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A novel method to determine register variation of a press by a densitometry tool

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Abstract

The print quality of a printing machine highly depends on good register variation values. The measuring of register variation is very important for putting a multicolor press in operation or for its repair and service. The manufacturers of print presses also need the evaluation of register variation to develop new products. The current industry standard method for measuring the register variation is based on image processing, which is a very expensive method. It was a great demand to determine the register variation by an alternative and affordable technique. In the present paper we introduce a new method to determine the register variation based on densitometry. In order to create a new method, a special color test target has been designed. The input of the method is the densitometric measurement values, and its output is the register variation value. The results of the method have been compared with those of an image processing method and the correlation coefficient between the results is almost 0.9. Since in the proposed method only a densitometer is needed, it can be considered as a very inexpensive alternative to the image processing methods. The results were also demonstrated to different specialists of a manufacturer of print press and received very positive feedback.

Keywords: sheet-fed printing, printing press, print quality, Neugebauer equation, Murray-Davies equation

1. Introduction

There are a number of factors that affect the print quality. Different tests and testing forms help to carry out the quality defects and help to control the printing process (Jang et al., 2004). The register variation during printing production is one of the most important print quality criteria. It is important not to confuse the terms register variation with registration and mis-registration. Hence in the following paragraph we give a short introduction to these terms.

In color printing, registration is the method of correcting the superimpositions of colors in halftone print. Mis-registration occurs when one or more colors in a set are not aligned. The mis-registration should be minimized during the make-ready time, and if it is in an acceptable range, then the printing production can begin. According to the standards, developed by International Organization for Standardization (ISO) for offset lithographic printing, the mis-registration should be less than 100 μm (excluding newspaper printing) between two or more colors (ISO 12647-2/13 and ISO 12647-3/13, 2013). There are different forms of register marks designed in order to check the accuracy of the registration. Manufacturers of printing presses offer to install an automated inline registration and register control system for adjusting the mis-registration on the modern offset presses (Otto and Rolf, 2005; Hauck, 2003; Blasius, Korinek and Reithofer, 1991). The register control systems have an accuracy of 30 to 50 μm by building an average value after measuring 10 to 80 printing sheets. Register variation occurs when the transportation of a printing substrate is not accurate from one printing unit (PU) to the next one. In a wet-on-wet printing (e.g. offset) register variation leads to doubling which causes visual color variation from one sheet to the other one. Register variation occurs because of some technical factors such as high printing speed, instability of the substrate, dampening, etc. Although attempts have been made to reduce the register variation (Hauck, 2007a to 2007e and 2008), in practice it is impossible to achieve a register variation value equal to zero. The tolerance and parameters of the register variation are given by German

Print and Media Industries Association (bvdm, 2002). For example, the standard deviation of register variation in the circumferential direction (press direction) from the first printing unit (PU1) to the last one has to be less than 19 µm for a 10-color offset printing press.

Obtaining a logical and acceptable register variation is a big challenge for all printing press manufacturers. Therefore it is very important to attain an acceptable tolerance of register variation in multicolor printing (bvdm, 2002; FOGRA, 2005). The commonly used method for measuring the register variation is based on image processing, which is a very expensive method. For example, the basic version of the register measuring system (LUCHS, 2014; Loh, 1998 and 2006) costs around 35.000 €. Therefore, there is a great demand to evaluate the register variation by an alternative inexpensive and affordable automatic technique. The authors of this paper previously introduced a new method for measuring the register variation (Hauck and Gooran, 2011). This method is based on spectrometry (CIE-XYZ tristimulus values) and gives similar results to the image processing method although it is much less expensive. However, some printing presses and ink inline control system manufacturers, such as manroland, KBA, QuadTech, and Grapho Metronic use a densitometry tool. The densitometry measuring is also faster than spectrometry and the measuring time is very important especially for the high speed running web presses. Therefore, there was a need and we were asked to modify our previous model to a densitometry-based method to be used in the presses that use a densitometry tool. In this paper we don't intend to discuss the pros and cons for densitometry or spectrometry in controlling the press. In the present paper a novel method to determine a metric value for the register variation based on densitometry is proposed and examined.

