Differential Gloss Visual Threshold Under Normal Viewing Conditions

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Abstract

The just-noticeable differences of visual gloss on reflective prints is studied in this paper. There exists no established standard viewing condition to study gloss as the *Standard Observers* condition when examining color. Hence, the normal viewing distance with free tilting angles at one direction is proposed as the viewing condition to evaluate gloss. The method of constant stimuli with forced choice procedure is chosen to conduct the psychophysics experiment. The sample space is divided into five groups in terms of the measured gloss reading, and observers are asked to compare with the reference in each group. Data is analyzed based on the assumption of *Gaussian psychome-tric model*, and a set of visual gloss differential threshold is obtained. Two experiments are also done on cyan and magenta print samples for comparison.

1. Introduction

The sensation of light is the foundation of human visual perception, and it can be further categorized into color, gloss, transparency, etc. If we confine our discussion within the domain of non-illuminating objects such as the reflective print, the light contributing to our visual sensation can be formulated as following[1,2]:

$$L_\lambda(\hat{\theta}_r) = \int R_\lambda(\hat{\theta}_i, \hat{\theta}_r) L_\lambda(\hat{\theta}_i) \cos\theta_i) d\omega_i \qquad (1)$$

where $L_\lambda(\hat{\theta}_i)$ and $L_\lambda(\hat{\theta}_r)$ represent the local incident and reflected light with angle $\hat{\theta}_i = (\theta_i, \phi_i)$ and $\hat{\theta}_r = (\theta_r, \phi_r)$. λ emphasizes that this equation is dependent on the wavelength of the light, and $d\omega_i$ is the solid angle in the incident direction. $R_\lambda(\hat{\theta}_i, \hat{\theta}_r)$ is the *Bidirectional Reflection Distribution Function*, BRDF, and it controls $L_\lambda(\hat{\theta}_r)$ with $L_\lambda(\hat{\theta}_i)$ being fixed. Color is perceived away from the specular angle where R_λ has only insignificant variation with respect to incident and perceiving angle, hence it is sufficient to describe L_λ in spectrum domain. On the other hand, the geometric appearance, for instance, gloss and haze, comes from the entire five dimensional space, (λ, θ_i, ϕ_i, θ_r, ϕ_r). As a result, unlike color, which can be compressed and reconstructed with three-component measurement, it is very difficult to derive an universal visual gloss function based on several measurements.[3,4] The current visual gloss measurement is to find the best correlation between a measurement with a specific angle and visual gloss ranking regarding the object of interest. Therefore, there exists many standard gloss measurements which are applicable to different types of objects.

In this paper, we focus on the differential gloss visual threshold on reflective prints. Note that the BRDF is a function of wavelength, incident and reflection angle. Hence, the perceived shininess of a print sample will also change with respect to these factors. As a result, there exists no standard observer viewing condition defined as when examining color.[3] We might have to compare the entire BRDF between two samples to correlate objective measurement and subjective evaluation if observers can freely handle them. This not only makes the measurement cumbersome but also the analysis extremely difficult because of the enormous amount of data. Hence, we adopt the graphic art standard viewing condition with overhead light offering well-defined source, which is explained in section 3.

2. Light Scatter and Gloss Perception

It is essential to first understand the physical model behind light reflection and scattering because the BRDF manipulates how light enters the human visual system. In general, surface reflection can be categorized into three origins: first-surface, multiple-surface and sub-surface reflection.[2] The light reflected from the first surface is highly directional. Hence, the smoother the surface, the more mirror-like an object becomes. That is, its BRDF is approaching to a Delta function centered at the corresponding specular angle. Nonetheless, the reflected light is also dispersed by the diffraction and interference processes, which results in diffused light near the specular angle. On the contrary, when light is reflected by multiple surfaces or subsurface, the reflected light becomes more diffused because of their complex geometrical distribution. As a result, it is possible to decompose the BRDF into three terms based on its inherent directional characteristics[2]:

$$R(\lambda) = R_s(\lambda) + R_{dd}(\lambda) + R_{ud}(\lambda) \qquad (2)$$

where R_s, R_{dd}, R_{ud} represents the specular, directional diffuse and uniform diffuse reflection respectively. The first surface reflection contributes to R_s and R_{dd}, and R_{ud} is composed by multiple-surface and sub-surface reflection factors. The BRDF is sometimes assumed to be isotropic, i.e., $R_\lambda = R_\lambda(\theta_i, \theta_r)$. Needless to say, this assumption is usually not valid on print samples because of the applied halftone screening angle, fusing direction, artifacts or edges.[5]

