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Measurement and Evaluation Method of Orange Peel

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Abstract

Orange peel is an important appearance quality factor that consists of an irregularity of a surface appearance that resembles the skin of an orange. Several measurement methods for evaluating orange peel have been proposed. However, the correlations of these methods with subjective evaluation scores are insufficient. The purpose of this paper is to develop a new measurement and evaluation method. The measurement system is composed of a spectral camera and lighting device for projecting an evaluation pattern on an object. An evaluation model using the frequency characteristics of the projected pattern image and human visual characteristics is proposed. The results show that the correspondence between the evaluation model values and subjective values is high. Because this method is based on visual inspection, it is expected to be suitable for a wide range of applications.

Introduction

In the visual appearance of materials, the gloss of the surface is an important quality factor. According to Hunter [1], gloss perception can be divided into six different types: 1) specular gloss, 2) contrast gloss, 3) distinctness-of-reflected-Image gloss, 4) haze 5) sheen, and 6) absence-of-surface-texture gloss. A traditional glossmeter is often used to evaluate the gloss appearance of materials in the manufacturing industry. The glossmeter measures the specular reflection gloss of a surface and the measurement method is standardized by ISO 2813 [2]. The glossmeter is useful for measuring the gloss of a surface. However, it is not suitable for evaluating distinctness-of-reflected-image gloss such as “orange peel” because it only measures specular reflection.

Orange peel is the appearance of irregularity on a surface that resembles the skin of an orange [3]. In particular, orange peel tends to be perceived in high gloss and black samples. Figure 1 shows an example of orange peel on black paint samples. The image on the right is worse than the left. Orange peel affects the perception of product quality.

Figure 1. Example of orange peel

Several measuring methods for evaluating orange peel have been proposed. For example, the method standardized by JIS K 7374 [4] measures the reflected light intensity from an object using different sizes of optical slits. The transmitted intensity M and shade intensity m of the slit are measured and the evaluation value is the ratio of $M + m$ to $M - m$. However, because it is not based on human visual characteristics, the correlation between the evaluation values and subjective values is not sufficient.

In contrast, a measurement method that uses a laser point light has been proposed [5]. This method optically scans a wavy light and dark pattern. A laser point light source illuminates the sample at a 60° angle and a detector measures the reflected light intensity at an equal but opposite angle. The optical profiles of the light intensity are measured by rolling across the surface of sample and these profiles are divided into several ranges using mathematical filter functions. This method can analyze the frequency characteristics of orange peel [6]. However, because it is necessary to contact when rolling across it, the surface of the sample could be damaged.

The purpose of this study is to develop a non-contact measurement system and evaluation model that correlates well with the subjective evaluation of orange peel.

Measurement Device

Figure 2 illustrates the setup of the measurement device. The device is composed of a spectral camera and lighting device projects an evaluation edge pattern on an object. The spectral camera measures the spectral images of 31 bands with 10-bit depth. The captured image size is 1280 × 1024 pixels, and the image resolution is about 725 dpi. Because the camera measures the spectral images, the measured image data can be converted into the L*a*b* color space. The light source of the lighting device is xenon. Xenon has a spectrum very similar to that of the sun. The illumination light is collimated by a telecentric lens. To measure the quality of the orange peel, a projection pattern is placed between the sample and the illumination lens. The projection pattern is a frosted glass with an edge pattern formed by aluminum evaporation. This measurement device captures the projected edge pattern on the object with the camera. To measure the projected image, the focus of the camera is adjusted to the virtual image instead of the surface of the object and the edge of the virtual image is distorted when the orange peel is strong.

