A New Method of Measuring Gloss Mottle and Micro-Gloss Using A Line-Scan CCD-Camera Based Imaging System

Yair Kipman, Prashant Mehta, Kate Johnson and Dave Wolin
ImageXpert, Inc.
Nashua, New Hampshire, USA

Abstract

Solid area quality is one of the fundamental attributes that contributes to the perception of overall image quality. Area coverage, darkness (such as density, intensity, L*), gloss, and solid area mottle are all aspects of solid area quality that are routinely quantified.

For example, measurement of overall gloss is quite common using commercially available glossmeters. And in recent years, many methods of quantifying solid area mottle have been developed and presented to the industry.

One critical aspect of solid area quality, referred to as gloss mottle, has not been addressed as widely. Gloss mottle is the appearance of variations in the magnitude of gloss across a surface. It can be comprised of both high and low frequency components and is inherently difficult to characterize.

In this paper, a new method for measuring gloss mottle will be proposed. A CCD-camera based system will be described and results will be presented that apply to both solid area gloss mottle and the gloss mottle of coatings that impact the quality of materials such as linerboard.

Introduction

There are many factors affecting the perception of image quality in digital hardcopy output. One that seems to influence the overall acceptance of the final product is gloss mottle. While it is now standard practice to measure the actual gloss value (the specular reflectance at a specified angle) for both unprinted media as well as for nominally solid areas, such characterization is not sufficient. Although a value for the overall gloss is a necessary component in quantitative assessment, it does not provide information regarding the uniformity of this attribute nor does it provide an indication of the resultant appearance.

The human eye is sensitive to variations in a nominally uniform image as well as to the actual absolute value of the shininess (characterized by gloss). Therefore, in order to provide quantitative image quality analysis that can be correlated to subjective preference, the macroscopic (and possibly the microscopic) nonuniformity of this quality must be measured.

While the development of an appropriate hardware setup and gloss mottle measurement method are certainly important, it is also desirable and often required to perform testing in a fast, automatic mode to accommodate production cycle-times. This must be taken into account during system design and implementation. To this end, a measurement system has been developed which images a relatively large area of a target using a line-scan camera. The image is analyzed immediately with a software application that provides quantitative uniformity data that can be tailored to report results at any spatial frequency. This allows the user to apply a weighting function to mimic the response of the human visual system.

Background

Measurement of absolute specular gloss is made with the light source and the detector at equal angles on opposite sides of the normal to the target surface. The angle at which gloss is measured most often varies between 20° and 85°, depending on the reflectance of the surface being tested and the specific application. Glossmeters measure the reflectance relative to a perfect reference reflector, namely a plane metal mirror, integrated over an area defined by the size of the detector aperture.

Given this measurement method, there are limits to how it might be applied to measure gloss uniformity. In order to achieve some measure of the uniformity of this directional reflectance, the glossmeter must be stepped across the sample such that gloss is measured at various locations. The results can be from contiguous locations, or they can be more statistical, depending on the pattern of measurement. In addition, the resolution or minimum spatial frequency is unchangeable and defined by the aperture, which is set by the instrument design implemented by the manufacturer.

Technical Approach

A novel approach to measuring gloss mottle is to use a linear collimated light source and a line-scan camera. Both the source and the detector are mounted at the specific required angle, and the hardware has been designed to accommodate multiple predetermined angles. A diagram of the hardware set-up is shown in Figure 1.

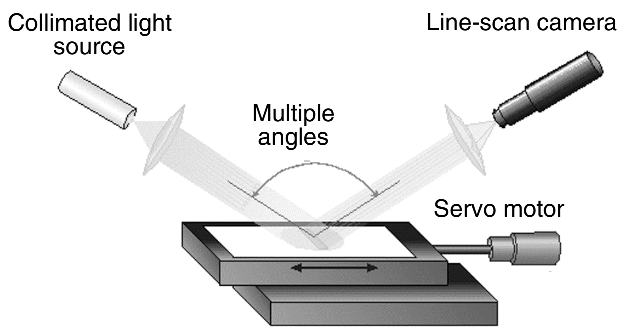

Figure 1. Hardware set-up

The use of a linear source was chosen since it provides more uniform illumination over the field of view than other illumination configurations. Illumination collimation guarantees the integrity of the incident angle. Further customization can be achieved since the illumination source can be limited spectrally by the introduction of a filter.

