Instrumental Analysis of Gloss and Micro-Gloss Variations in Printed Images

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Abstract

Gloss characteristics of printed images contribute significantly to visual image quality. However, traditional gloss instruments provided limited information about first surface optical characteristics of printed materials. In the current work, several new instrumental techniques for characterizing gloss and gloss variations in printed images have been developed. These instruments use a radiometrically calibrated digital camera to capture gloss images of printed surfaces that can be resolved spatially to provide micro-gloss information. The unique characteristics of the instrument is in the illumination optics. Illumination is not done with a traditional collimated source at an equal/opposite angle. Rather, the illumination system modulates the light spatially in such a way that much more quantitative information about gloss can be extracted from the images. The instrument quantitatively separates diffusely reflected light from the first surface light. The first surface gloss can then be related quantitatively to the physical topography of the surface.

Introduction

Gloss is a familiar attribute of printed images, and gloss meters are often used to measure one facet of image quality. However, the material properties associated with gloss and the way these properties influence image quality are not well understood. If gloss is first-surface light reflected at the air/image interface, in accord with the laws of specular reflection, then the total gloss reflectance should be a function only of the index of refraction of the material on the surface of the image. This simple model is certainly at work in printed images, but it is inadequate to describe and quantify the gloss metrics of image quality one observes visually. In order to explore in more detail the specular reflectance characteristics of printed images, a study of gloss has been carried out at the microscopic level. However, the instrument configured to carry out this study varied significantly from instruments commonly used for such analysis. This paper describes the unique attributes of the instrument and demonstrates its utility in examining substrates and printed samples.

The Instrument Not Used

In order to understand the instrument used in this project, it is helpful first to consider the most obvious instrumental configuration for such an analysis, illustrated in Figure 1. A digital camera is set at an angle that is equal to but opposite from the surface normal of the sample under analysis. In order to achieve a uniformly illuminated sample over a spatially wide area, a collimated light source is used.

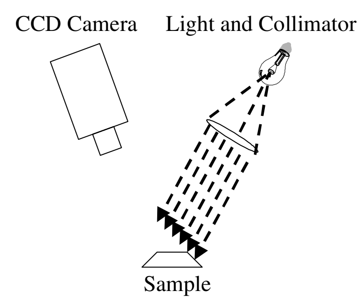


Figure 1. Spatial gloss analysis with a collimated light source (point source at infinity)

Instruments of this configuration have been very useful for qualitative characterizations of gloss variations in printed materials.[1-3] However, there are drawbacks to this technique, as illustrated by ray-tracing in Figure 2. Point **a** is illuminated only by a single ray from the collimated light source. This ray is reflected at an equal and opposite angle as illustrated by ray **A**. The lens of the camera focuses the ray at the image plane at **a'**. If the surface has texture such that point **a** is at an angle α other than horizontal, then the light is reflected as illustrated by ray **C**. This ray is also focused at **a'** provided the ray remains within the cone of aperture of the camera lens. In the captured image, the effect of ray **C** is indistinguishable from ray **A** because the point of focus is independent of the surface angle, α. The irradiance of light at the at point **a'** is also independent of surface angle as long as that angle is within the range required to send the ray into the aperture of the lens. Otherwise the brightness at that point is zero. In other words, an ideal collimated source will act as an angle threshold device and produce a bi-level image at the camera image plane. The threshold will occur at the angle α_t that reflects the light ray to the edge of the camera aperture. The resulting image is illustrated by the irradiance versus position (I vs. x) graph shown in Figure 2. Thus an ideal collimated source can provide only limited information about the surface angle deviations of the sample.

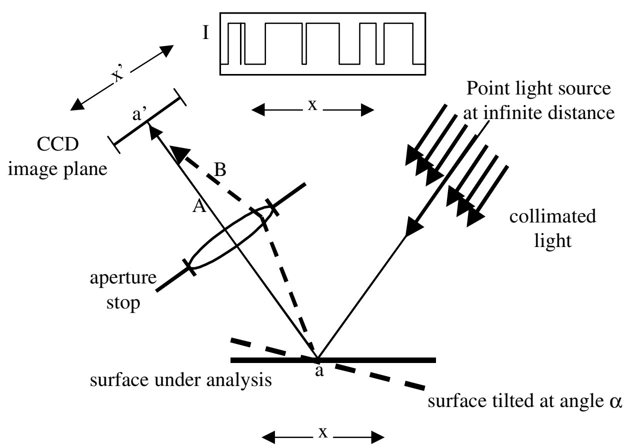


Figure 2. Spatial distribution of gloss using a collimate light source (point source at infinity)

A Spatial-Gonio-Light Modulator

Rather than using a point source at infinity (collimated light), we developed a new illumination geometry with spatial and goniophotometric characteristics capable of providing much more information about the surface of the sample under analysis.[4,5] Figure 3 illustrates the instrument used in the current study. The light source in this case is a long, thin source with a luminance gradient as illustrated.