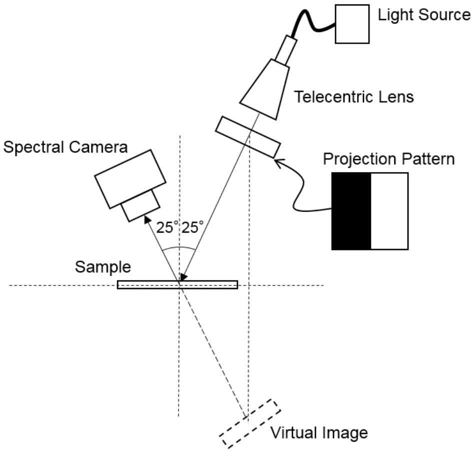


Figure 2. Measurement device

Subjective Experiment

To obtain subjective orange peel evaluation scores for the samples, a subjective evaluation experiment was performed using Scheffe's paired comparison method [7]. Two samples were chosen at random from nine samples. An observer compared these samples and ranked the left sample with respect to the right 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 samples, and the results were scaled using correspondence analysis [8]. Scheffe's paired comparison method can identify any small differences between samples.

Table 1 lists the experimental conditions. All samples used for the evaluation were solid black surfaces and were made by changing the thickness of a clear layer. Twenty-five observers with normal vision participated in this experiment. All observers were image analysis and evaluation engineers with an age range of 20–50 years.

Table 1. Experimental conditions

Evaluation Method	Scheffe's paired comparison
Number of Samples	9 (Solid Black)
Sample Size	150 × 105 mm
Presentation Order	Random
Panels	25
Viewing Distance	500 mm
Light Condition	D65

Figure 3 shows the observation conditions. The participants compared two samples under D65 illumination at a viewing distance of 500 mm while holding the samples. The orange peel was evaluated as the clearness of the shape of the fluorescent lamp reflected from the sample. Table 2 shows the results of the subjective experiments. The magnitude of the subjective score represents the strength of the orange peel. The 20° gloss values obtained by a glossmeter are also given in the table for reference.

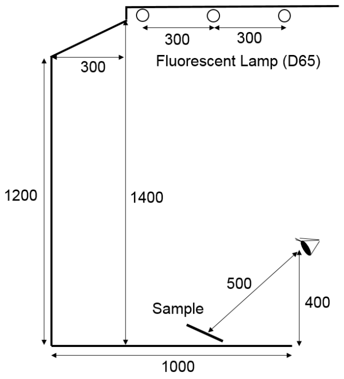


Figure 3. Observation condition

Table 2. Result of the subjective experiment

Sample	Score	G20(%)
1	1.05	85.3
2	0.42	86.9
3	0.76	85.2
4	0.30	85.7
5	0.07	86.4
6	-0.20	86.7
7	-0.62	86.0
8	-0.84	85.9
9	-0.95	85.3

Evaluation Method

In this session, the proposed evaluation method using the frequency characteristics of the projected pattern image and visual characteristics is described. The evaluation value is calculated using the following steps:

1. Sample measurement:

First, a standard white reflectance sample is measured using the device to normalize the sample spectral data. The luminosity values are denoted by $W(\lambda, i, j)$, where (i, j) denotes the spatial coordinates and λ denotes the wavelength. The system measures 31 bands from 400 nm to 700 nm in intervals of 10 nm. Next, the samples for the orange peel evaluation are measured using the device. The luminosity values are denoted as $O(\lambda, i, j)$.

2. Conversion from spectral data to L*:

Spectral image $O(\lambda, i, j)$ is normalized by white reference $W(\lambda, i, j)$ to convert it into reflectance image data $R(\lambda, i, j)$ using Eq. (1).

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

The tristimulus values XYZ are calculated using the spectral distribution $S(\lambda)$ of illuminant D65 and the 10-degree color-matching function $\bar{x}\bar{y}\bar{z}$ [9] shown in Eq. (2).

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

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 using Eq. (3).

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

The X_n, Y_n, and Z_n values are the tristimulus values of a perfect reflecting diffuser ($X_n=94.81, Y_n=100.0,$ and $Z_n=107.33$ for D65/10°).

3. Extraction of the image feature:

The L*image is trimmed to 800×800 pixels and binarized to extract the edge pattern of the projected image. Figure 4 shows examples of the binary images. The edge distortion of Sample 1 is the worst.