The aim of this paper is to propose an alternative method for the measuring of register variation of a printing press. Please notice that the measurement of the register variation will happen during the print production and has nothing to do with the registration and its tolerance during the make-ready phase.

First, in the present paper, a short description of the image processing method is given. Then authors' novel method to determine the register variation is described in detail. Finally, the experimental results of the proposed method are compared with those of the image processing method.

2. Image processing method

The image processing method is the industry standard to semi-automatically determine the register variation. LUCHS is the most known image analysis based device. In the following, this method is briefly explained although it is not described in detail by the PIDSID-Institution (the manufacturer of LUCHS) how the LUCHS method works. However, it is known that the device produces a high-resolution image of the measuring element shown in Figure 1 (LUCHS, 2014).

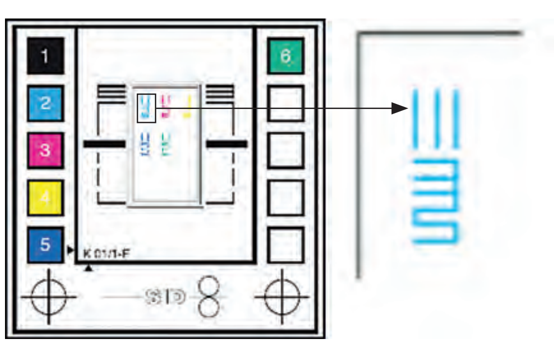

Figure 1: LUCHS measuring element and an enlargement of a part of it

The frame in Figure 1 is printed in the first printing unit (PU, in this example black) and the horizontal and vertical lines (Luchs, 2014) are printed in the following PUs (in this example cyan PU2, magenta PU3 and so on). The pixel positions of the horizontal and vertical lines will be determined and compared to those of the black frame.

Figure 2 illustrates the simplified work principle. The black frame ("F" in Figure 2) is for example about 1 × 1 mm. Line "a" is a horizontal base line printed in PU1 and "b" is a reference line printed in PU2. Now a high-resolution camera system takes an image of the frame and the reference line using for example 1000 × 1000 pixels. That means in this case it automatically gives a metric unit, i.e. 1 pixel/µm. The register value in the circumferential direction is defined as the distance between these two lines (lines "a" and "b"). Now, by measuring this distance in two consecutive printed sheets the register variation can be determined by taking the difference between these two register values.

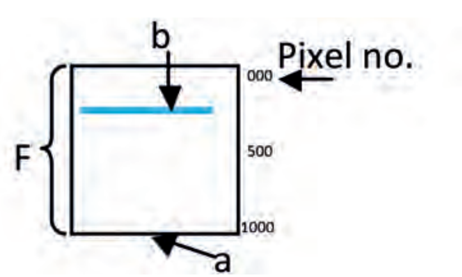

Figure 2: Simplified work principle of the image processing for evaluating the register variation

The register variation in the lateral (sidewise) direction is determined accordingly, decided by the vertical lines. The result of evaluating the register variations is illustrated by a graph and the calculated standard deviation. Notice that the absolute register value in each sheet is not so important for putting the press in operation or repair. The shape of the register variation distribution for a set of evaluated sheets is more important and the most important factor is their standard deviation. For more detail please see (LUCHS, 2014; Loh, 1998 and 2006).

3. Proposed method

3.1 Design, assumptions and restrictions

The goal of the proposed method is to determine the register variation by only using a densitometry tool. In order to do that a special and advantageous color stripe is needed. Figure 3 shows a sample for such a stripe for measuring the register variation between the second and the third PU. This figure illustrates an enlargement of the advantageous color stripe, which consists of solid patches (C_{solid}, M_{solid}, B_{solid}), and patches including single printed (C_{BaseL} and M_{RefL}) and partly overlapped lines and gaps (B_{olapL}). C, M and B stand for cyan, magenta and blue (magenta on cyan), respectively. How the width of these lines is chosen will be discussed later in this section. These patches are printed in two different printing units; in this example cyan is printed in PU2 and magenta in PU3. Generally the register variation is determined between two consecutive PUs (e.g. PU2 and PU3) or between the first and the last PU (e.g. PU1 and PU4 for 4-color printing).

