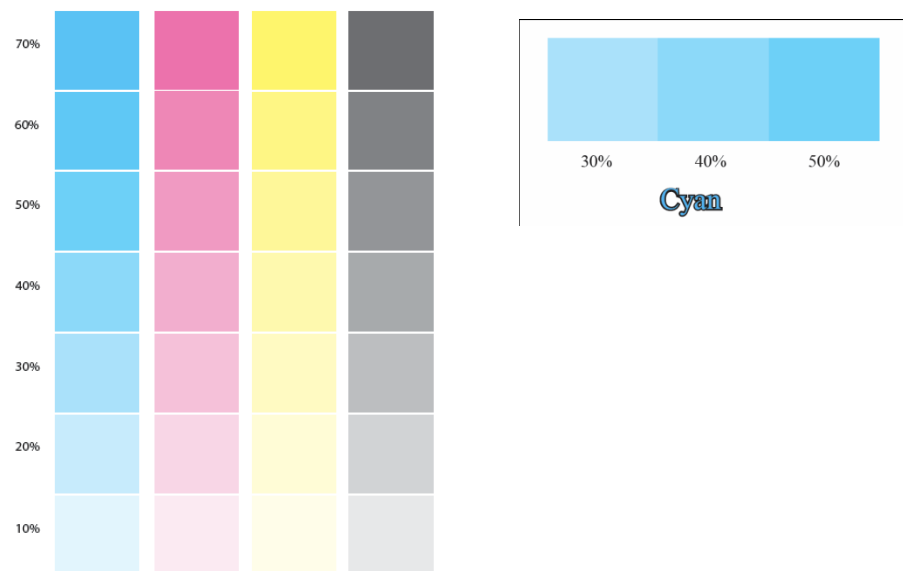

Figure 3. *Test form for the offset press (left) and the digital press (right) with cyan test patches only shown.*

Since coated and uncoated papers were used, recommended print densities for a #1 coated sheet and for uncoated offset print conditions were maintained. The varying thickness of between 70-lb and 100-lb sheets was taken into consideration and the printing pressure adjusted, so that similar print conditions were maintained during the offset press runs.For the digital press run the print quality was automatically adjusted based on the paper grammage.

Results for dot circularity

Another aspect of this study was to determine the dot circularity as a measure of print quality for the print production. A lower dot circularity number means that the dot is more round and less fuzzy. This means a more accurate reproduction of the printed dot. The dot circularity analysis was carried out by measuring the 30% tint value of cyan on all papers and for both printing processes. The dot circularity was measured at 2400 ppi with an analysis area of 545 mm^2. The average number of dots that were measured on the uncoated papers was approximately 8400 dots and approximately 15000 dots for the coated papers. The results for offset and digital press runs are shown in the following tables.

Paper Type	**Paper Name**	**Grammage**	**Topog-raphy Value**	**Average Dot Circu-larity**	**Average Standard Deviation**	**Rank in Relation to Other Papers**
Coated	Coated #2	100	16.32	16.14	6.17	1
Coated	Coated #5	100	21.14	18.41	11.34	2
Coated	Coated #1	148	20.8	22.07	20.96	3
Coated	Coated #4	90	8.48	23.07	24.19	4
Coated	Coated #3	170	21.14	38.17	80.27	5
Uncoated	Uncoated #1	104	75.51	28.16	29.05	1
Uncoated	Uncoated #2	148	87.88	30.16	40.87	2
Uncoated	Uncoated #4	148	21.73	37.39	59.10	3
Uncoated	Uncoated #5	104	153.08	42.41	67.85	4
Uncoated	Uncoated #2	104	486.73*	49.07	170.4	5

Table 3. *Results of the offset print runs for the tested coated and uncoated papers. The papers have been ranked based on dot circularity. * Paper is made from 100% post consumer waste and contains many colored speckles.*

In the image below a microscopic picture of paper uncoated #3 is shown.