The line-scan camera enables a large area of the target to be scanned very quickly into a single image buffer. The linear CCD array eliminates the problem of sufficient depth of field when imaging at an angle other than perpendicular to the working surface. Any remaining concerns are eliminated through the use of a telecentric lens, which compensates for the small variation in depth of field due to the lateral extent of the pixels in object space. System dynamic range can be adjusted by changing the F-stop of the lens, the scan speed or the integration time of the camera.

Samples are secured by using a vacuum chuck on top of a single axis motion stage. If larger targets or more area on a standard target need to be characterized, a second orthogonal axis may be used, and images stitched together prior to analysis. If a large volume of similar targets needs to be tested, an automatic document feeder can be integrated, and OCR or barcode labels can be read to automatically label or annotate data files by the printed sample identification.

The analysis software uses algorithms that quantify the intensity non-uniformity of the image based on user-definable filters for spatial distribution and contrast.

Image Capture Results

Ordinarily, images captured for image analysis are carefully free of specular reflections. For this study, a different geometry was used to isolate and image the spectral reflectance thereby changing the appearance of the captured images. Figure 2a shows an image of a printed black solid captured using a 45/0 geometry (illumination at 45 degrees, sensor positioned normal to sample surface).

Figure 2b shows the same patch on the same sample imaged with 60/60 geometry.

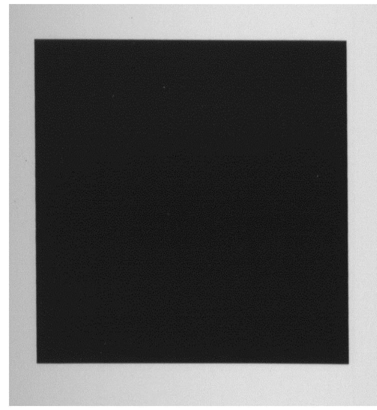

Figure 2a. Image of target at 45/0

Figure 2b. Image of target illuminated and imaged at 60 degrees

Obviously, the image contrast is drastically different, with the lightest areas being those with the highest gloss at this geometry. The realization of the dependence of image contrast on gloss mottle differences is the core of this measurement method.

Measurement Methodologies

There are several gloss mottle measurement methods that have been implemented as part of this development effort.

Tiled Cell Method

This gloss mottle measurement method is modeled after the ISO/IEC 13660 solid area mottle measurement. This method applies a cell of a specific size (such as 2mm × 2mm) and tiles it over the area to be measured. The gray average at each location is measured and the standard deviation of the averages is reported as the gloss mottle index for that specific cell size. A diagram of this method is shown in figure 3.

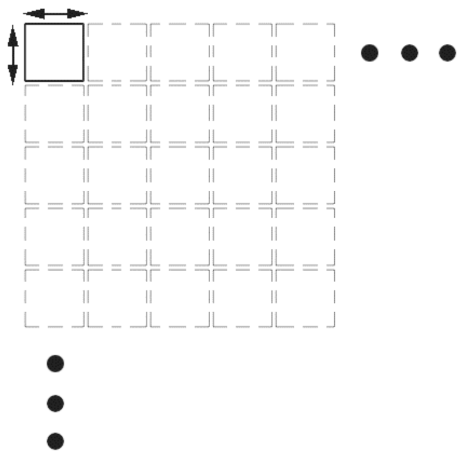

Figure 3. Tiled cell method

Changing to different cell sizes returns information about different spatial components. For example, for higher "frequency" components, smaller cell sizes could be used. Although this does provide an initial comparative measurement, this method does have significant limitations. For example, imagine the "worst case" gloss mottle scenario where the gloss differences across the sample are well defined and periodic. The specular image of such a sample could look like the image shown in figure 4, with the "dark" areas indicating areas of low gloss at the particular measurement angle, and the "light" areas indicating areas of higher gloss.