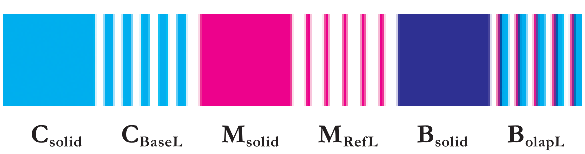

Figure 3: The enlargement of the measuring color stripe for the proposed method

The register deviations occur because of the inaccurate transportation of the printing substrate from PU2 to PU3. When the consecutive printed sheets are compared to each other, a variation of the position of the base lines to the reference lines can be visually observed (by using a 50× magnifying glass). Figure 4a illustrates an enlargement of a part of the partly overlapped lines (B_{olapL}) in Figure 3. Figure 4a shows the overlapped lines as they are designed in the prepress file and Figures 4b and 4c illustrate how they would look like if register variation occurs in two different directions.

So the width of cyan lines, blue lines (overprinted area), magenta lines and unprinted white gaps vary for different sheets related to the amount of the register variation (Figure 4). Of course, the width of these lines also corresponds to their coverage.

In the proposed model, the coverage of the lines (cyan, blue, magenta and the white gap) is determined for each printed sheet. Our focus in this part is on the vertical lines for the lateral register variation but a similar color stripe is designed using horizontal lines for the register variation in the circumferential direction.

Figure 5 shows an enlargement of a part of the single printed and the partly overlapped lines in the designed color stripe in the prepress file. As seen in Figure 5a the width of the basis line (cyan) and unprinted gap (white)

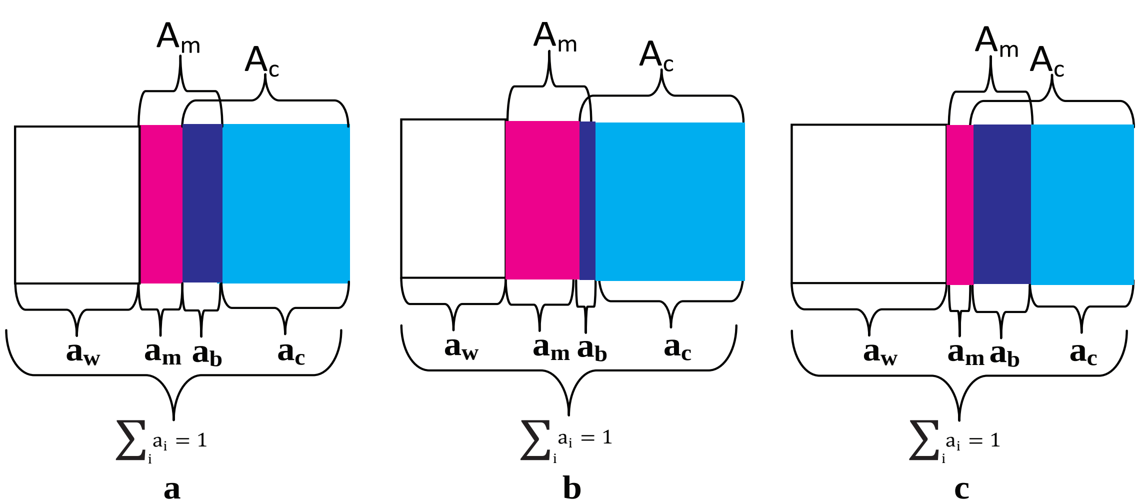

Figure 4: a) The overlapped lines in the prepress file and after make ready in the print; b) and c) the overlapped lines if the register variation occurs in two different directions

