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PHYSICAL INDICES FOR REPRESENTING MATERIAL PERCEPTION WITH REGARD TO GLOSSINESS, TRANSPARENCY, AND ROUGHNESS

Midori Tanaka et al.

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CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

PHYSICAL INDICES FOR REPRESENTING MATERIAL PERCEPTION WITH REGARD TO GLOSSINESS, TRANSPARENCY, AND ROUGHNESS

Tanaka, M.[1], Osumi, M.[2], Horiuchi, T.[1]
[1] Chiba University, Chiba, JAPAN, [2] Office Color Science Co., Ltd., Yokohama, JAPAN
midori@chiba-u.jp

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Abstract

The final goal of this study is to build a total appearance model for human perception of the qualities of a material. To achieve this objective, we propose physical indices for modelling perception with regard to glossiness, transparency, and roughness by investigating the relationship between measurable physical properties and the appearance of real materials in this study. In our physical measurements and subjective evaluations, we used 34 stimuli exemplifying ten material categories. As a result, we found physical indices corresponding to subjective perception as follows: (1) The index of perceptual gloss correlates to a nonlinear transform of physical glossiness. (2) The index of perceptual transparency corresponds to the luminance difference of material surfaces with white vs black backgrounds. (3) The index of perceptual roughness correlates to the edge intensity detected from the captured images.

Keywords: Total appearance, Glossiness, Transparency, Roughness, Psychometric evaluation, Physical measurement

1 Introduction

In addition to colour recognition, evolution has given us various other abilities for instant recognition of object qualities through sight. In the field of imaging science and technology, the study of the material appearance of objects has been actively discussed with consideration of the visual appearance information including factors such as surface texture in addition to colour. In our previous study, we investigated the perceptual appearance of materials obtained from real objects and their rendered images by conducting psychometric experiments. If perceptual characteristics can be estimated by physical measurements, human material perception can be effectively predicted without such psychometric experiments. Moreover, the establishment of new perceptual models and formulae is desirable for correctly representing the total perceptual appearance of real objects. Our specific objective is to find effective physical indices by analysing the relationship between physical qualities and the perceptual appearance.

2 Stimuli

In this study, we prepared a dataset of 34 stimuli (size: 50 mm x 50 mm) selected from 10 material categories—stone, metal, glass, plastic, leather, fabric, paper, wood, ceramic, and rubber—thereby covering a wide range of material appearances. Figure 1 shows all the materials with their names. Each category included two or more specific stimuli. A previous study (Albertazzi et al., 2013) showed that colour has a strong influence on perceptual qualities. Therefore, we tried to collect specific stimuli with low colour saturation.

3 Psychometric Evaluations

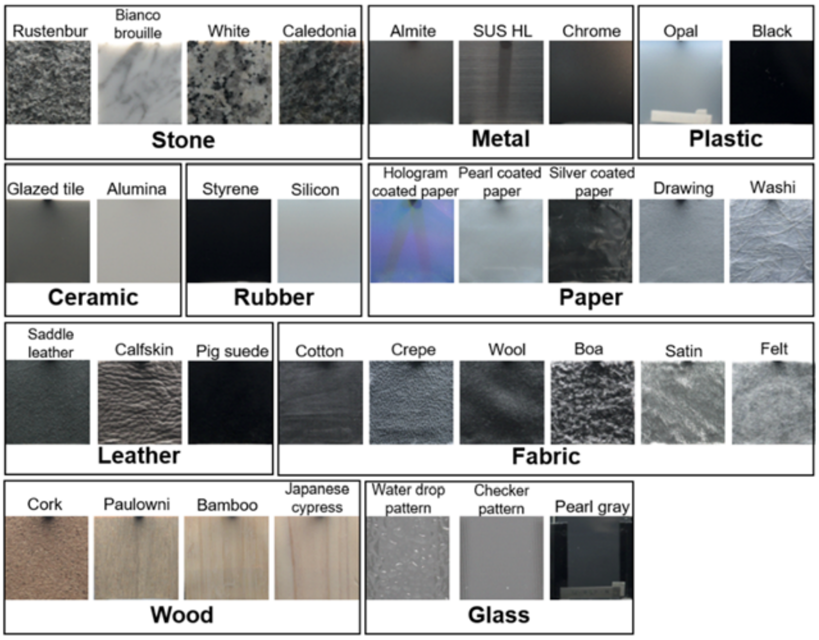
We used data from psychometric evaluations (Tanaka et al., 2015), which investigated the perceptual appearance of various materials using the same real materials as shown in Fig. 1.

