A New Method for Assessing Gloss Based on Digital Imaging

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Abstract

Various methods for quantifying gloss are described including psychophysical scaling, spectro-photometric measurement, and the use of a novel system based on digital imaging. Eighty-four samples covering a wide range of colour gamut and gloss level were assessed for gloss by a number of observers using a magnitude estimation method. Measurements made using two gloss-meters agreed only reasonably well with the visual results. A new measure, based on the difference between the CIE Y tristimulus values of the same sample, measured using a sphere-based spectrophotometer with specular included and excluded geometries, gave excellent agreement to the visual results. An imaging-based technique was established that used a distance profile method to give very good predictions of these visual results.

Introduction

Gloss is the percept associated with specular reflection from an object surface. Hunter[1,2] initially studied the gloss of various materials and defined six different gloss perceptions: Judd[3] later developed associated mathematical models. Many methods for quantifying gloss have been developed over the years and those most widely used are included in ASTM D523.[4] Billmeyer and O'Donnell[5] performed a psychophysical experiment for assessing gloss but using only neutral samples. They found a reasonable agreement between visual results and gloss-meter readings by using a cubic function to fit the two data sets. Serikawa and Shimomura[6] conducted an experiment for scaling gloss using a pair-comparison method and found a high correlation between the visual and gloss-meter results. Sève[7] also proposed a method to correlate visual gloss with the luminance factor in the specular direction. Paul[8] conducted an investigation using printed-paper samples and an instrument that illuminated the sample at 45° and with two detectors at 0° and the specular angle respectively. The results showed a large scatter. Ferwerda et al.[9] used an image synthesis technique to establish the relationship between the physical dimensions of glossy reflectance and the perceptual dimensions of glossy appearance. They found a good correlation between visual results and both distinctness-of-image (DOI) gloss, and contrast gloss. Lindberg et al.[10] investigated gloss level and gloss uniformity of white papers applying octave spatial band-pass filters to evaluate the coefficient of variation of the intensity in each octave band as suggested by Johansson.[11] A reasonable agreement was found between physical measurements and psychophysical judgements. These techniques were based on a small, high resolution, images, i.e. 10 mm x 10 mm images with 512 x 512 pixel resolution. This is close to the microstructure of the gloss variation and it represents very limited area of the samples. A proposed ISO standard introduces a new method for measuring gloss appearance based on the concept of visual luster.[15]

Scaling Experiment – Samples

Swedish Natural Colour System samples were used with an additional black pile sample having a very low gloss. Samples from the three NCS gloss scales, white, grey and black, were included. Each scale had samples at each of six gloss levels. Nineteen original chromatic colours were also used, each having one or two gloss levels. Additional samples were prepared by spraying a gloss or matt coating agent on top of duplicates of the original samples. In total, eighty-four samples were used in the study. Three instruments were used for gloss measurement: a Sheen Tri-microgloss meter with 60 degree measurement, a Dr Lange gloss meter (60 degree measurement)[16] and a GretagMacbeth CE7000A sphere-based spectrophotometer (d/8). For the latter, each sample was measured under conditions that both included and excluded the specular component. The CIELAB a*, b* coordinates of the samples are plotted in Figure 1.

A number of statistical measures were used in the data analysis to indicate the agreement between data sets. These included the coefficient of variation, CV, which is calculated by multiplying the root-mean-square difference between pairs of points in the data sets by 100 and dividing by the mean of the data. Another measure, CV', was used to indicate the variation within a single data set. CV' is calculated by multiplying the standard deviation of the data points by 100 and dividing by the mean of the data. For a perfect agreement between two sets of data, the value of CV should be zero. For no variation in a single data set, CV' should be zero. A CV and CV' value of 30 indicates a 30% disagreement between two data sets, and a 30% variation within a data set, respectively.

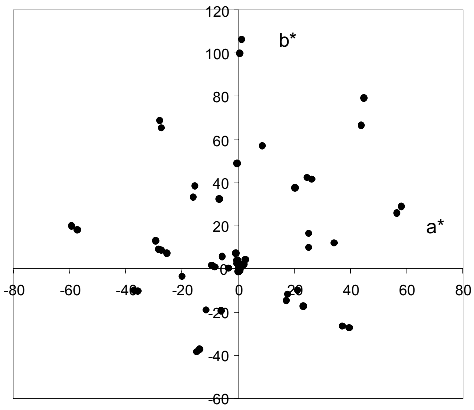


Figure 1. The distribution of the samples used in this study

The uniformity of all samples was examined. For each sample, five positions were measured with the Sheen gloss meter. The variation obtained had mean and maximum values of 0.08 and 0.25 in CV' units, respectively, based on 20 repeat measurements for the 18 neutral samples. The mean and maximum CV' values for all the samples were 6 and 15 gloss units respectively. It was found that the two types of samples (original and sprayed) had mean CV' values of 3 and 8 units respectively. Although, as might be expected, the sprayed samples were not as uniform as the original samples, they were considered visually acceptable for use in the experiments.

