Basic Principles Related to the Influence of the Paper Surface in Printing

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Abstract

A formalism is developed to model how a spatially dependent input image signal, modulated by ink, is transferred and distributed on a rough paper surface in different types of printing. The modeling is based on extensions of the classical approaches of ink transfer and system theory. The model is used to assess the effect of roughness on density and gloss noise in prints.

Introduction

The performance potential of paper in printing is commonly evaluated in terms of runnability (paper vs. press), printability(paper vs. ink) and Formation capacity (paper vs. imageinformation data). In the first place, runnability is related to the bulk properties of the paper, whereas printability and information capacity are influenced by surface properties. These include optical properties, chemical properties, and structural properties such as surface topology, porosity and rheological surface properties.

The focus of this paper is on surface topology, i.e. the surface profile, commonly called roughness. The motivation for this study arose from our interest in understanding the principles which govern the contribution of the paper surface to noise in prints in different printing processes. Our overall purpose is to provide a general framework for increasing quantitative understanding of the role of the micro-scale structure of the paper surface on printed quality.

Surface roughness is likely to influence image formation in the physical printing step, as well as in the optical and perceptual imaging steps (Figure 1). In printing, the surface profile may control both the transfer of ink to the paper and its distribution on the paper with consequent spatial variations in ink film thickness. The process may also modify roughness, for instance, as a result of interactions between printed paper, heat and moisture. The angular distribution of the surface reflection of printed surfaces, i.e. gloss, is determined by print roughness. Roughness variations constitute the source of gloss noise. Correspondingly, printed density and color may be affected by paper roughness through variations in ink film thickness and also through print roughness, depending on the measuring conditions[5]. When prints are viewed visually, the common understanding is that roughness may be perceived as surface non-uniformity[1].

What the significance of roughness is, is not clear. To provide insight into this problem, our study combines the classical ink transfer approach[9] and system analytical modeling of printing[4]. The model is used as a tool to assess how much variation is likely to originate m density and gloss in different types of printing.

Principles of Ink Transfer

In printing, the ink and paper first interact at the "impact" or "impression" step. Further interactions occur in setting and drying. The classical Walker-Fetsko ink transfer model[9] accounts for the phenomena in solid area printing in terms of ink quantities. The model is given by expression

$$g = A(f)[bB(f) + s(f-bB)] \tag{1}$$

where ink transfer g is dependent on the amount of ink f, contact function A(f),"immobilization" bB(f) and splitting. A constant proportion s is assumed to be split and transferred to the paper from the proportion of ink which has not been immobilized.

A number of modifications to the model have been suggested during the almost forty years that have elapsed since its publication, but these involve fine-tuning rather than fundamentally new ideas. This suggests that the mechanical phenomena of ink transfer are correctly formulated in the model. From a general standpoint, the model has a shortcoming: it neglects spatial effects. Hence, print noise cannot be predicted, nor can the model be applied to halftone printing.

Consistent with the objectives of our study, the model is modified by including spatial effects but neglecting absorption effects. The former introduce a spatially varying input image signal and spreading into the model: ink spreads sideways in transfer. Sideways spreading is also likely to take place in the polymeric compounds of paper and the ink-carrying surface, a plate or offset blanket. Consistent with a system analytical approach, spreading is depicted by convolution of the input image signal and a spreading function[4]. Exclusion

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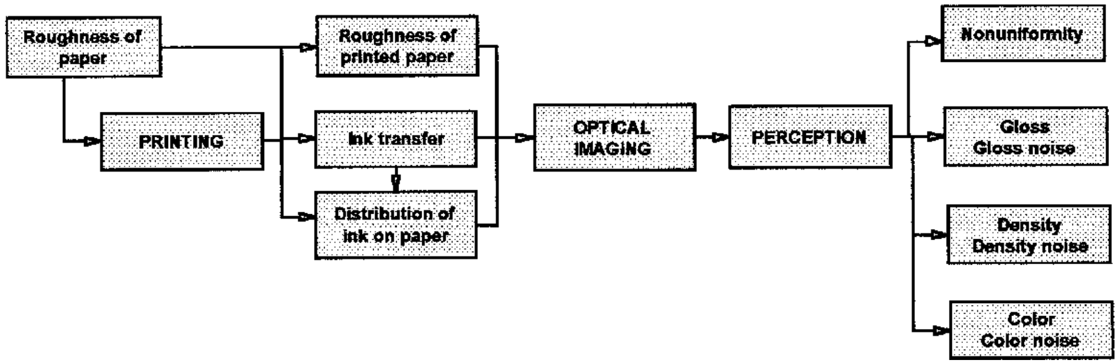

