https://doi.org/10.2352/ISSN.2470-1173.2019.6.MAAP-476

Evaluation of Sparkle Impression Considering Observation Distance

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Abstract

The sparkle impression is an important factor of appearance quality. The impression is generated by reflection from a material surface that contains metallic or pearl pigments. Although several methods of evaluating the impression have been proposed, there is insufficient correlation between the results of these methods and subjective evaluation because the impression depends on the observation distance. The present study developed a method of evaluating the sparkle impression considering the observation distance. To this end, a subjective evaluation experiment was performed for different observation distances and a measurement system comprising a spectral camera and lighting device was constructed. The evaluation model was proposed on the basis of the spatial frequency characteristics of the recorded image and human visual characteristics. The contribution ratio between subjective evaluation scores and evaluation values was high.

Introduction

Material appearance is becoming an important aspect of product design. In particular, the sparkle impression is an important quality factor of appearance in terms of customer satisfaction and buyer motivation [1][2]. The impression is perceived by the reflection of light from a material surface that contains metallic or pearl pigments [3] (Figure 1).

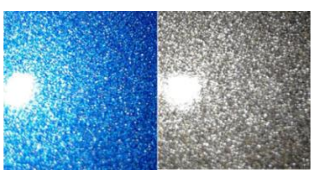

Figure 1. Example of the sparkle impression

The sparkle impression is a surface characteristic. However, it cannot be measured by a colorimeter because it is a textural property. Several methods of evaluating the impression have been proposed on the basis of measuring the reflection intensity and area of pigments using a camera [4]. Although the evaluation value is calculated from measurements, there is insufficient correlation between the evaluation values and subjective values of the sparkle impression. The reason is that the sparkle impression depends on not only the reflected intensity and area of pigments but also the observation distance because the resolution of the human eye changes with the observation distance. We assume that it is important to consider the observation distance in evaluating the sparkle impression.

The present paper develops a method of evaluating the sparkle impression considering the observation distance. To this end, a subjective experiment of sparkle impression is first conducted using Sceffe's paired comparison. We next construct a measurement system that consists of a spectral camera and lighting device. An evaluation model that uses spatial frequency characteristics and human visual characteristics is proposed. Finally, correlation between subjective evaluation scores and evaluation values is confirmed.

Subjective Experiment

To obtain sparkle impression scores of test samples, a subjective evaluation experiment was performed employing Scheffe's paired comparison method [5]. A pair of test samples was chosen at random from the samples. An observer compared these samples and ranked the left-side sample with respect to the right-side sample according to five levels: much weaker, slightly weaker, the same, slightly stronger, and much stronger.

The above comparison was performed for all possible combinations of the samples and the results were scaled through correspondence analysis. Scheffe's paired comparison method can identify small differences between samples. Table 1 gives the test sample conditions. The color of samples in the subjective experiment was metallic silver. The samples had five pigment grades depending on the pigment size. These samples were chosen uniformly from samples of more than 10 grades. The observation distance was 400 mm for samples 1 to 5 and 1000 mm for samples 6 to 10. The experiment was therefore conducted under three observation conditions (Figure 2). The angle of observation was 15 degrees toward the normal direction from the specular reflection angle. Table 2 gives the experimental conditions. Ten observers who were aged 20–50 years and had normal vision participated in the experiment. Participants compared a pair of samples under sunlight conditions (for the sun at its highest point in the sky).

Table 1 Sample conditions

No.	Color	Pigments grade	Observation distance
1	Silver	1	400 mm
2	Silver	2	400 mm
3	Silver	3	400 mm
4	Silver	4	400 mm
5	Silver	5	400 mm
6	Silver	1	1000 mm
7	Silver	2	1000 mm
8	Silver	3	1000 mm
9	Silver	4	1000 mm
10	Silver	5	1000 mm

