

An Inexpensive Micro-Goniophotometry You Can Build

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Abstract

This paper describes the design and use of a micro-goniophotometer. The instrument, configured with a CCD video camera and microscope optics, is meant to resolve goniophotometric measurements to microscopic dimensions for the study of the interactions between ink and paper in a variety of non-impact printing applications. Data for ink jet systems is used to illustrate the use of the instrument.

Introduction

Mechanics Illustrated is a well known technical journal for the lay audience and attracted many young minds to pursue science or engineering as a life long profession. One of the characteristics of Mechanics Illustrated which excited many of us aspiring scientists was the title format "An Inexpensive — You Can Build", and many were the dedicated week ends spend in a basement "laboratory" trying to duplicate the projects described in these articles. "Inexpensive" and "You Can Build" are not commonly found in professional science and engineering anymore. We hope this articles might be a useful exception.

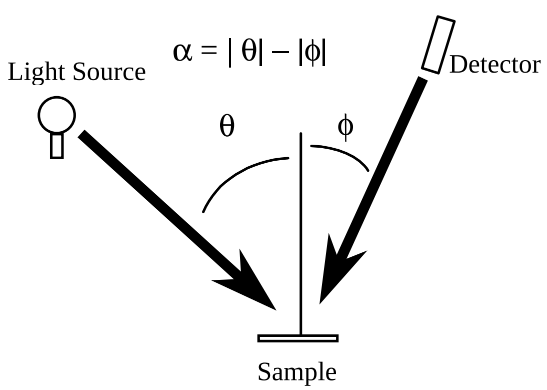

Figure 1. Typical configuration for a goniophotometer.

A goniophotometer is an instrument which measures the light reflected from a material as a function of the angles of illumination, θ, and detection, ϕ, as illustrated in Figure 1. When the two angles are equal and opposite $\theta = -\phi$, then "gloss" is measured, and a goniophotometer is particularly useful for measuring the angular width of the gloss reflection from the surface of a material.[1] So, a goniophotometer resolves reflection to small angles. A different reflection instrument, called a microdensitometer, can measure light reflected from a material resolved to small fractions of a millimeter and is useful for measuring, for example, image resolution and granularity. The device described below was designed to resolve both angular goniophotometry and spatial microdensitometry, but to do so at a minimum instrumental cost.

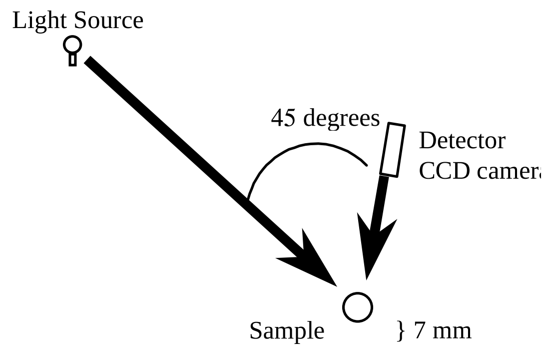

Figure 2. Configuration for the micro-goniophotometer.

The Instrument

Typical goniophotometers configured as illustrated in Figure 1 are very large instruments which accurately control the angular position of the light source and the light detector used to measure reflectance. However, in the current instrument both the light source and the light detector were mounted in fixed positions as illustrated in Figure 2. Many different light sources were found to function well in this instrument. The CCD camera used as the detector was focused on a 3 mm wide portion of the surface of the sample, and the sample was wrapped around a cylinder of 7 mm diameter. The result was an image of the surface of the cylindrical sample, as illustrated in Figure 3, which clearly revealed a sharp band at the position on the sample surface corresponding the equal and opposite angles of illumination and detection. Knowing the dimensions of the image and the geometry of a circle, the lateral position of each pixel in the image could be related by geometric calculation to the difference angle, $\alpha = \theta + \phi$. The value of α varies with position across the image, and gloss is observed at the Snell's Law angle of $\alpha = 0$, or $\theta = -\phi$. Thus by performing a lateral scan of the image in software, a goniophotometric curve of surface radiance (relative units) versus α is generated, as illustrated for a coated and a non-coated paper illustrated in Figure 4. The output of the camera was linear in surface radiance because the CCD camera used in the instrument provided a linear video signal versus irradiance at the image plain of the camera, and the surface of the paper sample is focused on the film plane through a lens.

