An Evaluation Method for Microgloss Uniformity

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Abstract

*Microgloss uniformity affects the final image quality of electrophotographic printers. The microgloss is the noise of the micro-gloss differential, and occurs because of either insufficient pressure or toner blistering. Microgloss uniformity evaluation methods have been proposed previously. However, these methods have not been used to establish a standard method. The purpose of this paper is to establish a simple quantitative microgloss evaluation method. The measurement device is composed of a charge-coupled device (CCD) camera and vertically-incident lighting equipment. Because the measurement geometry is 0°/0°, the measuring device is small in size and the camera angle adjustment process is simple. In addition, polarizing filters are inserted into the optical path to suppress any internal diffuse reflected light. The RGB (red-green-blue) image measured by the CCD camera is converted into an L*a*b* image. The L* image is then Fourier transformed to obtain the Wiener spectrum. An evaluation model using Hunter whiteness, a visual characteristic, and the Wiener spectrum was proposed. As a result, the contribution of the evaluation model and the subjective score was 0.94. Because this method is simple, it is expected to find widespread application in the printing industry.*

Introduction

Gloss is an important factor in image quality, along with tone reproduction, color reproduction, graininess, and sharpness. In particular, microgloss uniformity in electrophotographic printers affects the image quality. This effect is sometimes called gloss granularity or orange peel. The toner is fixed to the paper in a fuser under applied heat and pressure. However, if the process is not performed with uniform heat and pressure, noise tends to occur in the gloss. As shown in Figure 1, the microgloss is effectively the noise of the micro-gloss differential, and occurs because of insufficient process pressure or toner blistering.

Measurement and analysis methods for microgloss uniformity have been proposed previously [1, 2]. We developed a measurement and evaluation method for microgloss uniformity in 2001 [3]. The method used vertically-incident lighting equipment, was simple and showed high correlation with perception of the uniformity. However, the method has not been established as a standard evaluation method because the verification provided was insufficient. The purpose of this study is to improve the original measurement method and establish a new evaluation method.

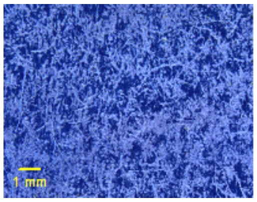

***Figure 1**. Microgloss of an electrophotographic image.*

Measurement Device

Figure 2 shows a schematic illustration of the measurement device. The device is composed of a charge-coupled device (CCD) camera and vertically-incident lighting equipment. Because the measurement geometry is 0°/0°, the measuring device is small in size and the angle adjustment process of the camera is simple [3]. In addition, polarizing filters are inserted into the optical path, parallel to each other, to suppress any internal diffuse reflected light. While the toner surface has a polarization characteristic, the inter-diffusion has no polarization characteristics. It is therefore possible to suppress the internal diffuse reflected light using the filters. The illumination light is collimated using a light control film.

Table 1 shows the device configuration. The camera is a 3-CCD camera with 12 bit depth. The measured images are saved as 16 bit tiff images (color). The captured image resolution is approximately 2900 dpi and the sampling pitch is 8.8 µm. The measurement area is 12×9 mm. Figure 1 shows a solid image of cyan measured using this device. The gloss structure of the solid image is emphasized in the figure.

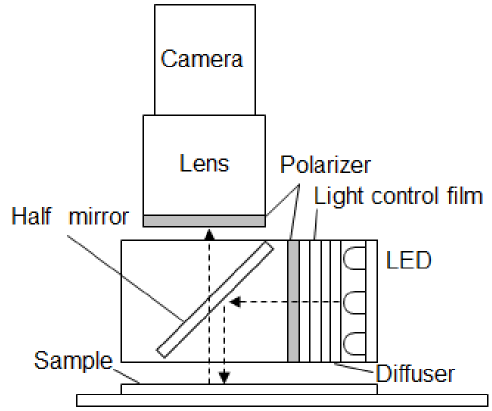

***Figure 2**. Schematic illustration of the device*

Table 1 Configuration of the device

Camera	C7780-20 (Hamamatsu Photonics K.K.)
Light	LFV2-50-SW2 (CCS Inc.)
Lens	AE20B2 (FUJINON) MAF75B (FUJINON)
Polarizer filter	PL-LFV2-50 (CCS Inc.) 52-S-PL (Kenko Tokina Co., Ltd.)
Light control film	52390-J (Edmund Optics)

Subjective Experiment

To obtain subjective microgloss uniformity evaluation scores from the samples, subjective evaluation experiments were performed. Seven scale samples were made via paired comparison and 35 evaluation samples were ranked by comparison with the scale samples.

