The Characterization of Gloss from Detailed Semigoniometric Measurements—An Update

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Abstract

Surface gloss is an important paper property. The interest in gloss exists because of its profound impact on the quality of printed matter. The quality issues relate to both printed and unprinted substrate. High gloss is often regarded as good in a print since it increases the apparent dynamic range. The shadow tones in a print especially are seen as deeper than on a similar but less glossy print. Varnished magazines are examples of high-gloss prints. On less smooth substrates the gloss may result in a disturbing mist on top of the print that decreases the apparent dynamic range. These effects can often be seen in newsprint, for example.

In a previous paper we have studied the characteristics of gloss on relatively raw paper surfaces. It is clear from the measurements that there are two classes of gloss originating from facets on the surface and fibers. The fibers close to the substrate surface have an orientation such that there are specular reflections 180° apart when the specimen is rotated. The small facets only reflect specularly in one orientation. The work reported here is using the same setup as in the previous paper with 0°/60° observation/illumination angles and 360° rotation in the plane of the surface. There are two additions, however. One difference is that we have increased the photometric resolution using HDRI technique. The image registration of the position has also been improved by more sophisticated tracking software.

The results from this exercise on low grammage newsprint quality demonstrate that there is a gloss asymmetry in the orientation of the machine direction (MD). The average gloss in the reverse direction is considerably higher than in the MD direction itself.

Introduction

Fundamental properties of paper are complex and involve many scientific disciplines. In this presentation we will limit ourselves to a small segment relating to paper optics and more specifically to the problem of gloss. The turbid nature of paper substrates makes the light that enters the sheet scatter. However, some of the impinging light is reflected already at the surface. Depending on the properties of the surface some of the light is reflected back specularly, e.g., gloss. On a printed substrate this may be both detrimental and beneficial to the quality of the print. The angular distribution of the specular reflection is very important and determines the effect it has on the print quality. With a wide distribution it is not possible to create a large dynamic range. The print is perceived as being misty. There is a haze over the print that is the result of many small specular reflections. However, with a smooth uniform surface having highly oriented gloss (with a narrow distribution) the quality in terms of dynamic range is improved.

Previous work has shown the importance of gloss in the contest of perceived and technical quality. Saarelma and Oittinen (1991) and Oittinen (1991) have discussed the aspects of how to define and measure technical print quality with focus on gloss. Arney (1993) has studied a gloss-related problem of how to acquire the surface topography from a substrate. Extending the models regarding print on paper has also been done by Kruse and Wedin (1995) and Arney and Engeldrum (1995a, b). 3-D modeling of light diffusion in paper was also simulated by Gustavsson et al. (1995). These models do not take gloss effect into account. Neither does the dissertation of Gustavsson (1997).

Béland et al. (2000) have shown that gloss variation relates well to quality, as does the width of the light scattering distribution. Ferwerda (2001) proposed a model for gloss perception. Lindstrand (2005) presents an apparatus for measuring gloss on a curved rotating surface.

Nyström and Kruse (2005) have studied high-resolution prints on paper with focus on the halftone prints. Nyström (2009) describes the instrumentation developed at Linköping University for the purpose of detailed multispectral analysis.

The present paper is a continuation of the work reported in Kruse (2009) with the difference that more precise measurements are performed and that a different surface is analyzed. In this presentation an HDRI technique has been used to increase the dynamic range of the captured gloss data. The examined surface is a low grammage newsprint quality.

The investigation confirms the measurements from Kruse (2009) that gloss from the unprinted surface is created by different sources, fibers, and facets (in lack of a better word). An additional conclusion drawn here is that the gloss is not symmetric with respect to the machine direction (MD). The gloss is more prominent in the direction opposite to the MD.

