A Memory Effect in Sheet-Fed-Offset Printing

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Short Abstract

We are presenting a method to quantify the similarity of local mottling patterns in consecutively printed copies in sheet fed offset printing. It employs image registration to extract precisely defined image regions in a series of printed copies. The similarity of these image regions is calculated using point wise correlation. By analysing the similarity in the mottling patterns in printing runs over several thousand copies we demonstrate that there are mottling patterns that are time stable and in fixed positions of the print. We call this repeated occurrence of mottling patterns over hundreds of printed sheets a ‘memory effect’ in offset printing. Between 20% and 50% of the print mottle in two print trials consisted of such location and time stable patterns. It can be speculated that this time stable mottle is related to printing press parameters (e.g. rubber blanket, printing form….), whereas the remaining, non-stationary mottle is related to local variations of the printed paper or stochastic variations in the printing process.

Keywords: print mottle, image analysis, pattern, offset printing

1. Introduction and Background

Mottling is defined as an undesired unevenness in perceived print colour, print density or print gloss. An even printed image is assumed to be generated due to a perfect interaction of the three main components involved during the printing process, namely the printing press, the printing ink and the substrate (i.e. paper). Print mottle is the result of an imperfect interaction between any of the three components which leads to uneven transmission or absorption of the printing ink and thus to print mottle.

Depending on the phenomena causing the imperfect interaction, there are three common types of mottle back-trap mottle, water interference mottle and ink-trap mottle (Sadovnikov *et al.*, 2008). Besides this definition, Fahlcrantz divided print mottle into two components: a systematic and a stochastic component (Fahlcrantz, 2005). The stochastic component of print mottle describes the randomly distributed noise in the final print. This random pattern is often accompanied by a systematic component. The systematic mottle component is perceived as a structured pattern, it can be caused by vibrations of the printing machine (Krzyzkowski and Pyryev, 2011) or by periodic structural patterns in the paper like wire marks (MacGregor and Conners, 1987).

In this study we are investigating a new type of mottle. We analyse the time stability of stochastic mottling patterns which occur repeatedly over a longer series of printed sheets. We call this a ‘memory effect’ in print mottle, because some mottle structures seem to be remembered over time. As an example please refer to Figure 4 where two consecutively printed sheets show identical mottle features *in the exact same location* of the printed colour field. The key point is, that a time stable mottle pattern at fixed positions occurring in consecutively printed sheets indicates that the printing press is also involved in the development of the print mottle. It can be speculated that this type of mottle might result from some local modifications of the rubber blanket that systematically changes the ink transfer in certain positions. Although a stochastic variation during the printing process cannot be ruled out, such as random ink-surface adhesion failure (Alm *et al.*, 2015), we do not consider this in the current discussion. Our work also does not focus on finding the reasons for such location and time stable mottle patterns but introduces a method capable to capture and quantify this ‘memory effect’, i.e. the similarity between the mottling patterns in consecutively printed sheets.

2. Materials and Methods

2.1 Paper Samples

The examined paper samples were commercial glossy wood free coated (WFC) paper grades. The samples are divided into three groups: a standard WFC paper (135 g/m², coat weight per side 31 g/m²) and two reference WFC samples (115 g/m², coat weight each side 24 g/m²). The first reference sample was referred to be of good print quality (WFC+) and the second reference sample was referred to be of poor print quality (WFC-).

2.2 Printing Machine and Printing Sequence

Two print trials were performed within this study. All paper samples were printed on a 6 colour *Heidelberg SM XL 8* sheet fed offset press with a printing speed of 8 000 sheets/h. The printing plates used were AGFA Amigo. The ink used for the print trial was a NOVAVIT® Supreme Bio and the rubber blanket was a Continental® SP Evolution. The colour sequence was key black (K), cyan (C), magenta (M), yellow (Y), pantone blue (P) and last black (B).

2.2.1 Print trial A

In this trial only one type of WFC paper (i.e. the standard WFC paper) was printed. First 1 000 sheets of standard WFC paper (135 g/m²) were printed with 6 colours. The printing machine was stopped and the last printing unit (B) was lifted off. Afterwards 100 sheets were printed with 5 colours. The same procedure was performed for the remaining printing units. As a result, a stack of 1 500 sheets consisting of 100 sheets (K), 100 (K+C), 100 (K+C+M), 100 (K+C+M+Y), 100 (K+C+M+Y+P) and 1 000 with all six colours was obtained. Figure 1 shows the obtained stack and the numbers underneath the colour represent the amount of back-traps of one colour.

After printing the paper sheets were scanned and the mottle patterns were analysed. From the first 1000 sheets (printed with all 6 colours, i.e. the bottom part of the stack in Figure 1) we selected, 3 sheets every 50th sheet (1,2,3,51,52,53,101,102,103 etc…). From the sheets printed with 1 to 5 colours (Figure 1, upper part of the stack) we selected 3 sheets every 15th sheet (1,2,3,15,16,17,30,31,32, etc…). From each selected sheet five different colour fields were scanned: 40% tone value C, 100% C, 80% K, 80% B and the mixed colour field 100% C/60% M. We used a flatbed scanner (*Epson Perfection 4990®*) at 1 200 dpi (i.e. 21.17 µm/pixel) resolution.