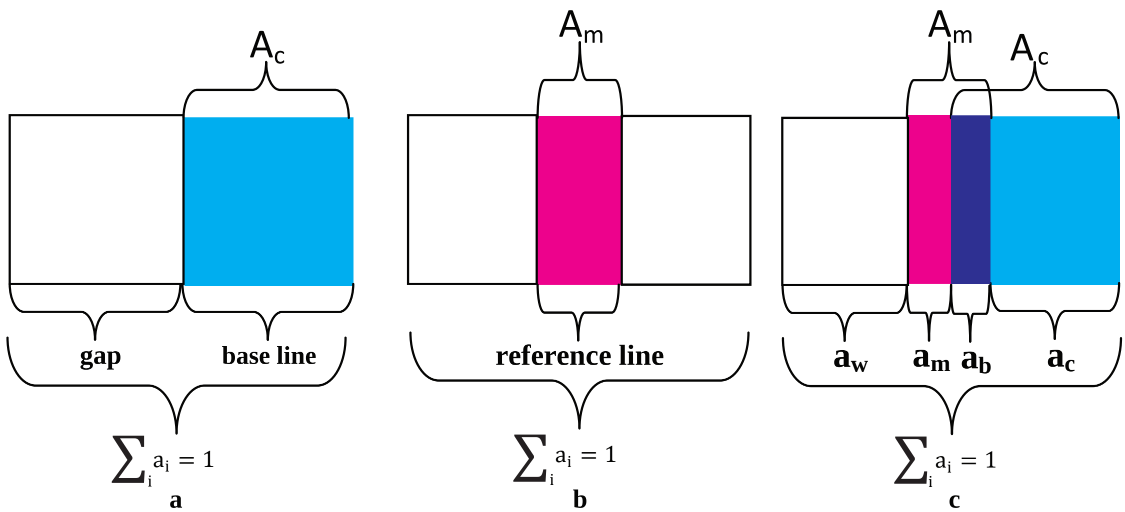

Figure 5: Enlargement of a) base line (C_{BaseL}), b) reference line (M_{RefL}) and c) partly overlapped (B_{olapL})

are equal and correspond to the area coverage 0.5 or 50 %. The width of the reference line (magenta) and the unprinted gap corresponds to 0.25 and 0.75, respectively, see Figure 5b. In Figure 5c, the width of the overlapped area (blue) corresponds to 0.125. The width of pure cyan, pure magenta and the unprinted gap correspond to (0.5 – 0.125 = 0.375) and (0.25 – 0.125 = 0.125), and (0.5 – 0.125 = 0.375), respectively.

The variation in the width of cyan (corresponds to a_c), blue (a_b), magenta (a_m) and paper (a_w) lines in Figure 5c due to register change can be used to determine the amount of the register variation. However, in this study we use the variation of the width of blue line (corresponds to the coverage a_b) to determine the register variation. Notice that a_c, a_b, a_m and a_w denote the coverage of the corresponding color, which are proportionally related to their width. According to Figure 5c, the working range of this system to detect the register variation corresponds to 12.5 % in each direction (left or right). In this design the width of the cyan lines and magenta lines in Figure 5a and 5b are 128 and 64 µm, respectively. This means that this design is able to detect the register variation up to 0.125 × 256 = 32 µm in each direction, which means a total register variation of 64 µm. Normally, this working range is enough to put the press in operation (FOGRA, 2005 and bvdm, 2002). It is possible to expand the width of the lines and the unprinted gaps in the design to increase the working range if demanded. In our experiment a densitometry tool with a measuring spot of 3 mm in diameter was used. If there is a need to increase the width of the lines then we recommend using a measuring spot bigger than 3 mm in diameter.

Here we need to add that the width of magenta lines is chosen to be less than (in this case half) that of the cyan lines to avoid total coverage of the patch B_{olapL} in Figure 3 due to dot gain, which could decrease the dynamic range of the measurement data. We also need to add that the effect of dot gain is included in the equations of the proposed method, see Section 3.2.

