Measurement of Differential Gloss Using a μ-Goniophotometer

Susan Farnand and David Nilosek; Rochester Institute of Technology, Rochester, NY

Abstract

Differential gloss is the term used in print media to describe the condition where areas of a printed image, especially adjacent areas, appear to reflect light in different ways giving these areas varying gloss appearance. This phenomenon is quite common in dry toner electrophotographic imaging and some ink jet imaging technologies where the first surface reflection properties of the toner or ink and the substrate can be markedly different. Also, high density areas composed of multiple layers of toner can have substantially different specular reflection properties than low density areas composed of a sparse layer of toner through which areas of substrate remain visible. Differential gloss, while well known, is difficult to quantify in a meaningful way. Recently, a pilot experiment was conducted that indicated that it may be possible to quantify gloss artifacts using a device called a μ-goniophotometer. This device, previously described in detail in the literature, measures specular reflection at all angles, not just the one equal and opposite angle to the light source as is done with a traditional glossmeter.[1,2,3] *This device creates a curve or Bi-directional Reflectance Distribution Function (BRDF) for the sample measured. Because it also generates a series of these curves along the length of the sample, a quantification of the variability of the measured specular light, σ, is available. It was this variability that was found to relate to the degree of gloss artifact detected by observers, on average, in flat field images. And it is this variability that was posited to serve as a function of the degree of differential gloss apparent in an image. In the first steps toward testing this theory, experimentation was conducted involving the measurement of patches. The patches were created in conjunction with a differential gloss scaling experiment conducted by the W1.1 Committee on Perceptual Measurement of Gloss. Prints of three scenes were made on equipment exhibiting a range of differential gloss behavior. The prints were visually scaled by observers in several locations across the United States. To make comparative objective measurements, prints of the W1.1 Perceptual Gloss Measurement Committee's patch target were also made. An evaluation of the measured data generated using both a traditional glossmeter as well as the μ-goniophotometer relative to the visual data will be described.*

Introduction

Differential gloss is a phenomenon where different areas of the same image reflect light differently, leading to an uneven appearance of gloss across the image. This can produce effects in complex images where detail has almost the appearance of an oil painting and certain large uniform areas may be highly reflective while adjoining areas may not be. These effects can be pleasing or disturbing, depending on the image, the application, and the observer. Being able to measure these effects would be useful in the development of printers and printer products such as inks, toners, and substrates. Depending on the application, differential gloss may be something to avoid or accentuate. In either case, having an understanding of the parameters which lead to differential gloss is important. Being able to reliably measure the phenomenon of differential gloss is a key tool for accomplishing this. Currently, gloss is measured almost exclusively with a glossmeter. This device has a relatively large sampling area that is not capable of capturing the fine detail in the gloss on a printed surface. Experimentation was conducted to begin to look at the possibility of measuring differential gloss using an instrument developed at the Rochester Institute of Technology called a μ-goniophotometer.

Background

For much of this decade, a team has been in place with the charter to develop perceptual image quality metrics for the appearance of gloss. The INCITS W1.1 Image Quality for Printer Systems *ad hoc* committee was established by W1, the Office Equipment subcommittee of INCITS which is the ANSI Technical Advisory Group for ISO/IEC Joint Technical Committee 1, which is responsible for the standardization of the arena of Information Technology[4]. One of the tasks undertaken by this committee is to develop an image quality scale for the visual attribute of differential gloss. As reported at EI IQSP, two approaches were undertaken to do this; the Image Quality Ruler method based on ***ISO 20462-3*** and Interval Scaling with two anchor stimuli. The visual results in each case are compared to measured results made using a traditional glossmeter. This instrument functions by measuring the light reflected off a sample at an angle equal to an opposite of the angle of the light source. Another approach to measuring gloss is to measure the first surface light being reflected at all angles, not just the one equal to and opposite of the angle of the light source. This can be accomplished by changing the angle of the light source, the detector, or the sample. This latter approach was adopted in the development of the μ-goniophotometer at the Rochester Institute of Technology.

The general set up of the RIT μ-goniophotometer is illustrated in Figure 1.[5] Further details of the instrument can be found in previously published reports.[1,2,3] Basically, the printed sample is wrapped around a cylinder and illuminated with a line light source that is collinear with the cylinder. The light source is sufficiently long and sufficiently far from the cylinder to approximate an infinitely long source at infinity. The light from the source is linearly polarized. A second polarizer is placed between the cylinder and the camera lens. An electronic camera having a long working distance so that parallax across the width of the sample can be disregarded captures two images of the sample, one with parallel and one with crossed polarizers. These images are subtracted from one another to produce a difference image that contains only that light which maintains polarization when it is reflected from the sample. The bulk scattered light, which is randomly polarized, is eliminated from the measurement.

