Study of Pigment and Optical Response Distributions in Newsprint

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Abstract: The quality of the printed screen dots is one of the critical factors that determine the over all quality of a printed halftone image. In this paper the spatial distribution of pigment is recorded and its relation to optical response and local paper grammage in printed screen dots on newsprint is analyzed. It is shown that light scattering inside the paper structure to some extent hide large irregularities in the pigment distribution. It is also shown that a hole in a screen dot will be optical mitigate by the paper structure as a result of multiple light scattering inside the bulk. We also show experimentally the hue shift in the border zone of the screen dot. A halo of light around the pigment area, which shifts from cyan towards green, has been determined around a cyan screen dot. Influence from the cyan pigment can be spotted in the optical response up to a distance of at least 20 μm from the measured pigment particle.

Introduction

An important factor for print quality is the dot gain. Mechanical dot gain occurs during the transfer of ink from the plate to the paper. The optical dot gain on the other hand has its origin in scattering and reflection of light on the paper

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surface and inside the paper structure. The combined effect of the mechanical and optical dot gain results in an increase of the area of the printed screen dots in relation to the dots on the lithographic film.

In principal, the optical effect on halftone print has been known for a long time and many attempts have been made to describe the distortion, most notably by Yule and Nielsen (1951). In this paper we want to present results from physical observations about what happens around a printed dot as a consequence of interaction between the pigment and the underlying paper. Difficulties arises when the optical dot gain are to be directly measured by optical means, because the information carried by the photons are subject to the same optical interaction between the printed dot and the underlying structure. For a correct observation of the optical dot gain we have to find a non-optical technique to establish where the pigments really are on the paper structure.

Optical properties of the paper structure

Paper is a very complex material. This is obvious when trying to understand the optical properties of a paper structure and its effect on the printed result. When light impinges on a paper sheet light can be transmitted through the paper or reflected back at the paper surface. It can also be absorbed in the paper structure. These are straightforward optical effects. Because of the complex structure inside the paper, light can also be diffusely transmitted through the paper or diffusely reflected by the bulk of the paper. The diffuse transmission and reflection are caused by multiple light scattering inside the paper structure. Some different pathways the photons can take, when interacting with the paper structure, are illustrated in Figure 1 (left).

In Figure 1 (right) a halftone print has been placed on the paper surface. The arrows illustrate different possible pathways a photon can propagate through the

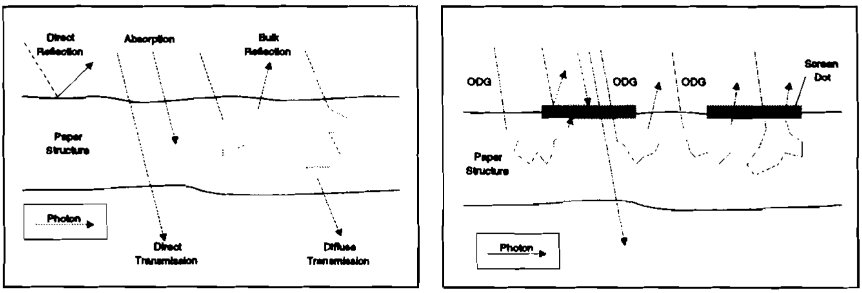

Figure 1: Light scattering in paper structure.

structure. The photon pathways that primarily contribute to the optical dot gain are denoted with "ODG" in the figure. The property common for most of the ODG-paths are that the photons have passed a long distance inside the paper structure before leaving it.

The length of the pathways inside the paper structure that photons undergo have been experimentally studied by Carlsson et. al. in 1995a. In that study very short, subpicosecond, pulses from a high-power laser were used together with a fast streak camera. This arrangement made it possible to measure, with a high time resolution, how a light pulse passing through a sheet of a paper was delayed. Typical results from such an experiment are shown in Figure 2. The curves represent measurements on paper sheets with different grammage. This shows that light transmitted through a sheet of paper, because of the multiple scattering, typically can have traveled distances as much as ten times the paper thickness inside the sheet

