MODELING LOCAL PRINT DENSITY VARIATIONS IN INDUSTRIAL GRAVURE PRINTS

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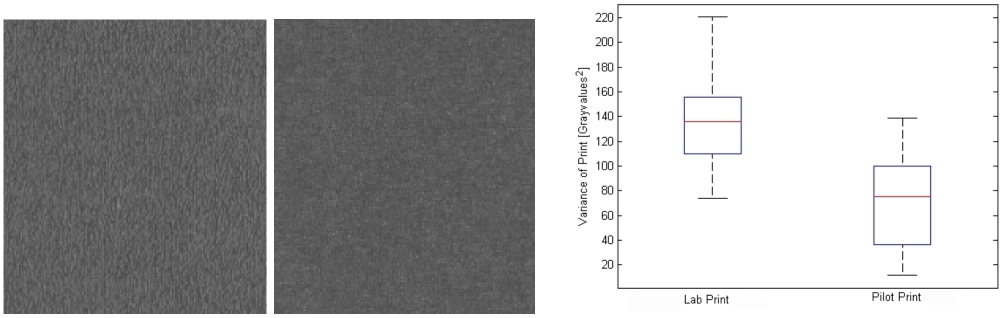
1 Introduction

Modeling of print density variations from local paper properties has been a widely used approach to investigate the reasons for print unevenness. Local paper properties are measured, and the maps of these paper properties are spatially aligned (registered) with an image of the print. In the combined dataset local print density is then modeled from the measured local paper properties. Earlier studies focused on the effect of local grammage and/or topography on local print density variations, e.g. [1, 2, 3]. We will also examine models of local print density as a function of local paper properties. All papers were printed on a lab press *and* an industrial printing press, Figure 1.

- In addition to local grammage and topography we also incorporate data for local ink penetration and local refractive index in our models.
- We use a modeling technique that permits to analyze the degree of redundancy (interrelation) between the model variables.
- The r^2 value for the models has been found to be low for laboratory prints $r^2 = 0.15$-0.45, which has already been observed earlier [1, 2, 3, 4]. The r^2 was higher for industrial prints ($r^2 = 0.3$-0.65).
- We will demonstrate that the lower r^2 in laboratory prints descends from print density variations introduced by the printing process and not by the paper.

2 Materials and Methods

We analyzed commercial SC papers from different European paper producers. For all papers we measured local grammage (beta formation), topography and local ink penetration intensity [5]. Finally local effective refractive index (Surfoptics system [6]) was determined, this parameter is supposed to give some information about surface porosity. For the laboratory prints the paper properties were measured *before* print, for the industrial prints the paper properties were measured *after* print with the ink previously removed from the paper surface.



(a) Laboratory print 70% tone, variance of grayvalues $\sigma^2 = 121$.

(b) Industrial print 70% tone, variance of grayvalues $\sigma^2 = 52$.

(c) Variance of grayvalues in industrial ($\mu_i = 71.59$) and laboratory ($\mu_l = 125,75$) prints.

Figure 1: Gravure 70% tone value, laboratory print (a) and industrial print (b) both printed on the same paper (sample area 3x3cm). Grayvalue variance at 100dpi (c) in 12 laboratory prints and 12 industrial prints .

3 Modeling Results

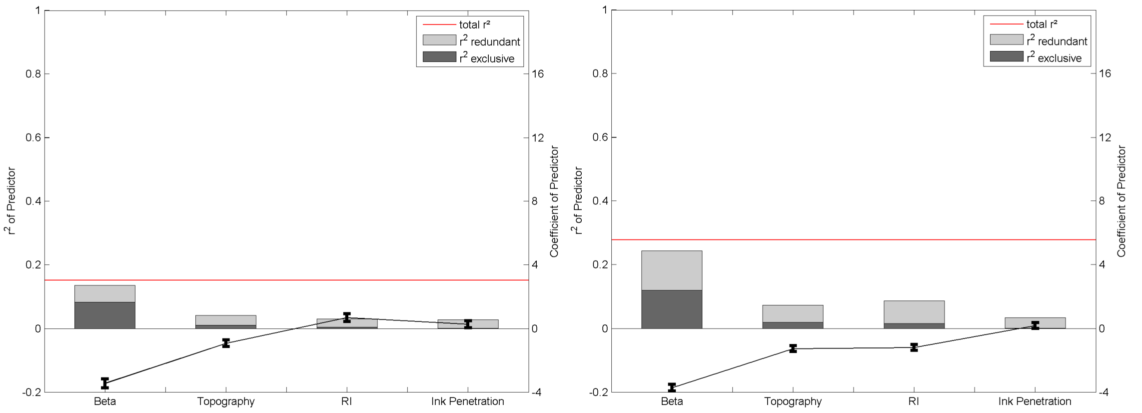
Local print density was modeled as a function of the local paper properties, results for the 70% tone value are shown in figure 2. The modeling procedure is based on linear regression [7]. The influence of the individual paper properties is shown as the bars in figure 2. A key feature of the modeling procedure is, that the r^2 value for each local paper property can be split into two parts. A *redundant part* (light gray part of the bar) consisting of information that is also provided by the other variables and an *irredundant part* (dark gray) of the information which is exclusively provided by this paper property.