An illustration of a captured image is shown in Figure 2.[6] A horizontal scan of this image produces a bidirectional reflectance distribution function or BRDF. A scan is also made in the vertical direction along the peak of the specular band, at $\alpha = 0$, where α is the mean surface angle of the sample. The variation in this peak value is recorded as the standard deviation of the maximum specular reflection. This value, along with other features of the BRDF such as the height, area, and width, may be considered for use in the measurement print surface properties including the appearance of gloss.

Experimentation

The W1.1 gloss committee designed experimentation to develop a scale of the appearance of differential gloss. The experimentation was composed of two tests; an anchored scaling test to establish an interval scale and a test using the ISO 20462-3 quality ruler to translate that scale into Just Noticeable Differences or JNDs. Researchers at the Rochester Institute of Technology participated in both elements of this experimentation. The first test was visual scaling of differential gloss level relative to two anchor stimuli. The test involved nine different substrate and printing technology combinations including inkjet with pigment and dye inks on various substrates and dry and liquid electrophotography on various substrates and under various fusing conditions. Three scenes, Figure 3, for each of the selected nine combinations were used, yielding 27 test samples. In testing that took place at two Hewlett Packard facilities and Kodak as well as RIT, observers were asked to rate each of the 27 test samples relative to two anchors, one having a relatively low level of differential gloss and one having a relatively high level of differential gloss. The low level was arbitrarily assigned a value of 25 and the high level a value of 80. A scene depicted tailoring supplies was selected for the anchor prints. The experiment was conducted under simulated D50 lighting conditions. At RIT; the test was conducted twice, once in a light booth with diffuse, simulated D50 lighting and once with a direct, simulated D50 light bulb.

In the second segment of the experimentation, observers were asked to rate each of the 27 samples relative to the ISO 20462 quality rulers. The test scenes were matched with the quality ruler scenes as shown in Figure 3; the test picnic scene was rated against the ISO 29462 Picnic ruler, the Paint Girl scene was matched against the Birthday ruler and the Dresser-top scene was matched against the ISO 20462 Downtown ruler. The ISO 20462 rulers vary in sharpness, so the observers were required to rate sample prints against image rulers having both different scenes and a different artifact.

The 40-patch ISO/IEC 19799 differential gloss test chart, Figure 4, was printed using each of the printing combinations used in the visual scaling experimentation. These patch targets were used to quantify the gloss range and the magnitude of gloss uniformity for each of the printing combinations. 20 and 60 degree gloss of each of the patches on each of the nine targets was measured. Five of the printing combinations were also selected for measurement using the RIT μ-goniophotometer. These included the glossiest patch, the least glossy patch (as measured using the glossmeter), as well as a black patch and the paper white patch.

Results and Discussion

The results of the RIT differential gloss scaling experiment are shown in Figure 5 relative to the results from two other sites. These results indicate that the RIT test results correlate well with the results obtained at the other experimental sites. Though there are a few prints in the region of the scaled data that falls about half way between the two anchors, about 45-60, that do not correlate well between Site 2 and the other sites, in general the results are quite respectable, especially for psychophysical experimentation. And it is reasonable that the test prints that are viewed as furthest from either anchor print would have the noisy results. The fact that the results from the different sites correlate well with one another suggests that observers are generally capable of reliably scaling differential gloss level. The results of the RIT experiment conducted under diffuse and directional lighting conditions are shown in Figure 6. These results show that the observers' performance in this anchored scaling test did not change markedly due to the change in lighting conditions. This was somewhat unexpected since the appearance of gloss is angle dependent. However, the observers were allowed to handle the samples, which allowed them to tilt the samples to an angle at which the gloss was most apparent. While some observers commented that it was easier to scale the differential gloss under the direct lighting conditions, the end results did not change significantly due to the lighting conditions.