3.1 Method

In the experiment, the participants were asked to make judgments based on the perceptual qualities of real materials. Figure 2 shows the experimental environment using a viewing booth (Macbeth Judge II) with a CIE D65 Average North Sky Daylight. The inside of the viewing booth was covered with low-gloss black felt. The viewing distance was 300 mm, and the viewing angle was always 0°. The distance from the light source to the centre of the material was 230 mm and the stimulus was placed at an inclination angle of 5° to the vertical direction. The observers evaluated the perceptual glossiness, transparency, and roughness using a 6-point scale [0-5] for each stimulus in the real material dataset. The procedure of the experiment followed that of the conventional report (Fleming et al. 2013). Ten participants, nine males and one female, participated in this experiment. All the experiments were conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

3.2 Results

All the observers had normal colour vision and enough visual power to judge the appearance of the material surface. Most of our results were identical to Fleming's study, but there were some significant differences. Our study included some less conventional stimuli such as hologram coated paper, silver coated paper, and satin.



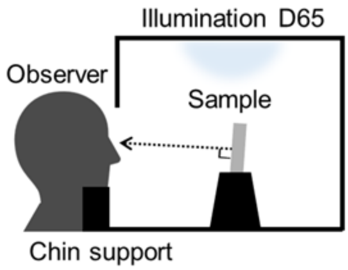


Figure 1 – Experimental material dataset **Figure 2 – Experimental environment**

4 Physical Measurements

To obtain the physical characteristics, we captured the images of 34 stimuli and made various optical property measurements. For the physical measurement, as listed in Table 1, we used the following six devices: a multi-angle spectrophotometer (BYK-Gardner GmbH, BYK-mac i), a digital camera (Canon, 5D Mark IV), a gonio spectrophotometer (Murakami Color Research Laboratory GSP-2), two gloss meters (Rhopoint Instruments, Rhopoint IQ-S and Canon, RA-532H), and another spectrophotometer (Konica Minolta, CS-2000).

4.1 Image Properties

As image capturing devices, we used the multi-angle spectrophotometer and the digital camera. The image properties used for our analysis are summarized in Table 1(a). As basic properties, we investigated the statistical features in both the frequency and image domains. In our preliminary investigation, the anisotropic features in the frequency domain were found to be correlated with the psychometric evaluations (Tanaka et al., 2016, 2017). Therefore, we analysed the anisotropic features in the frequency domain. We also applied the Laplacian filter to obtain the edge intensity of texture information. In addition to analysing their textures, we captured the images of real materials with white and black backgrounds to detect the light transmitted through the materials (which indicates transparency).

4.2 Optical Properties

As measurement devices to investigate optical properties, we used five devices, excluding the digital camera. The image properties used for our analysis are summarized in Table 1(b). As basic properties, we investigated the statistical features from the bidirectional reflectance distribution function (BRDF), because spatial changes in the reflection produced by minute unevenness of the surface can affect judgments of perceptual appearance. We also measured properties such as gloss scale, haze, and distinctness of image (DOI), which can be measured with a standard gloss meter. In addition to the above reflectance property, we also measured the luminance for each stimulus with different white and black backgrounds.

Table 1 – List of Devices and Measured Physical Properties

(a) Image properties

Device	Property
Multi-angle spectrophotometer BYK-mac i	Condition: (Diffused, A-normal -15°, 45°, 75°) - Anisotropy histogram: Skewness, Kurtosis, Variance, Average - Grey histogram: Skewness, Kurtosis, Standard deviation
Digital camera 5D Mark IV	Condition 1: (The same as psychometric evaluation) - Anisotropy histogram: Skewness, Kurtosis, Variance, Average - Grey histogram: Skewness, Kurtosis, Standard deviation, Average, Entropy - Edge intensity by applying Laplacian filter to the grey image with 300×300 pixels. Condition 2: (Difference image between white and black backgrounds) - Anisotropy histogram: Skewness, Kurtosis, Variance, Average - Grey histogram: Skewness, Kurtosis, Standard deviation, Average