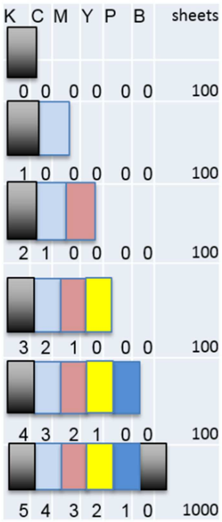


*Figure 1. **Print trial A.** The stack of printed sheets obtained from the trial. The numbers*

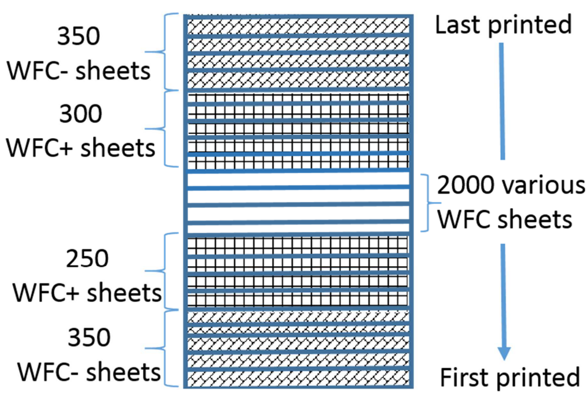


*Figure 2. The stack of sheets obtained from **print trial B**.*

below the colours represent the amount of back-traps of one colour.

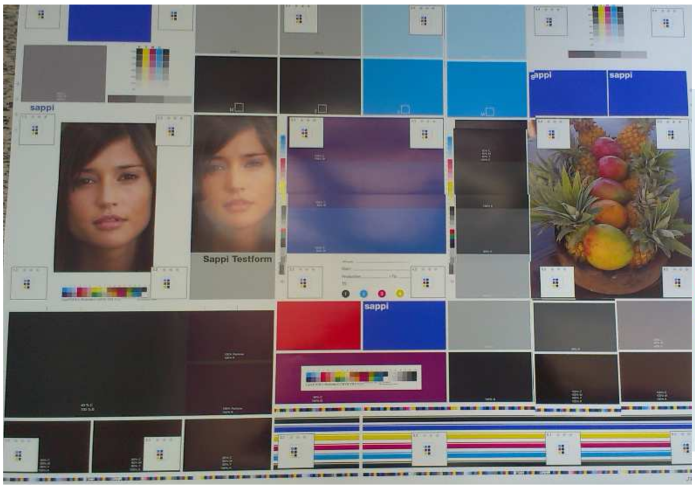
2.2.2 Print trial B

Here one WFC paper with good print quality (WFC+) and one paper with poor print quality (WFC-) was printed on the same printing machine (*Heidelberg SM XL 8*). These papers were printed with 6 colours at 8 000 sheets/h. First 350 sheets of WFC- and then 250 WFC+ sheets were printed. Then 2 000 sheets of various other WFC papers (not examined) were printed. Finally, again 300 WFC+ sheets and 350 WFC- sheets were printed (see Figure 2).

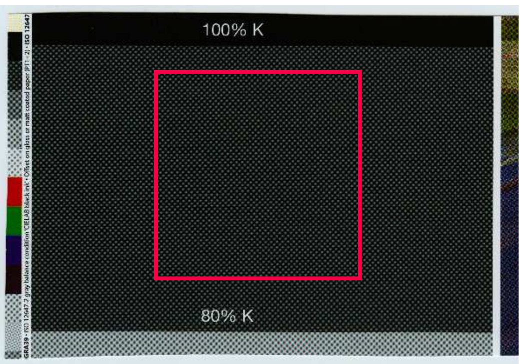
After printing the paper sheets were scanned and the mottle patterns were analysed. From each printed WFC- and WFC+ stack the 10 first printed sheets and 10 last printed sheets were selected (e.g. for the first printed WFC- stack: 1,2, … 9,10,341,342, … 349,350 and for the first printed WFC+ stack: 1,2, … 9,10,241,242, … 249,250). From each selected sheet the same colour fields were scanned and examined as for print trial A.

2.3. Image Analysis

An example of the print form containing all colour fields used for this study is shown in Figure 3(a). Figure 3(b) depicts an 80% K colour field which shows the size of the finally examined area (50x50 mm²; red square).



(a) Test print form.



(b) Colour field 80% K from the print test form with extracted image region.

Figure 3. (a) The test print form. (b) From each sheet a defined part from a colour field is extracted, here the 80% K colour field.