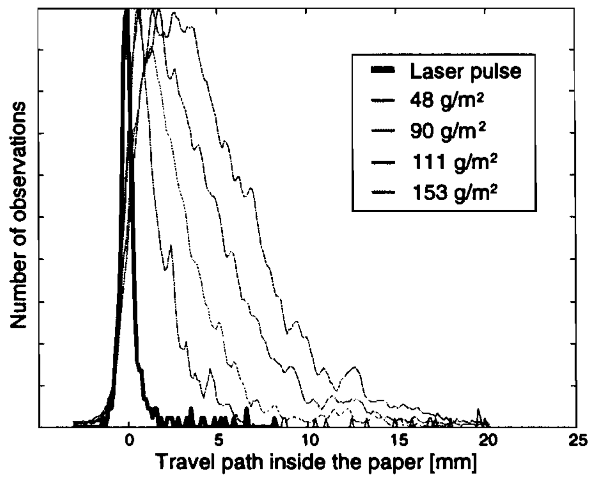

Figure 2: Time resolved transmission measurement for paper sheets with different grammage.

Modelling of paper structure and print

When studying the influence of the paper structure, the structure has to be simplified and approximated. Modeling the optical properties of a paper sheet, simplification have to be made often to the level of no remaining structure. The most well known example of is the Kubelka-Munk model (Kubelka *et al.*, 1931, Steel 1935, Kubelka, 1948, 1954). The Kubelka-Munk model was aimed at describing a layer of paint on a solid surface which is homogeneous and isotropic. Several other models have been developed were the layered structure of paper is included (Scallan *et al.*, 1972, 1974, Borsch *et al.*, 1976, Scallan 1985, Leskelä, 1993, 1994, 1995, Carlsson *et al.*, 1995a).

A model based on a layered structure gives a rough approximation of the optical properties of a paper sheet. An attempt to develop the model one step further has been made by Carlsson *et. al.* (1995b). In their work a three-dimensional model of the fibre and pore structure of a paper is used. In a three-dimensional model a print can be included, for example as a screen dot. This has been demonstrated in (Carlsson *et al.*, 1997).

Experimental parameters

In our experiment we have used a half tone area printed on ordinary 45 g/m^2 newsprint. The screen dots having a diameter of 200 μm. The screen ruling is 85 lines/inch corresponding to a screen cell width of 294 μm. A rectangular area containing 8 screen dots printed with cyan ink has been investigated in detail.

For each screen dot the optical response, the pigment distribution and the local grammage was measured. The amount of pigment and its distribution together with the local grammage were measured with a non-optical technique. The optical and non-optical techniques used different geometrical arrangement. Through image processing the recorded data were transformed into a co-ordinate system in common for both recordings.

Optical response

The optical response of the screen dots was measured with a three-chip color CCD-camera and the data was then transformed into the HSI-color system. The resolution of the captured image was 2 μm per pixel in both x and y directions. The captured output from the camera for one printed screen dot is shown in Figure 3a. The transformed color-parameters: hue, saturation and intensity are displayed in Figure 3b,d,f.

Pigment distribution

The distribution of the amount of pigment was measured with a nuclear microprobe using the PIXE technique (Particle Induces X-ray Emission) (Johansson *et al.*, 1988). This method has been demonstrated on printed areas in (Kristiansson *et al.*, 1994, 1995, Nilsson *et al.*, 1997). In Figure 3c the pigment distribution is shown for the screen dot in Figure 3a. The resolution of the non-optical technique is the same as for the optical technique, 2 μm in both x and y directions.