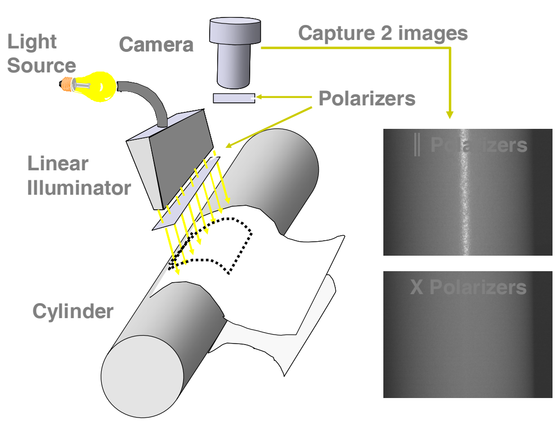

Figure 1. *The basic structure of the RIT μ-goniophotometer.*[5]

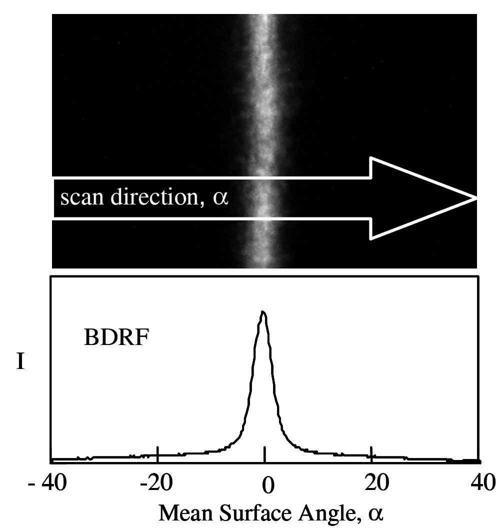

Figure 2. *Illustration of an image and a BRDF from the μ-goniophotometer*[6].

Figure 3: *The top row shows the three scenes from the differential gloss visual scaling experiment. The bottom row shows the ISO 20462-3 quality ruler scenes that were used for each of the differential gloss scenes.*

Figure 4. *The ISO/IEC 19799 Differential Gloss Test Chart*

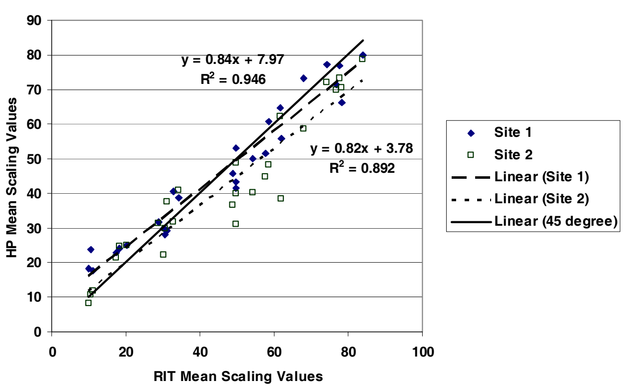

Figure 5. *Mean scaling data from two other test sites relative to the RIT data. The solid line represents the one-to-one relationship between RIT scaling values and those of the other sites.*

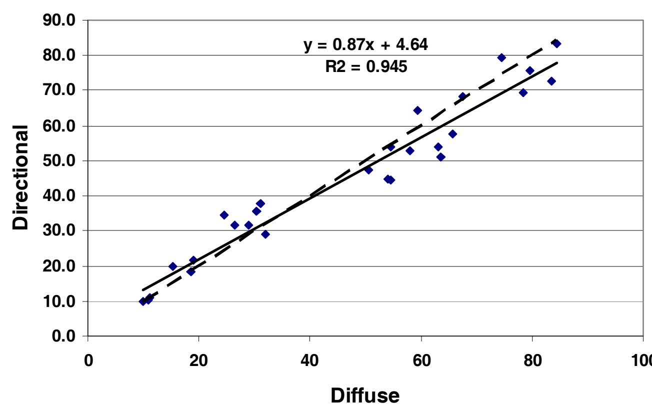

Figure 6. *The differential gloss level scaling results generated using directional versus diffuse lighting conditions. The dashed line, which represents the one-to-one relationship between directional and diffuse mean scaling values, has a reasonable fit to the data.*

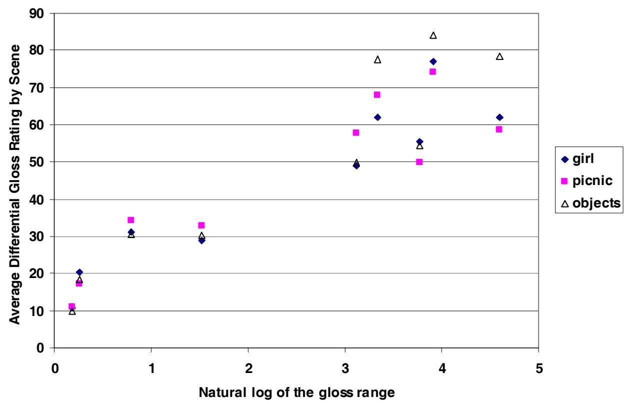

Figure 7. Mean differential gloss rating across testing sites as a function of the 20° gloss range for each of the nine printing combinations.

