Gloss and Material Constancy in the Change of Light Source Size

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Abstract

It is well-known that gloss appearances are observed as the results of association among various physical factors. In order to analysis this association, perception for constancy is very important characteristic features. In this paper, therefore, we verify the influence in gloss and material constancy under the artificial environment by changing the shape and size of light source. We performed two type observations in subjective evaluation, one is the "gloss appearance" which is mainly observed the distribution of specular reflection, and the other is "material appearance" which is mainly observed all distribution of specular and diffuse reflection influenced roughness as whole appearance of object. We prepared two kinds of object which has different roughness, and four kinds of light image generated by LCD projector. A paired comparative experiment was performed under different light source with real object. As the result, there was no obvious gloss constancy when we observed only the distribution of specular reflection, since the shape and size of light source gave a great influence to the gloss perception. On the other hand, an effect of material constancy appeared when we observed all distribution of specular and diffuse reflection influenced roughness as whole appearance of object.

1. Introduction

In everyday life, we need to identify various objects by using their features, which are size, shape, and appearance caused by surface reflection. These features, especially for appearance, are varied depending on the lighting condition such as power, direction, and spectral distribution. Here, it is well-known that these appearances are observed as the results of association among various physical factors. For example, the color appearance is specified by multiplication of light source color (spectral distribution of light source) and object color (reflectance of object). Since the rate of contribution by each color is uncertain, it is difficult to recognize which color is changed when the appearance of object is changed. In order to respond this ill-posed problem, we have an ability to estimate the primary color of object through an adaptation, even if only the light source color is changed. It is called as color constancy which is remarkable ability of human eyes.

For the color constancy, Von Kries suggested that human eyes can correctly perceive the color of objects by producing the chromatic adaptation [1]. This reasonable assumption is based on the scaling change of cone sensitivity with absolute white to compensate for the change of light source color. Improved chromatic adaptation model was proposed in which the nonlinear process is appended to Von Kries's chromatic adaptation model [2]. Based on these adaptation models, color constancy of human vision such as brightness, saturation and color is applied to many applications as a reasonable approximation. Numerical model about CIECAM97 and CIECAM02 are famous contributions of color constancy for an accurate estimation of human vision [3][4][5].

Other visual perception is also expected to have some constancy. For example, gloss appearance is one of the important features for object recognition and material classification. According to the chromatic adaptation model, gloss appearance is also affected in varying degree about brightness of specular reflection and contrast between surface and diffuse reflection. Gaël *et al*. performed gloss constancy test by using real surface with two different light angles [6]. In their experiment, observer can accurately arrange test peaces in a unique order of roughness under different light condition. Gaël *et al*. conclude that this result is proof enough for gloss constancy in human vision. However, their experiment has different from reality about the light condition which is changed only light angle in their paper. Generally in real world, light condition must change not only light angle but also light distribution and/or shape of illumination.

In this paper, therefore, we perform experiments for gloss and material constancy under the artificial environment. By changing light sources with various shape of illumination, we investigate detail characteristic which relate to gloss and material constancy. Moreover, we use multi-dimensional scaling to analysis the order of gloss and material appearance based on the perceptually uniform gloss space proposed by Pellacini *et al.* in [7].

2. Perceptually uniform gloss space

We perform experiments of the perceived difference about gloss and material appearance to clarify the degree of gloss and material constancy. For this purpose, the quantitative characteristics were needed to express glossiness. We used the perceptually uniform gloss space by Pellacini *et al*. They performed experiment of the perceived difference about gloss appearance with rendering images. These images were rendered with an isotropic version of Ward's light reflection model. Ward defines this BRDF model as follow.

$$\rho(\theta_i,\phi_i,\theta_o,\phi_o)=\frac{\rho_d}{\pi}+\rho_s\cdot\frac{\exp[-\tan^2\frac{\delta}{\alpha^2}]}{4\pi\alpha^2\sqrt{\cos\theta_i\cos\theta_o}}\ , \qquad (1)$$

where $\rho(\theta_i, \phi_i, \theta_o, \phi_o)$ is the surface BRDF, θ_i, ϕ_i, and θ_o, ϕ_o are spherical coordinates for the incoming and outgoing direction, and δ is the half-angle between them. Three parameters of Ward's model are ρ_d, ρ_s, α, where ρ_d is the diffuse reflectance on the object surface, ρ_s is the specular reflectance on the object surface, and α is the spread of the specular lobe [8].

Pellacini *et al*. analyzed the results of subjective evaluation by multi-dimensional scaling (MDS). MDS is one of the analysis techniques for similarity and dissimilarity in the combination of objects. It is possible to arrange the data such as the distance between the several points in given number of dimensional space [9].