Experimental System

The instrument used in the investigation is described in Kruse (2009). For a more detailed description the reader is referred to Nyström (2009). Briefly, the instrument is composed of a vertically positioned high-resolution black-and-white camera pointing to a motor-controlled horizontal moving table where the specimens are placed. The illumination source is a xenon lamp. Its light is guided through an optical fiber that can be inclined to the substrate surface. The setup with the camera in 0° and the illumination 60° is chosen for its resemblance to a natural reading situation. Through the optical arrangement resolutions down to 1.5 micrometer per pixel are readily obtained. In this work 5 micrometer resolution has been used. Focus, position, rotation, choice of optical filter, illumination angle, and exposure time are all controlled by software.

In Figure 1 below two images from the same position of the sample are shown. The only difference between the two images is the orientation of illumination.

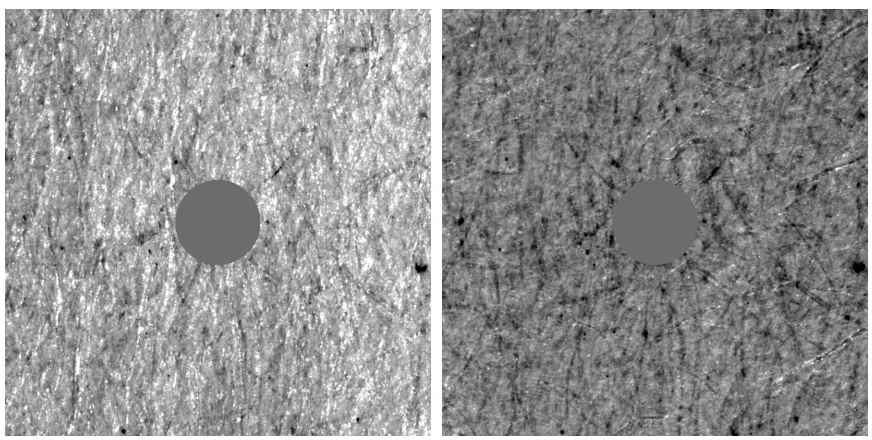

Figure 1. *An example of the same patch illuminated from two different angles 180° degrees apart in the plane of the paper surface.*

Measurements

The measurements were carried out automatically by setting up a program for the Oden instrument. The images were captured in 360° rotational orientations using an increment of one degree that is a full revolution. In each orientation three images were captured with three different exposure times. This allows for applying HDRI technology in order to increase the photometric resolution.

All the images are digitally transformed to the orientation of the first image. Consequently a stack of images is created where the position in the stack corresponds to the angle. This allows for simple processing of the data in the rotational dimension.

Analysis

The first step in the processing of the image data is to increase the photometric resolution using the three exposures of the same patch. The reason for this step is the nature of gloss. A good affordable digital camera has a photometric resolution of 12 reliable bits that corresponds to a range of 1:4000. This is not enough to capture the gloss peaks. Some of the gloss reflection is concentrated in a very narrow sector with a large peak in the specular direction. This cannot be captured reliably by one exposure in the camera. That is why more than one image is needed. In HDR capture it is not uncommon to use seven exposures and in some cases even more. In our case we have limited ourselves to a set of three exposures.

The processing of the set starts with the image corresponding to the longest exposure (see Figure 2). The image is segmented on the basis of limiting in the highlight areas. Because of the limiting the data is corrupt and should not participate in the further processing. With a mask corresponding to the valid sample values it is possible to merge the image with the one with second longest exposure. The merge operation has to take into account that the image samples correspond to different exposure times. In principle the sample values are inversely proportional to the exposure time. However, there are other properties of the camera that makes it a little bit more complicated. Since the data values for samples of the two images under the mask in principle should be the same a simple least squares approximation procedure is used to find the gain factor between the captures. In order to make it more general we have proceeded to establish a second order polynomial that relates the values to each other assuming that the same equation holds for the entire surface. Having established the polynomial we can transform the data values for the two exposures to the same range. This being done, it is straightforward to merge the data from the two exposures. In general one could apply different weighting of the two samples, but in this investigation we have used a simple arithmetic average. The merged image now has higher photometric resolution than the two original ones. The next step is to merge the result of the previous merger with the image corresponding to the next smaller exposure time. Considering that the uncertainties of the data from the images to be merged are different, one might consider applying a more elaborated weighting scheme. In our case we have used arithmetic averages in all steps.