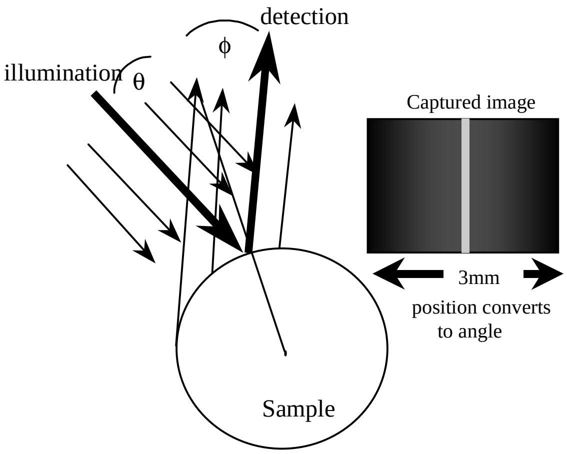

Figure 3. Detail of the cylindrical sample illustrating the relationship between lateral position in the captured image and the goniophotometric angle.

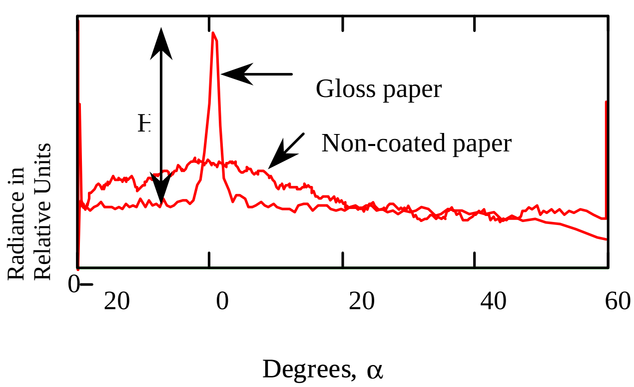

Figure 4. Typical goniophotometric scans from the instrument in Figure 3 for a plain paper and a gloss coated paper.

Calibration of the Instrument

The angular calibration of the instrument was achieved by geometric calculation. The camera lens was positioned 150mm from the film plane of the camera with extension tubes, and the working distance between the lens and the sample surface was 58 mm. With a sample size of 7 mm diameter 58 mm from the lens, the angle subtended by the sample was approximately arctan(7 / 58) = 6.9 degrees. This was distributed over the angular range of the circular sample ranging from +90 degrees to the camera to -90 degrees to the camera. The position of the Snell's Law angle ($\alpha = 0$) was located by noting the position of the gloss peak in a gloss sample or, when measuring a diffuse sample with no clearly defined gloss peak, by the gloss peak in a separate reference sample. The angular resolution of the instrument was determined by the magnification of the lens and the sampling interval from the video frame grab process. In the current instrument, with a field of view of 3 mm, the data was resolved at 0.5 degrees per sample interval at $\alpha = 0$.

Radiometric calibration involved the measurement of a set of coated and non-coated paper samples which varied in gloss from near zero to near 80 percent, as measured by a HunterLab-48 gloss meter set to measure standard "20 degree gloss" units. The 20 degree gloss was selected as most relevant to the current instrument since the gloss peak at $\alpha = 0$ corresponded to a 45 / 2 = 22.5 degree gloss angle. Figure 5 shows the correlation between the height of the gloss peak (H in Figure 4, expressed in arbitrary units) and the measured 20 degree gloss of the sample. The peak height in subsequent measurements were expressed in 20 degree gloss units using the least squares correlation line from this data. Also, the flat background in the goniophotometric curves correlated well with independent measurements of 45/0, diffuse reflectance ("visual density" measurements) of the paper samples.

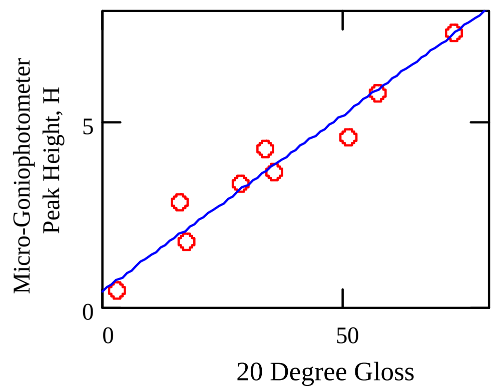

Figure 5. Correlation between the height of the gloss peak and independently measured values for 20 degree gloss.