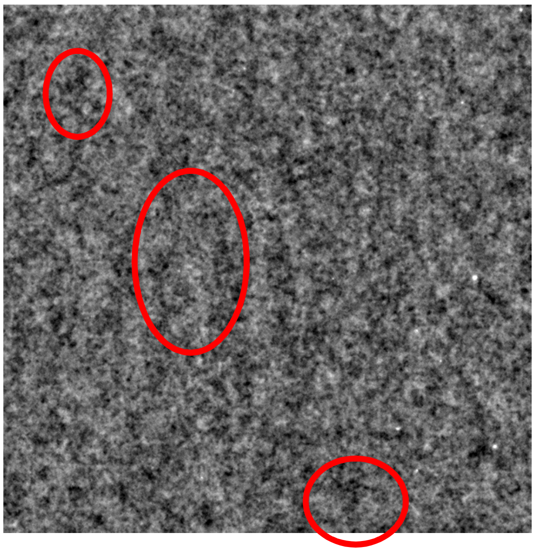
For image analysis, first the exact same region of a scanned colour field is extracted from consecutive sheets using image registration. Image registration is a procedure where exactly the same region in different images is extracted and brought to congruence. The images are registered by applying a shape preserving coordinate transform where the edge points of the colour fields were used as registration marks (Hirn *et al.*, 2008).

After registration, a set of images showing exactly the same regions in the colour fields for all printed sheets is available. Figure 3(b) shows one image of a registered 80% K colour field. From these images, a sub-image is extracted from every sheet resulting in a set of sub-images, which is then used for analysis. The final size of the analysed sub-images is 50x50 mm² (i.e. the size of the square in Figure 3(b)).

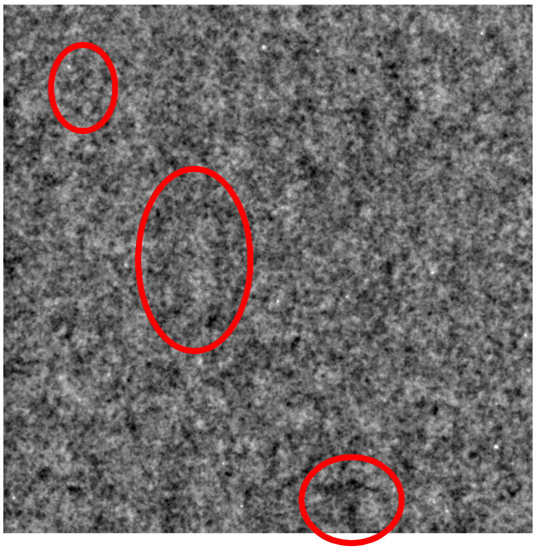
After extraction, the sub-images of all samples were descreened and then post processed in two ways. On the one hand, spectral filtering (i.e. a FFT pass band filter) was performed by a pass band filter in the wavelength band of 1-16 mm. The reason for spectral filtering is that the human eye visually perceives non-uniformities differently at different length scales. The region of interest for visual perception of print mottle according to Johansson is located in the wavelength band of 1-16 mm (Johansson, 1993). This type of filtering produces images where only the structures most relevant for print mottle are preserved.

On the other hand, the images were rescaled to a pixel size of 250 µm. That is the size of structures, which the human eye can resolve under good illumination at a viewing distance of 30 cm (Olzak and Thomas, 1986). Hence, at a pixel size of 250 µm *all* structures perceived by the human eye are preserved.

The final result of scanning, filtering and rescaling can be seen in Figure 4. It shows two 80% K fields from consecutively printed sheets which were spectral filtered in the relevant region for print mottle, the images were extracted from the print as indicated in Figure 3(b).



(a) Extracted image region from sheet #1000



(b) Extracted image region from sheet #1001

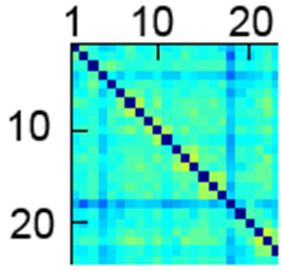
Figure 4. Example of two contrast enhanced images extracted from two 80% K regions of consecutively printed sheets (print test A). The images were spectral filtered (wavelength band 1-16 mm). Some mottling features occurring in exactly the same location in both prints are highlighted by ellipses (size of images: 50x50 mm²).

In order to evaluate the location and time stability of the mottle pattern we quantify the similarity between the extracted and spectral filtered images. We apply point wise correlation of the registered images (Hirn *et al.*, 2008) where the coefficient of determination (R^2) is the resulting measure of similarity between the images. The coefficient of determination explains how much of the variance in one data set is explained by another (or several other) data set(s) (Neter *et al.*, 1996). A value of $R^2 = 1$ between two images indicates that the mottle pattern in these prints is exactly the same, a value of $R^2 = 0$ indicates that there is no similarity at all. Analysis of R^2 was performed for both types of images, i.e. the pass band filtered and the rescaled images.