Figure 1. Influences of surface roughness in printing.

of absorption effects allows immobilization to be replaced with deposition of ink in the roughness profile of the paper. These modifications give the following expression for spatially dependent ink transfer:

$$g(x) = A(x)\, f(x) \otimes h(x)\, [s+dz(x)] \quad (2)$$

In the model the input image signal is depicted by f(x). The model could be envisioned to be applicable to printing methods which use inks in fluid form.

The formulation of the model includes four mechanisms:

- spatially dependent initial contact between ink and paper (A(x)),
- spreading of ink from contact points (convolution $\otimes$ with h(x)),
- deposition of ink in the recesses of the paper surface, depending on the paper roughness (dz(x))and
- splitting(s).

In an extreme case, ink transfer and distribution on a rough surface may be controlled by any of these mechanisms as shown and illustrated in Figure 2. The frequency plane representations of the model are also given.

Ink transfer is controlled by paper smoothness under pressure, i.e. the contact between ink and paper when the ink carrying surface is non-deformable. Letter press printing, and also gravure in part, falls in this category. Whether the contact area is determined exclusively by the surface topology of the paper or whether spatially dependent deformation of the paper plays a role remains to be studied.

Ink distribution in contact printing is spreading controlled when sideways ink flow from contacting areas is considerable. In non-contact printing, ink is initially applied on the surface as a smooth layer. Spreading tends to cause ink to flow sideways from smooth points. This may even result in depletion of ink from initial contact points. At boundaries between printing and non-printing areas, as in halftone printing, spreading along fibers is often observed

Deposition-controlled ink distribution is encountered in contact printing when the ink-carrying surface is deformable and is compressed into the recesses of the paper, causing ink to be deposited in the recesses. It is commonly assumed that the conditions in offset printing are of this type.

The fourth alternative is a fully splitting-controlled case that results in constant ink film thickness.

Analysis of Print Noise

Depending on the mechanism controlling ink transfer, printed density and gloss and their variations become different. In what follows, approximative expressions are presented for mean ink film thickness (g), density (D) and gloss (G) and their variations (σ_g, σ_D, σ_G). The noise values represent total noise, i.e. noise integrated over spatial frequency. From the data, the signal-to-noise ratio (SNR_{db}) is calculated for density and gloss using the expressions

$$SNR_{db\,D} = 20\ \lg \frac{D}{\sigma_D}, \quad SNR_{db\,G} = 20\ \lg \frac{G}{\sigma_G} \quad (3)$$

In the contact and spreading-controlled cases, approximate expressions for mean density and their variations are calculated from mean reflectance (R) as

$$D = -1gR,\ R = \int 10^{-kg}\ x\ P_g(g_x)dg \quad (4)$$

where $p_g(g)$ is determined by the proportion of contact area, k is twice the absorption coefficient and g_x is the local ink film thickness. It is assumed that surface reflection does not influence density. Density noise is obtained from the reflectance variation [calculated using $p_g(g_x)$] as

$$\sigma_D = \frac{\sigma_R}{R \ln 10} \quad (5)$$

Because of the complete surface coverage in the deposition and splitting-controlled cases, SNR is calculated directly from ink film thicknesses assuming linearity between density and ink film thickness.

The expressions are compiled in Table 1. Those for density and density noise in the contact and spreading controlled cases are given assuming density to be infinite and gloss to be unity (on the scale of 0...1) at contact points. The assumption although made only for the sake of simplicity is justified as far as density is con-