The paired comparison testing was conducted using Scheffe's paired comparison method [4]. Figure 3 shows an image of the experimental setup and the spatial conditions for the illumination. Two samples were chosen at random from the seven scale samples. An observer compared these samples and ranked the left side sample with respect to the right side sample using the following levels:

1. much worse
2. slightly worse
3. the same
4. slightly better
5. much better

This comparison was performed for all possible combinations of the samples and the results were scaled using correspondence analysis [5]. Scheffe's paired comparison method can identify any small differences between the samples. However, because the observer must evaluate all sample combinations, the process is time-consuming. Table 2 shows the experimental conditions used. All samples used for the evaluation were produced by electrophotography and were black solid images. The samples were made while varying the paper type used and controlling the fusing conditions of the printer.

Twenty-five observers with normal vision participated in these experiments. All observers were image analysis and evaluation engineers with an age range of 20–50 years. They compared two samples at a viewing distance of 350 mm. The samples were evaluated for the quality of their microgloss uniformity. Table 3 shows the results of the subjective experiments. The paper types and the 60° gloss values are also given in the table.

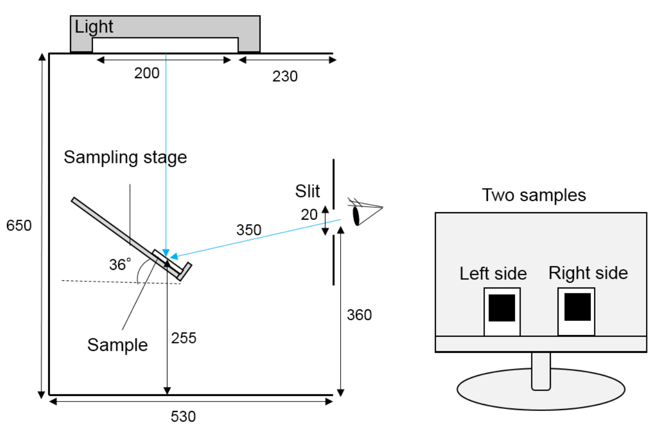

***Figure 3**. Scheffe's paired comparison method setup*

Table 2 Experimental conditions

Evaluation method	Scheffe's paired comparison
Number of samples	7 (black)
Sample size	Image size 30 × 30 mm Blank size 10-20 mm
Presentation order	Random
Panels	25
Viewing distance	350 mm
Geometric arrangement	Mirror reflection

Table 3 Subjective scores

Sample	Score	G60(%)	Paper Type
1	0.93	4.7	My recycled paper GP
2	0.69	5.8	Type6200
3	0.44	6.4	My recycled paper 100W
4	0.12	5.1	My recycled paper GP
5	-0.25	7.8	Type6000
6	-0.76	9.9	FC art paper
7	-1.17	35.4	FC art paper

Next, 35 color samples were ranked by comparison with the scale samples. The samples were printed with cyan, magenta, yellow, red, green, blue, and black solid images while varying the paper type and controlling the fusing conditions of the printer as before.

Figure 4 shows an image of the experimental method using the scale samples. The scale samples were placed on the left of the evaluation samples. The observers then compared the evaluation samples to the scale samples over a range of 1–7 points (in 0.5 point increments). For example, if the observer felt that the quality of the evaluation sample was equal to that of the sample at point six on the scale, the evaluation sample was then given a score of six. If the observer felt that the quality of the sample was midway between that of the 6- and 7-point scale samples, the evaluation sample was given a score of 6.5. The score was then scaled to correspond with the previous correspondence analysis results (as shown in Table 3). Finally, the scaled evaluation values for each sample were averaged. The viewing conditions were the same as those of the previous experiment.