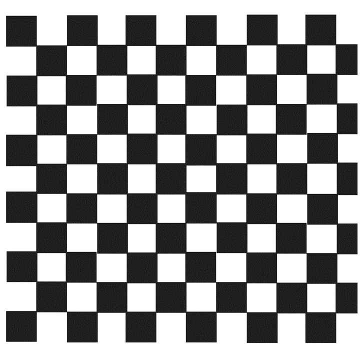

Figure 4. "Worst case" gloss mottle

If the tiling method were applied to this image, there are many combinations of sizes and placement that could return errant values. For example, if the cells overlapped the checkerboard such that each cell included some equivalent portion of light and dark areas, the gray average in each cell might return a similar value. This would result in a standard deviation of the average cell value (the gloss mottle index) that would be quite small in spite of the fact that the apparent gloss mottle might be quite severe.

Gloss Mottle Bins

This measurement method is derived from previous work the authors developed for solid area mottle analysis. The basis of this method is the widely accepted notion that mottle that has larger and higher contrast components is considered to be more objectionable than mottle that is comprised of smaller areas of lower contrast. Of course, the human visual response function responds to both size (via spatial frequency) and contrast. In this case, the "mottle" we are quantifying is gloss mottle.

In this approach, gloss mottle analysis is based on "clusters". Clusters are defined as contiguous regions of pixels that fit certain pre-defined criteria in terms of both size (effective diameter) and relative contrast. Different size and contrast bins are constructed to examine both the spatial content of the gloss mottle and the contrast. A typical set-up uses a series of different size bins (0.5-1 mm effective diameter, 1-2 mm effective diameter, 2-4 mm effective diameter …). Contrast limits are usually defined according to the range of samples. For gloss mottle quantification, only light clusters were included in the analysis. Typically, test set-up would include bins that identify clusters of specific sizes that are at least 1 gray level lighter than the average gray level within the region of interest (ROI), 2 gray levels lighter than the average, and 4 gray levels lighter than the average.

Once clusters of specific sizes and contrasts are counted, a weighted sum can provide a single number for first order comparative analysis. Generally, the weighted sum is constructed to apply higher weights to larger sizes and higher contrasts. (Please note that this weighted average could be modified quite easily to better reflect the non-monotonic nature of the human visual response to spatial information). However, in addition to reporting this one comparative number, maintaining the individual bin data allows the user to trace mottle back to its component parts and potentially aid in separation of variables to support root cause analysis.

Measurement Results

To exercise the system for the purposes of this study, several samples of various substrates were measured for absolute gloss using a glossmeter at 60 degrees. Then the samples were evaluated using the newly developed system with 60/60 geometry. The images were analyzed using several of the available measurement methods. A 2mm × 2mm cell was tiled in a 16 × 16 matrix. The gray average and standard deviation of each cell were measured. Figure 5 shows the results from the absolute gloss measurement and two statistical measurements: the standard deviation of the averages of each cell (this is the method that is similar to ISO/IEC 13660 solid area mottle) and the average of the standard deviations of all of the cells.

	Gloss 60 deg	StDev of Averages	Avg of StDevs
Sample 1	19.1	2.278	4.157
Sample 2	19.9	5.508	4.705
Sample 6	98	12.442	20.968
Sample 9	101	5.826	22.669
Sample 11	125.3	7.131	9.742

Figure 5. Table of results from tiled cell method

The standard deviation of the averages gives an indication of the "uniformity" of the gloss mottle at the specific sampling rate (2 mm × 2mm). A uniform distribution of gloss mottle at this spacing or some even divisor of this spacing would result in similar values, which would translate into a low standard deviation of averages. On the other hand, the average of the standard deviations indicates the overall variation of the measured area. For these samples, the two metrics track well with each other for all of the trial samples except for sample 9. This indicates that the variation in the gloss mottle in sample 9 is averaged out at 2mm × 2mm, yet it persists in the standard deviation measurement. However, no spatial distribution information is preserved.