3.2 Basic calculations

In Figure 5c, assume that a_c is the coverage of cyan (base line), a_b is the coverage of blue (overprinting area of cyan and magenta), a_m is the coverage of magenta (reference line), and a_w is the coverage of white (unprinted area) after print. A_c is the coverage of the single printed base line, which is determined by measuring C_{BaseL} region in the color stripe, see Figure 3. A_m is the coverage of the printed reference line, which is determined by measuring M_{RefL} region in the color stripe, see Figure 3. Notice that the effect of dot gain is included in the determined values of A_c and A_m because the calculations are based on the measured optical density after print, which also includes the effect of dot gain (Namedanian and Gooran, 2011). It has to be mentioned that the effect of dot gain is taken into account for each printed sheet.

As mentioned before the register variation from sheet to sheet corresponds to the variation of the coverage of the blue lines (a_b).

In Figure 5c it can easily be seen that

$$a_c = A_c - a_b \quad [1]$$
$$a_m = A_m - a_b \quad [2]$$
$$a_w = 1 - A_c - A_m + a_b \quad [3]$$

3.3 Register variation determination based on densitometry

As mentioned before, some printing presses and ink inline control system manufacturers such as manroland, KBA and QuadTech use a densitometry instead of a spectrometry tool in order to control the press. This method is proposed for these applications.

Let R denote the reflectance value of the densitometer (demonstrated with β in some literatures). The relationship between optical density and reflectance is as follows:

$$R = 10^{-D} \qquad [4]$$

where D is the optical density and is measured with the complementary filter of the overprinted ink (magenta in our experiment). Recall that in this experiment cyan is printed in PU2 and magenta in PU3. We recommend using the densitometer in the absolute optical density mode and for each sheet measuring its own paper's optical density value. This minimizes the additional noise that might occur because of the quality variation of the paper surface.

In the densitometry method the concept of the color stripe in Figure 3 is used. Since it is easier to write the equations using R (reflectance) than D (density) all equations are written using R, which is converted to D at the end. The Neugebauer equation (Neugebauer, 1937) can be written as

$$R_t = \sum_i a_i R_i \qquad \sum_i a_i = 1 \qquad [5]$$

where R_t denotes the total reflectance of the halftone print and R_i denotes the reflectance value of cyan, magenta, blue or paper. For B_{olapL} region in Figure 3, Equation 5 becomes

$$R_t = \left[\left(A_c - a_b\right) R_c\right] + \left[\left(A_m - a_b\right) R_m\right] + \left(a_b R_b\right) + \left[\left(1 - A_c - A_m + a_b\right) R_w\right] \qquad [6]$$

where A_c and A_m are calculated by Murray-Davies equation (Murray, 1936)

$$A_i = \frac{R_w - R_i^{Line}}{R_w - R_i^{Solid}} \qquad [7]$$

where the index i is c for cyan and m for magenta and w denotes the unprinted gap (paper). Therefore, R_w denotes the reflectance of the bare paper. The superscript Solid and Line denote the solid and line screened patches for the corresponding color, see Figure 3. For example, R_c^{Solid} and R_c^{Line} are the measured reflectances of C_{solid} and C_{BaseL} in Figure 3, respectively. In our previous work we assumed that the coverage for cyan and magenta lines after print could be different in C_{BaseL} and M_{RefL} compared to their corresponding coverage in B_{olapL}. We observed in all of our experiments that this difference is negligible. Therefore, in the following we don't take that into account.