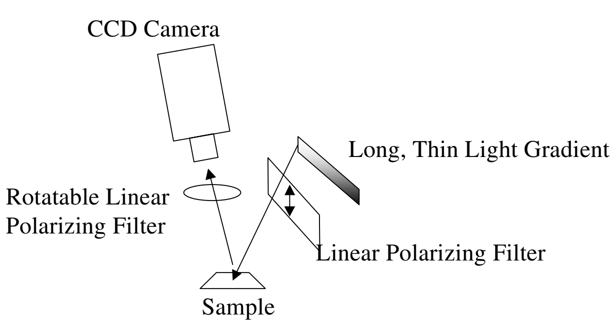


Figure 3. *Configuration of instrument used in the study*

At first glance, the illumination geometry shown in Figure 3 would seem not to be useful for gloss analysis since most points on the light source are at angles that are not in the specular direction from the camera.

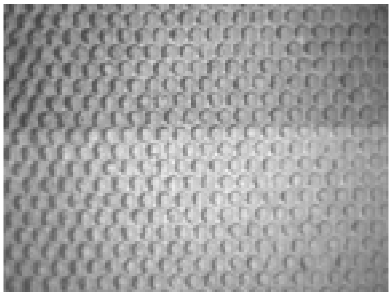
If the sample were perfectly flat then indeed no specular light would reach the camera. However, surface topography is well known to play a major role in the gloss characteristics of materials, and most printing substrates are not flat on a micro scale.[6-8] At any given point on the sample surface, the actual surface angle, α, is likely to be different from the mean angle of the sample, α = 0 (horizontal). The angle of the surface at that point will reflect gloss light from some point on the light source into the camera. The corresponding point on the image plane of the camera will therefore be at an irradiance that is proportional to the radiance of the light source at that point. By selecting an appropriate spatial distribution of the radiance of the source, it is easy to correlate the pixel value of the captured image with the tilt angle, α, of the sample at that point.

Removing The Diffusely Reflected Light

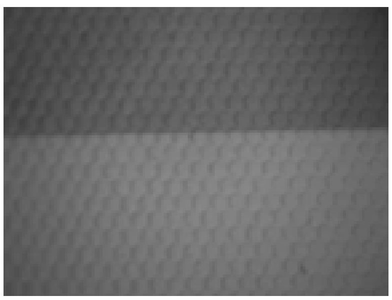
An experimental difficulty with the system shown in Figure 3 is the relative brightness of the diffuse light reflected from the sample. However, diffuse and specular light can easily be separated with linear polarizing filters. The illuminating light is linearly polarized, as illustrated in Figure 3, and the light captured by the camera utilizes a second linear polarizer (analyzer). Light that enters the bulk of the sample is scattered by multiple reflections within the material. When the light emerges as diffusely reflected light, the direction of polarization has been scrambled. The gloss light, however, reflects from a single surface and preserves polarization. Images can be captured with the polarizing filters aligned and crossed as illustrated in Figure 4. Crossing the polarizers has no effect on the diffusely reflected light, but the gloss light is significantly attenuated. Therefore, the difference image (C = A - B) is an image only in gloss light. Moreover, since the illuminator is as shown in Figure 3, the brightness of the gloss light in Figure 4C is directly related to the topographic angle of the surface.

Figure 5 illustrates a proprietary synthetic substrate used for very high quality ink jet imaging. Figure 5A was captured under raking angle illumination at 10 degrees from the horizontal. This is a common technique for visually examining the surface topography of substrates, and small variations in surface angle are manifested by small variations in the captured pixel values.

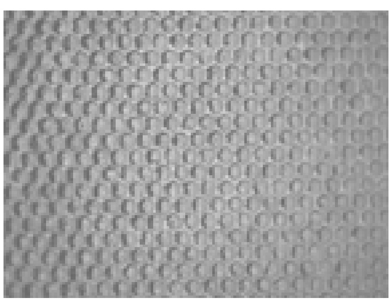
Figure 5B is the difference image in gloss light as described in Figure 4C. The image shown in Figure 5B is exactly in registration with the image in 5A and clearly contains much more detailed information about the surface. The gloss image technique is much more sensitive to variations in surface angle than is the traditional raking angle technique. Of particular interest is the scratch mark revealed as the brighter pixel values in 5B. This mark was put on the sample by lightly moving a finger nail over the surface, but it is not apparent under ordinary raking angle illumination. The gloss imaging technique, however, clearly reveals the mark. Moreover, variations in the pixel values of the gloss light can be related quantitatively to variations in the surface angle of the sample, as follows.