According to figure 2 local ink penetration and formation have the strongest interrelation with local print density variations. In the light tone only formation and, to a small extent, topography are relevant. For the 100% full tone ink penetration is the dominating variable. A considerable part of the information provided by formation is redundant, i.e. it is also contained in the other variables. Local refractive index shows little and mostly redundant r^2, thus this predictor is irrelevant.

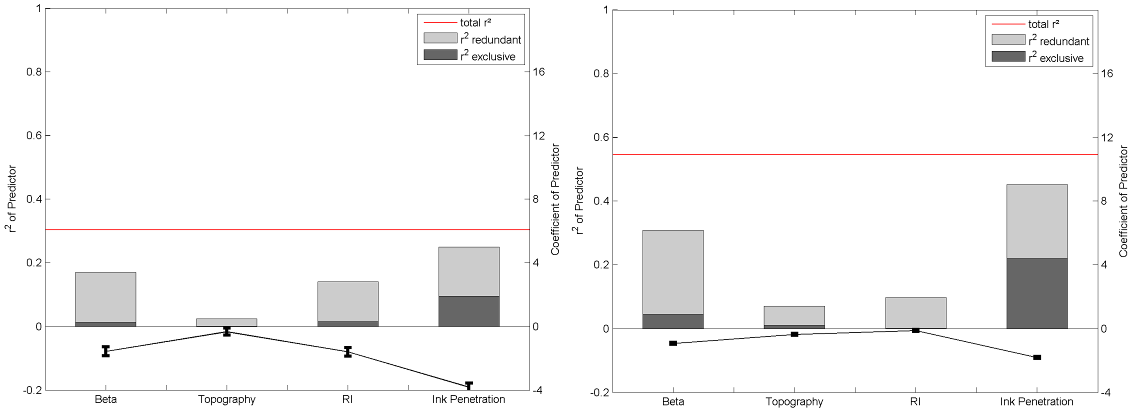
4 Difference in Model R^2

The models of the industrial print always have a considerably higher r^2 value than the laboratory print, compare figure 3. *Qualitatively* the models give the same results as demonstrated in Figure 2, the relative importance of the variables is similar in the light tones (a) and (b) as well as the full tone (c) and (d). The mechanisms are apparently the same, why is the industrial print giving a much better model? The answer lies in the definition of the r^2 value. It is defined [8] as the ratio

$$r^2 = \frac{\sigma^2_{model}}{\sigma^2_{data}}. \tag{1}$$

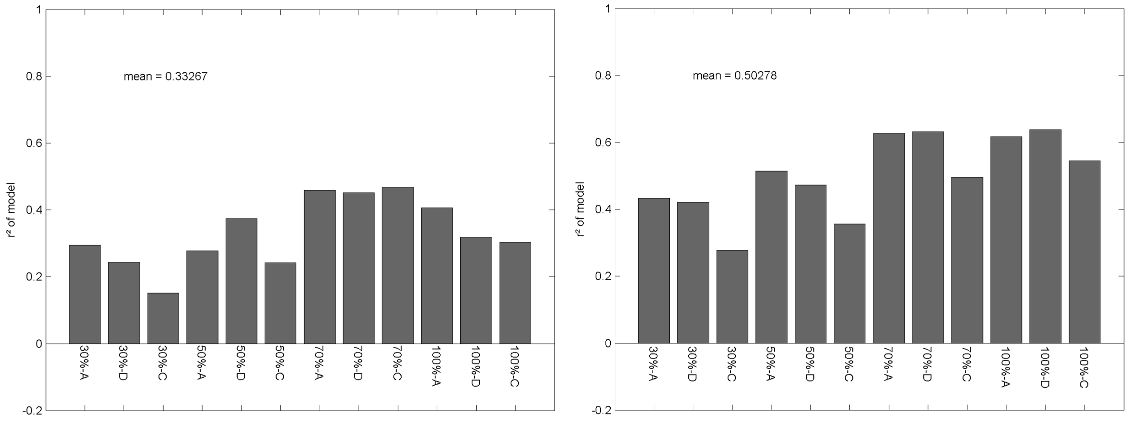


(a) 25% tone laboratory print (b) 30% tone industrial print



(c) 100% tone laboratory print (d) 100% tone industrial print

Figure 2: Linear regression models of 30% and 100% tone *laboratory* print (a, c) vs. 25% and 100% tone *industrial* print (b, d) of the same paper. The bars give the r^2 between *one* variable and local print density, split in redundant and irredundant information introduced by this variable. The red line gives the r^2 for a linear model using all four variables local grammage, surface topography, refractive index and printing ink penetration.