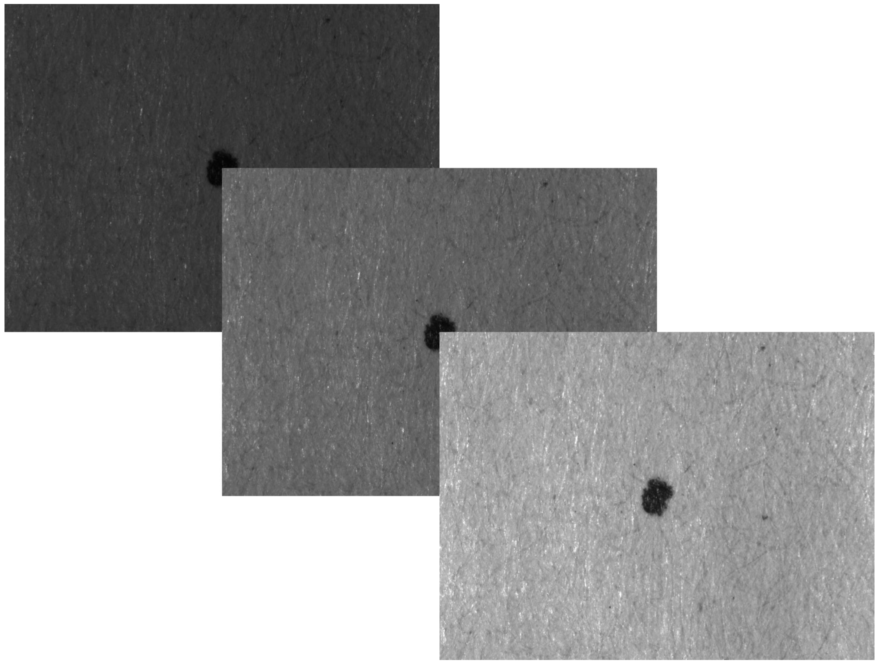

Figure 2. *Three exposures. Short exposure top left and down right long exposure.*

The digital preprocessing of the data resulted in a set of geometrically and optically well-calibrated images each captured in HDRI with extended photometric resolution and illumination from 360 different orientations for a full revolution.

The set of images were observed and positions of high variation and small extent were located and examined. A subset of these was selected for further analysis—the selection criteria being size and regular shape. The Figure 3 below shows 360 sets of small surrounds of one of these locations. In order to better see the data a pseudo colored version is also shown.

In Figure 4 a detail of Figure 3 is shown pseudo colored. The plot below shows the reflection in the actual gloss location. It has a pronounced peak in one angular position. The actual facet and the illuminating beam determine the trailing edges of the plot. The light source is not infinitesimally small but has a certain extent and the light rays are not perfectly parallel. Since the geometric dimensions of the specular reflection are small the width of the plot is most probably due to the illumination.