Scaling Experiment – Observations

Thirteen observers assessed each sample in a Macbeth SpectraLight II Viewing Cabinet which provided diffuse, simulated D65 illumination. Seven observers performed the experiment twice. Thus, in total, 20 observations were accumulated for each sample. The samples approximately 750 x 750 mm and were mounted on white cardboard to facilitate handling. The samples were all opaque, thus mounting them on card did not alter their appearance. Observers were asked to tilt the sample until an angle with a maximum gloss perception was found as illustrated in Figure 2. Each observer was asked to estimate the gloss of each sample against a reference gloss sample, which was assigned a gloss value of 50.

The observer performance was evaluated in terms of precision and repeatability. For the former, each observer's individual and mean visual results were compared - the observers' mean results were treated as the standard. For the latter, each observer's first and second assessments were compared. The mean values for all observers were 16 and 18 CV units for precision and repeatability respectively.

The visual results were used to test the performance of two sets of the instrumental measurements. It was found that the two gloss-meters gave the same degree of performance in predicting the visual results with a CV value of 21, which is reasonable but poorer than the observer precision (CV = 16). A new measure, $\Delta Y_{SCI\text{-}SCE}$, however, gave a much better fit to the visual data (CV = 9). Figure 3 shows the associated scatter diagrams, $\Delta Y_{SCI\text{-}SCE}$ vs. visual data (a) and Sheen gloss value vs. visual data (b).

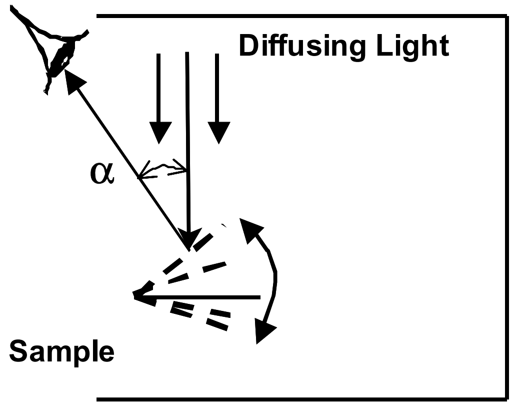


Figure 2. The geometric set-up for psychophysical experiment

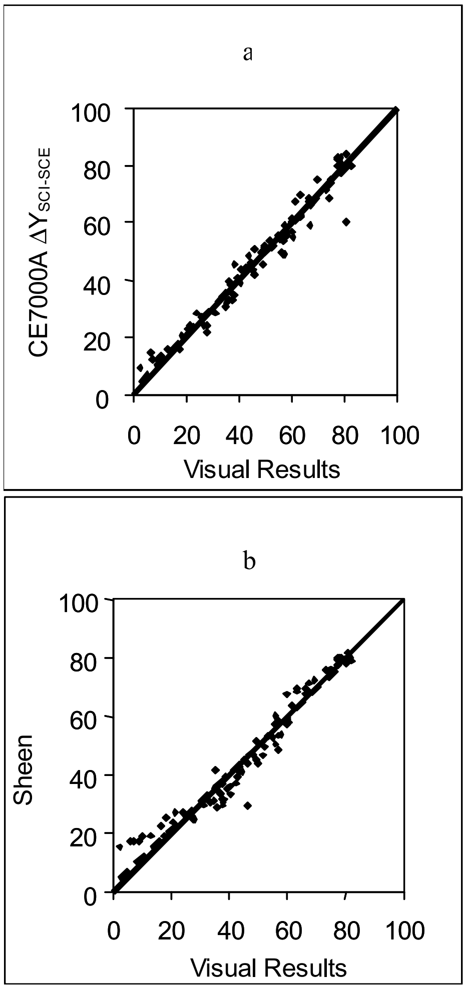


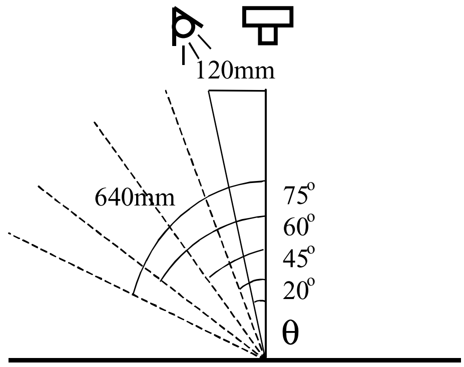
Figure 3. A plot of $\Delta Y_{SCI\text{-}SCE}$ as a function of the visual results (a) and Gloss Value as function of the visual results (b)

It can be clearly seen in Figure 3 (b) that the gloss-meter results over-predict low gloss (matt) samples. A similar, but smaller, trend is also shown in Figure 3 (a). Overall however, the CV value of 9 represents a lower spread than the observer precision for which CV = 16.