(b) Optical properties

Device	Property
Multi-angle spectrophotometer BYK-mac i	Condition: (incident angle (A-normal) -45°, acceptance angle (A-normal) 60°, 30°, 20°, 0°, -30°, −65°) - BRDF histogram: Skewness, Kurtosis, Standard Deviation
Gonio spectrophotometer GSP-2	Condition: (incident angle -50°~+50° (in 10° steps), acceptance angle 0°) - BRDF histogram: Skewness, Kurtosis, Standard Deviation
Gloss meter Rhopoint IQ-S	Gloss scale (20°, 60°, 85°), Haze, LogHaze, DOI, Peak specular reflectance (Rspec), Reflected image quality (RIQ)
Gloss meter RA-532H	Gloss scale (20°, 60°, 85°), Specular width (C20, C60), Haze, DOI, BRDF volume (20°, 60°), BRDF intensity (20°, 60°)
Spectrophotometer CS-2000	Luminance (Black and white backgrounds)

5 Relationships between Physical Properties and Perceptual Appearance

The significance of the psychometric evaluations for each stimulus was verified using a t-test after excluding the outlier data using the Smirnoff–Grubbs test. The correlations between the psychometric evaluations and the physical characteristics were calculated, and the following strong correlations were confirmed for each appearance factor.

- Perceptual gloss was strongly correlated with the gloss unit (GU) scale measured by the gloss meters and the BRDF statistics measured by the Gonio photometer.

- Perceptual transparency was strongly correlated with the luminance difference of real materials and the variance of anisotropy histogram obtained from the difference images between black and white backgrounds.
- Perceptual roughness was strongly correlated to the edge intensity of the captured image. In addition, the skewness and the standard deviation of the grey histogram had significant correlation.

From these findings, we further considered describing the psychometric evaluations of perceptual appearance from the most correlated physical properties.

5.1 Glossiness

We define the normalized psychometric assessment value of glossiness as "*Perceptual Gloss* (PG)," which is given as follows:

$$Perceptual\ Gloss\ [\mathrm{PG}] = \alpha(Physical\ Gloss)^m\ [GU] \quad (1)$$

where

α: Normalization factor,

$Physical\ Gloss$: Maximum value among physical gloss {Gloss 20°, 60°, 85°} (ISO2813),

m: Multiplier factor ($m = 0.58$).

The correlation for the 34 stimuli is shown in Fig. 3(a). By using the maximum physical gloss scale among three measurement angles (20°, 60°, 85°) based on ISO2813 as 'physical gloss', the correlation was best with perceptual gloss evaluations (R^2=0.724). Stimuli that could not be estimated with sufficient accuracy were glasses, fabrics, and stones that have transparency and roughness as well as glossiness.

5.2 Transparency

"*Perceptual Transparency* (PT)" was defined as the psychometric assessment value of transparency using the physical measurements data as follows:

$$Perceptual\ Transparency\ [\mathrm{PT}] = \alpha(Luminance\ Difference)^m \quad (2)$$

where

α: Normalization factor,

$Luminance\ Difference$: Luminance difference with white vs black backgrounds,

m: Multiplier factor ($m = 0.60$).

The correlation for the 34 stimuli is shown in Fig. 3(b). We confirmed that the correlation between PT and the characteristics of physical measurement was very high (R^2=0.938).