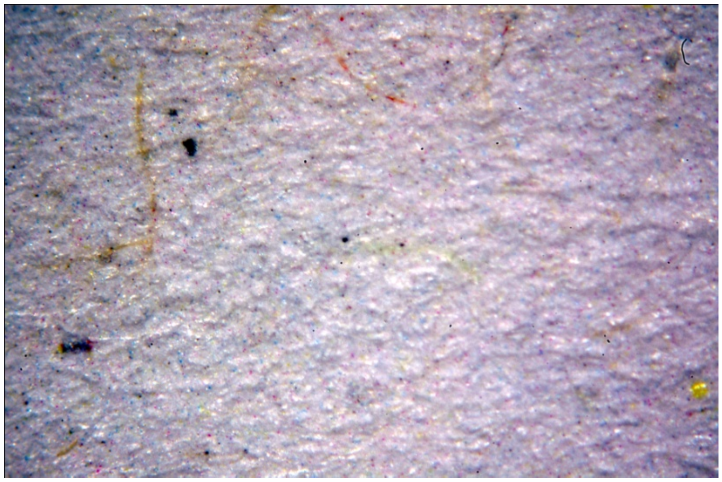

Figure 4. *Microscopic image of Uncoated #3, 60 times magnification.*

From Table 3 the following can be deducted form the results. There seems to be no clear correlation between topography and dot circularity. One would think that a lower topography value indicates a smoother surface therefore the reproduction of the printed dot should be more accurate. Also for uncoated paper there seems to be no real correlation. The first three papers show similar topography values, yet produce different dot circularity values. That there is no real correlation between topography and dot circularity can be seen in Figure 5.

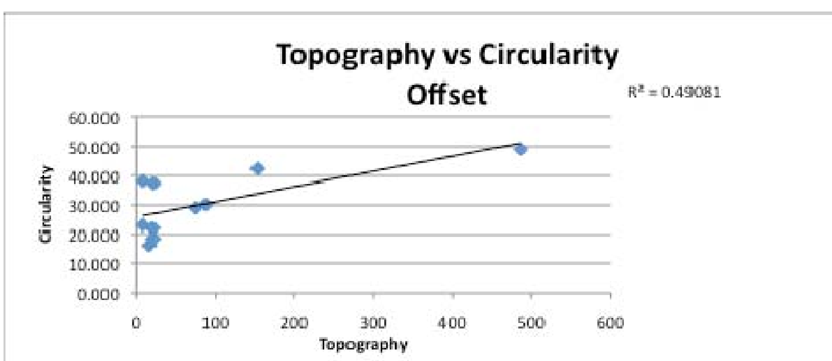

Figure 5. Correlation between topography and dot circularity for all tested papers for the offset press runs.

The analysis that was done for the offset prints was also done for the prints done on the digital printing press. The results for this analysis can be seen in Table 4.

Paper Type	Paper Name	Grammage	Topography Value	Average Dot Circularity	Average Standard Deviation	Rank in Relation to Other Papers
Coated	Coated #5	100	139	20.06	13.06	1
Coated	Coated #2	100	108	20.25	13.00	2
Coated	Coated #3	170	139	21.84	15.40	3
Coated	Coated #1	148	110	22.07	27.44	4
Coated	Coated #4	90	150	33.26	32.32	5
Uncoated	Uncoated #2	148	282	24.47	21.39	1
Uncoated	Uncoated #4	148	201	26.70	26.38	2
Uncoated	Unocated #1	104	275	32.21	38.88	3
Uncoated	Uncoated #5	104	309	36.24	48.52	4
Uncoated	Uncoated #3	104	601*	47.02	99.71	5

Table 4. *Results of the digital print runs for the tested coated and uncoated papers. The papers have been ranked based on dot circularity. *Paper is made from 100% post consumer waste and contains many colored speckles.*

From Table 4 it can be seen that there seems to be some kind of correlation between the dot circularity and the measured topography values for the tested papers. This can also be seen in Figure 6.

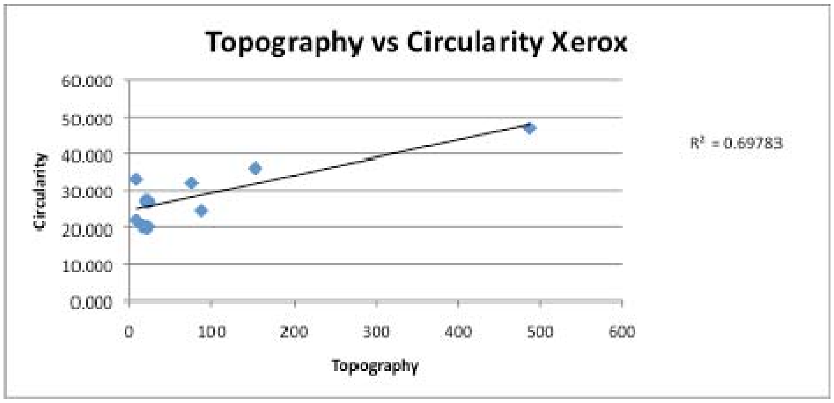

Figure 6. *Correlation between topography and dot circularity for all tested papers for the digital press runs.*

Although the r^2-value for the correlation between dot circularity and paper topography is not very good, it is much better then for the offset press runs. This could mean that the paper topography has a greater influence on the print quality, based on dot circularity, for the tested papers digital press then the tested offset press.