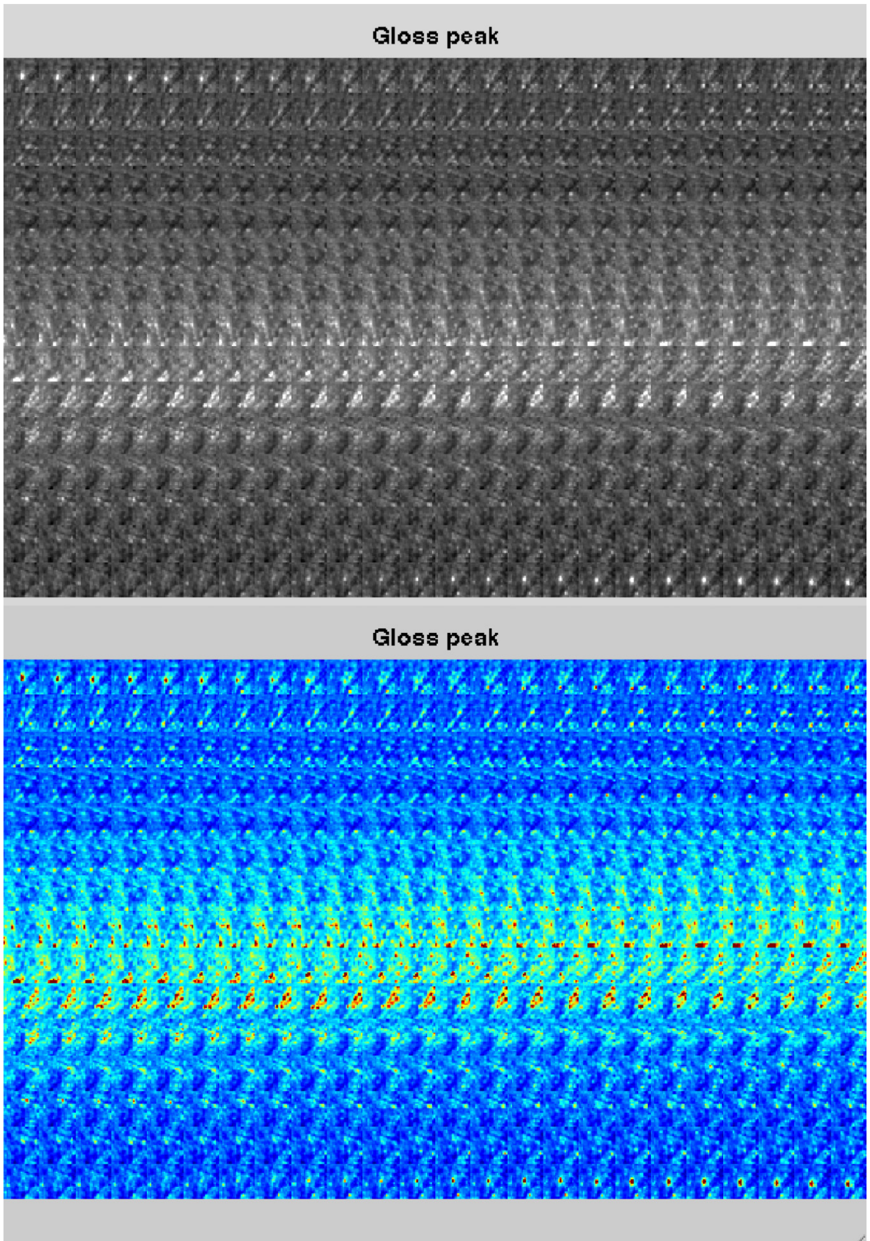

Figure 3. *The image is composed of 360 small patches covering one location organized in 15 rows of 24 each. Lower image is pseudo colored.*