5.3 Roughness

We define "*Perceptual Roughness* (PR)" as the psychometric assessment value of roughness by using the physical measurements data such as texture characteristics as follows:

$$Perceptual\ Roughness\ [\mathrm{PR}] = \alpha(Texture\ Characteristic)^m \quad (3)$$

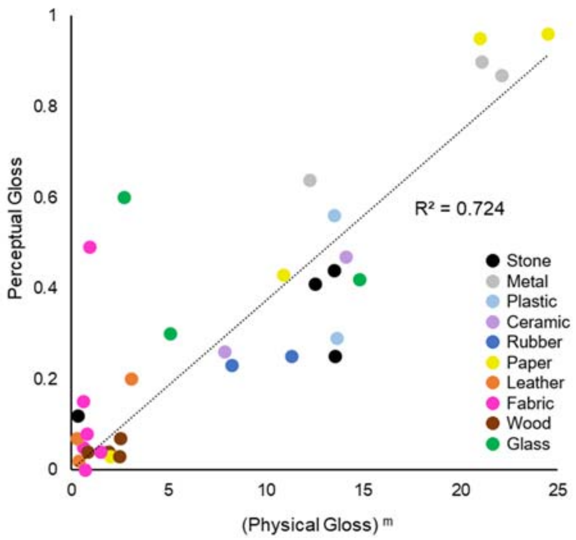
where

α: Normalization factor,

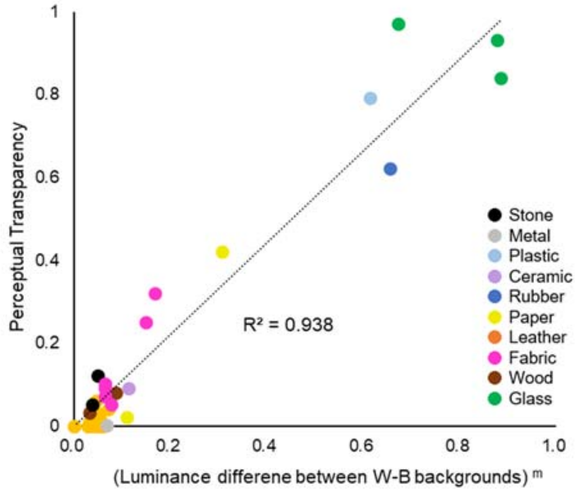
$Texture\ Characteristic$: Edge intensity using the Laplacian filter,

m: Multiplier factor ($m = 0.39$).

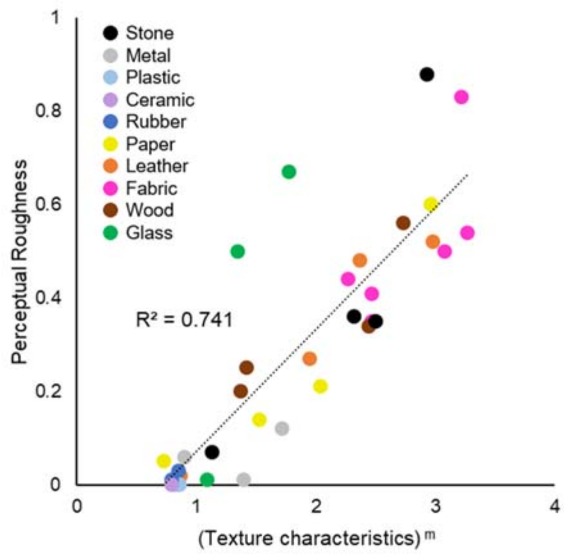
The perceptual roughness was estimated by applying the Laplacian filter to a captured grayscale image. The correlation for the 34 stimuli is shown in Fig. 3(c). We confirmed a high correlation for PR (R^2=0.741), but four data stood apart from the linearization line. The material categories of these outliers were glass, stone, and fabric, and they had very uneven surfaces as a common characteristic.



(a) Glossiness



(b) Transparency



(c) Roughness

Figure 3 – Relationship between physical values and perceptual appearance

6 Conclusion

In this study, we found effective indices for representing material appearance by analysing the relationship between the physical data and the perceptual appearance. In our physical measurements and subjective evaluations, we used various materials comprising ten material categories to describe the three appearance factors of glossiness, transparency, and roughness. As a result, we observed physical indices for describing each appearance factor as follows: (1) The index of perceptual gloss corresponded to a nonlinear transform of physical glossiness. (2) The index of perceptual transparency corresponded to the luminance difference of material surface upon white and black backgrounds. (3) The index of perceptual roughness was correlated to the edge intensity detected from the captured images. The estimate of each appearance factor will be further improved obtaining further experimental data in the future. Our results indicate that it may be possible to construct a total appearance model representing not only colour but also multiple appearance factors such as glossiness and roughness.

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