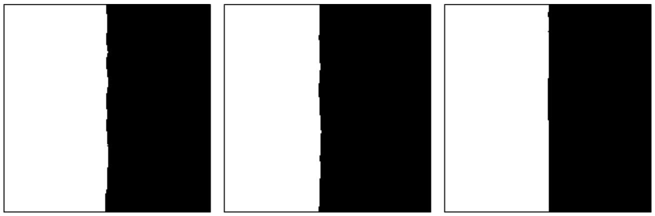
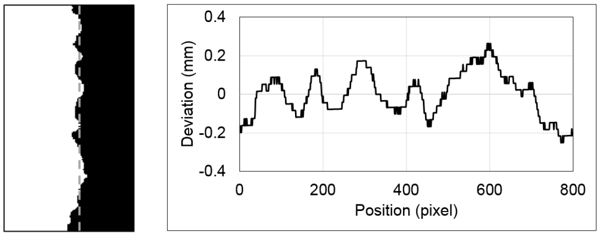

Sample 1 Sample 5 Sample 9

Figure 4. Example binary edge images

The edge is approximated by a straight line to quantify the distortion of the edge pattern. The straight line is fitted using the least squares method to the edge. The deviation between the edge shape and the straight line is calculated, which indicates the distortion of the edge. Figure 4-(a) shows an enlarged view of the edge region of Sample 1. The fitted straight line is indicated by a dashed line. Figure 4-(b) shows the deviation between the edge shape and the straight line.



(a) Edge shape (b) Deviation of the edge pattern

Figure 4. Calculation of the edge distortion

4. Visual characteristic weighting:

The deviation is processed using Fourier transform to apply the visual characteristics. Figure 5 shows the frequency characteristics of Samples 1 and 9 after the Fourier transform. The vertical axis is amplitude *F(v)* and the horizontal axis is the spatial frequency *v* [cycle/mm].

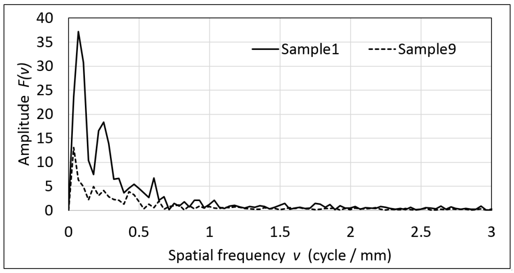


Figure 5. Example of the frequency characteristic

The frequency characteristic is weighted by the visual transfer function *(VTF),* which represents the frequency response of human vision. *VTF* reflects how the resolution of the human vision changes according to observation distance. This evaluation model used the Dooley and Shaw VTF model [10] shown in Eq. (4).

$$VTF\,(u) = 5.05\exp(-0.138u)\{1-\exp(-0.1u)\} \qquad (4)$$

u: spatial frequency (cycle/degree)

The observation distance is assumed to be 500 mm and the *VTF* is converted from cycle/degree to cycle/mm. Figure 6 shows the *VTF(v)* when the observation distance is 500 mm. The vertical axis is visual sensitivity and the horizontal axis is spatial frequency *v* [cycle / mm]. The peak of the sensitivity is about 0.6 cycle/mm.

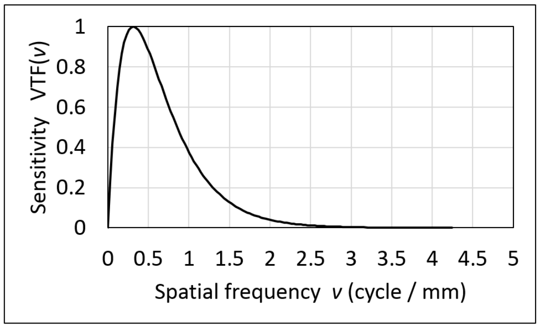


Figure 6. Visual transfer function (VTF) (observation distance : 500 mm)

Orange peel noise *N* is calculated using Eq. (5), which is the integral of the frequency characteristic after weighting.

$$N = \int F(v)\cdot VTF(v)dv \qquad (5)$$

v: spatial frequency (cycle/mm)

Results and Discussion

Figure 7 shows the result of the correlation between the orange peel noise *N* and the subjective evaluation scores. There was a strong positive correlation. The relation of noise *N* and score was approximated using a logarithmic function according to the Weber–Fechner law. The magnitude of a subjective sensation increases proportionally to the logarithm of the stimulus intensity.