Results of tone value increase analysis for offset printing

A more traditional way of analyzing print quality is to evaluate the tone value increase of the printed sheets. The recommended tone value increase values for coated #1 sheets is 18–22% and 24–28% for uncoated offset papers (PIA, 2007). If the tone value increase is too high it could be possible that the ink was too low in viscosity or too much printing pressure had been applied. The table below depicts these values for the tested coated and uncoated stocks.

Paper Name	50% Screen Density	Solid Ink Density	Dot Area of 50% Screen Tint	Calculated Tone Value Increase	Average Tone Value Increase	TVI Recommend. (Offset)
Coated #2						
C	0.51	1.6	71	**21**	22	18–22
M	0.52	1.15	75	**25**		
Y	0.5	1.53	70	**20**		
K	0.52	1.64	71	**21**		
Coated #4						
C	0.49	1.55	70	**20**	20	18–22
M	0.5	1.15	74	**24**		
Y	0.44	1.48	66	**16**		
K	0.5	1.6	70	**20**		
Coated #3						
C	0.5	1.55	70	**20**	21	18–22
M	0.52	1.13	75	**25**		
Y	0.44	1.45	66	**16**		
K	0.51	1.62	71	**21**		
Coated #1						
C	0.48	1.53	69	**79**	18	18–22
M	0.47	1.12	72	**22**		
Y	0.43	1.45	65	**15**		
K	0.47	1.58	68	**18**		
Coated #5						
C	0.52	1.6	72	**22**	20	18–22
M	0.48	1.19	72	**22**		
Y	0.47	1.58	68	**18**		
K	0.51	1.64	71	**21**		

Paper Name	50% Screen Density	Solid Ink Density	Dot Area of 50% Screen Tint	Calculated Tone Value Increase	Average Tone Value Increase	TVI Recommend. (Offset)
Uncoated #5						
C	0.43	1.16	68	**18**	23	24–28
M	0.5	1	76	**26**		
Y	0.44	1	71	**21**		
K	0.58	1.23	78	**28**		
Uncoated #4						
C	0.48	1.18	72	**22**	24	24–28
M	0.52	1.03	77	**27**		
Y	0.5	1.04	75	**25**		
K	0.51	1.19	74	**24**		
Uncoated #2						
C	0.56	1.26	77	**27**	27	24–28
M	0.54	1.02	79	**29**		
Y	0.49	1.03	75	**25**		
K	0.61	1.25	80	**30**		
Uncoated #3						
C	0.54	1.26	75	**27**		24–28
M	0.55	1.05	79	**29**		
Y	0.49	1.03	75	**25**		
K	0.63	1.25	81	**31**		
Uncoated #1						
C	0.5	1.26	72	**22**		24–28
M	0.54	1.04	78	**28**		
Y	0.46	1.04	72	**22**		
K	0.58	1.22	78	**28**		

Table 5. *Tone value increase results for the tested papers for offset print runs.*

From Table 5 it can be seen that the tone value increases for the offset print runs was within the recommended values (PIA, 2007) for coated and uncoated papers.

Results of tone value increase analysis for digital printing

The same tone value increase analysis that was done for the offset printed sheets was repeated for the digitally printed sheets. The tone value increase is higher than for comparable offset printed papers that can be seen in Table 6.

Paper Name	**50% Screen Density**	**Solid Ink Density**	**Dot Area of 50% Screen Tint**	**Calculated Tone Value Increase**	**Average Tone Value Increase**	**TVI Recommend. (Offset)**
Coated #2						
C	0.73	1.78	82.75	33	30	18–22
M	0.69	1.85	80.72	31		
Y	0.49	1.32	71.04	21		
K	0.79	1.78	85.20	35		
Coated #4						
C	0.76	1.8	83.95	34	31	18–22
M	0.71	1.86	81.63	32		
Y	0.53	1.38	73.55	24		
K	0.79	1.75	85.30	35		
Coated #3						
C	0.74	1.78	83.18	33	31	18–22
M	0.73	1.89	82.44	32		
Y	0.52	1.37	72.91	23		
K	0.77	1.7	84.71	35		
Coated #1						
C	0.71	1.71	82.10	32	28	18–22
M	0.66	1.8	79.38	29		
Y	0.46	1.29	68.86	19		
K	0.75	1.86	83.37	33		
Coated #5						
C	0.74	1.78	83.18	33	31	18–22
M	0.7	1.79	81.37	31		
Y	0.51	1.35	72.33	22		
K	0.8	1.82	85.44	35		