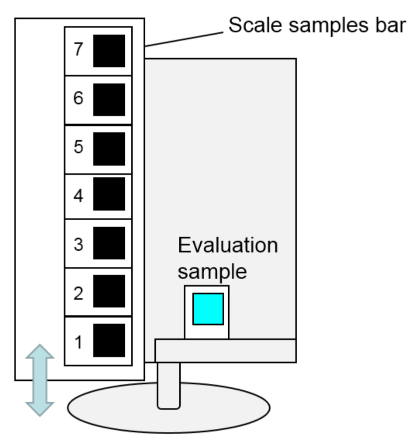

***Figure 4**. Comparison experiment using the scale samples*

Calculation of Subjective Evaluation Values

The microgloss uniformity evaluation value was calculated as follows:

1. Measurement of Reference Sample

A reference sample to be used for shading compensation was measured using the device. The sample was a white polyester film (Lumirror 125E20, PANAC Co., Ltd.) The measured luminosity values are defined as $R_r(i, j)$, $G_r(i, j)$ and $B_r(i, j)$, where (i, j) denotes the spatial coordinates.

2. Measurement of Evaluation Samples

The samples for microgloss uniformity evaluation were measured using the device. The luminosity values were defined as $R_m(i, j)$, $G_m(i, j)$ and $B_m(i, j)$. The images were trimmed 1024×1024 pixels and the shading of the images was corrected using Eq. (1). R_{mean}, G_{mean} and B_{mean} are the mean values of $R_r(i, j)$, $G_r(i, j)$ and $B_r(i, j)$ as shown in Eq. (2). N is a pixel number ($N=1024$). $R_s(i, j)$, $G_s(i, j)$ and $B_s(i, j)$ are the data after the shading correction.

$$\begin{cases} R_s(i,j) = R_m(i,j) \Big/ \left(\dfrac{R_r(i,j)}{R_{mean}} \right) \\ G_s(i,j) = G_m(i,j) \Big/ \left(\dfrac{G_r(i,j)}{G_{mean}} \right) \\ B_s(i,j) = B_m(i,j) \Big/ \left(\dfrac{B_r(i,j)}{B_{mean}} \right) \end{cases} \tag{1}$$

$$\begin{cases} R_{mean} = \dfrac{1}{N \times N} \sum_{j=0}^{N-1} \sum_{i=0}^{N-1} R_r(i,j) \\ G_{mean} = \dfrac{1}{N \times N} \sum_{j=0}^{N-1} \sum_{i=0}^{N-1} G_r(i,j) \\ B_{mean} = \dfrac{1}{N \times N} \sum_{j=0}^{N-1} \sum_{i=0}^{N-1} B_r(i,j) \end{cases} \tag{2}$$

3. Normalization of the Measured Samples

$R_s(i, j)$, $G_s(i, j)$ and $B_s(i, j)$ were normalized into a range of 0–100 using Eq. (3).

$$\begin{cases} R(i,j) = 100 \cdot \left(\dfrac{R_s(i,j)}{2^{16}-1} \right) \\ G(i,j) = 100 \cdot \left(\dfrac{G_s(i,j)}{2^{16}-1} \right) \\ B(i,j) = 100 \cdot \left(\dfrac{B_s(i,j)}{2^{16}-1} \right) \end{cases} \tag{3}$$

4. Conversion from RGB to L*a*b*

The *RGB* data that was normalized was then converted to *XYZ* data in the *sRGB* color space using Eq (4). Then, the $X(i, j)$, $Y(i, j)$ and $Z(i, j)$ data are converted into $L^*(i, j)$, $a^*(i, j)$ and $b^*(i, j)$ data. The explanation of the conversion from *XYZ* to $L^*a^*b^*$ is omitted here because it is a well-known process.

$$\begin{pmatrix} X(i,j) \\ Y(i,j) \\ Z(i,j) \end{pmatrix} = \begin{pmatrix} 0.64 & 0.3 & 0.15 \\ 0.33 & 0.6 & 0.06 \\ 0.03 & 0.1 & 0.79 \end{pmatrix} \begin{pmatrix} 0.644471 \times R(i,j) \\ 1.191894 \times G(i,j) \\ 1.203135 \times B(i,j) \end{pmatrix} \tag{4}$$

5. Calculation of Evaluation Value

An evaluation model using the spatial frequency characteristics of the lightness noise and the Hunter whiteness has been proposed.

