The Effects of Color on Gloss Appearance and Measurement

Susan Farnand and Ling Ye; Rochester Institute of Technology, Rochester, NY

Abstract

Experimentation was conducted to examine the performance of two instruments in predicting the perceptual gloss levels of patches of various colors. To explore this question, the ISO/IEC 19799 Differential Gloss Test chart was printed on a variety of substrates using a variety of inks on several printers. These printing combinations spanned a significant range of apparent gloss levels. The cyan, magenta, yellow, and black patches off the test targets were measured using both a traditional glossmeter and a μ-goniophotometric device developed at the Rochester Institute of Technology. This device, previously described in detail in the literature[1-3], 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, creating a curve or Bi-directional Reflectance Distribution Function (BRDF) for the sample measured. In addition, the device generates a series of these curves along the length of the captured gloss band of the sample, allowing a measure of the variability of the specular light, σ, to be calculated. Previous psychophysical experimentation indicated that the width of the peak of the BRDF curve was found to be an excellent predictor of the appearance of gloss for black patch samples when used in conjunction with the gloss variability. Additional characteristics of this curve such as the height of the peak and the total area under the peak may be useful in relating physical measurements of specular reflection to the appearance of gloss. Possible useful relationships between these elements of the BRDF feature vector and the gloss appearance for patches of varied colors were examined using data generated by a psychophysical experiment comprising an anchored scaling technique in which the patches are visually assessed with respect to two reference patches, one having low apparent gloss and one having a high level of apparent gloss. The performance of this device relative to that of a traditional glossmeter when measuring uniform color patches was examined.

Introduction

Today glossmeters are used almost universally for measurement of apparent gloss. These devices typically measure gloss at by quantifying the light reflected off a sample at a single angle; the angle equal to and opposite of the angle of the light source. When light is reflected at angles substantially different from that equal and opposite angle, which is the case for non-uniform gloss, the performance of the traditional glossmeter begins to deteriorate. Recently, a new instrument called a μ-goniophotometer was developed at the Rochester Institute of Technology for measuring the material properties of printed images, including apparent gloss. This device works by measuring reflected light at all angles, rather than just the one equal and opposite to the light source. Initial work with this instrument has centered on uniform black patches. More recently, researchers at RIT have begun to use this device with patches of colors other than black. This experimentation was conducted to examine the performance capability of the μ-goniophotometer for measuring apparent gloss of patches created with ink or toner of a color other than black.

Background

The general set up of the Rochester Institute of Technology μ-goniophotometer is illustrated in Figure 1.[4] Further details of the instrument can be found in previously published reports.[1-3] 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.[5] 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.

Recently, anchored scaling psychophysical experimentation was conducted to explore the efficacy of the RIT μ-goniophotometer for measuring perceived gloss level and gloss uniformity. The testing was performed using black patches exhibiting non-uniform gloss that were generated using dry toner electrophotography. Although these samples did not represent a wide range of gloss level, it was of interest to understand how their significant range of uniformity might affect the appearance of gloss level. The patches were measured with the RIT μ-goniophotometer. The observers participating in the experiment were asked to scale the samples in terms of overall gloss level relative to two anchor patches arbitrarily assigned the values of 25 and 80. The results, shown in Figure 3, clearly indicate that, for this data, a function involving elements of the μ-goniophotometric feature vector provide an excellent predictor of visual gloss level. Since the initial testing suggested that the μ-goniophotometer proved promising for generating a metric for perceived gloss for uniform black patches, testing was undertaken to investigate possible relationships between the μ-goniophotometer measurements and the perception of gloss for patches of colors other than black.

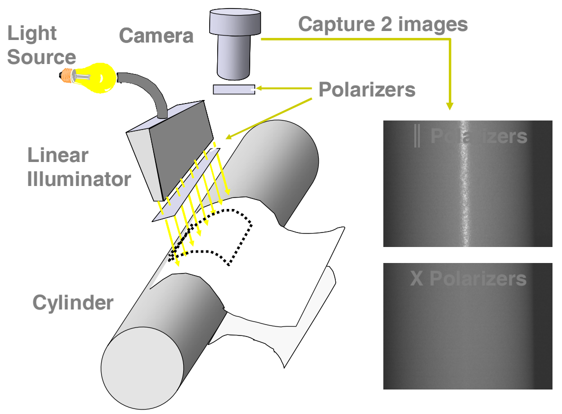

Figure 1. The basic structure of the RIT μ-goniophotometer. [4]