Thus, a useful set of visual data relating to gloss has been derived, using a large number of samples, and a correlation found between those visual data and a scale based on spectrophotometric measurement using a sphere instrument.

Developing Imaging Systems for Evaluating Gloss

A system for assessing gloss using a digital camera was also developed. This work was divided into two stages: specification of the illumination/viewing geometry suitable for capturing the full range of gloss in a reflection sample, and the development of image processing algorithms capable of predicting a gloss value. A camera characterisation model based on a 4th order polynomial model was first derived to convert the pixels of the camera RGB image (device dependent values) into equivalent CIE XYZ tristimulus values (device independent values).[17,18]



$\theta = \sin^{-1}(120/640) = 10.8^o$

Figure 4a. Testing illumination and viewing geometry

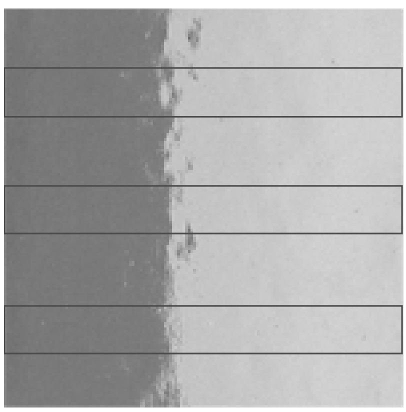


Figure 4b. An image of a sample captured under the 0/11 geometry. Three marked areas were profiles to be used for quantifying gloss

Several illumination/viewing geometries were tested as shown in Figure 4a. It was found that, with the light sources used, illumination at approximately 11° gave the most effective results in showing the gloss distribution for a particular sample. This angle agreed well with that found in the earlier psychophysical experiments (see Figure 2). Figure 4b gives an example of the image captured from a sample. The full range of gloss from low (left) to high (right) can be seen across the surface of the sample.

Imaging Techniques

Octave Band-Passing Filters

Lindberg et al.[10-14] investigated the gloss level of printed paper samples using spatial band-pass filters to calculate CV' values for the intensity in each of the octave bands. A Discrete Fourier Transform was applied to images in CIE XYZ colour space, octave band-passing filters were applied and the CV' values obtained for each band. Three models were developed by fitting the visual results obtained in the psychophysical experiment based upon the 1st, the 2nd and the combined 1st and 2nd octave band.

In addition to the above CV' values, a tangent function was also derived which is capable of linking the Y tristimulus value of any coloured sample to the CV' values of different bands. The model is given in Equation 1.

$$Gloss = (Octave\ Band\ CV \times \tan[a\ln(Y_{max})-b] \quad (1)$$

where Y_{max} is the maximum Y value of a sample, and a and b are coefficients for different bands.

The results obtained using these models were compared with the visual results and it was found that their performance was disappointing: the results ranged from 24 to 29 CV units which were much worse than those for observer accuracy (CV = 16).

Distance Profile

A new method based upon a distance profile was developed. For each digital image captured, a 150 by 150 pixel square image was sampled, Figure 4b. It can be seen that the image included a transition from high gloss to low gloss. By applying a camera characterisation model, it was possible to calculate the CIE XYZ and L*a*b* values for each pixel. The distribution of luminance factor (Y) and Lightness (L*) against the distance from left to right of the image is called the distance profile.

Figure 5a and 5b show distance profiles in Y and L* units respectively. Each diagram corresponds to one neutral colour and includes six or four gloss levels. It can be seen that the trends are highly consistent in that a high gloss sample has a steep profile and a low gloss sample has a flat profile.

The next step is to develop a model to approximate the visual gloss perception based upon the distance profile. Two methods were developed: one based upon the highest value in the Y profile (designated as ΔY method) and the other based upon the largest gradient of the L* profile (which occurred in the steepest region). Figures 5a and 5b also illustrate the way to determine the ΔY and gradient of L* method, respectively. The performances of these two methods are given in Figures 6a and 6b respectively. It can be seen that both methods perform well with CV values of approximately 17, which is close to the observer accuracy. The 95% confidence interval was also shown for each data point in Figures 6a and 6b.