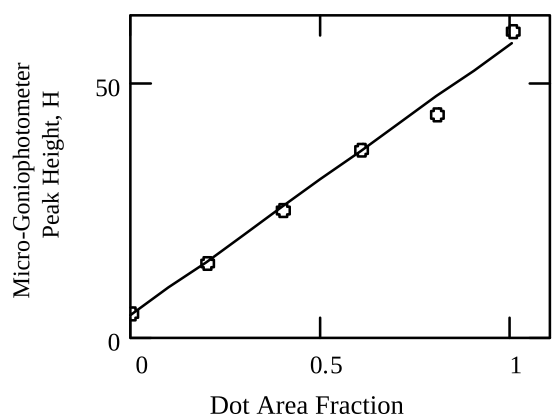

Figure 6. Gloss as a function of dot area fraction for a halftone image made by a phase change ink jet system.

Gloss and Microstructure

A halftone gray scale was printed with a Tektronics phase change ink jet system. The halftones were traditional clustered dot, AM halftones at 60 "LPI" (dots per inch). The halftone dots were clearly glossy relative to the non-coated paper on which they were printed. The average gloss of the sample was measured as the average peak height in the micro-goniophotometer. In this case, the gloss band covered several dots and spaces between dots to give an average gloss for the sample. This was confirmed and correlated with the 20 degree standard gloss measurements. The data, as illustrated in Figure 6, varied linearly with the halftone dot area fraction, showing the "Murray-Davies" relationship can apply to gloss reflectance as it does to diffuse reflectance in a halftone image.[2]

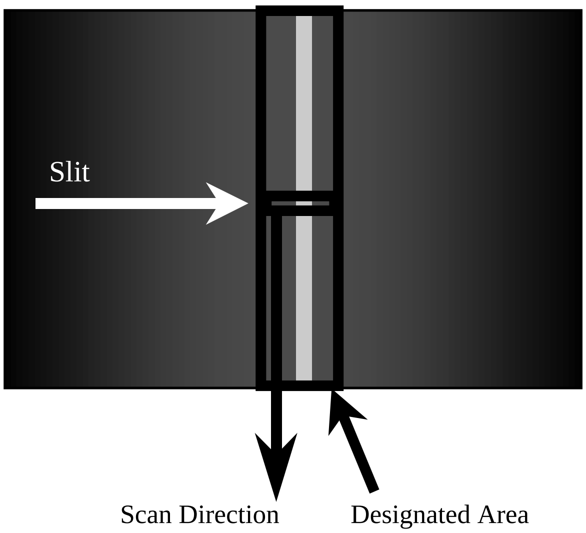

Figure 7. Illustration of spatial scan across the gloss band in the micro-goniophotometer.

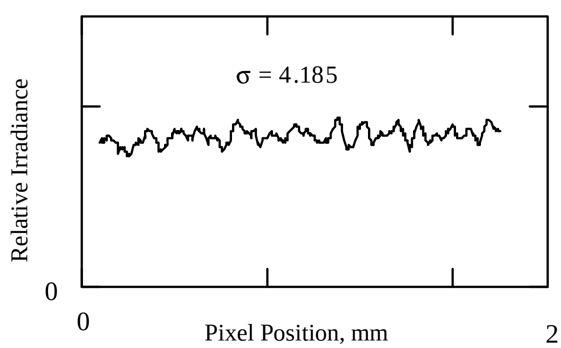

Figure 8. Example of gloss "RMS granularity" from a spatial scan illustrated in Figure 7.

Gloss "RMS granularity" also can be measured, as illustrated in Figures 7. A slit is defined and scanned in the vertical, or spatial, direction of the goniophotometric image. Figure 8 shows the result for an AM halftone image at 60 dpi printed by a thermal ink jet engine at 300 dpi addressability. The regular structure of the granularity clearly shows the difference in gloss between the substrate and the ink. Figures 9 and 10 show the measured gloss and granularity as functions of the dot area fraction, F. The gloss again follows the expected linear relationship between substrate and ink gloss, but granularity increased continuously with F. At F = 1 the granularity was found to be much more random, indicating two sources for the measured value of the RMS granularity, σ. One is from the systematic variation between ink and substrate gloss, which would be expected to peak near F = 0.5. The other is a random gloss variation due to random variations in film formation on the surface of the ink.