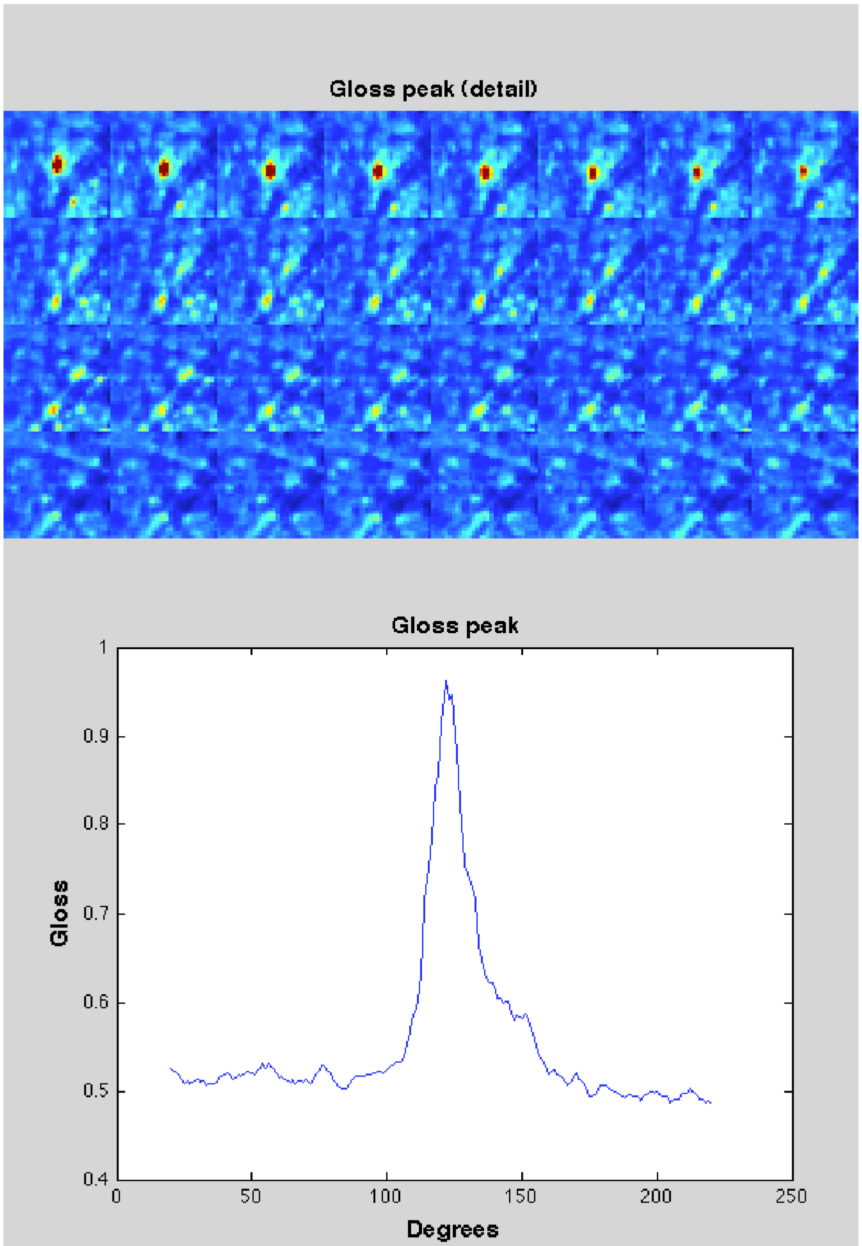

Figure 4. *Pseudo colored details of Figure 3 and the plot of one specific gloss location in the middle of the small sub images.*