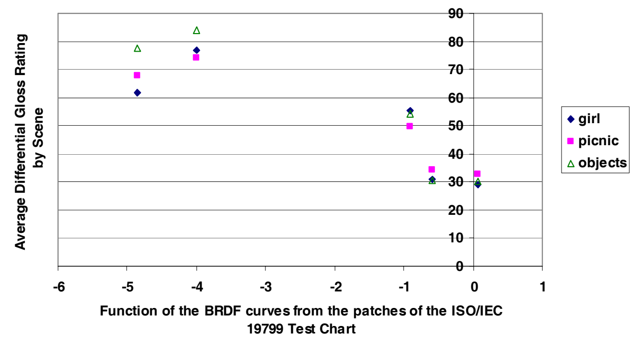

Figure 8. The mean differential gloss rating across testing sites as a function of the width of the BRDF curves for the three test scenes.

Figures 7 and 8 show the differential gloss scaling values averaged across all observers from three test sites for the three test scenes. Figure 7 shows this data as a function of the natural log of the 20° gloss range for each of the nine printing combinations calculated by finding the difference between the highest gloss value and the lowest gloss value of the patches on the ISO/IEC 19799 Gloss target. Figure 8 shows the same data plotted relative to a function of the differences of the widths and heights of the BRDF curves for each of the printing combinations. Both measurement devices provide reasonable relationships, with R^2 values of .88, .70, and .87 for the Picnic, Paint Girl, and Dresser-top Objects scenes, respectively for the μ-goniophotometric data and .82, .88, and .87 for the Picnic, Paint Girl, and Dresser-top Objects scenes, respectively for the 20° gloss range data. It may be useful to note here that the μ-goniophotometric data is based on five data points while the glossmeter data is based on all nine print combinations. If only the five print combinations used in generating the μ-goniophotometric data are considered in analyzing the glossmeter data, the R^2 values drop to .72, .84, and .75 for the Picnic, Paint Girl, and Dresser-top Objects scenes, respectively.

Differences for the three scenes are apparent in both Figures 7 and 8. Note especially in Figure 7 that, for three of the four print combinations having the highest measured gloss ranges, the Dresser-top Objects scene scales higher for differential gloss. That there are one or two printing combinations with high measured gloss range for which the Dresser-top Objects scene does not rate higher suggests that there is something about these printing combinations that handle the high frequency content in such a way that the differential gloss is less apparent. These printing combinations were not included in the μ-goniophotometer analysis. It would be very interesting to if the differential gloss relationship for these printing combinations for this high frequency scene can be teased out of features of the BRDF curves produced by the μ-goniophotometer. It should be noted that at lower measured gloss ranges, the Dresser-top Objects scene rates similar to or slightly lower in apparent differential gloss than the other two scenes, indicating that the high frequency differential gloss is less apparent at lower levels.

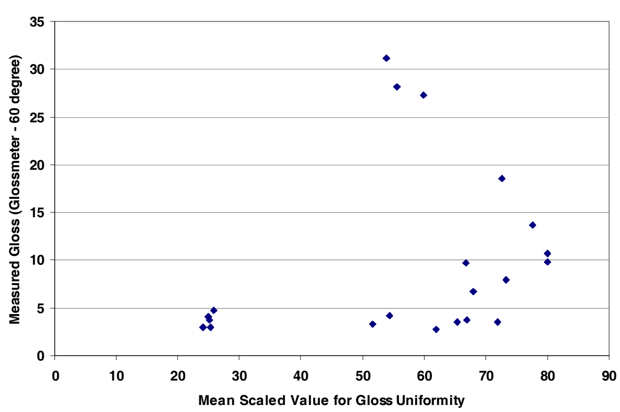

Figure 9. 60° gloss data plotted relative to the mean scaled values of gloss uniformity for black patches.

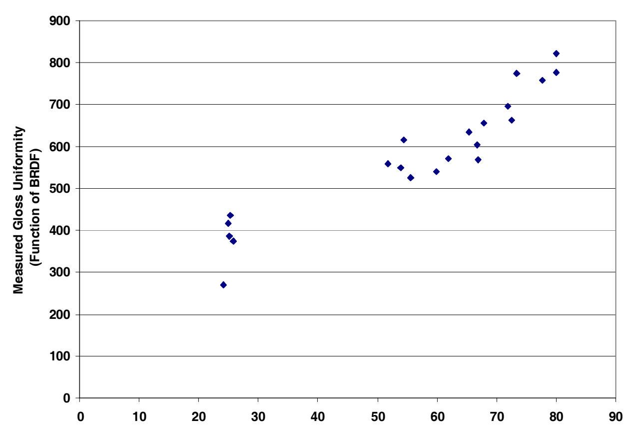

Figure 10. Gloss uniformity as measured using a μ-goniophotometer as a function of the scaled gloss uniformity for black patches.