The perception of gloss can be classified into the following types: Specular gloss, Sheen, Contrast gloss, Absence of Bloom gloss (AOB gloss), Distinctness of Image gloss (DOI gloss), and Surface Uniformity gloss (Microgloss).[3,6] The specular gloss and sheen are contributed by the specular and directional diffused reflection near the specular angle while DOI and AOB gloss are determined by the ratio between the specular and directional reflection. Assuming the BRDF can be approximated by a Gaussian model, the DOI and AOB gloss is determined by the standard deviation, σ, of the fitted model.[5] Contrast gloss appears when surfaces dominated by the specular reflection and uniform diffused reflection respectively are perceived by observers at the same time, and Microgloss is usually caused by surface nonuniformities which results in reflection variation in a fine scale.

2.1. Visual Gloss on Print Samples

The Print samples are composed of heterogeneous material: colorant and paper substrate. The colorant can be toners, ink drops, pigment ink etc. Colorants are laid down on paper substrate in a contone or halftone pattern. Since colorants absorb certain portion of light spectrum, the uniform diffused light reflected from subsurface carries strong color information while the specular and directional diffused reflection is similar to the incident light source. It is obvious that perceived color on a print sample will become less saturated when the spread of the directional diffused reflection increases. Moreover, since the glossmeter measures at the specular angle, and, according to Equation (2), the perceived specular gloss on a matte print sample should contain more color information than on a glossy one. This effect should be eliminated to obtain a more accurate specular gloss reading, for example, the "*Perfect-White Diffuse Correction Factor*" defined in the ASTM procedures.[3]

In this experiment, the size of chosen print samples is approximately 1.25 square inch with 100% toner coverage to minimize the possible texture effect. We select print samples to reduce the Microgloss or gloss variance perceived by observers and surface finish is approximately uniform. However, controlling gloss uniformity is very difficult to accomplish on regular paper. Moreover, none of the print samples possesses high gloss reading to offer sufficient DOI and AOB gloss sensation to observers. Since observers are allowed to tilt the viewing angle, we can further deduce that observers can perceive specular gloss at or near the specular angle, and they can also perceive contrast gloss while comparing the specular and diffused light concurrently or sequentially. Nonetheless, all of the print samples involved in one group of experiment have very similar color measurement. That is, the uniform diffused light reflected from these samples can be assumed to be the same. As a result, we can conclude that the specular gloss contributes the most to the perceived gloss.

To test the validity of the light reflection model noted previously, we propose a Roughness mixture model (RM model) for measured gloss on toner-based print samples, which is modified from the Quadratic mixture model.[7] When an object is seen from a distance, the assumption can be made that the surface height distribution is approximately gaussian with standard deviation σ_r being the *rms roughness* controlled by temperature, pressure, etc.. The *rms roughness* was shown to control the specular reflection.[2] Imagine that surface roughness is higher at the midtone coverage and lower at both ends, we can approximate the measure gloss change versus single toner coverage by a quadratic function.[7] According to the Neugebauer equation, we propose the following equation to describe the roughness degree relative to the toner coverage:

$$\alpha_r = 1 - (1 - c)(1 - m)(1 - y)(1 - k) + f_o(c, m, y, k) \tag{3}$$

where *c, m, y, k* are the percentage coverage for the associated color and $f_o(c, m, y, k)$ accounts for the excessive increase over 100% coverage. The proposed RM model is listed as following:

$$g_{mix} = \sum_{i=1}^{4} w_i g_i(\alpha_r) \tag{4}$$

$$w_i = p_i / \sum_{j=1}^{4} p_j \tag{5}$$

where g_i and p_i are the fitted quadratic function and the percentage coverage for each color channel. Apply the RM model to various types of paper and fusing conditions, and we found that the mean and the standard deviation of the 60-degree gloss estimation error are -0.12 and 2.54 respectively. Although the RM model only estimates the specular gloss on print samples, it demonstrates that the light reflection model provides a good starting point to correlate between physical measurement and human perception. For example, it is possible to determine the range of perceived specular gloss appearing on a printed image without measurement. Moreover, we can extend to other off-specular measurements to correlate with the perceptual gloss.