The coefficients of determination between the images are displayed in R^2 matrices for each colour field. The structure of the matrix is shown in Figure 5(a). The indices are in accordance with the order of the selected stack of printed sheets from bottom (first printed) to top (last printed). For example in print trial A, indices 1 to 3 represent the images of the first three printed sheets in the stack. The consecutive three indices (i.e. 4-6) represent the 51st to 53rd printed sheet, because 50 sheets are skipped in between (see description of print trial A. As a consequence, the last three indices (i.e. n-2, n-1 and n) represent the last three printed sheets (i.e. the top of the stack in Figure 1). The square matrix ($m = n$) is symmetric since R^2_{12} and R^2_{21} are identical because the similarity is equal in both directions. An example of a section of an R^2 matrix is displayed in Figure 5(b). The main diagonal represents R^2 values between one and the same image (e.g. R^2_{11}). As this is the similarity between one and the same image, R^2 is 1 for the main diagonal.

$$\begin{bmatrix} {R^2}_{11} & {R^2}_{12} & {R^2}_{13} & \dots & {R^2}_{1n} \\ {R^2}_{21} & {R^2}_{22} & {R^2}_{23} & \dots & {R^2}_{2n} \\ {R^2}_{31} & {R^2}_{32} & {R^2}_{33} & \dots & {R^2}_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ {R^2}_{m1} & {R^2}_{m2} & {R^2}_{m3} & \dots & {R^2}_{mn} \end{bmatrix}$$

(a) Structure of the R^2 matrix



(b) Example of the upper left part of an R^2 matrix.

Figure 5. Structure (a) and an example of a section (b) of an R^2 matrix.

For print trial B the structure of the R^2 matrix is similar. Since sampling was a little different compared to print trial A, the first 10 indices (n = 1-10) represent the images of the first 10 printed sheets of WFC- (i.e. at the bottom of the whole stack in Figure 2, sheet 1-10) and the next 10 indices (n = 11-20) the images of the 10 last printed sheets of WFC- (i.e. at the top of the bottom WFC- stack in Figure 2, sheet 341-350). This allocation applies also for the other WFC+ and WFC- samples of the stack obtained from print trial B.

The variance (i.e. squared standard deviation) of each image was also calculated and depicted on top of the R^2 matrices (Figure 6 to Figure 10) and is a measure for the print unevenness in the image. A lower variance indicates lower print unevenness, whereas a higher variance indicates a higher print unevenness. Thus, not only the similarity between the print mottle patterns in the images can be quantified, but also the development of print unevenness over time is captured.

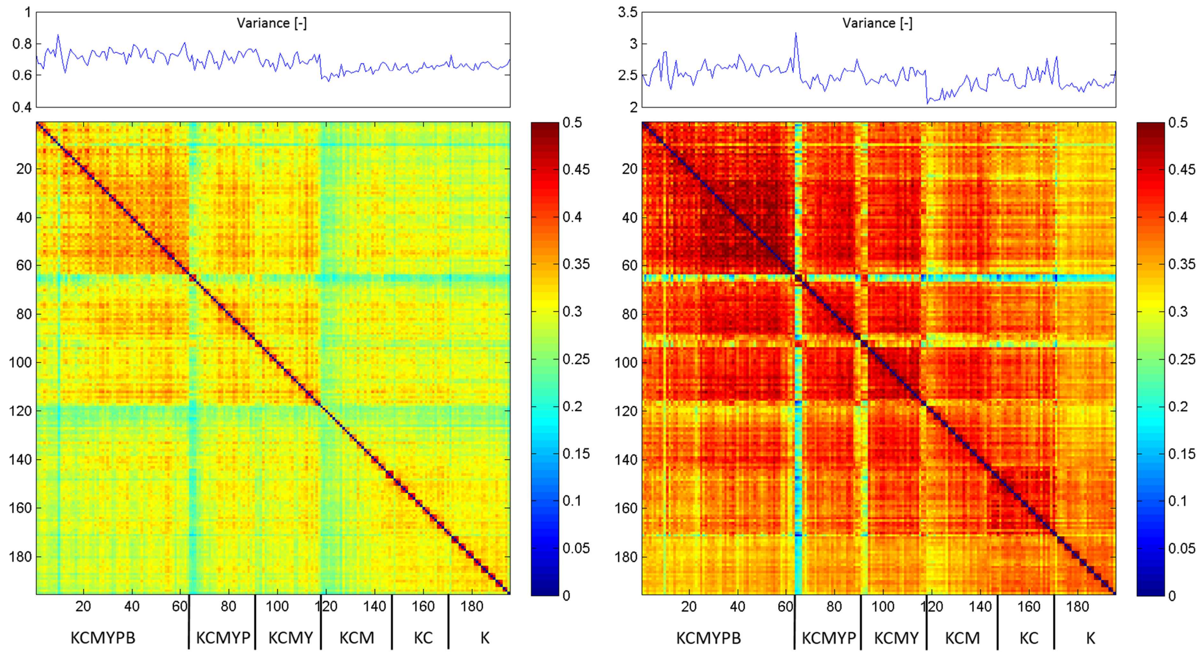
3. Results and Discussion

3.1 Print trial A

In this print trial the printing units were lifted off one after the other. In Figure 6(a) and (b) the R^2 matrices for the colour field 80% K are depicted. Figure 6(a) shows the matrix where all images were spectrally filtered within the wavelength band 1-16 mm, whereas the images in (b) were rescaled to a pixel size of 250 µm. Above the R^2 matrices the variance of each image is plotted. Below the matrix, the printing units which were active are shown. The sequence is the same as the order in Figure 1 (bottom to top implies first printed to the last printed). Thus, KCMYPB means that all printing units were active and K means only the K unit was active.