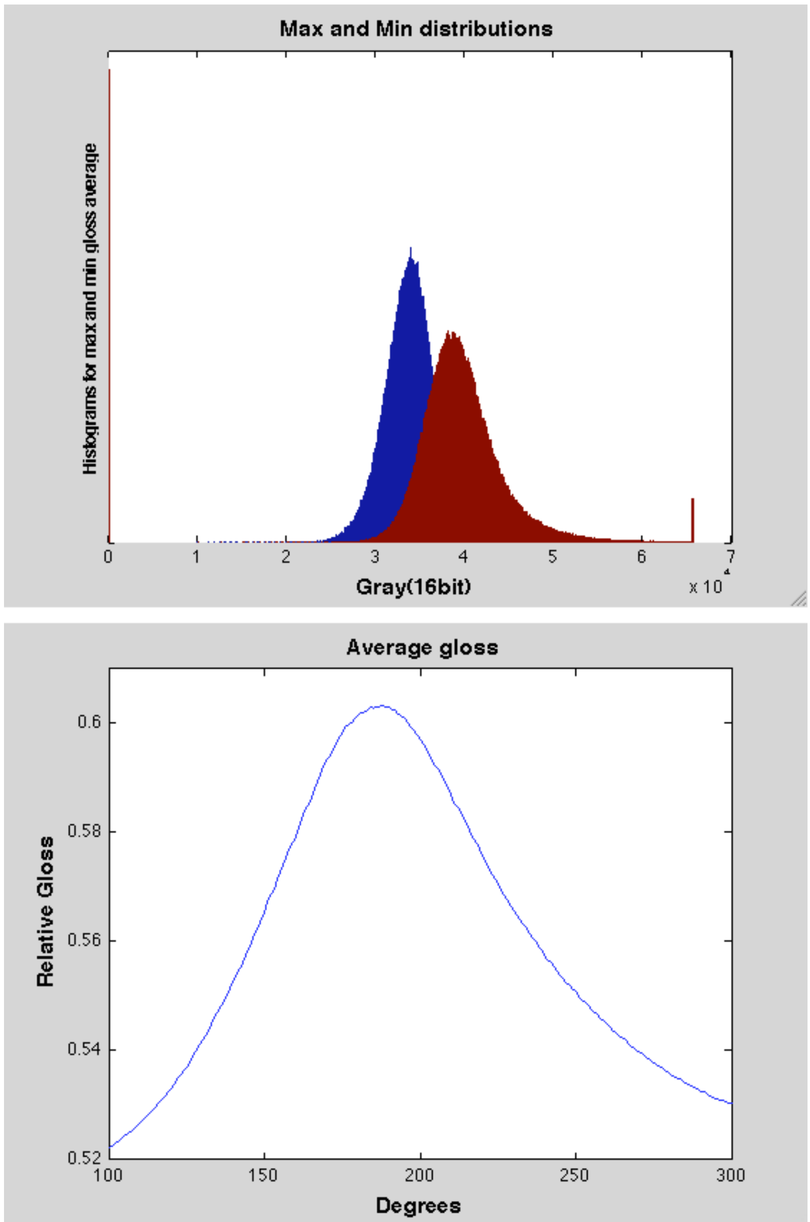

Figure 5. *Plot of the histograms for the two images with maximum and minimum average gloss (above). The average gloss as a function of rotation around 180° is shown below.*

The sequence of gloss images was then subjected to averaging in order to see how the average gloss varied with rotation. In the image sequence the ones with the highest and the lowest average reflection were identified. In Figure 5 (top) the histograms of the images corresponding to the maximum and minimum averages are shown. It can easily be observed that the peaks have different values. The widths are also different with the histogram corresponding to the image with the highest gloss level being widest. The maximum reflection occurs around angle 180° and the minimum around 0°.

The first image in the sequence corresponds to 0° orientation. This is also the MD direction. In Figure 5 (bottom) the plot of the average reflection is shown around 180°. As can be seen from the figure the peak occurs at approximately 180°. The uncertainty as to the exact peak orientation is due to how precisely the sample has been placed on the sample holder.

Conclusions

The conclusions of the previous paper concerned the different types of gloss that occur (on uncoated paper). The fibers that display reflections in two opposite orientations, 180 apart, and the facets that only reflect in one orientation, once per revolution. The class with high first harmonic was not as evident as the one with the second harmonic (Kruse, 2009). The latter gloss areas were probably the result of reflection from micro facets with mirror-like properties. It could be seen from the image data that they were quite small and not at all as large as the areas of the other class. This is confirmed in the present paper (in higher photometric resolution).

The additional conclusion that can be drawn from this study is that not only do the individual gloss locations vary with the orientation of the illumination but also the average gloss. The plot of average gloss as a function of orientation angle demonstrates clearly that there is a maximum occurring opposite the machine direction. The histograms of the maximum and minimum average gloss also show that the magnitude of the difference in character is substantial both in the mean and variation.

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