The spatial frequency characteristics are calculated by multiplying a Wiener spectrum by a visual transfer function. The Wiener spectrum is obtained from the 2D Fourier transform of the lightness fluctuation. Eq. (5) shows the lightness fluctuation $L^*_f(i, j)$. L^*_{mean} is the mean value of $L^*(i, j)$.

$$L_f^*(i,j) = L^*(i,j) - L^*_{mean} \tag{5}$$

The Fourier transformation of $L^*_f(i, j)$ is defined as $F(u,v)$ where (u, v) denotes the spatial frequency. The Wiener spectrum $WS(u, v)$ is $|F(u, v)|^2$, which is the intensity of the spatial frequency $F(u, v)$. $WS(u, v)$ is then transformed into $WS(u)$ of one dimension by averaging the intensity of each frequency to simplify the calculation of the evaluation value.

The visual transfer function (VTF) $V(u)$ uses a model that is considered in ModelFest [6].

$$V(u) = 10^{0.275-1.536\cdot(\log(u)-0.472)^2} \Big/ 10^{0.275} \tag{6}$$

u : *spatial frequency (cycle/degree)*

The spatial frequency characteristic X is calculated using Eq. (7). The integration range is 0–12 c/deg.

$$X = \int_{0.0}^{12.0} \sqrt{WS(u)} \cdot V(u) du \tag{7}$$

$WS(u)$: *Wiener spectrum*
$V(u)$: *Visual Transfer Function*

The Hunter whiteness W is calculated using Eq. (8). a^*_{mean} and b^*_{mean} are the mean values of $a^*(i, j)$ and $b^*(i, j)$.

$$W = 100 - \sqrt{(100 - L^*_{mean})^2 + a^{*2}_{mean} + b^{*2}_{mean}} \tag{8}$$

The microgloss uniformity evaluation value (MGV) is calculated using Eq. (9).

$$MGV = p_1 \cdot X^{p_2} (100 - W)^{p_3} + p_4 \tag{9}$$

$p_{1\text{-}4}$: *parameters*

Here, $p_{1\text{-}4}$ are the parameters that were determined via a nonlinear regression analysis.

Results and Discussion

p_{1-4} were calculated using the measured and subjective score values ($p_1 = 1.10$, $p_2 = 0.482$, $p_3 = 0.357$ and $p_4 = -2.28$). Figure 5 shows the correlation between the subjective scores and the MGV. An R-squared value of 0.94 was obtained.

Here, the influence of the VTF is confirmed. Figure 6 shows the results for the MGV when using the VTF model proposed by Dooley and Shaw [7]. The VTF is often used to evaluate the image granularity [8]. The evaluation method proposed in 2001 [3] used the model of Dooley and Shaw. The contribution rate is slightly lower when compared with the model of ModelFest (Figure 5). Figure 7 shows both VTFs. The VTF of the ModelFest model has a peak at a lower frequency than that of Dooley and Shaw. As a result, it can be said that the perceptual sensitivity to microgloss noise is high in the lower frequency band when compared with the granularity.