Figure 6 reveals that the print mottle of one sheet is related to the print mottle of other sheets. It shows further that the print mottle is persistent for a rather long period of printed sheets. The correlation drops after a printing unit has been lifted, especially after lifting B and Y. However, when restarting printing after lifting off, the similarity of the print mottle again rises, which means that after a brief interruption due to the lifting of a printing unit some part of the earlier mottling structure re-appears in the print. We termed this systematic re-occurrence of mottling patterns over a large amount of printed sheets ‘memory effect’.

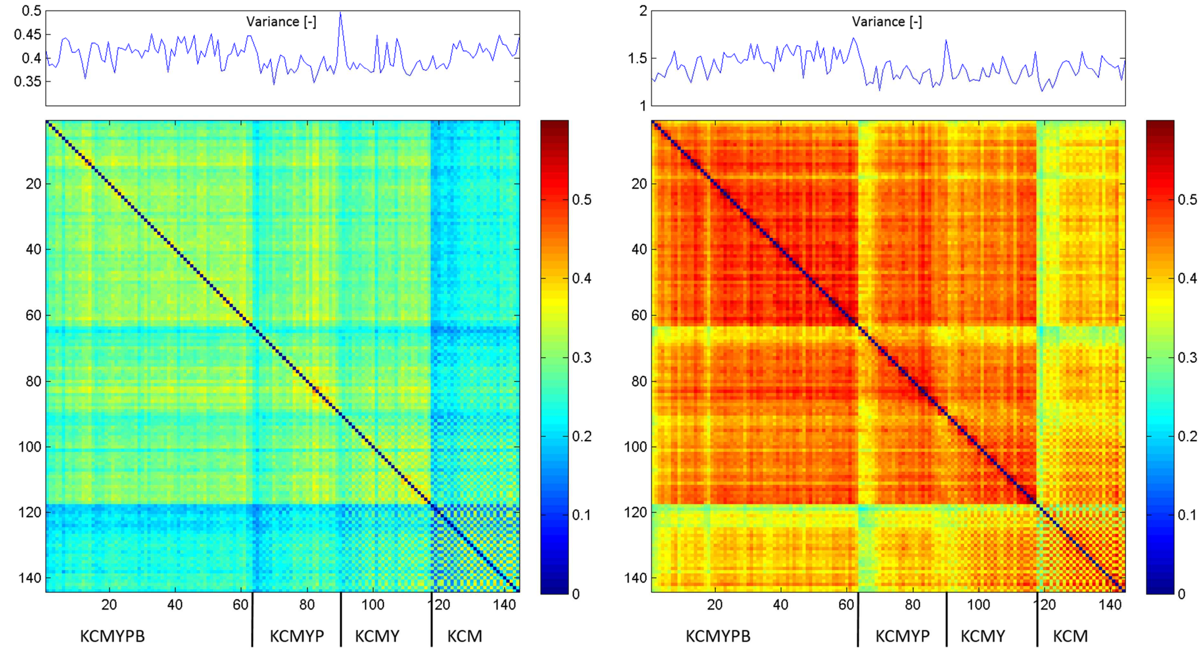
The correlation between two images is higher when they are located close to each other, i.e. when they have been printed shortly one after another. In the R^2 matrices, R^2 values of images printed close to each other in time are located in the plot region surrounding the main diagonal. The highest correlations were found in the R^2 matrix with the rescaled images (Figure 6(b)). There, R^2 is close to 0.50. R^2 is lower in the region of interest for print mottle (1-16 mm wavelength band, Figure 6(a)). However, even after 1 000 sheets the R^2 between the print mottle of the first and the last sheet is still close to 0.35. It seems, that there is an inherent print mottle which stabilises after restarting and is continuously re-occurring.



(a) Colour field 80% K, 1-16 mm *(b) Colour field 80% K, 250 µm*

Figure 6. R^2 matrices of colour field 80% K. In (a) images were spectrally filtered (wavelength band 1-16 mm) and in (b) the images were rescaled to a pixel size of 250 µm.

Furthermore, Figure 6 shows that the variance (i.e. print unevenness) decreases after lifting of the printing units, especially after lifting B and Y. This agrees with the common notion that print unevenness decreases with decreasing number of back-traps.



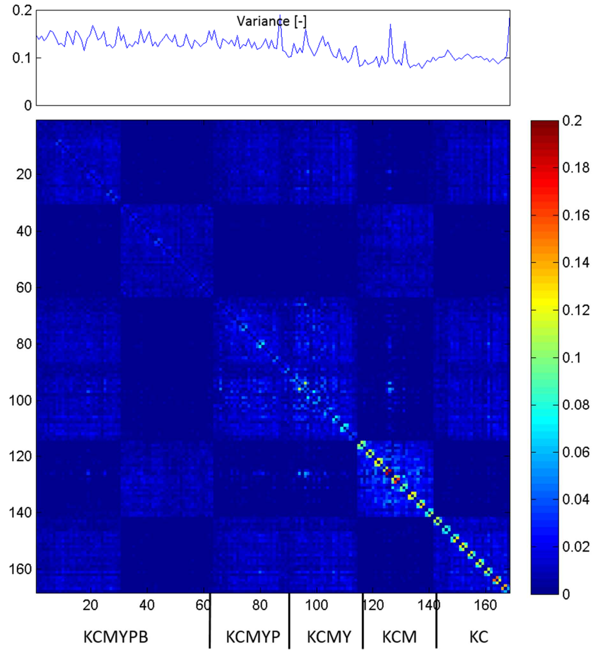
(a) Colour field 100% C/60% M, 1-16 mm *(b) Colour field 100% C/60% M, 250 µm*

Figure 7. R^2 matrices of colour field 100%C/60% M. In (a) images were spectral filtered (wavelength band 1-16 mm) and in (b) the images were rescaled to a pixel size of 250 µm.