3. Experiment Design

The method of constant stimuli with forced choice procedure is selected for this experiment.[8] Print samples are placed on a board with gray background with matte finish to minimize possible distraction. Observers are asked to evaluate samples at the normal viewing position under standard lighting condition, *D50*, and they can freely tilt the samples to acquire overall gloss sensation. However, observers are not allowed to move away from this viewing position. Two print samples being compared are placed in the immediate juxtaposition where the human visual acuity is at its highest point. Observers are asked to select the sample with higher perceived gloss. Groups of samples with measured 60-degree gloss readings at approximately 10, 20, 30, 45, and 60 are chosen. 18 observers participated the first experiment using black samples and another 18 observers took part in the second experiment with cyan and magenta samples.

4. Result Analysis

The measured 60-degree gloss readings on selected print samples range from 7 to 70, which coincides with the suggested range where 60-degree gloss measurement correlates visually the most.[3] Because print samples in each group are selected to have similar surface finish, as noted in section 2, we assume that the specular gloss influences the whole visual gloss the most. As a result, the 60-degree gloss reading is adopted as the objective metric for quantifying the geometric property of print samples. A *Gaussian psychometric model* is assumed to describe the perceptual gloss.[9] Let the *X-axis* be the gloss reading difference between the reference and test samples, and the *Y-axis* represent the possibility of a test sample perceived being glossier than the reference, the Gaussian psychometric model assumes that x and y can be be fitted by the following:

$$y = \int_{-(\alpha+\beta x)}^{\infty} 1/\sqrt{2\pi} e^{-u^2/2} du \tag{6}$$

where α and β are the controlling parameters. We can transform data to formulate a linear system under the constraint that observers are forced to guess when they do not see any difference in terms of gloss. Figure 1 and 2 demonstrates the experiment result and fitted Gaussian curves done on black, cyan and magenta print samples with 100% toner coverage. Note that cyan and magenta samples are used for comparison, only two reference point were selected. It is well known that the 75% detection point under the dual forced choice procedure is equivalent to the 50% statistical detection threshold, we can derive the differential threshold for visual gloss from fitted curves at each gloss reference level, and the result is shown in Figure 3. Under the power law proposed by S. Stevens,[9] a power function is fitted to correlate the visual glossiness sensation with the 60 degree gloss reading, a geometrical property of a print sample:

$$JND_{g60} = 0.14 \text{ x } (G_{60})^{0.96}. \tag{7}$$

The associated *p-value* is 0.0019 which shows a good agreement is achieved between the estimated data and the fitted power curve. The estimated statistical thresholds for cyan and magenta samples with 60 degree gloss reference being 20 and 50 respectively in Figure 3 show that they correlate well with black samples at low gloss reading, but the estimated magenta threshold is much lower than black and cyan samples at high gloss reading. Although this result seem to suggest that the perceived color contributed mainly by the uniform diffused reflection from print samples will affect visual glossiness similar to the *Perfect White diffuse correction factor* in the current ASTM document, a different conclusion was reached by the experiment done on painted specimens, which notes that luminance is insignificant with respect to perceived gloss.[4] It is thus necessary to further investigate the correlation between the color and gloss sensation.