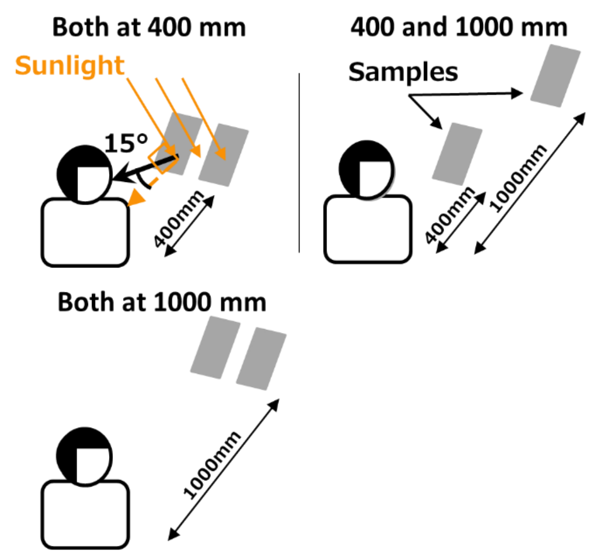

Figure 2. Observation conditions

Table 2 Experimental conditions

Presentation Order	Random
Number of Subjects	10
Observation Distance	400 and 1000 mm
Light Condition	Sunlight (culmination altitude)

Table 3 presents the results of the subjective experiment. The subjective scores were scaled through correspondence analysis [6]. The magnitude of the score represents the strength of the sparkle impression.

Table 3. Results of the subjective experiment

No.	Score
1	-0.657
2	-0.608
3	-0.222
4	0.501
5	1.530
6	-0.659
7	-0.659
8	-0.426
9	0.082
10	1.117

Measurements

Figure 3 is a schematic illustration of the measurement system. The system comprises a spectral camera and a lighting device. The spectral camera recorded spectral images in 31 bands with 10-bit depth. The captured image size was 1280 by 1024 pixels. The image resolution was approximately 1000 dpi (25 µm/pixel). Because the camera recorded spectral images, the images can be converted into L*a*b* format. The lighting device had a xenon light source, which has a spectrum similar to that of sunlight. A telecentric lens collimated the illumination light. The measurement angle was 45 degrees and the illumination angle was 15 degrees from the specular angle to the normal direction.

The brightness contrast in an image was more conspicuous for a sample having a strong sparkle impression than for a sample having a weak sparkle impression. Figure 4 shows an example of recorded images. The contrast in the left image is stronger than that in the right image.

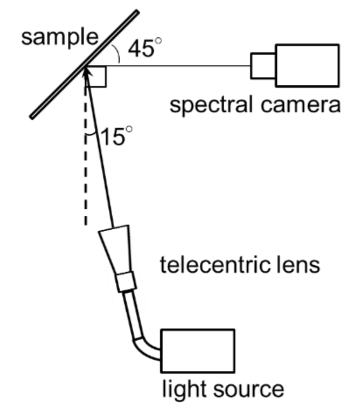

Figure 3. Measurement system

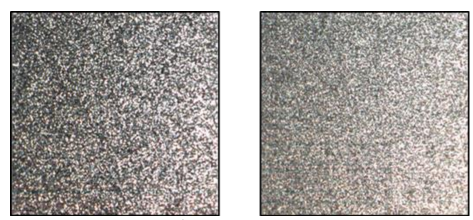

Figure 4. Example of recorded images.

Evaluation Method

We proposed an evaluation model of the sparkle impression applying the graininess evaluation method, which uses spatial frequency characteristics of printed material [7]. Evaluation values were calculated as follows.

1. Conversion from spectral data to L*

The spectral image $O(\lambda, i, j)$ was normalized by the white reference $W(\lambda, i, j)$ to obtain the reflectance image data $R(\lambda, i, j)$ using Eq. (1). Here, λ denotes the wavelength while i and j denote the spatial coordinates.

$$R(\lambda,i,i)=\frac{O(\lambda,i,j)}{W(\lambda,i,j)} \tag{1}$$

The tristimulus values X, Y, and Z were calculated using the spectral distribution $S(\lambda)$ of illuminant D65 and the 10-degree color-matching function $\bar{x}\bar{y}\bar{z}$ [8] as shown in Eq. (2).