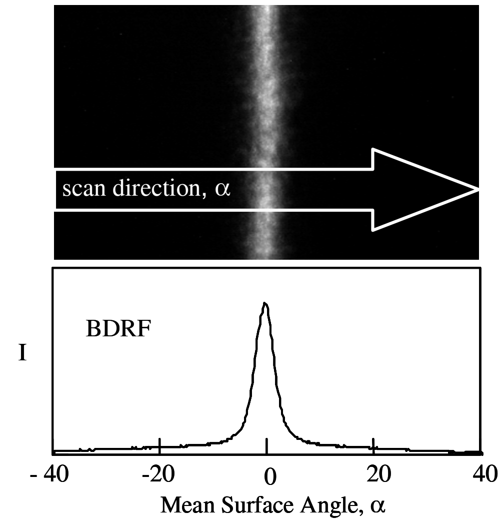

Figure 2. Illustration of an image and a BRDF from the μ-goniophotometer[5].

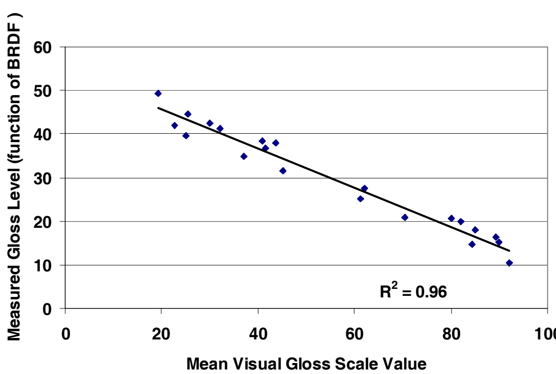

Figure 3: The measured gloss level, using the RIT μ-goniophotometer relative to the mean scaling values for visual gloss level for black patches printed using dry toner electrophotography on an array of substrates and varied fusing conditions.

Experimental

The experimentation consisted of an anchored visual scaling test to establish an interval scale of apparent gloss level. The test stimuli were patches derived from the 40-patch ISO/IEC 19799 Differential Gloss Test chart, Figure 4. This target was printed on a variety of printer equipment using a variety of substrates and inks. Seven different substrate and inkjet printing technology combinations, including pigment and dye inks on an array of substrates, exhibiting a broad range of gloss levels were chosen for the analysis. Five patches; cyan, magenta, yellow, black, and paper white, from the Test Charts were used for each of the selected seven combinations, yielding 35 test samples. Ten observers, all RIT students and personnel, were asked to rate each of the test patches relative to two anchor stimuli, one having a relatively low level of differential gloss and one having a relatively high level of differential gloss. As in the experiment involving black patches, the low level was arbitrarily assigned a value of 25 and the high level a value of 80.

The experiment was conducted in a light booth under simulated D50 lighting conditions. The observers were allowed to handle the test samples and anchor stimuli.

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

The patches used in the visual experiment were measured using a BYK Gardner micro-TRI-gloss glossmeter (20° and 60° gloss) as well as the RIT μ-goniophotometer. Because the surfaces of some of the samples used in this experimentation were somewhat brittle, a relatively large cylinder was installed on the μ-goniophotometer to prevent the sample surfaces from cracking when they were wrapped around the cylinder for measurement.

Results and Discussion

The results of the gloss scaling experiment are shown in Figures 5 and 6. These results indicate that the 20° and 60° gloss

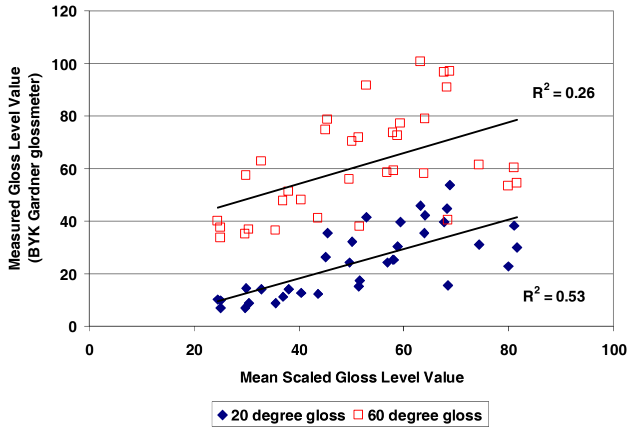

Figure 5: *The measured gloss level, using a standard glossmeter as a function of the mean scaling values for visual gloss level for a cyan, magenta, yellow, black, and white patches printed using seven different substrate and ink combinations.*