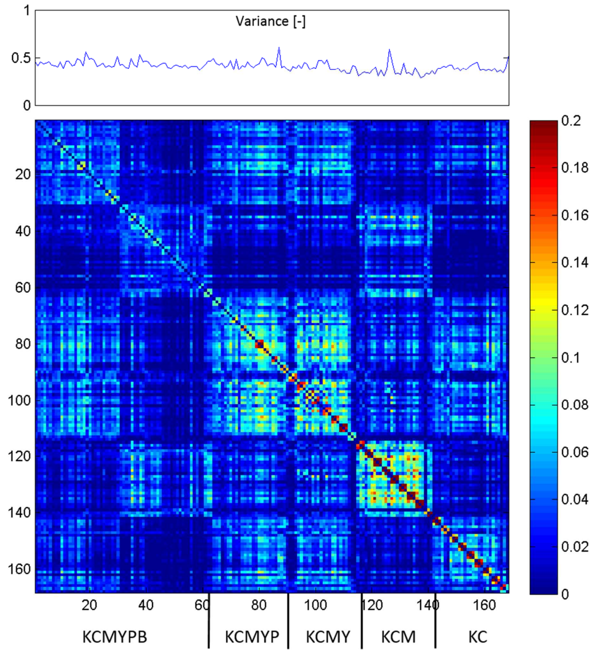
Figure 7 shows similar results for the mixed colour field 100% C/60% M. R^2 is stable for a rather long period of time. It is up to 0.55 when looking at the rescaled images (Figure 7(b)). For the regions of interest for print mottle (Figure 7(a), 1-16 mm wavelength band), R^2 is up to 0.40. The correlation decreases after lifting the B, P and Y printing units and increases again with further printing. When printing KCM, an alternating pattern seems to occur which is shown by the alternating R^2 in the KCM part of the matrix in Figure 7(a) and (b). This means that the similar print mottle does not occur on every consecutive sheet, but on every second or third sheet, suggesting that the phenomenon is either unstable or related to a patterning on the original paper tambour.

The print unevenness decreases when lifting B, but increases when lifting Y. Usually print unevenness is expected to decrease with decreasing amounts of back-traps, but in Figure 7(a) the variance has the same level when comparing KCM and KCMYPB which is assumed to be related to the alternating R^2 in the KCM part of the matrix.

The results for 40% C and 80% B reveal findings similar to the 80% K and 100% C/60% M fields. In contrast, however, the R^2 matrices of the full tone 100% C present different results (see Figure 8(a) and (b)). There is little to no correlation (only up to 0.15) between the images. Furthermore, the low correlation is only stable for about 3 printed sheets in a row. This suggests, that the time stable and re-occurring print mottle is not a problem for full tone printing. It is yet unclear why this is the case.