(A) Polarizers Aligned



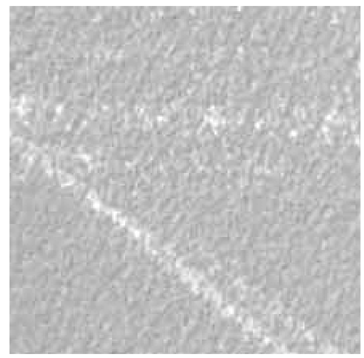
(B) Polarizers Crossed



(C) Difference Image

Figure 4. Images of a texture embossed photograph.

(A) Raking Angle 10 Degrees from horizontal



(B) Gloss Light Image

Figure 5. Analysis of a Smooth Inkjet Substrate

Angle Calibration

The relationship between surface angle and mean pixel value can be found experimentally as illustrated in Fig. 6. A smooth reference sample is tilted to a series of known angles, α, and the corresponding mean pixel value, P, at a selected location is measured. Note the angular variation $\Delta\alpha$ is half the corresponding angle variation at the illumination gradient. By appropriate selection of the illumination gradient, the relationship between P and α can be made linear as illustrated in Fig. 6. Corrections for cos lens fall-off and other artifacts also need to be taken into account, but careful experimentation allows a useful calibration of P vs. α.

In the example shown in Figure 6, the illuminator gradient ranged over only about 10 degrees, so pixel values were distributed over a range of α of only 5 degrees. The result is Figure 5(B), and the pixel histogram of the image is shown by the solid line in Figure 7. The histogram was not distributed symmetrically about the peak, which was selected as a reference angle of $\alpha = 0$. Histogram segmentation demonstrated the scratch was indeed the cause of the a-symmetry, so the left half of the histogram was folded over the right half, as shown in Figure 7(B). Then a difference was calculated and is shown as dotted line (C) normalized to a peak value of 1.00. This is a measure of the distribution of angles within the scratch, and the peak of the distribution is 0.20 degrees from the mean surface angle.

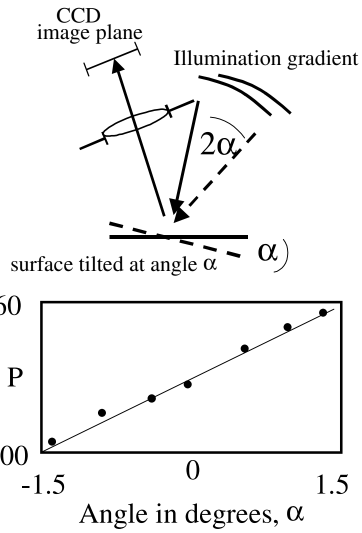


Figure 6. Angle Calibration Procedure

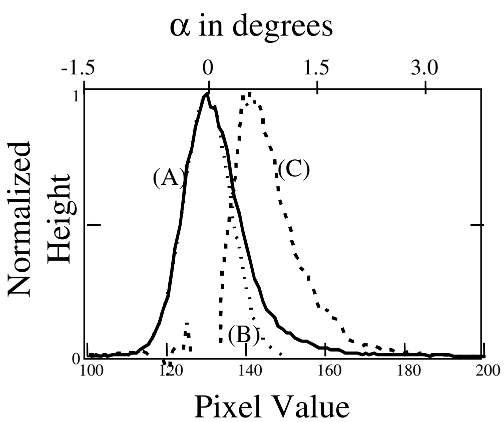


Figure 7. Histogram Analysis of Figure 5(B) shown in solid line (A). Dotted line (B) is the left side of (A) folded over to the right side to show the non-uniform shape of the histogram. Line (C) is the difference normalized to a peak value of 1.0.

Conclusion

By adjusting the gradient illumination, it is possible to measure variations in gloss reflection of a sample in a way that shows more than just the presence or absence of gloss. The topographic angle distribution of the surface under analysis can be measured. The sample examined in Figure 5 is a high gloss, very smooth substrate used for high quality ink jet imaging. Analysis under raking angle illumination is a common technique for the analysis of topography,[9,10] but in this case no significant information could be extracted about the surface topography. The surface variation is just too small to measure by raking illumination. However, by selecting an appropriate range of illumination brightness for the illuminator, surface topography was easily observed in specular light. Moreover, by additional analysis of the nature of the polarization of the gloss light, it may be possible to extract information about the index of refraction of the material and, perhaps, the variation in the index of the material. These experiments are currently underway to further develop instruments for the analysis of gloss variations in printed materials.

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Biography

Jonathan Arney is an associate professor at the Center for Imaging Science at Rochester Institute of Technology. He received his BS degree from Wake Forest College, and Ph.D. in chemistry from the University of North Carolina. He joined the research staff of Mead Corporation in 1981, and RIT in 1991. Dr. Arney Jonathan received the IS&T Journal Award (Science) in 1990, and the Raymond C. Bowman Award in 1996 for contributions to education in the field of Photographic and Imaging Science.