$$\begin{cases} X(i,j)=k\int S(\lambda)\cdot\bar{x}(\lambda)\cdot R(\lambda,i,j)d\lambda \\ Y(i,j)=k\int S(\lambda)\cdot\bar{y}(\lambda)\cdot R(\lambda,i,j)d\lambda \\ Z(i,j)=k\int S(\lambda)\cdot\bar{z}(\lambda)\cdot R(\lambda,i,j)d\lambda \\ \quad k=100/\int S(\lambda)\cdot\bar{y}(\lambda)d\lambda \end{cases} \tag{2}$$

Next, $X(i, j)$, $Y(i, j)$, and $Z(i, j)$ data were converted into $L^*(i, j)$, $a^*(i, j)$, and $b^*(i, j)$ data using Eq. (3).

$$\begin{cases} L^*(i,j) = 116\{Y(i,j)/Y_n\}^{1/3} \\ a^*(i,j) = 500\{(X(i,j)/X_n)^{1/3} - (Y(i,j)/Y_n)^{1/3}\} \\ b^*(i,j) = 200\{(Y(i,j)/Y_n)^{1/3} - (Z(i,j)/Z_n)^{1/3}\} \end{cases} \quad (3)$$

X_n, Y_n,, and Z_n are tristimulus values of a perfectly reflecting diffuser (X_n = 94.81, Y_n = 100.00, and Z_n = 107.33 for D65 and 10°).

2. Calculation of spatial frequency characteristics of the L* image

The L*image was trimmed to 600 × 600 pixels. The spatial frequency characteristics of the L* image were obtained from the Fourier transform. For conversion to one-dimensional spatial frequency characteristics, cyclic average values for each spatial frequency (cycles/mm) were calculated. Figure 5 describes this step. In the plot of one-dimensional spatial frequency characteristics, the vertical axis is the amplitude $F(\upsilon)$ and the horizontal axis has the units of cycles per millimeter.

3. Weighting of human visual characteristics

One-dimensional spatial frequency characteristics were weighted by human visual characteristics, namely the contrast sensitivity function (*CSF*) or visual transfer function. *CSF* is the frequency response characteristic of human vision and represents the change in the resolution of human vision with the observation distance. The present evaluation model uses the *CSF* model of Dooley and Shaw as expressed in Eq. (4) [9]. Here, v is the spatial frequency (cycles/degree).

$$CSF(v) = 5.05\exp(-0.138v)\{1 - \exp(-0.1v)\} \quad (4)$$

Figure 6 shows *CSF* for observation distances of 400 and 1000 mm. The vertical axis is the visual sensitivity and the horizontal axis is the spatial frequency υ (cycles/mm). *CSF* is converted from units of cycles per degree to units of cycles per millimeter. The sensitivity peaks at approximately 0.8 and 0.3 cycles/mm.

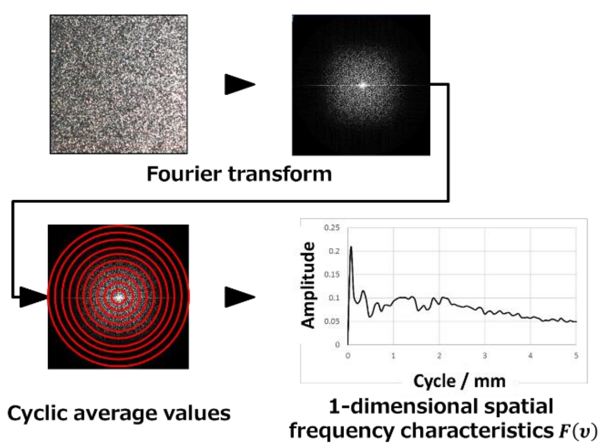

Figure 5. Calculation of spatial frequency characteristics of the L image*

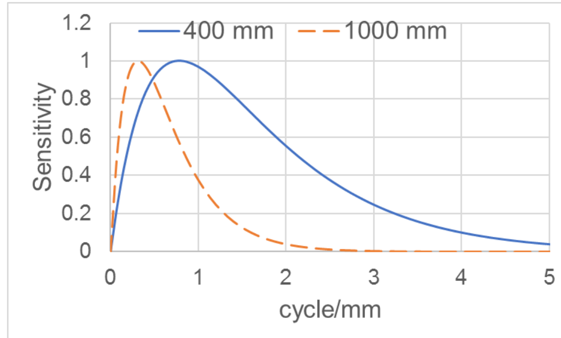

Figure 6. Human visual characteristics for observation distances of 400 and 1000 mm

4. Calculation of the strong reflection value

The sparkle impression is also affected by metallic pigments having particularly strong reflection. The strong reflection value (*SR*) is calculated by taking the average of high L* values of pixels. In this study, we used the 20 pixels having the highest values of L*.