Table continues next page

Paper Name	50% Screen Density	Solid Ink Density	Dot Area of 50% Screen Tint	Calculated Tone Value Increase	Average Tone Value Increase	TVI Recommend. (Offset)
Uncoated #5						
C	0.75	1.56	84.55	35	33	24–28
M	0.74	1.66	83.63	34		
Y	0.54	1.25	75.40	25		
K	0.8	1.45	87.25	37		
Uncoated #4						
C	0.76	1.53	85.13	35	33	24–28
M	0.8	1.66	86.03	36		
Y	0.49	1.23	71.87	22		
K	0.88	1.42	90.25	40		
Uncoated #2						
C	0.7	1.56	82.31	32	31	24–28
M	0.8	1.66	86.03	36		
Y	0.47	1.21	70.46	20		
K	0.75	1.41	85.55	36		
Uncoated #3						
C	0.73	1.51	83.97	34	31	24–28
M	0.73	1.62	83.38	33		
Y	0.45	1.28	68.09	18		
K	0.81	1.47	87.48	37		
Uncoated #1						
C	0.74	1.61	83.86	34	21	24–28
M	0.73	1.7	83.04	33		
Y	0.53	1.29	74.30	24		
K	0.78	1.6	85.55	36		

Table 6. *Tone value increase results for the tested papers for digital print runs.*

The tone value increase measured for the digitally printed test sheets lies between 28 and 33% regardless of the paper types that were chosen for the test runs. The measured TVI values are even higher than the recommended tone value increases for uncoated offset papers. The tone value increases seen here are closer to the ones that are recommended for newsprint applications (PIA, 2007).

Halftone mottle and visible print mottle

Print mottle can be caused by an uneven paper surface, water interference, back-trapping, and ink trapping. The mottle caused by the paper surface is in relation to non-uniform absorption properties, non-uniform base sheet contributing to gloss variations. Print mottle can also be caused an optical incompatibility between the base-sheet and the coating.

The visible print mottle is the mottle of a solid print ink surface, while the half-tone mottle, as the name indicates, is a non-uniformity within the printed half-tone dots.

It was tried to find a possible correlation between the roughness of the paper surface and the visible print mottle. The mottle measurements were done at 1200 ppi and the area of interest was 517 mm^2. The measurements were done on a 30% tint of cyan.

The measurement data in regards to roughness and visible print mottle can be seen in Table 7.

Paper	Rough	Mottle
Coated #4	2.97	0.29
Coated #2	3.83	0.57
Coated #5	4.53	0.42
Uncoated #4	4.59	0.51
Coated #3	4.60	0.37
Coated #1	6.90	0.51
Uncoated #1	15.76	1.20
Uncoated #2	16.21	1.80
Uncoated #5	16.60	3.20
Uncoated #3	25.85	2.50

Table 7. *Visible print mottle and roughness values of the tested papers.*

A visual representation of these values can be seen in Figure 7.

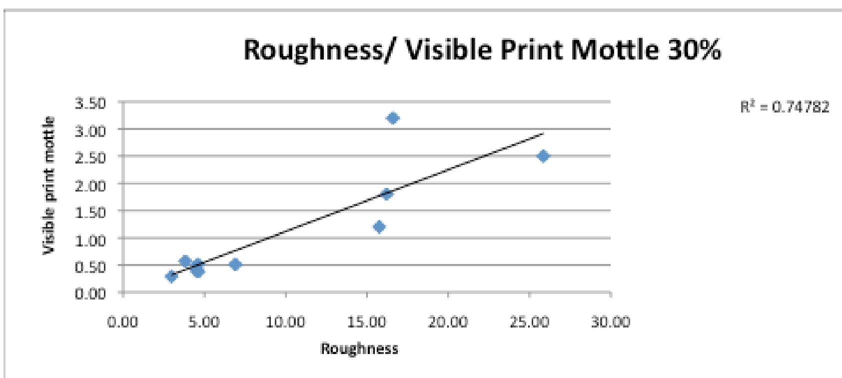

Figure 7. Visual print mottle versus the roughness of the measured papers.