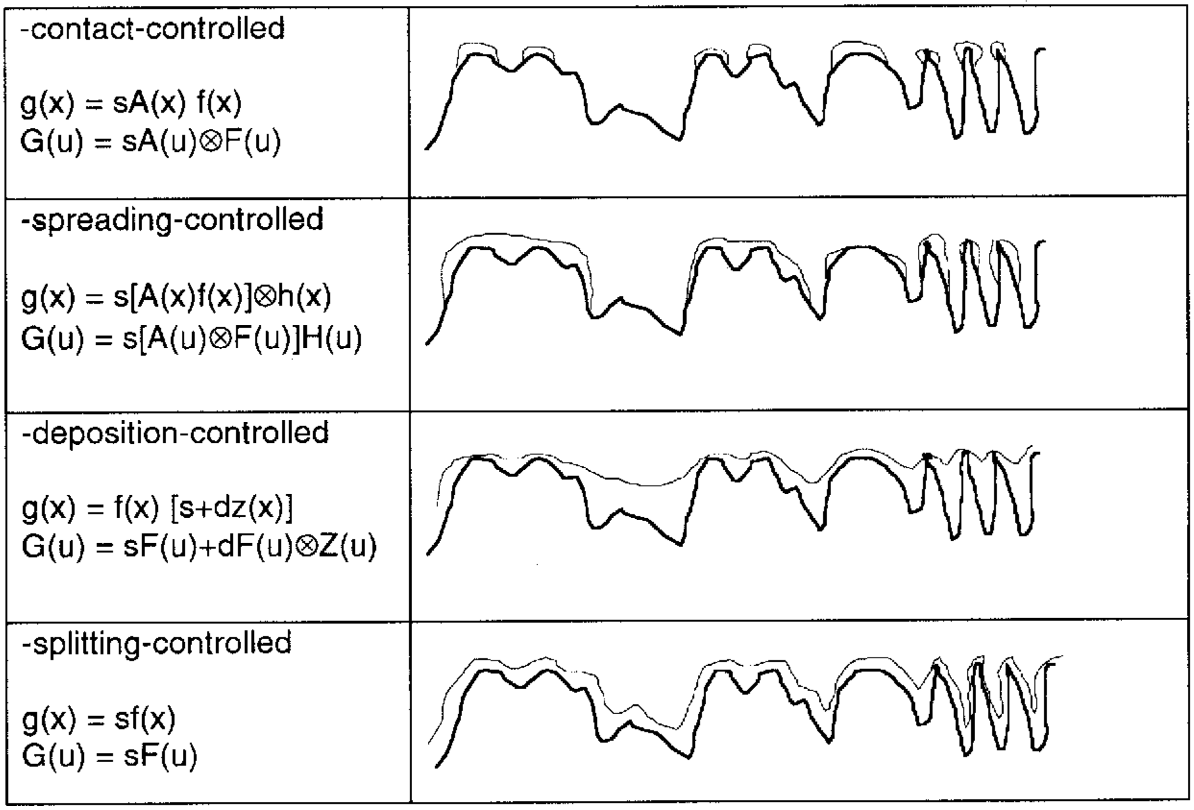

Figure 2. Mechanisms of ink transfer.

cerned by the fact that the influence of surface reflection has been omitted The assumption of perfect specular gloss at contact points is consistent with the understanding that gloss is a measure of a relatively smooth area.

With these assumptions, density and gloss noise in the contact and spreading-controlled cases are somewhat differently affected by the mean contact area. Calculations show that the signal-to-noise ratio for density is smaller than that for gloss. The difference is less when finite levels are assumed for density at contact points. Yet, the SNR values for both density and gloss are small: at 90 percent coverage $SNR_{db\ D}$ is -2 and $SNR_{db\ G}$ about 10. The distribution of noise at different frequencies is determined by the size distribution of the contact and non-contact areas. Profilometric measurements of printing papers[8] suggest that the size statistics of contact and non-contact area are similar and that a fair proportion of the area is too fine to be visually discernible as noise. It does, however, influence the mean values of density and gloss[2]. Optical post spreading also acts by reducing the visibility of noise.

The deposition controlled case is reduced to the splitting-controlled case when there is no deposition. When deposition takes place, density and density noise are governed by profilometric surface roughness parameters, the mean depth of roughness and the rms value of roughness. At filling of the roughness volume, $SNR_{db\ D}$ is approximately controlled by the ratio ofthe splitting coefficient and rms roughness R_q, because on paper surfaces R_a and R_q, values are similar. In decibels, $SNR_{db\ D}$ obtains values of the order of 10. In no-contact printing the splitting coefficient equals one, which improves $SNR_{db\ D}$ by about 6 db.

Table 1. Mean ink film thickness, density and gloss and their variations in prints.