5. Calculation of evaluation values

The evaluation value (EV) used for evaluating the sparkle impression is expressed in Eq. (5). This equation is a logarithm considering the Weber–Fechner law, which means the magnitude of a subjective sensation increases proportionally to the logarithm of the stimulus intensity [10]. Here, parameters p_1 and p_2 were determined via nonlinear regression analysis (p_1 = 0.92 and p_2 = −4.96) and υ is the spatial frequency (cycles/mm).

$$\mathrm{EV} = \log(\int F(\upsilon) \cdot CSF(\upsilon) d\upsilon \cdot SR^{p_1}) + p_2 \quad (5)$$

Results

Figure 7 shows the evaluation results. The vertical axis gives the subjective evaluation scores while the horizontal axis gives the evaluation values. In the figure, there is a strong positive correlation and an R-squared value of 0.81 is obtained ($p < 0.001$). These results indicate that the proposed model has good correlation with the subjective evaluation.

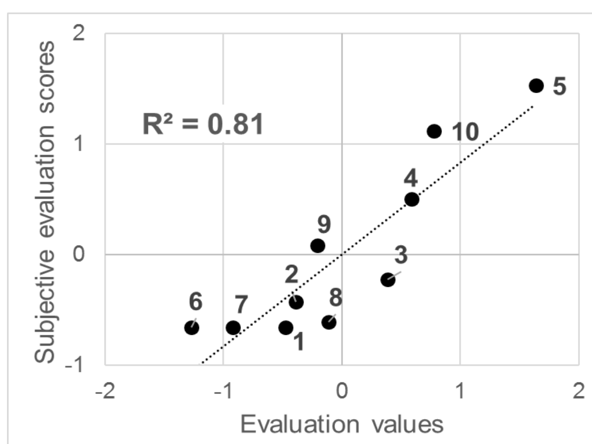

Figure 7. Subjective scores and evaluation values

Discussion

Although the proposed model used *CSF* for human visual characteristics considering the observation distance, the evaluation scores of samples 6 to 10 were smaller than the subjective scores. The reason is assumed to be that *CSF* was proposed on the basis of the experimental result using the image displayed on the cathode ray tube. In contrast, the sample surfaces were bright owing to the reflection of light from metallic pigments. From the above, regarding the sparkle impression observed from a long distance, we assumed that the human sensitivity at high frequency is higher than the sensitivity of *CSF*.

To confirm the hypothesis, a verification experiment was performed by changing the observation distance of *CSF*. To shift the human sensitivity peak in the high-frequency direction regarding the sparkle impression observed from a long distance, for samples 6 to 10, EV was calculated using *CSF* for a distance shorter than the observation distance of 1000 mm. Figure 8 shows *CSF* for observation distances of 500, 700, and 900 mm. The figure confirms that the human sensitivity peak shifts toward the high-frequency domain as the observation distance decreases.

Figure 9 shows the evaluation results. Parameters p_1 and p_2 in Eq. (5) were determined via nonlinear regression analysis for each observation distance. The figure confirms that the R-squared value improves as the human sensitivity in the high-frequency domain increases.