From Figure 7 it can be seen that there is trend towards a correlation between visible print mottle and roughness of the paper. The measurement data also shows that the smoother the paper is, the lesser is the visible print mottle.

A similar analysis for a possible relationship between the topography of the tested papers and the visible print mottle was also conducted. The measurement values for this analysis can be seen in Table 8.

Paper	Topography	Mottle
Coated #4	8.48	0.29
Coated #3	8.61	0.37
Coated #2	11.93	0.57
Coated #1	19.80	0.51
Coated #5	22.32	0.42
Uncoated #4	21.73	0.51
Uncoated #1	75.51	1.20
Uncoated #2	87.88	1.80
Uncoated #5	153.08	3.20
Uncoated #3	486.73	2.50

Table 8. *Visible print mottle and topography values of the tested papers.*

A visual representation of these values can be seen in Figure 8.

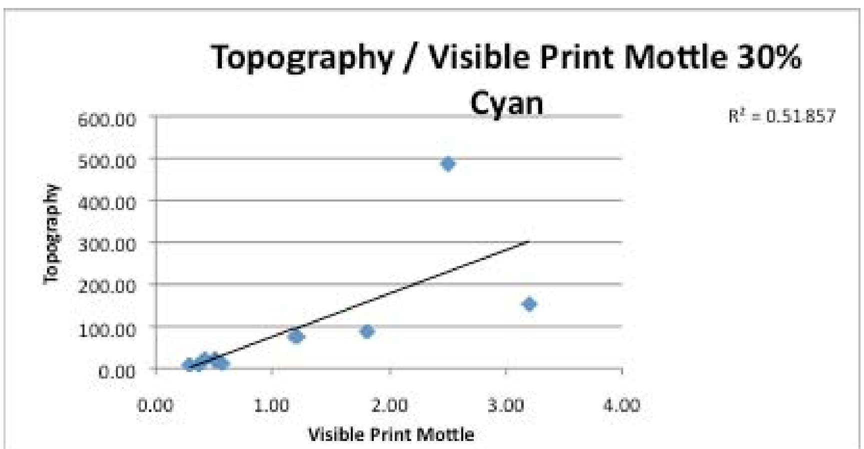

Figure 8. *Visible print mottle versus the topography of the measured papers.*

When the results from the topography and the roughness measurements against the visible print mottle are compared it can be said that there is more likely correlation between the roughness and the visible print mottle then it is between the topography and the visible print mottle.

Since the topography measurement of the recycled paper is probably influenced by the colored speckles in the paper, the topography value has been removed from Figure 8. The new figure can be seen in Figure 9.

From Figure 9 it can clearly been seen that there is a strong correlation between visible print mottle and the topography values. The visible print mottle increases when the paper has a higher topography value, meaning they have a rougher surface.

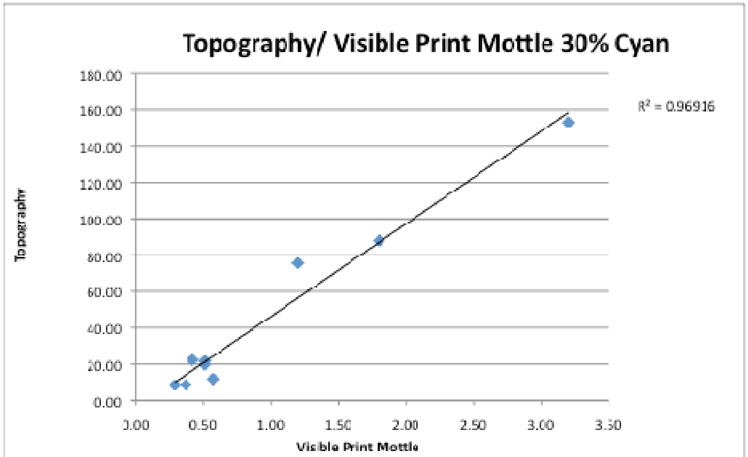

Figure 9. *Visible print mottle versus the topography of the measured papers (the data point of the recycled paper has been removed.*

Visible print mottle and halftone print mottle

The measurement data for visible print mottle and half-tone print mottle can be seen in Table 9.