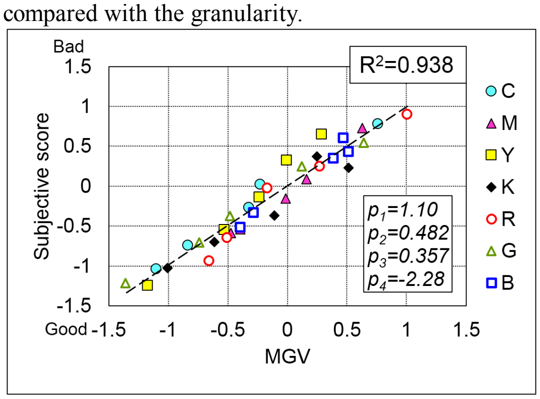

Figure 5*. Subjective score and the MGV*

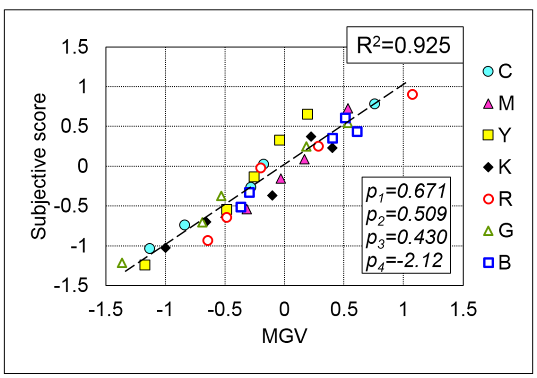

Figure 6*. MGV found using the VTF of Dooley and Shaw*

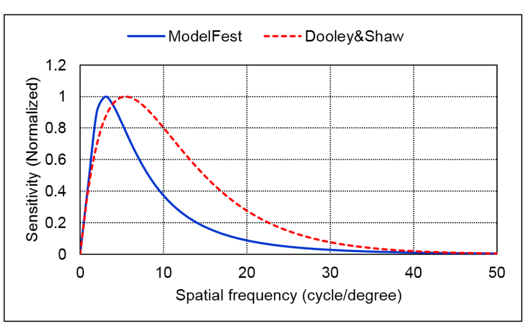

Figure 7*. Visual transfer functions for the two models*

Applications to inkjet Printing

An application of the proposed evaluation method to inkjet image printing was attempted. The evaluation samples were printed by an experimental inkjet machine while varying the paper type and controlling the amount of coating liquid. The subjective experiment was conducted using a single stimulus method. The observers assessed the image quality on a five-grade impairment scale, as shown in Table 4. The assessed values of each sample were then averaged. Table 5 gives the experimental conditions.

Table 4 Five-grade impairment scale

Score	Impairment
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Table 5 Experimental conditions

Number of samples	21 (C, M, Y, R, G, B, K)
Presentation order	Random
Panels	16
Viewing distance	350 mm
Geometric arrangement	Mirror reflection

The samples were measured under the same conditions as those used in previous experiment. Figure 8 shows an example of a measured image. The microgloss of the ink-jet image is observed. Figure 9 shows the relationship between the MGV and the subjective score. Because the contribution rate is high, this evaluation method is effective for the ink-jet image.

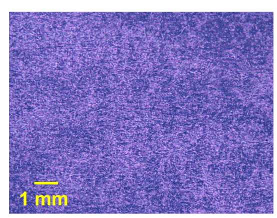

Figure 8. *Microgloss of the inkjet image.*

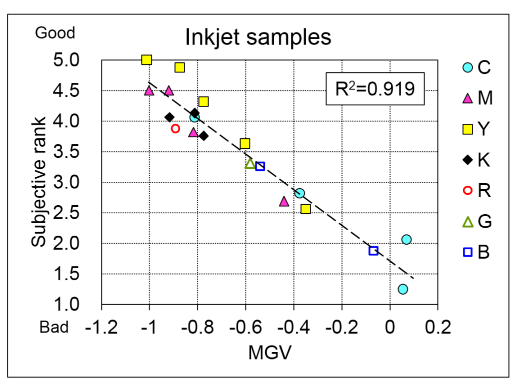

Figure 9. *Results for the inkjet samples*

Conclusions

A new measurement and evaluation method for microgloss uniformity has been developed. The method is based on the spatial frequency characteristics of the noise and the Hunter whiteness showed good correlation with the subjective evaluation scores. Because this method is simple, it is expected to find widespread application in the printing industry.

In future work, this method will be applied to measurement of the uniformity of metal coatings.

References

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Author Biography

Takuroh Sone received his MS in Applied Physics from Hokkaido University in 2007. Since 2007, he has worked for Ricoh Company, Ltd. His work has focused on image evaluation of hard copies. He is a member of the Imaging Society of Japan.