(a) Colour field 100% C, 1-16 mm

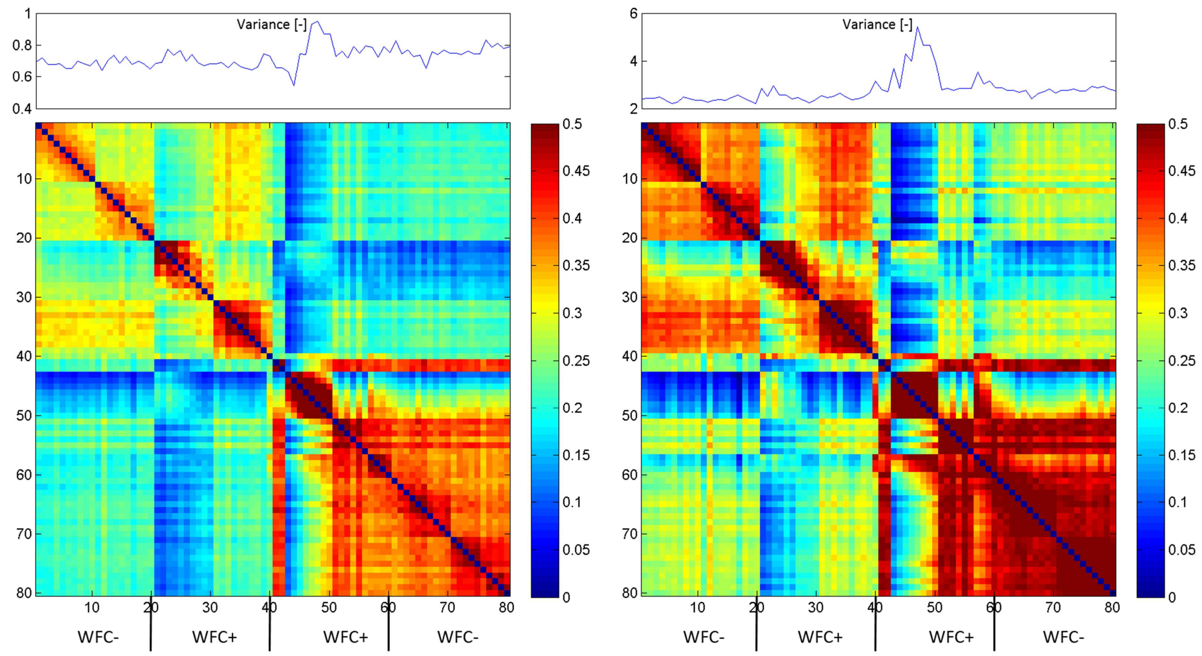


(b) Colour field 100% C, 250 µm

Figure 8. R^2 matrices of colour field 100%C. In (a) images were spectral filtered (wavelength band 1-16 mm) and in (b) the images were rescaled to a pixel size of 250 µm.

3.2 Print Trial B

In print trial B stacks of WFC+ and WFC- samples were distributed in an entire stack (compare Figure 2). Below the matrices in Figure 9(a) and (b) the order of the distributed samples in the printed stack is described. Firstly the R^2 of the 10 first and 10 last printed WFC- samples, immediately afterwards R^2 of the WFC+ samples and secondly the R^2 of the WFC+ and WFC- samples again. As shown in Figure 2, there were approximately 2 000 sheets of various WFC grades (Figure 9(a) and (b) between number 40 and 41) between the two WFC+ stacks.



(a) Colour field 80% K 1-16 mm

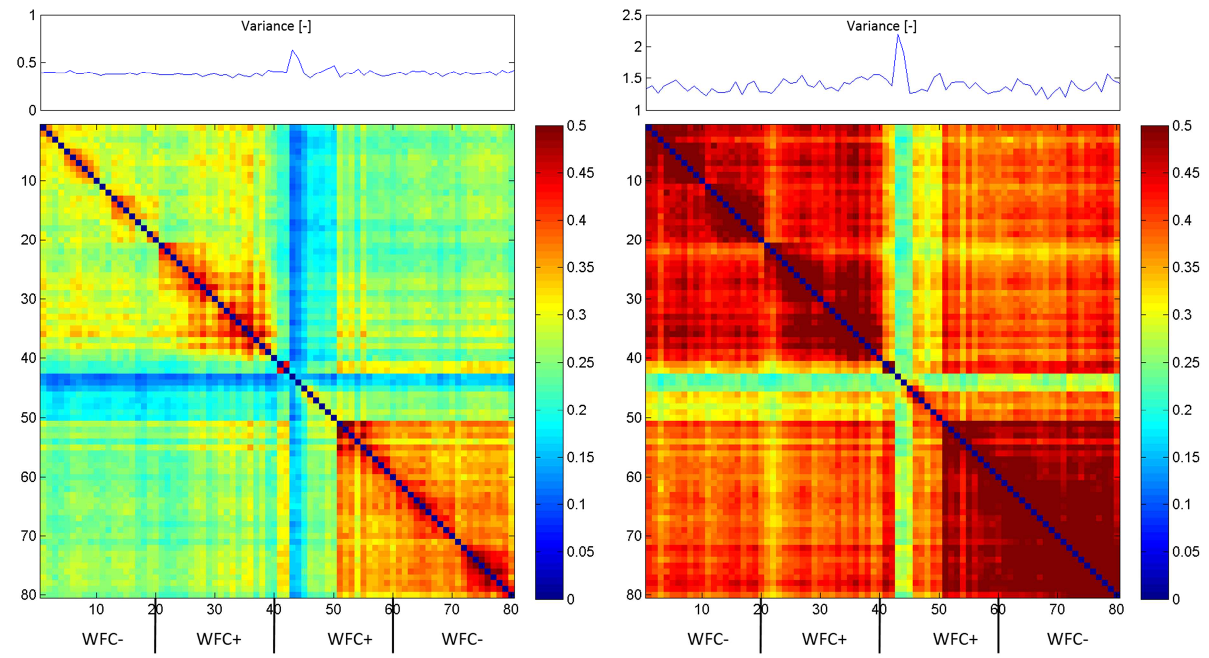
(b) Colour field 80% K, 250 µm

Figure 9. R^2 matrices of colour field 80%K. In (a) images were spectral filtered (wavelength band 1-16 mm) and in (b) the images were rescaled to a pixel size of 250 µm.

The print mottle pattern for the first 10 WFC- sheets (see Figure 9(a) and (b), numbers 1-10) show values of an R^2 up to 0.45 and similarly for the last 10 sheets printed in the first stack (see Figure 9(a) and (b), numbers 11-20). Since there were 350 WFC- sheets printed, this tells us that R^2 decreases from the beginning to the end of the stack which can be seen in the R^2 matrix where the images of numbers 11-20 are correlated to numbers 1-10. These findings are similar to those of the second stack (WFC+). Within 10 sheets the correlation is higher, and subsequently decreasing when reaching the end of the stack. However, there is also a correlation between the print mottle observed in the WFC- and WFC+ images (up to 0.37).