The scene dependency suggests that the patch target will not be enough to predict differential gloss performance of ink or toner and substrate combinations. Additional information pertaining to the performance relative to spatial characteristics will be needed. This is something that it will be difficult for a simple glossmeter to provide due to the relatively large sampling area needed to make a single measurement. Fine detail is averaged out. The μ-goniophotometer however, was developed to capture fine detail. The performance difference is demonstrated to some degree by evaluating apparent gloss uniformity data relative to measured values of black patches, Figures 9 and 10. The data in these graphs was generated in an anchored scaling experiment similar to the one conducted in the differential gloss scaling test.[7] In the gloss uniformity scaling experiment however the stimuli were black, electrophotographically printed patches. It is evident in Figure 9 that the 60^o gloss value is a miserable predictor of apparent gloss uniformity, as would be expected due its relatively large sampling area. This instrument was not designed to do this. The μ-goniophotometer however was developed to evaluate this kind of detail. The data in Figure 10 suggests that the μ-goniophotometer may provide a reasonable approach to predicting apparent gloss uniformity. If this instrument can be used to evaluate gloss uniformity, it may be reasonable to use to evaluate high frequency differential gloss. To examine this, targets other than simple patch targets will be needed, something, perhaps, like a bar code targets.

Observers were also asked to rate the 27 print samples relative to the ISO 20462 Quality ruler. The RIT results were inconclusive with regard to differential gloss level because too few observers were able to scale the differential gloss level relative to the sharpness rulers. The observers could or did not separate the idea of quality from their assessments of differential gloss level. Essentially, rather than rate the differential gloss level, they rated the perceived quality of the apparent differential gloss. And the two did not correlate. There was no consistent relationship between perceived quality and the level of the differential gloss. This is not to say that none of the observers, taken individually, could produce consistent relationships between level and quality of differential gloss. Several of them had relatively high positive correlations between sharpness and differential gloss level. A few of them had high negative correlations between sharpness and differential gloss level, indicating that they preferred higher differential gloss. And some observers preferred readily apparent differential gloss to low overall gloss levels and rated the prints accordingly, despite being specifically being instructed to rate differential gloss level.

Conclusion

The differential gloss scaling experimentation indicated several things. First, that lighting conditions did not have a significant impact on the differential gloss scaling results under the experimental conditions employed. A second result was that the scaling experiment conducted at the Rochester Institute of Technology correlated well with the tests that occurred at other sites. Additionally, it was determined that a high differential gloss level can not always be assumed to indicate lower perceived image quality; for a small percentage of observers, this was not the case. The quality of the gloss appearance is affected by the gloss level as well as the differential gloss and it is difficult for some observers to separate the two. The most important result of the experimentation, however, may be that, for some print combinations, a scene dependency existed. In these cases, which involved printing combinations having high measured gloss ranges, the Dresser-top Objects scene, which contained a great deal of high frequency content, was scaled higher for apparent differential gloss than the other two scenes. Traditional glossmeters can not measure high frequency gloss characteristics, but the RIT μ-goniophotometer may have this capability as demonstrated by its ability to measure gloss uniformity. The data also suggests that pigmented inks, dye-based inks, and toners behave differently with respect to differential gloss. The μ-goniophotometer is intended to measure the specular reflection properties of materials. It is believed that protocols can be established to measure the differential gloss performance of these various print media. In the coming months, measurement of targets involving high frequency content such as bar codes will be conducted to determine if the gloss variation measure, or some other component of the BRDF feature vector, can be used to better relate to the appearance of differential gloss.

References

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Author Biography

Susan Farnand is a graduate of Cornell University and the Rochester Institute of Technology's Masters of Imaging Science program. After working for Eastman Kodak Company for many years on assignments involving electrophotography and imaging science, she joined the Rochester Institute of Technology in the position of Research Scientist in the Printer Research and Imaging Systems Modeling (PRISM) lab. In this capacity, she is involved with investigations into gloss appearance, fusing and toner interactions, and image quality. She also has also taught color science to a variety of audiences and participated with the INCITS W1.1 ad hoc team charged with developing a standard for color rendition for printing systems since its inception and is a member of IS&T.