Mechanism	Ink film thickness	Density	Gloss
Contact-controlled A mean area of contact	$g = sA$ $\sigma_g = s[A(1-A)]^{1/2}$	$D \doteq -\lg(1-A)$ $\sigma_D = (\ln 10)^{-1}[A/(1-A)]^{1/2}$	$G \doteq A$ $\sigma_G = [A(1-A)]^{1/2}$
Spreading-controlled A contact area as a result of spreading	$g = sA$ $\sigma_g = sA[(1-A)/A]^{1/2}$	$D \doteq -\lg(1-A)$ $\sigma_D = (\ln 10)^{-1}[A/(1-A)]^{1/2}$	$G \doteq A$ $\sigma_G = [A(1-A)]^{1/2}$
Deposition-controlled R_a mean depth of paper roughness, R_q rms value of paper roughness	$g = s + dR_a$ $\sigma_g = dR_q$	$D = k(s + dR_a)$ $\sigma_D = kdR_q$	$G = G_{paper}(1-d)+d$ $\sigma_G = \sigma_{G\ paper}(1-d)$
Splitting-controlled	$g = s$ $\sigma_g = 0$	$D = ks$ $\sigma_D = 0$	$G = G_{paper}$ $\sigma_G = \sigma_{G\ paper}$

Without assuming a model which relates roughness and gloss, print gloss cannot be directly related to roughness, although it can be related to smoothness. It can, however, be related to paper gloss and filling of the roughness volume. The expression given in Table 1 is based on the assumption that with an increase in the degree of deposition, print gloss increases linearly from paper gloss toward the maximum level of one. Correspondingly, gloss noise decreases from the level measured from the paper to zero at complete filling of the roughness profile. In other words, $SNR_{db\ G}$ ranges from the signal-to-noise ratio of the paper to infinity. According to measurements using an experimental set-up for gloss noise[6,7], the $SNR_{db\ G}$ for paper is typically in the range of 10. . .20.

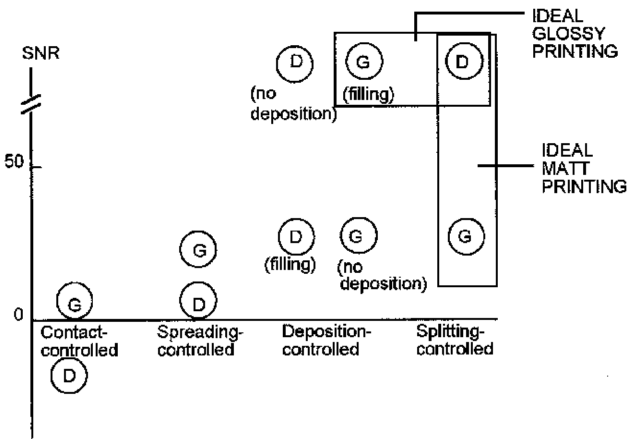

Figure 3. SNR of density (D) and gloss (G) when ink transfer is controlled by different mechanisms.

No ink film thickness variation, and thus no density variation either, arises in the splitting-controlled case. Under the simplified assumption that an evenly split ink fi]m follows fully the contours of the paper surface profile, no change in gloss or gloss noise compared to the paper is obtained; $SNR_{db\ G}$ is as stated above (10...20).

Clearly the performance of printing, expressed as the SNR of density and gloss, is highly dependent on the mechanism of ink transfer. The mechanisms are summarized in Fig. 3. Contact and spreading controlled ink distribution provided contact is in complete represent the worst cases. Spotting controlled ink transfer is desirable when a high density but no gloss, i.e. a matt surface, is required. When high values of SNR of density and gloss are desired the surface should initially be smooth so that filling of roughness would not give rise to any variation in ink film thickness through deposition.

Conclusions

A formalism was presented for spatially dependent ink transfer to paper and applied to find limits to the contribution of the surface topology of paper to print noise. It was found that total density and gloss noise, i.e. noise integrated over spatial frequency, may be considerable. Some of the noise is likely to be invisible to the human eye. It does, however, influence the mean values of density and gloss adversely.

It is the understanding of the authors that the formalism can be used as a research tool to identify the controlling mechanisms of ink transfer and ink distribution on a rough surface. Such knowledge is required in analyses of interrelations of print quality and paper properties.

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