Equations 6 and 7 give

$$R_t = \left[\left(\frac{R_w - R_c^{Line}}{R_w - R_c^{Solid}} - a_b\right) R_c^{Solid}\right] + \left[\left(\frac{R_w - R_m^{Line}}{R_w - R_m^{Solid}} - a_b\right) R_m^{Solid}\right] + \left(a_b R_b^{Solid}\right) + R_w - \left(\frac{R_w - R_c^{Line}}{R_w - R_c^{Solid}} R_w\right) - \left(\frac{R_w - R_m^{Line}}{R_w - R_m^{Solid}} R_w\right) + \left(a_b R_w\right) \qquad [8]$$

Where R_t is the measured reflectance value of the patch B_{olapL} in Figure 3 and R_c^{Solid}, R_m^{Solid}, R_b^{Solid} and R_w denotes the measured reflectance value of the solid cyan, magenta, blue and bare paper. Now, a_b is determined by using Equation 8, which is shown in Equation 9.

$$a_b = \frac{R_t + R_w - R_c^{Line} - R_m^{Line}}{R_b^{Solid} + R_w - R_c^{Solid} - R_m^{Solid}} \qquad [9]$$

Finally, the reflectance values in Equation 9 are replaced by their corresponding optical density values to get

$$a_b = \frac{10^{-D_t} + 10^{-D_w} - 10^{-D_c^{Line}} - 10^{-D_m^{Line}}}{10^{-D_b^{Solid}} + 10^{-D_w} - 10^{-D_c^{Solid}} - 10^{-D_m^{Solid}}} \qquad [10]$$

3.4 Evaluation of the register variation

For the evaluation of the register variation, a number of consecutive printed sheets are needed. Normally, the print machine manufacturers evaluate a series of about 30 to 50 consecutive printed sheets. This number of sheets allows a meaningful evaluation and statistics. Assume that we have a series of measured data of a_b for n printed and measured sheets. The arithmetic average of a_b is determined by

$$\overline{a_b} = \frac{1}{n} \sum_{i=1}^{n} a_b^i \qquad [11]$$

where a_b^i is the coverage of blue (a_b) for printed sheet no. i.

Now the centered and metric transformed value (r_i) of a_b is calculated by Equation 12.

$$r_i = \left(a_b^i - \overline{a_b}\right) \delta \qquad [12]$$

The factor δ is used to transform the centered coverage to a metric amount [μm].

As discussed in Section 3.1, in this experiment the width of a cyan line is 128 μm, which corresponds to the coverage of 0.5. Therefore, a coverage of unity means

$128 \times 2 = 256$ µm and thereby $\delta = 256$ µm. Now the factor δ converts the coverage (i.e. a_b) to a metric unit. For example, if a_b is equal to 0.35 for sheet no. 1 and equal to 0.5 for the consecutive printed sheet (i.e. no. 2) then we will have a shift of 0.15 which corresponds to 0.15×256 µm = 38.4 µm.

4. Experimental results, comparisons and discussions

The graph of the register variation and the standard deviations are the most important data for evaluating and interpreting the register variation of a press. In order to evaluate the proposed method the results are compared with those of the LUCHS method which is the industry standard in the field.

Figure 6 shows the designed test form containing six LUCHS measuring elements and our designed color stripe in the middle. The elliptical marked areas show the needed elements in our experiment. These three marked areas correspond to the three demonstrated patches in Figure 3. This special design of the test form is necessary because of the following reasons. The paper dimension is not absolutely stable. Paper dimension changes during the printing process due to different tensions in different locations of the paper and other parameters, such as the dampening in ratio to the ink. The difference in tensions partly depends on the location of the print subject on the paper sheet. For example, in the locations with high coverage of ink the tension is higher than in the locations with lower coverage. The adhesion power between the ink and the printing blanket and between the ink and the paper cause tension. This tension disturbs the paper dimension, which increases in the high-speed printing. That means this problem should be taken in mind when designing the test form to compare the LUCHS and the authors' method. That is why six LUCHS elements were located in different areas around our color stripe. The comparison of the LUCHS values achieved by these six LUCHS elements is used to determine the paper instability, which is demonstrated in Table 1, column 4.