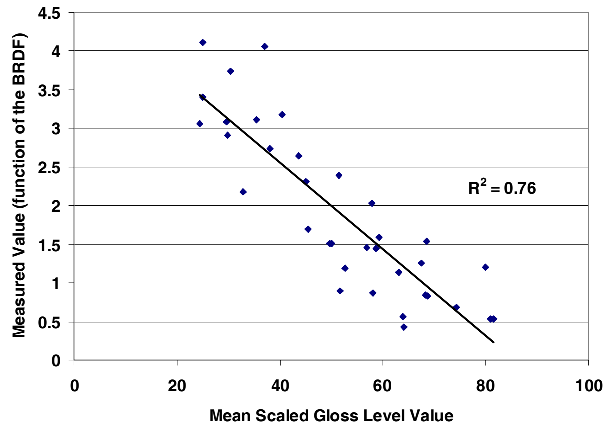

Figure 6: *The measured gloss level using the RIT μ-goniophotometer relative to the mean scaling values for visual gloss level for cyan, magenta, yellow, black, and white patches printed using seven different substrate and ink combinations.*

measurements produced by the glossmeter, Figure 5, are relatively weak predictors of visual gloss level for these samples when the samples are considered as a set. The measured values of gloss level derived from features of the BRDF curves generated by the μ-goniophotometer show improved performance in predicting the visual gloss of the sample set as a whole, as shown in Figure 6. This data represents just one function of many possible that could be derived from the elements of the generated by the μ-goniophotometer. Further investigation into other possibilities will be undertaken in the coming months.

To further understand the relationships between the measured and visual scaling values, the data was analyzed by color and printing combination. Looking first at color, the experimental data is shown in Figures 7 and 8. The data in Figure 8 suggests that the μ-goniophotometric measurements can be used to generate reasonable relationships with the visual data. Indeed, the R^2 values of the measured value versus visual gloss level relationships, second column of Table I, support this case. This data indicates that the μ-goniophotometer does the best job with the yellow and cyan patches. Its weakest performance was with predicting the visual gloss for the black patches, which seems incongruous with past studies that have indicated that the instrument predicts the apparent gloss of black patches very well. A few possibilities for this discrepancy are that the patches in this test had an expanded gloss range over those in the initial work, covering higher gloss patches than were used earlier. Further effort may be needed with the experimental protocols for higher gloss samples on the RIT μ-goniophotometer. Another factor that may well have played a role in this difference is that the measurements in this experimentation were made with red, green, or blue filtered light, where in past testing, no filters were used when measuring black samples. This, if a factor, may have affected the performance of the μ-goniophotometer in predicting the visual gloss for the paper as well. Finally, there were fewer samples and fewer observers in this experimentation, which may have increased the level of experimental noise. In any case, the inferior performance of the black patches relative to the other colors indicates that further work is needed. The stronger performance of the μ-goniophotometer in predicting the visual gloss level for the other colors indicates that there is a distinct possibility for improvement. The relationships between the measured values and the scaled values for are better for any one color than for the set of samples as a whole. The fact that the visual gloss levels for other colors were reasonably well predicted is encouraging.

Table I: The R^2 values for the measured gloss level to visual gloss level relationships by color for the two instruments being examined in this experimentation; the BYK Gardner glossmeter and the RIT μ-goniophotometer.

Patch	μ-G	20 deg	20deg no S7
C	0.84	0.55	0.96
CMYK	0.75	0.56	**0.34**
M	0.78	0.6	0.83
Paper	0.79	0.48	0.8
Y	0.86	0.46	0.63

The 20° gloss data in column three of Table I suggests that the glossmeter does not perform acceptably for predicting the visual gloss when the data is parsed by color. However, examination of Figure 7 reveals that there is a cluster of data points, one of each color, perceived to be considerably glossier relative to the other print combinations than is predicted by the measurement data from the glossmeter. Separating the data by substrate, Figure 9, it is apparent that there is one printing combination, S7, that does not fit in well with the other printing combinations. This is the printing combination that includes the substrate having the highest visual gloss level. With this printing combination removed, the performance of the glossmeter in predicting visual gloss goes up for the sample set as a whole (the relationship has an R^2 value of about .75) and for each of the colors considered individually, except for black, as seen in the final column of Table I. For the black samples performance actually decreases substantially. Visual inspection of the black print samples reveals that there are gloss non-uniformities clearly