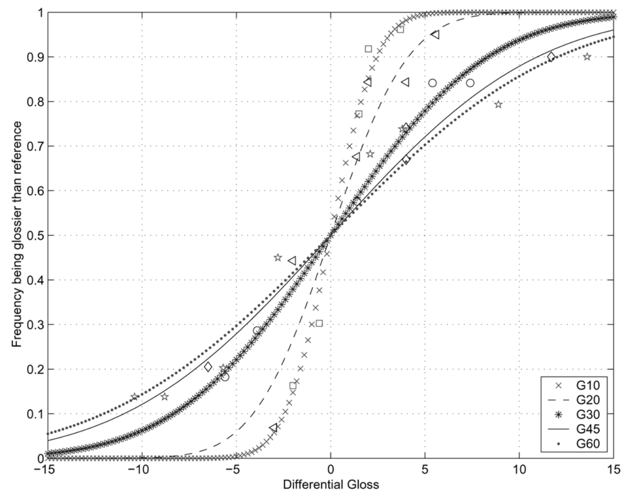

Figure 1. Visual Threshold Experiment for 100% Black Patches

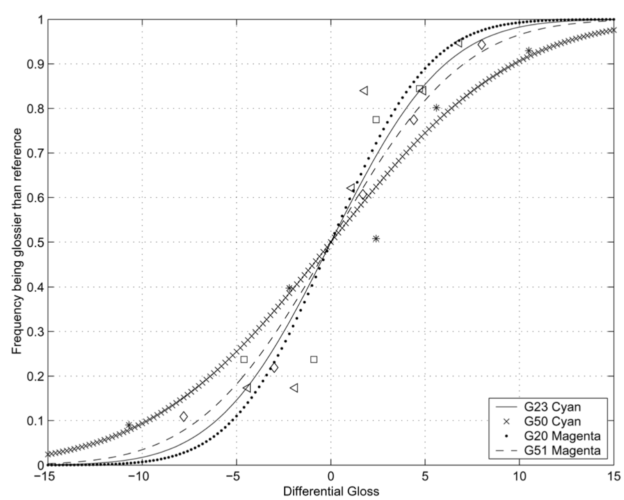

Figure 2. Visual Threshold Experiment for 100% Cyan and Magenta Patches

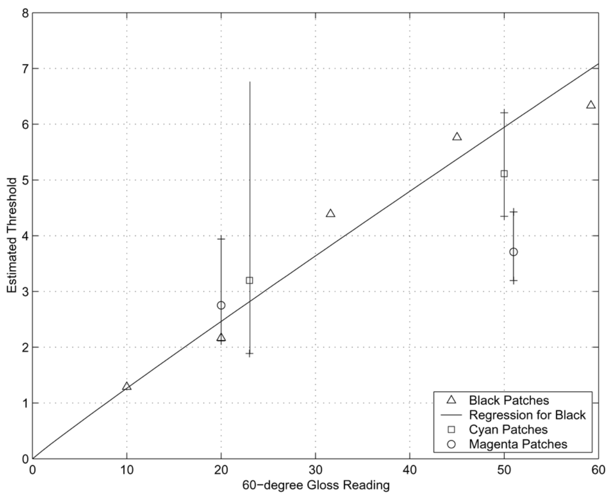

Figure 3. Visual Threshold and 85% confidence intervals for C, M, and K and the regression curve

5. Conclusion

The visual gloss differential threshold on print samples is studied in this paper. Five gloss references are selected with 60 degree gloss reading ranging from 10 to 60 and 100% toner coverage. Print samples are chosen so as to have similar surface uniformity within each group. The *Gaussian psychometric model* and *Power law* is assumed and a fitted power function of the visual gloss statistical threshold is shown in Equation 7. Note that the threshold will change when other visual gloss attributes as explained in section 2 are included. For example, we found that the sample which exhibits less gloss nonuniformity is perceived more frequently as being glossier than the other sample even though it has lower specular gloss reading. As a result, it is highly likely that multiple gloss attributes will contribute simultaneously to perceived gloss, which is different from the conclusion of unidimensional gloss sensation drawn in the painted specimen experiment.[4] Hence, further experiment and measurement is needed to correlate among multiple visual gloss attributes.

6. References

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7. Biography

Chunghui Kuo received his Ph.D in Electrical and Computer Engineering from University of Minnesota and joined *NexPress* since 2001. His research interest is in image processing, image quality and neural network applied in signal processing. He is a member of *IEEE* signal processing society and *SPIE*.

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