In the following, the graphic and the numerical results of the LUCHS device and the densitometry methods are demonstrated. For testing and comparing both methods it was necessary to have samples with a high dynamic of register variations. Hence the samples were produced under following printing conditions: The test was carried out using a Roland 700, a sheet-fed offset

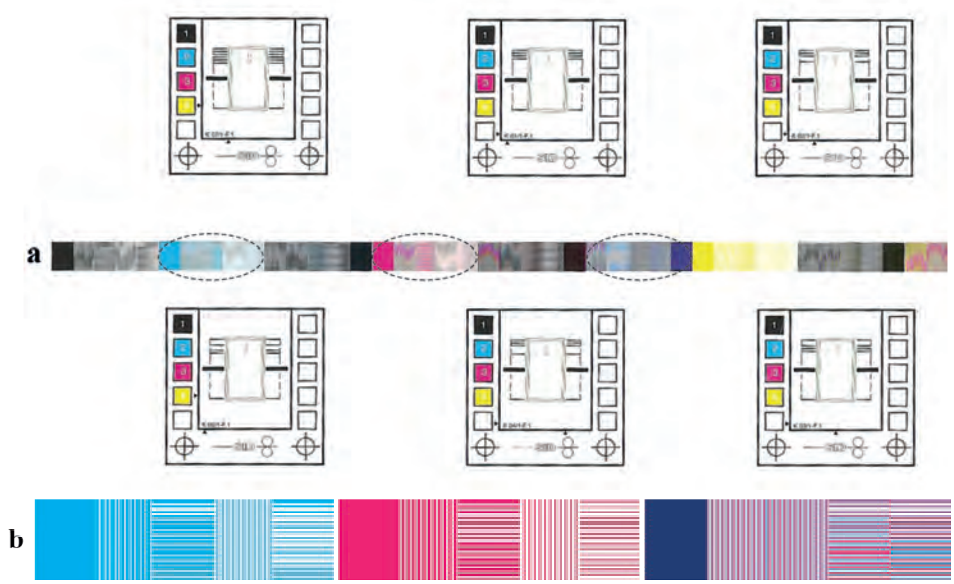

Figure 6: a) The six LUCHS elements are placed around the designed color stripe – the elliptical marked areas show the needed elements; b) the enlargement of the needed elements (these elements correspond to the three demonstrated patches in Figure 3)

Table 1: Up: the comparison of the standard deviation between the LUCHS and the introduced methods; down: correlation coefficients between LUCHS and the proposed methods

	LUCHS method	Densitometry method	Paper instability (LUCHS)
Standard deviation	8.5 µm	8.8 µm	abs [9.2 – 8.5] = 0.7 µm
The linear correlation between LUCHS register values and densitometry register values: 0.87.			

press, installed in manroland Print Technology Center in Offenbach, Germany. The press was accelerated from 8 000 to 13 000 sheets/hour with open driver shaft. The used paper substrate was a stable both side glossy coated 150 g/m². For the densitometric measurements a Color Pilot from Grapho Metronic (manroland) was used. This experiment was done by experts of a printing press manufacturer. A set of consecutive printed sheets (48 sheets) from this run has been evaluated. Most of the modern sheet fed offset presses have double impression cylinders. Therefore every impression cylinder and every transfer cylinder has two different gripper systems. The register variation value of the consecutive printed sheets will be evaluated separately for the first gripper system using odd and for the second gripper system using even printed sheets. That is necessary for analyzing the register variations of a modern press. Hence the graphics, Figure 7, are drawn using red (odd) and blue (even) curves. Figure 7 shows the graph of the centered registered value in [μm] for LUCHS (S_i) and our proposed method (r_i in Equation 12). For the result of the LUCHS method we used the middle LUCHS element in the upper row. It can be seen that the shape and the characteristic of the curves of the two methods are similar. As discussed in Section 1 the absolute register value of each sheet is not so important. The shape of the register variation for a set of evaluated sheets is more important and the most important factor is their standard deviation (FOGRA, 2005 and bvdm, 2002). In Table 1, the standard deviation and the linear correlation of the two methods are shown. The difference of the standard deviation between the two methods is only 0.3 μm, which is very satisfying in comparison to the range of the register variation (FOGRA, 2005 and bvdm, 2002). The correlation coefficient value between LUCHS and the proposed method is also shown in Table 1. The achieved correlation coefficient values are close to 0.9, which shows a satisfactory correlation between the methods. In order to figure out the instability of the paper surface we even compared the results of the LUCHS method using the six LUCHS elements. We took the arithmetic average value of the LUCHS elements and compared it to the results of the middle LUCHS element in the upper row. As seen in Table 1, this difference is about 0.7 μm.