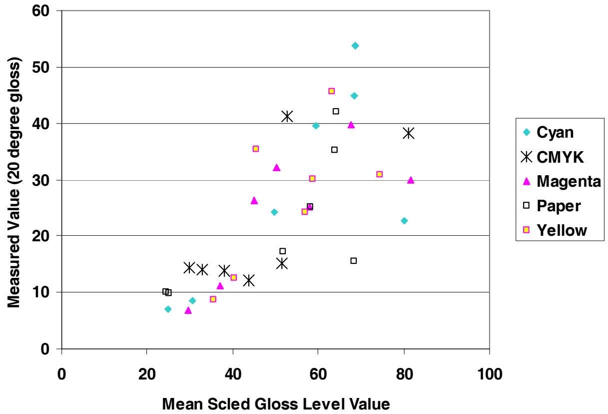

Figure 7: *The measured 20° gloss level as a function of the mean visual gloss level for cyan, magenta, yellow, black, and white patches printed using seven different substrate and ink combinations.*

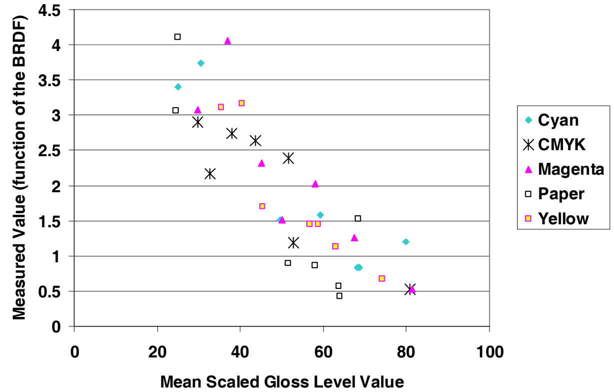

Figure 8: *The measured gloss level, using the RIT μ-goniophotometer, relative to the mean scaling values for visual gloss level for cyan, magenta, yellow, black, and white patches.*

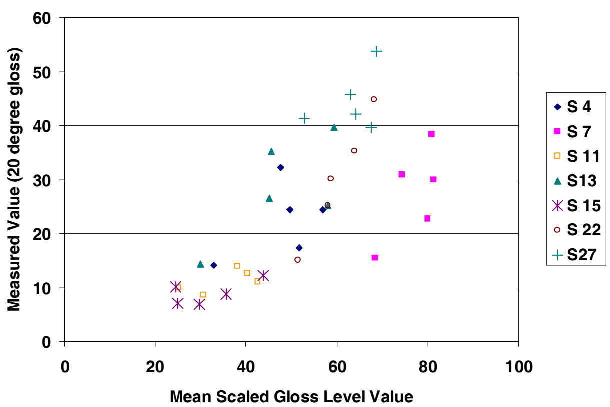

Figure 9: *The measured 20° gloss level as a function of the mean visual gloss level shown by the seven different substrate and ink combinations.*

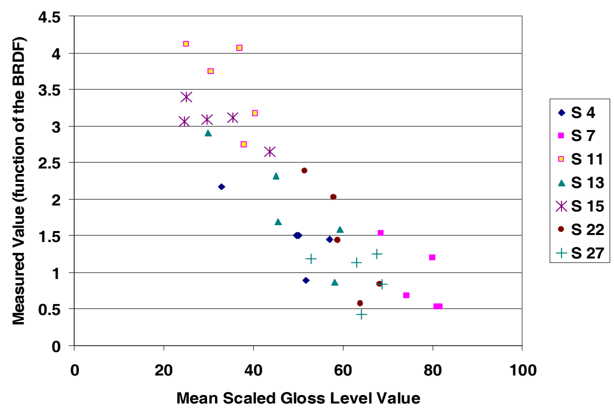

Figure 10: *The RIT μ-goniophotometric gloss level, relative to the mean visual gloss level, shown by the seven substrate and ink combinations.*

visible on at least two of them. Previous experimentation has shown that these non-uniformities can significantly distract the glossmeter though the human eye has little trouble looking around them to assess the appearance of gloss.