(a) Model r^2 for laboratory prints.

(b) Model r^2 for industrial prints.

Figure 3: Model r^2 for 12 laboratory prints (a) and industrial prints (b) of commercial SC papers. Both datasets contained papers A and C, papers B and D have been produced on the same paper machine and have very similar properties. For each paper four tone values were printed: one light tone (25% vs. 30%) two mid-tones (40% and 60% vs. 50% and 70%) and full tone (100%). In both cases the model was a multiple regression model with four predictors: formation, topography, refractive index and printing ink penetration.

The denominator σ^2_{data} is the total variance in the data, i.e. the variance of the local print density values. The numerator σ^2_{model} is the variance of the modeled print density values. Thus the r^2 value is the fraction of variance in the data (measured local print density) which can be explained by the model (modeled print density).

It is crucial to understand that σ^2_{data}, i.e. the unevenness of the print, has two sources. First of all the paper causes local variations in print density, the variance σ^2_{paper}. However also the printing press itself introduces unevenness, the variance $\sigma^2_{printing}$. Such printing press induced print density variations are - in the case of gravure print - for example blade streaks, whiskering due to high ESA voltage, too high or too low ink viscosity, uneven gravure of the cylinder or pressure variations in the printing nip. Rewriting $\sigma^2_{data} = \sigma^2_{paper} + \sigma^2_{printing}$ in Eq. 1 gives

$$r^2 = \frac{\sigma^2_{model}}{\sigma^2_{paper} + \sigma^2_{printing}}. \tag{2}$$

As we use local paper properties to predict local print reflectance our models can only explain *paper related* print reflectance variations. However the printing process induced variance $\sigma^2_{printing}$ is considerable for the laboratory print. Figure 1 illustrates that the total variance of the print is considerably higher for the laboratory print, σ^2_{data} has here a mean value of $\mu_l = 125, 75$. For the industrial print σ^2_{data} has a mean value of $\mu_i = 71.59$. The key observation is that this difference *must be caused by the printing process, because it is the same papers printed on two presses*. This explains the lower r^2 value for the laboratory print: a large part of the mottle is not caused by the paper but descends from the printing press.

The validity of the ideas outlined above can be supported by analyzing the differences in print reflectance variations between laboratory- and industrial print as shown in Figure 1. The ratio of print reflectance variances is $\frac{\sigma^2_{data-lab}}{\sigma^2_{data-ind}} = \frac{125.75}{71.95} = 1.76$. Reconsidering equation 2 and assuming that σ^2_{model} should be equivalent for both prints we can postulate that the ratio of r^2 for industrial- and laboratory print $\frac{r^2_{ind}}{r^2_{lab}}$ should be about the same as $\frac{\sigma^2_{data-lab}}{\sigma^2_{data-ind}}$[1]. Taking average values $r^2_{ind} = 0.503$ and $r^2_{lab} = 0.333$ from the actual modeling results, figure 3, we obtain $r^2_{ind}/r^2_{lab} = 1.51$. This result differs somehow from the estimated value of 1.76, still it supports the ideas described above. So by *only comparing the print reflectance variance - i.e. the print mottle - of the same paper* from lab- and industrial print we have a rough estimate how much better the models of the industrial print will be.

5 Conclusions

The applied statistical modeling approach provides a structured method to quantify *relevance* as well as *redundancy* of the examined paper properties and their interrelation to local print density variations. The same variables were identified to be relevant in industrial and laboratory print. Local ink penetration intensity is most important followed by formation. Topography was found to be of little importance and local refractive index was irrelevant.

The results demonstrate that the low coefficients of determination in the model of laboratory print does not necessarily mean that these model findings are irrelevant. The laboratory print correctly identifies the relevant paper properties responsible for print density variations. However the high variance introduced by the printing process itself leads to a low r^2 value. Analysis of print unevenness and modeling results of 12 paper samples printed on a laboratory- and an industrial printing press support this theory.

Thus for investigation of print mottle by analysis of aligned paper property maps - if applicable - *industrial prints* should be analyzed. In the field of modeling local print density from local paper properties these findings motivate further research with industrial prints as most of the work reported in the literature had focused on laboratory prints.

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[1] $\frac{r^2_{ind}}{r^2_{lab}} = \frac{\frac{\sigma^2_{model}}{\sigma^2_{data-ind}}}{\frac{\sigma^2_{model}}{\sigma^2_{data-lab}}} = \frac{\sigma^2_{data-lab}}{\sigma^2_{data-ind}} = \frac{125.75}{71.95} = 1.76$

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