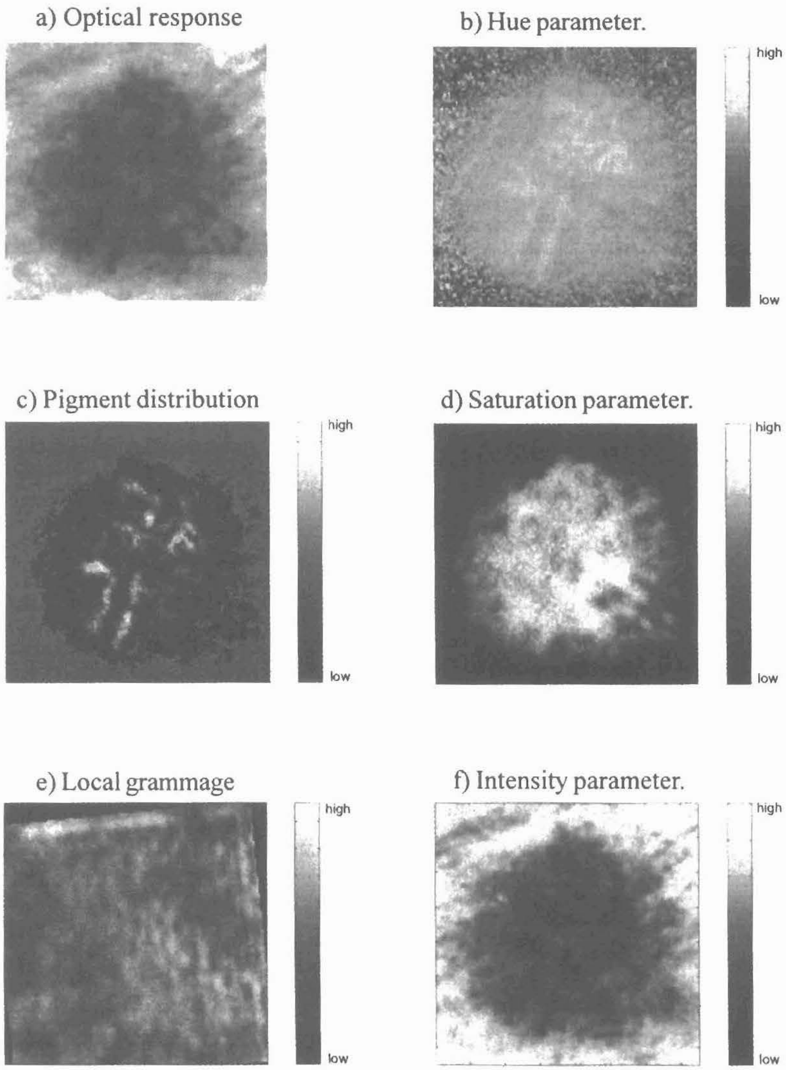

Figure 3: Measured paraneters for a single screen dot.

Local grammage variations

Simultaneously with the pigment measurement, a recording of the local grammage was made on the same physical spot. The technique that was used is called STIM, Scanning Transmission Ion Microscopy. This technique relies on measuring the energy loss of the protons to map the mass in each pixel. This technique has been earlier demonstrated on newsprint (Kristiansson *et al.*, 1996). In Figure 3e a density map of the paper, on which the screen dot in Figure 3a is printed, is shown.

Results

In Figure 4 the measured amount of pigment in each pixel (on the y-axis) is plotted against the corresponding hue-values (on the x-axis) for a single screen dot. The figure shows that the pigments create a narrow color tone with a spreading towards lower hue values. With high amounts of pigments there is an upper limit of the hue value. For low amounts of pigment the hue parameter tends to be distributed toward lower values. This means a color-shift towards green, which is the direction of the hue values of the paper.

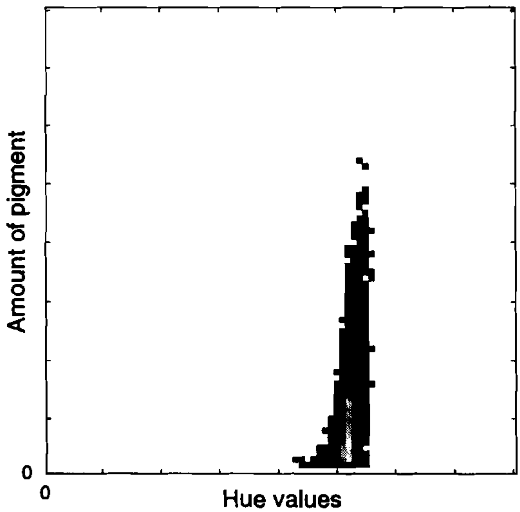

Figure 4: Correlation plot between pigment concentration and hue value.