This issue is addressed by the second measurement method, gloss mottle bins, showed a similar trend in results. The following graph Figure 6) shows the cluster counts of each bin size for each sample.

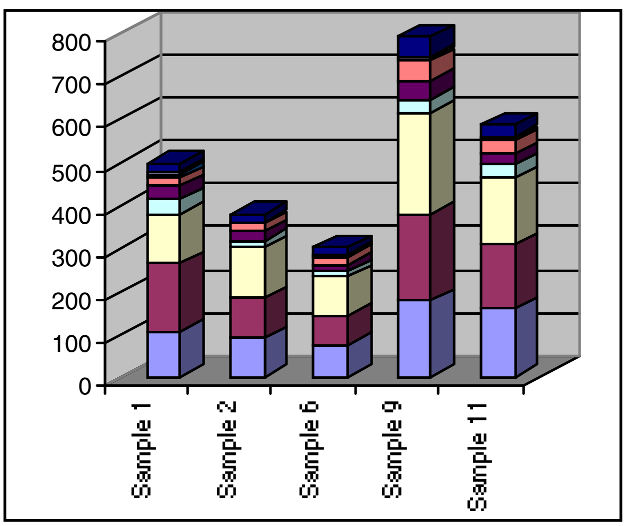

Figure 6. Cluster counts from gloss mottle bins method

Sample 9 showed the highest overall cluster count indicating the highest amount of gloss mottle at the sizes evaluated. The smallest sizes are at the bottom of each stack and the bottom three stacks are the counts for the .5mm to 1mm effective diameter range. This component was averaged out of the tiled cell results, but is preserved in this method.

Figure 7 shows the weighted sum results, which gives higher weights to larger and higher contrast clusters than smaller, low contrast clusters. Again, the results are consistent: sample 9 has the highest weighted sum indicating the highest overall gloss mottle level.

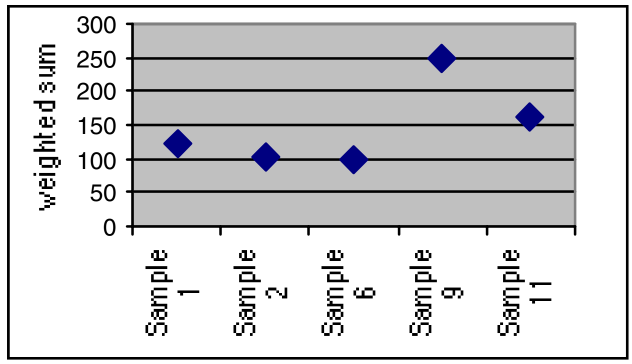

Figure 7. Weighted sum

Conclusion

The initial studies show that this combination of line-scan camera technology and flexible image analysis software is quite promising for the objective analysis and quantification of gloss mottle. Future studies will include the application of a 2-D FFT as an alternative measurement methodology. In addition, metrics will be assessed for correlation to visual assessments. System development will expand to fulfill the requirements of a wider range of sample types.

Biography

Mr. Kipman is the founder and president of ImageXpert Inc., the industry leader in automated image quality inspection systems. Mr. Kipman founded ImageXpert in 1989.

Over the past decade, Mr. Kipman has guided the company to the forefront of the image quality industry. ImageXpert now offers a diversified product line that addresses the needs of a wide range of markets including image quality and related fields. Mr. Kipman holds a M.S. in mechanical engineering, with a major in electro-optics from the University of Connecticut and a B.S. from the Technion Institute of Technology.