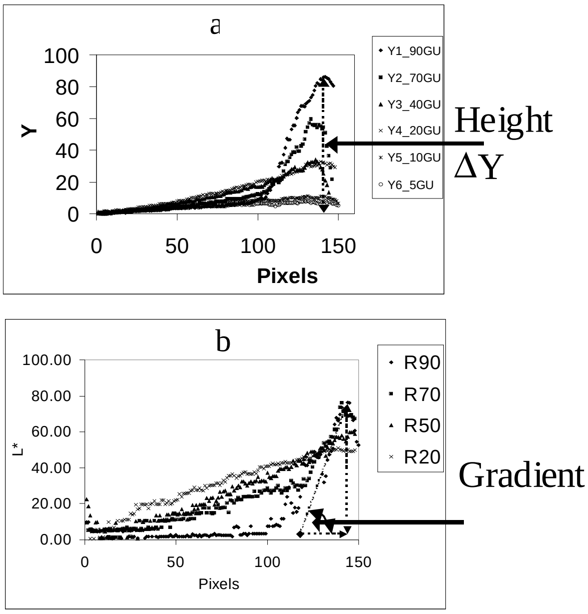


Figure 5. Distance profiles for (a) ΔY method and (b) Gradient of L method*

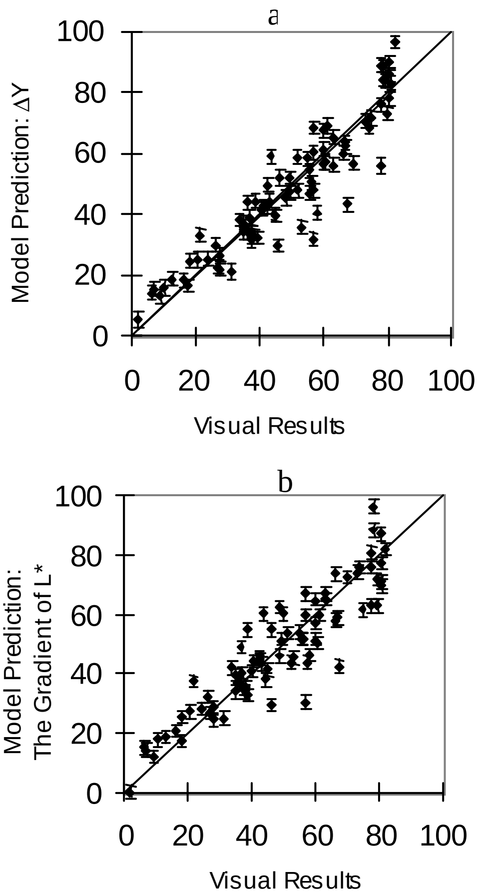


Figure 6. The visuals results plotted against (a) predicted gloss results (ΔY) and (b) gradient of L.*

Conclusions

Gloss is an important parameter for assessing total appearance. In this study, 84 samples were assessed for gloss twenty times using thirteen observers.

The observer precision was found to be 16 CV units, which set a target for the instrumental methods to achieve. Various instrumental methods were investigated including the use of glossmeters, a spectrophotometer and digital imaging technology. The performances for all the instrumental methods investigated are summarised in Table 1.

Table 1. Summary the performance of different instrumental methods for assessing gloss in terms of CV

Spectrophotometer (DYSCI-SCE)	9
Distance profile- DY	17
Distance profile- Gradient L*	18
Gloss-meter (Sheen)	21
Octave band 1	29
Octave band 2	25
Octave bands 1+2	29

The results clearly showed that using the $\Delta Y_{SCI-SCE}$ scale can achieve a close agreement with visual results.

The conventional measurements using a gloss-meter also predicted the visual results reasonably well, but there tended to be an over-prediction for low gloss (matt) samples.

A system based upon a digital image was developed and two distance profile methods investigated. These gave good predictions of the visual results (similar to the observer accuracy) and outperformed octave band methods.

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Biography

Wei Ji received his MSc. degree in Colour Imaging Science from Colour and Imaging Institute (CII) at University of Derby in 2001 and currently carries out his Ph.D. research at the same institute. His Ph.D. project has primarily focused on the appearance of objects, which include colour, gloss, transparency and opacity, and surface texture. He developed different models for assessing above attributes by using conventional instrumental measurements, digital imaging methods, as well as human observations.