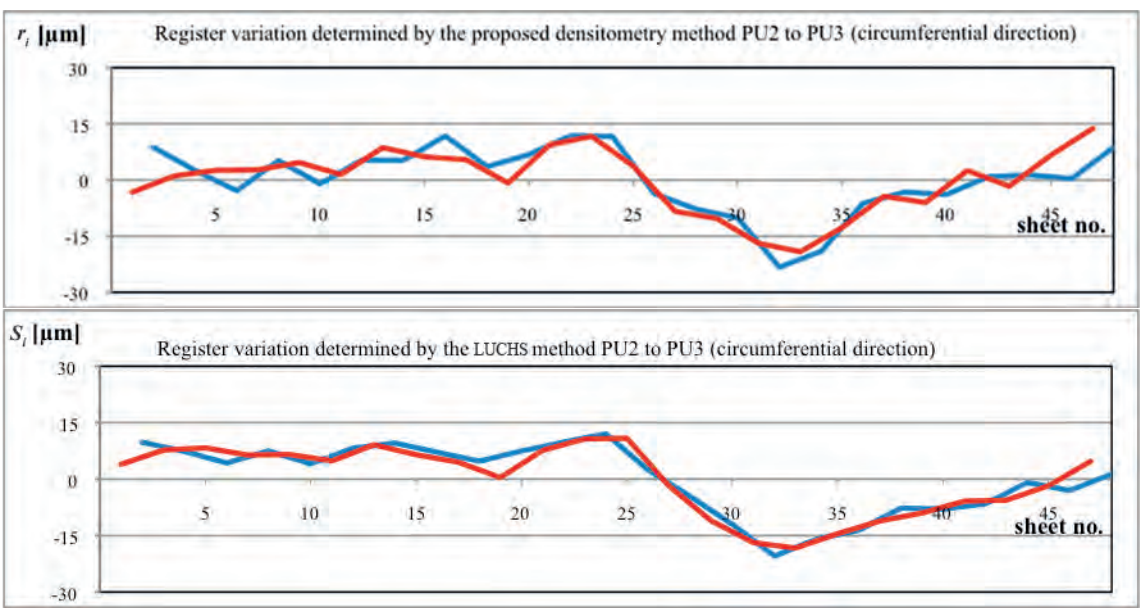

Figure 7: The comparison of the register variation graphics between the LUCHS (s_i) and the proposed method (r_i); the red curves demonstrate the odd and the blue ones the even results of the register position

5. Conclusion and discussion

As demonstrated, the achieved results of the proposed method are comparable to the image processing method. The proposed method can be applied to all other offset printings (web offset printing) because it is the same optical principle in the measurement methodic and generally the print quality of the lines (base and reference line) in sheet-fed and web offset printing is comparable. However, at the moment this method has only been tested for offset printing. Whether this method can be applied to determine register variation for other printing processes, such as flexography, screen printing and gravure printing, is going to be investigated in future work.

The register variation can be determined in any printing company dependent on their measuring equipment, either the Densitometry method (presented in this paper) or the Spectrometry method (Hauck und Gooran, 2011), can be used. The needed measuring tool is available in almost all printing companies. The biggest advantage of the proposed method is that it is less expensive compared to the image processing method. Dependent on the paper size and the number of LUCHS elements and evaluated sheets the image processing method can be time consuming and not ergonomically satisfactory for the operator. In a press with ink inline control system using a densitometric system, the evaluation of register variation can be done automatically. Therefore, the proposed method in combination with inline ink control press can be fully automatic, which saves time, human resources and costs.

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