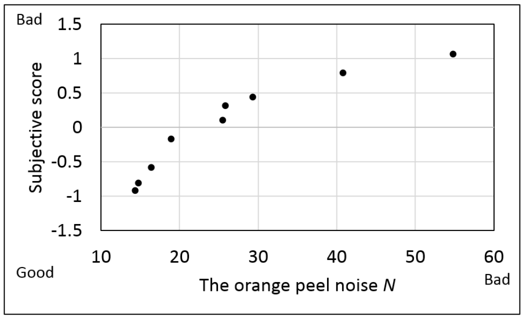


Figure 7. The subjective scores and the orange peel noise N

The orange peel evaluation value (*OPEV*) is proposed based on the above result. Its formula is calculated using Eq. (6).

$$OPEV = p_1 \cdot \log(N+1) + p_2 \tag{6}$$

Here, parameters p_1 and p_2 are determined via a nonlinear regression analysis ($p_1 = 1.55$ and $p_2 = -5.03$). To prevent divergence of the evaluation value at zero, 1 was added to *N*. Figure 8 shows the correlation between *OPEV* and the subjective evaluation scores. An R-squared value of 0.957 was obtained.

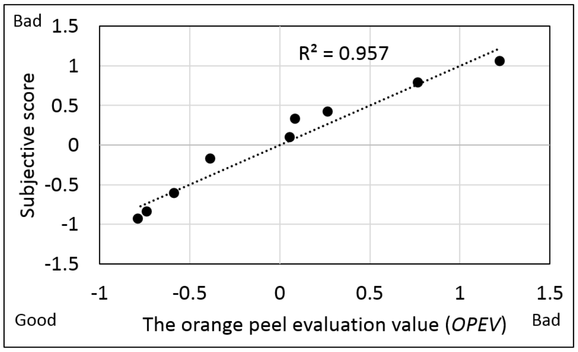


Figure 8. Subjective scores and OPEV

Verification

In order to confirm the validity of this model, a verification experiment was performed using “ACT Orange Peel Standard samples”, which consist of ten 4×6 inch panels with graduated degrees of orange peel from rough to smooth. Each panel within the set is painted solid black and ranked from 1 to 10.

Figure 9 shows the correlation between OPEV and orange peel ranking. The correspondence of the evaluation model with the rank is very high.

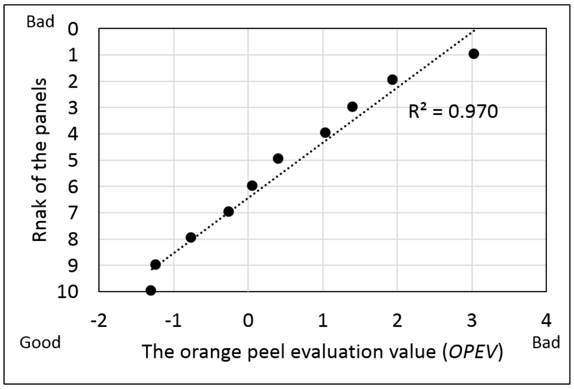


Figure 9. Ranks of ACT panels and OPEV

Conclusions

A new measurement and evaluation method for the orange peel was developed. The method is based on the distortion of a projected edge image and the frequency response characteristics of human vision. The evaluation values showed good correlation with subjective scores. Because the method is a non-contact evaluation method, it will be suitable for a wide range of applications.

Furthermore, the method will be able to evaluate colored samples because the measurement device uses a spectral images.

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