Holes inside a screen dot

Inside some screen dots there are areas that have no pigment on them, so called pin-holes. In Figure 5a a three-dimensional plot of the pigment distribution for a selected area of a screen dot is shown. In the middle of the plot there is a small hole with an area of approximately 24 μm^2. A line intersecting the three-dimensional plot, marked A and B, is plotted in Figure 5b. In Figure 5a the same printed dot region as in Figure 5a is measured and the diagram illustrate how the corresponding hue values behaves as seen by the optical detection system.

Following the line from A to B one can see that large variations in the amount of pigment only slightly effect the hue values. In one position however, we can see a relation between the amount of pigment and hue value. This area corresponds to the hole. When there is no pigment, as in the case of a hole, the hue value can be observed to be shifted towards green. The green color is a result from the yellow tone of the paper combined with the cyan color from the screen dots.

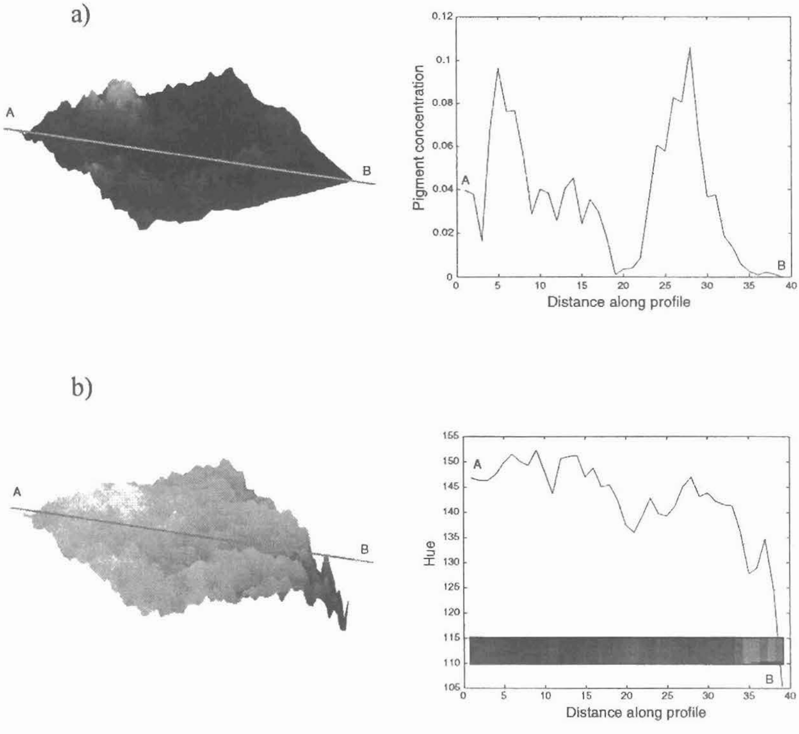

Figure 5: 3D illustrations of a hole

When analyzing a hole it is obvious that paper has a forgiving nature. That means that the hole in the screen dot will, to some extent, be "optically" erased due to the light scattering in the paper structure. This is because the photons, which impinges on the hole, will scatter in the paper structure. This will result in a less visible hole, the hole is "optically" mitigated.

When analyzing the end of the line close to point B the hue values decrease rapidly and are shifted towards a greener color. The reason for this phenomenon is that we now are close of the border of the screen dot and the number of surrounding pigments are significantly lower than for a hole. This effect can be seen in the three-dimensional image of hue-values (Figure 5). The conclusion is that the hue values only slightly changes over a small hole but decrease rapidly at the border of the screen dot.

Calculation of the color shift in- and outside a printed screen dot

An interesting possibility is to calculate whether a color shift occurs in the interior of a screen dot and also if such shifts occurs outside a screen dot. With knowledge about the precise pigment distribution and the corresponding optical response from a single screen dot a synthetic image reflecting these color shifts can be calculated. Due to the uneven borderline of such a screening dot this calculation has to be done in two steps.