For the μ-goniophotometric data, Figure 10, it appears that printing combinations S7 and S11, especially the magenta sample, may be scaled just slightly higher, relative to the other print combinations, than the measurement data would suggest it should be, but it is not too far off. Printing combination S11 is one of the printing combinations that includes a substrate with a low level of visual gloss. In general, however, the substrate and ink type used (printing combination) does not have as significant effect on the predictive capabilities of the μ-goniophotometer as was the case with the glossmeter; it is the color of the patches that has the larger impact, as shown by the data in Table II.

The R^2 data for the measured gloss level versus visual gloss level relationships for each printing combination in Table II shows that the 20° gloss metric does an admirable job of predicting visual gloss for the S22 printing combination. The μ-goniophotometer also does a respectable job with this printing combination as well printing combinations S13. And the 60° gloss measurement works reasonably well for predicting the apparent gloss levels of the patches on the S11 printing combination. However, the data in Table II indicates that, in general, none of the measurements predicted the visual gloss values especially well when the data is considered by printing combination. This may be in part because of the limited number of patches included for each printing combination, which could serve to make the data fairly noisy. Perceptual gloss level for printing combination S27 was especially poorly predicted by all the measurements. The black sample, and, to a much lesser extent, the magenta and cyan samples, for this ink and substrate combination had visible gloss non-uniformities that likely affected instrument performance. If the variability of the BRDF curve is given more weight in the μ-goniophotometric calculation, a relationship between measured and scaled values with an R^2 value of about .9 can be achieved. However, the relationships for the other print combinations are adversely affected. Further work is needed to optimize the protocols for predicting visual gloss using the μ-goniophotometer.

Table II: The R^2 values for the measured gloss level to visual gloss level relationships by ink and substrate combination for the BYK Gardner glossmeter and the RIT μ-goniophotometer.

Target	20 degree	60 degree	μ-G
4	0.34	0.07	0.61
7	0.47	0.43	0.48
11	0.56	**0.8**	0.44
13	0.51	0.11	**0.79**
15	0.43	0.27	0.66
22	**0.98**	0.12	**0.81**
27	0.19	0.03	0.07

Conclusion

This experimentation was conducted to examine the capabilities of two instruments, the RIT μ-goniophotometer and a BYK Gardner micro-TRI-gloss glossmeter, in predicting visual gloss level for an array of colored patches generated using a variety of inks and substrates. Neither instrument predicted visual gloss level particularly well when the data set was considered in its entirety. With either instrument, however, better results were achieved when the data set was separated by the color of the patches. The μ-goniophotometer predicted visual gloss reasonably well. The 20^o and 60^o gloss measurements did not correlate well with the visual scale values when the data was split by color, unless one of the printing combinations was eliminated from the dataset. With the problematic samples removed, that glossmeter did quite well in predicting visual gloss for all but the black samples, which exhibited some gloss non-uniformities. Past studies have shown that the glossmeter does not perform as well in predicting visual gloss for samples exhibiting some level of gloss non-uniformity. When the data set was parsed by printing combination, neither instrument reliably predicted visual gloss level. Each worked well with certain substrate and ink combinations, but failed miserably with other. The ink and substrate combination S27 in particular was a difficult one to characterize. It will be interesting to investigate this printing combination in further detail. It will also be interesting to investigate further the effects of color on the performance of the μ-goniophotometer as a step toward developing effective protocols for measuring visual gloss on samples of various colors and gloss levels.

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References

[1] J.S. Arney, Ling Ye, Eric Maggard, and Brian Renstrom, "Gloss granularity of electrophotographic prints", in press, J. Imag. Sci. & Technol, **51**, (2007)

[2] J.S. Arney, P.G. Anderson, and Hoon Heo, "A Micro-Goniophotometer and the Measurement of Print Gloss", J. Imag. Sci. & Technol., **48**(5), 458 (2004).

[3] J.S. Arney and Hung Tran, "An Inexpensive Micro-Goniophotometry You Can Build", IS&T's PICS Conference on Digital Image Capture, Reproduction, and Image Quality, Portland, Oregon, April 2002; p. 179-182.

[4] J. S. Arney and S. P. Farnand, "An Update on the Print Research and Imaging Systems Modeling Laboratory at the Rochester Institute of Technology", IS&T Chapter Meeting Rochester, NY, May 2007.

[5] J.S. Arney and D. Nilosek, "Analysis of Print Gloss with a Calibrated Micro-Goniophotometer", in press, (2007).

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.