Paper	Rough	Visible Print Mottle	Halftone Print Mottle
Coated #4	2.97	0.29	9.80
Coated #2	3.83	0.57	230.00
Coated #5	4.53	0.42	7.30
Uncoated #4	4.59	0.51	3.40
Coated #3	4.60	0.37	6.00
Coated #1	6.90	0.51	9.40
Uncoated #1	15.76	1.20	5.90
Uncoated #2	16.21	1.80	21.80
Uncoated #5	16.60	3.20	18.30
Uncoated #3	25.85	2.50	10.70

Table 9. *Measurement data of visible print mottle and halftone mottle.*

The measurement data in Table 8 can be seen in Figure 10.

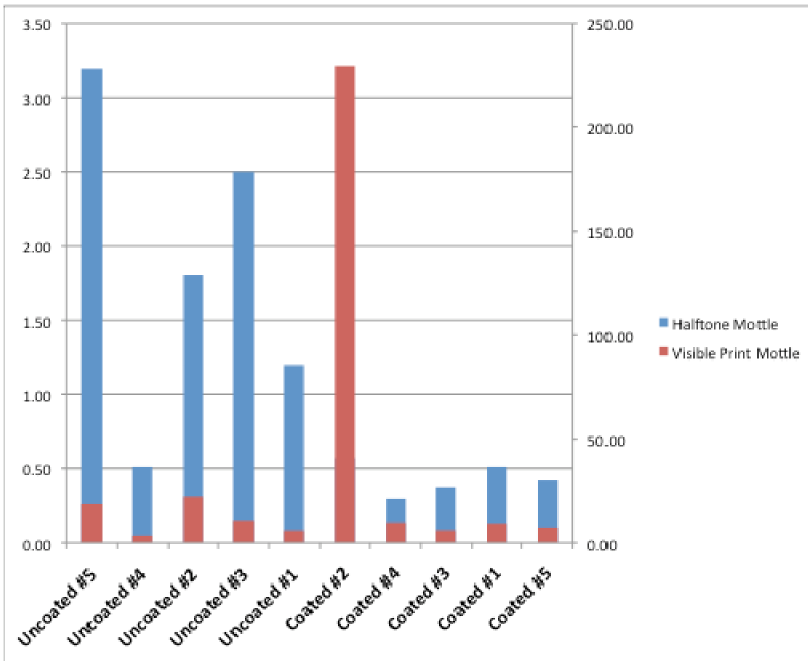

Figure 10. *Visible print mottle and half-tone print mottle of the tested papers.*

From Figure 10 it can be seen that the visible print mottle improves as the quality of the paper increases. Reasons for print mottle caused by the paper can be non-uniform surface absorption of the paper, a non-uniform base-sheet which can contribute to gloss variations and surface galvanization. Print mottle can also be caused by an optical incompatibility between the base-sheet and the coating. Other reasons for increased print mottle can include things like uneven coating weight, binder migration, and poor base-stock formation. Since we are not familiar on how the tested papers were manufactured it is not possible to make any conclusions into the above listed possibilities.

Conclusions

From the variety of the tests conducted in this study it can be said that the roughness of papers can be determined by analyzing images of paper surfaces. The images were taken at 60 times magnification and the analysis was done using a plug-in for ImageJ software and Print Target software. There is certain correlation between the roughness values obtained by both software solutions. Although the correlation is not perfect it is possible to predict what the roughness values will be, if the measurements from one software solution are available.

The analysis between the topography measurements and the dot circularity for both printing processes revealed a correlation between the both parameters for the digital printing technology but not for the offset technology. The lower the topography value, the smaller is the dot circularity number, meaning the printed dots are more round and the print quality is better. There is a clear correlation between the topography values of the tested papers and the visible print mottle. The rougher a paper surface is, the higher the measured topography value is and the higher the visible print mottle will be.

There was one tested paper, which contained 100% recycled post consumer fibres. A picture of this paper can be seen in Figure 4. The colored speckles influence mainly the topography measurements, since the measurement is done through image analysis and the speckles skew the measurement data.

Conventional print quality measurements, like tonal value increase (TVI), showed that the offset printed samples fall within the recommendations given by PIA for a coated and an uncoated sheet. The tonal value increase for the digital printing process was higher in comparison to the offset printing process, but it did not influence the dot circularity measurement results.

It was also tried to find a correlation between topography and roughness visible mottle and halftone mottle. There is a correlation between the roughness measurements and the visible print mottle. The visible print mottle improves as paper quality increases while half-tone mottle remains relatively unchanged.

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