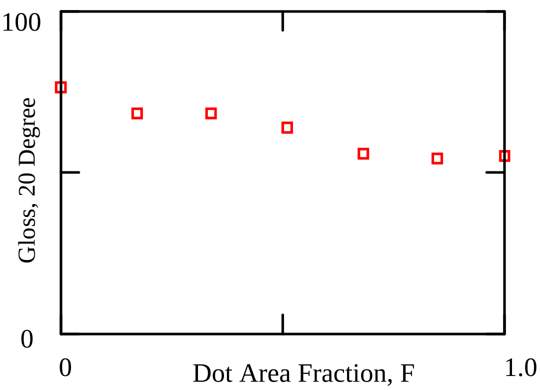

Figure 9. Gloss versus dot area fraction for a clustered dot halftone printed by thermal ink jet with black ink.

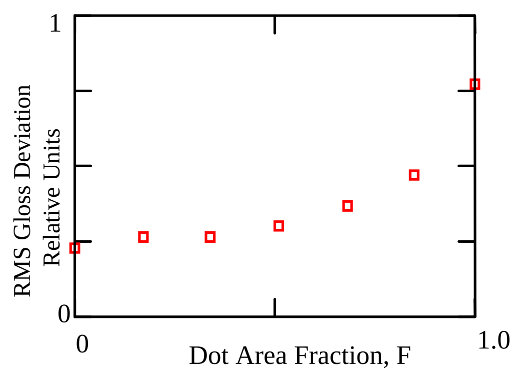

Figure 10. Gloss RMS noise versus dot area fraction for the ink jet samples of Figure 9.

Another micro-gloss characteristic which one can measure is "Distinctness of Gloss", or DOG. This metric was defined in terms of this particular instrument by placing three light sources, instead of one, in the instrument such that the corresponding three gloss bands were 5.0 degrees apart. This was chosen as a distinctness measure because it was very analogous to a tri-bar resolution measurement in traditional microdensitometry, and thus well understood by the authors, and because it was expected to correlate with traditional "distinctness of image gloss" discussed in texts on gloss.[1] Figure 11 shows a typical curve for the tri-bar goniophotometric experiment. The DOG metric is defined in the figure 11, and Figure 12 shows the variation in DOG with dot area fraction for the same printed samples as described in Figures 9 and 10. The decline in distinctness as F increases correlates with the increase in RMS granularity, which is consistent with increased spatial noise in ink film formation.

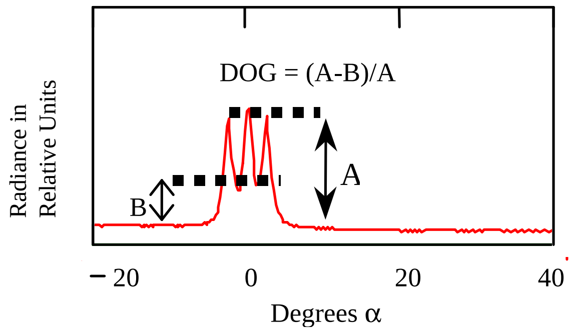

Figure 11. Gloss tri-bar pattern for measurement of the distinctness of gloss.

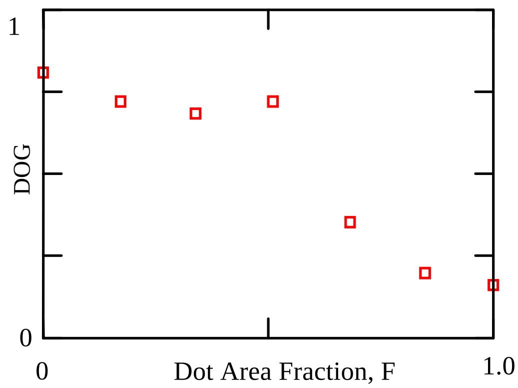

Figure 12. Distinctness of gloss versus dot area fraction for the ink jet samples of Figure 9.

Conclusion

The micro-goniophotometer described in this work clearly does not provide the angular resolution of state of the art goniophotometers or the spatial resolution of state of the art microdensitometers. However, the experimental trade-offs between angular an spatial resolution were chosen to provide useful information in a study of gloss characteristics of non-impact printing technologies. This work is on-going, and the authors are finding significant insights into image formation through the analysis of micro-goniophotometry using this simple instrument. Hardware details and software details have not been provided in this manuscript since any video capture and analysis package, coupled with any CCD video camera and microscope optics would be capable of providing the analysis described above.

Acknowledgment

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References

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2. J.S. Arney, P.G. Engeldrum, and H. Zeng, *J. Imag. Sci. & Tech*, **39**, 502 (1995).