At the beginning of the second WFC+ stack there seems to appear a print defect, but disappearing afterwards. The 3rd to 10th image (in the second WFC+ stack) are highly correlated to each other, but not to the rest of the stack. It can also be seen in the variance of the images. The variance is higher as compared to the rest of the images. After disappearance of the print defect, the R^2 between the 10 last images of the WFC+ stack and the images of the WFC- stack is very stable. There is even a correlation between the sheets printed at the beginning and after 3 000 sheets which is shown by the upper right part of the R^2 matrices (Figure 9(a): 0.20, and Figure 9(b): 0.25). R^2 is higher for the rescaled filtered images (Figure 9(b), 250 µm) and is a little lower in the relevant wavelength for print mottle (Figure 9(a), wavelength band 1-16 mm).

Figure 10 shows the R^2 matrices for 100% C/60% M. For the first stack of WFC- and WFC+ the correlation is higher for the images of the sheets printed close to each other in time. R^2 is lower for the images which are printed with hundreds of sheets lying in between, but is stable. These R^2 matrices prove that another print defect shows up in the second WFC+ stack. The variance in Figure 10(a) and (b) is higher where the print defect occurs. However, the print defect disappears, because the images printed afterwards correlate with the first printed ones again. It is apparent from Figure 10 that R^2 is higher than 0.50 for the rescaled images (Figure 10(b), 250 µm) and up to 0.50 for the print mottle wavelength band (Figure 10(a), wavelength band 1-16 mm).



(a) Colour field 100% C with 60% M, 1-16 mm *(b) Colour field 100% C with 60% M, 250 µm*

Figure 10. R^2 matrices of colour field 100%C with 60% M. In (a) images were spectral filtered (wavelength band 1-16 mm) and in (b) the images were rescaled to a pixel size of 250 µm.

The results for the other colour fields (80% B and 40% C) are similar to those presented above. However, like in the previous print test A, the 100% C field shows little to no correlation (compare Figure 8). These findings suggest that the print mottle of these images is not only time stable and re-occurring within one paper grade, but is also stable over various paper grades. It is yet unclear where this time stable and re-occurring effect ('memory effect') is generated.

4. Conclusions

We have introduced a method that quantifies the degree of similarity between the mottling patterns in consecutively printed sheets. The similarity between the prints was measured using point wise correlations, it was collected and displayed in R^2 matrices. The similarity of the print mottle patterns in five different colour fields was investigated. The images were examined in the relevant region for print mottle (i.e. wavelength band 1-16 mm) and in the region where all structures are perceived by the human eye (>250 µm).

The results show that there exists a re-occurring print mottle which can be found over a large number of printed sheets. We observed this print mottle memory effect over more than 3 000 copies, even when different paper grades were printed. In one printing trial the R^2 for a 100% C/60% M colour field was up to $R^2 = 0.50$ in the wavelength band which corresponds best with the human perception of print mottle. That means that up to 50% of the mottling structure visible in this colour field is a re-occurring mottling pattern. In another trial, the correlations between the different images in the 100% C/60% M colour field was considerably lower with $R^2 = 0.30$.

Our method detects re-occurring mottle patterns appearing at fixed positions, thus it can be speculated that this mottle is related to modifications of the rubber blanket in the printing press. The remaining mottle should be related either to variations in local paper properties that lead to local variations in ink transfer and light absorption or assigned to stochastic interactions in the process.

Acknowledgments

The authors gratefully acknowledge financial support of the Austrian Research Promotion Agency (FFG). Furthermore, the authors thank Sappi Austria Produktions GmbH for their help to run the print trials.

References

Alm, H., Ström, G., Schoelkopf, J., and Gane, P. (2015). Ink-lift-off during offset printing: A novel mechanism behind ink-paper coating adhesion failure. *Journal of Adhesion Science and Technology*, 29(5): pp. 370–391.

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

Hirn, U., Lechthaler, M., and Bauer, W. (2008). Registration and point wise correlation of local paper properties. *Nordic Pulp and Paper Research Journal*, 23(4): pp. 374–381.

Johansson, P. (1993). Print mottle evaluation by band-pass image analysis. In *Advances in Printing Science and Technology*, IARIGAI, pp. 403.

Krzyzkowski, J. and Pyryev, Y. (2011). Analysis of vibration of printing unit of offset printing press. *Challenges of Modern Technology*, 2(2): pp. 31–34.

MacGregor, M. A. and Conners, T. E. (1987). Image analysis of an LWC paper reveals wire mark in the print density variations. *Tappi Journal*, 70(9): pp. 95–99.

Neter, J., Kutner, M., Nachtsheim, C., and Wasserman, W. (1996). *Applied Linear Statistical Models*. Irwin, Chicago, 4th edition.

Olzak, L. A. and Thomas, J. (1986). *Seeing Spatial Patterns*. John Wiley & Sons.

Sadovnikov, A., Lensu, L., and Kälviäinen, H. (2008). On estimation of perceived mottling prior to printing. *Proceedings of SPIE - The International Society for Optical Engineering*, Vol. 6808.