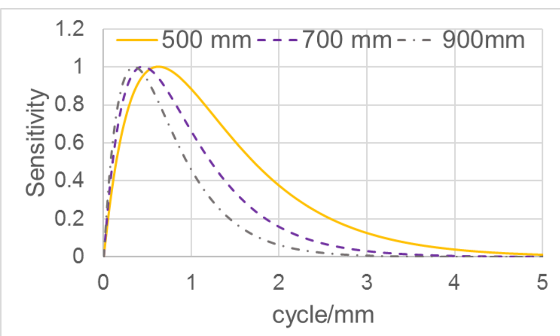

Figure 8. Human visual characteristics for observation distances of 500, 700, and 900 mm

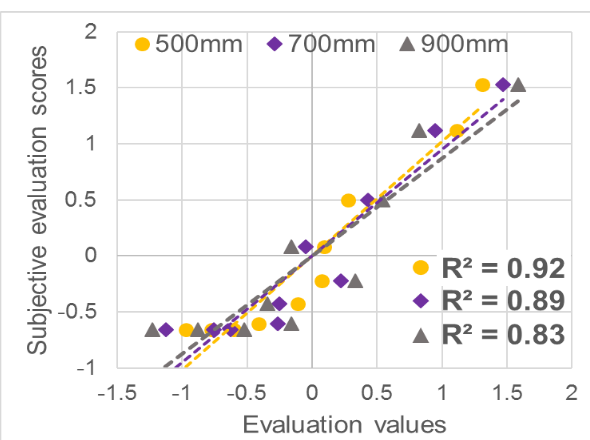

Figure 9. Subjective scores and evaluation values for different CSF

The above results reveal that the sparkle impression is more sensitive to the high-frequency domain than the graininess of printed material.

Conclusions

We proposed an evaluation model for the sparkle impression. To develop a method of evaluating the sparkle impression, we performed a subjective experiment under three observation conditions and proposed a model considering strong reflection from metallic pigments. Evaluation values showed good correlation with subjective scores. Additionally, to improve the correlation with the subjective scores, we examined the sensitivity to a change in visual characteristics at several observation distances. Verification results show that we need to consider a new human visual characteristics model in evaluating the sparkle impression while considering the observation distance.

We plan to propose new human visual characteristics and to evaluate the sparkle impression considering the material surface color in future work.

References

[1] P. Iacomussi, M. Radis and G. Rossi, “Brightness and sparkle appearance of goniochromatic samples,” Electronic Imaging, Material Appearance 2016, pp.1-6, 2016.

[2] C. S. McCamy, “Observation and Measurement of the Appearance of Metallic Materials. Part I. Macro Appearance.” COLOR research and application, Vol.21, pp.292-304, 1996.

[3] Li-Piin Sung, Maria E. Nadal, Mary E. McKnight, Egon Marx and Brent Laurenti, “Optical Reflectance of Metallic Coatings: Effect of Aluminum Flake Orientation,” Journal of Coatings Technology, Vol. 74, No. 932, pp.55-63, September 2002.

[4] Omar Gómez, Esther Perales, Elísabet Chorro, Valentín Viqueira, and Francisco M. Martínez-Verdú, “Visual and instrumental correlation of sparkle by the magnitude estimation method.” Applied Optics, Vol. 55, Issue 23, pp. 6458-6463, 2016.

[5] Scheffé, H., "The Analysis of Variance," New York: John Wiley & Sons, Inc., 1959.

[6] Hirschfeld, H.O. A connection between correlation and contingency. Mathematical Proceedings of the Cambridge Philosophical Society, vol.31, no.4, pp.520-524, 1935.

[7] Susumu IMAKAWA, Makoto HINO and Kenji KAGITANI, “Noise Evaluation Method for Halftone Color Image,” Ricoh Technical Report, No. 23, 1997.

[8] ISO 11664-2:2007 Colorimetry -- Part 2: CIE standard illuminants.

[9] R.P.Dooley and R.Shaw, "Noise Perception in Electrophotography," J. Appl. Photogr. Eng., Vol. 5, No. 4, pp.190-196, 1979.

[10] S Hecht, “The visual discrimination of intensity and the Weber-Fechner law,” Journal of general physiology, vol.7, no.2, pp.235-267, 1924.

Author Biography

Shuhei Watanabe received his B.A. in applied engineering from Hosei University in 2015. Since 2015, he has worked at Ricoh Company, Ltd. His work has focused on the quantification of material appearance using imaging technology. He is a member of the Color Science Association of Japan.