The first step considers the color shift inside the screen dot. First the geometrical center of gravity for the screen dot based on the pigment parameter (figure 3c) is calculated. Then for each pixel, containing pigment, the distance to the center of gravity is calculated. For each pixel inside the dot a table is constructed contain-

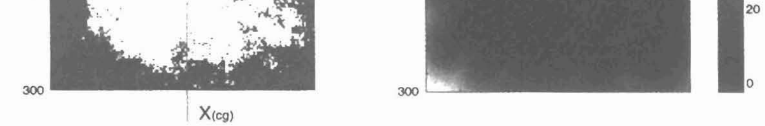

Figure 6: a) Center of gravity for pigment image. b) Distance image

ing the distance to the center and also the values for the different recorded parameters. In Figure 6a all pixels that contains any ink pigment is shown.

All pixels with their distances within a certain interval form together a concentric circle. The optical parameters are then averaged within the particularly concentric circle. Doing that for each possible circle a diagram can be formed which describes the average behavior as a function of the distance to the dot center. The color shift inside the dot can then be plotted as a function of the distance to the center of a screen dot.

In the second step the color shift outside the dot is considered. Because the dot border is uneven a special procedure has been applied. The distance from each pixel, containing no pigment, to the nearest pixel containing any pigment is calculated. An image showing those distances to the nearest pigment pixel is given in figure 6b. Lighter areas correspond to pixels with longer distance to any pigment pixels. Darker areas shown a shorter distance. A table is created containing the distance to the nearest pixel with any pigment, as well as the values of the corresponding optical parameters. In the table all pixels having no pigment are represented. Now, the averaged values for each one of the optical parameters are calculated for all pixels with the same distance to nearest pigment. Thereby, changes of an optical parameter as a function of the distance to the nearest pigment pixel can be calculated.

Discussion

A synthetic image of the color shift around the border zone of a screen dot is shown in Figure 7. For the upper image labeled "Variations of the hue value" the saturation and intensity values of the optical response are set to 100%. By doing this one can visualize the color-vector only, which is represented by the hue values.

The image labeled "Original RGB image" a representation of all these optical parameters hue, saturation and intensity combined is displayed. This better represent how the eye would interpret the printed result. However, the color representation from the digital plotter will distort the true shade.

The position of the borderline has been calculated by analyzing the pigment distribution as a function of distance from the center of the screen dot. At a certain distance from the center there will be a very quick drop in the number of pigment pixels. This is a result of the uneven border of the screen dot. The boarder line is placed in the middle of this region.

Scrutinizing the variations of hue values inside the dot we find significantly changes as a function of distance to the center. The changes vary regular with the distance to the center. These regularities can not be an effect by the fibre structure because the used method to calculate the color shift is not effected by the paper structure. Such geometrical distortion is suppressed by this method. The regularity is also present in the pigment parameter. Before any further conclusions can be drawn more test prints have to be measured to verify this phenomena.

When analyzing the outside region of the screen dot one can see that the cyan pigment will create a halo of light around the pigment area, which shifts from cyan towards green. Influence from the cyan pigment can be spotted in the optical response up to a distance of at least 20 µm from the measured pigment particles of the screen dot.

These results illustrate the complexity of the interaction between the pigment and the underlying paper structure. When analyzing the correlation between pigment distribution and the corresponding optical response it is obvious that the paper structure has an important role for the final print result. It has been shown that the paper structure has a "forgiving" function. This phenomenon is very prominent when the pigments are unequally distributed in a screen dot. A small hole inside a screen dot will be partly optical erased by the paper structure as a result of the multiple light scattering inside the bulk.

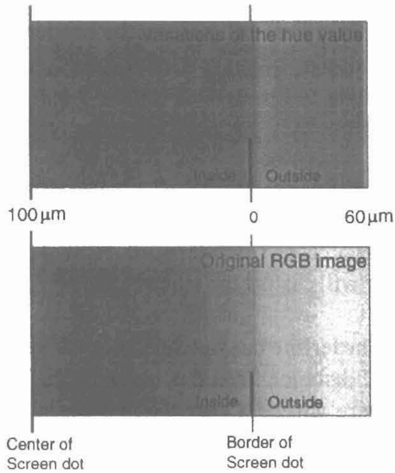

Figure 7: Color shift in- and outside a screen dot.

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