The most appropriate number of dimensions is obtained as the following stress formula.

$$stress = \sum_{i,j} [\delta_{i,j} - d(x_i, x_j)]^2 \ , \tag{2}$$

where $\delta_{i,j}$ is the input proximities, x_i and x_j are the recovered locations in the n^{th} dimensional solution, and $d(x_i, x_j)$ is a measure of the distance between them. In MDS, the stress value is minimized in each dimension. Since there are many stress formula, there are many kinds of MDS algorithm. Pellacini *et al*. used the PROXSCAL algorithm [10] to analyze the data. By this analysis, they found parameters that were calculated from the parameters in Ward's light reflection model as follows.

$$d = 1 - \alpha \ , \tag{3}$$

$$c = \sqrt[3]{\rho_s + \frac{\rho_d}{2}} - \sqrt[3]{\frac{\rho_d}{2}} \ , \tag{4}$$

where d is defined as distinctness-of-image(DOI) gloss parameter, and c is defined as contrast gloss parameter.

By using these parameters, in this paper, we challenge to clarify the degree of gloss and material constancy under the situation where the lighting condition was changed and the surface roughness was not changed.

3. Experiment

3.1 Purpose

The purpose of this experiment is to verify the gloss and material constancy by changing a size and shape of light. Here, it is noted that we pay attention to evaluate two parts of appearances, one is "gloss appearance" which is mainly observed the distribution of specular reflection, and the other is "material appearance" which is mainly observed all distribution of specular and diffuse reflection influenced roughness as whole appearance of object. We build the light booth that can perform a pair comparative experiment, and analyze influence on gloss and material appearance using MDS in perceptually uniform gloss space.

3.2 Setup

Figure 1 shows a light booth that can use the binocular septum method to perform a paired comparative experiment under different light source with real object. The dimension of the light booth is 960mm height, 475mm width, and 356mm depth. At the top of this booth, LCD projector (EPSON EB-1900) is set as a light source. A white paper is inserted at the middle of light booth, where is a focus plane of projector. Here, the light booth is covered with black nonwoven fabrics to prevent redundancy light in the projection plane. In order to evaluate the gloss and material constancy by changing the shape of light, we prepare four kinds of light image generated by LCD projector as shown in Figure 2. We use area light and three circular lights where the radius of light size is 18.5mm (40 pixel on projection image), 37.1mm (80 pixel on projection image), and 55.6mm (120 pixel on projection image), respectively. These light sources are adjusted to same illuminance on the observation plane, and the value of illuminance is about 12.8 lx.

As the objects for evaluation in comparison experiment, we use two real objects as shown in Figure 3. These objects form a cylinder shape which has 50 mm diameters and 100 mm length. These objects are wrapped by different papers which have same chromaticity but different roughness. Figure 4 shows the measurement results of BRDF in each wrapped papers.

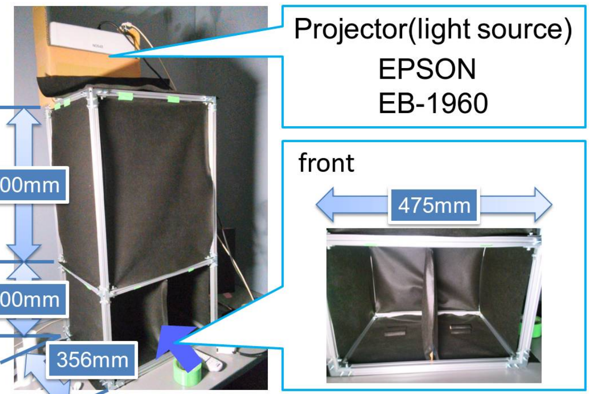
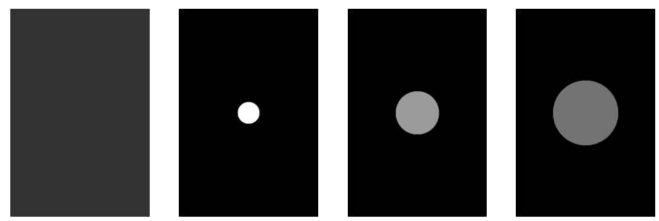


Figure 1. *Experiment system for our evaluation*

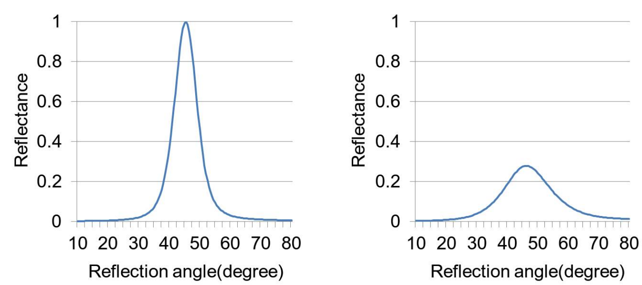


(a) (b) (c) (d)

Figure 2. *Four kinds of light image. (a) area light. (b) circular light with 40px, (c) circular light with 80px, and (d) circular light with 120px*

(a) (b)

Figure 3. *Two kinds of object. (a) is wrapped by high gloss paper. (b) is wrapped by low gloss paper*



(a) (b)

Figure 4. *Reflectance of wrapped papers, (a)high gloss paper, (b) low gloss paper*

3.3 A paired comparison experiment

Ten subjects in their twenties participated in this experiment. In this experiment, wrapped objects were put in the light booth, and the subjects viewed pairs of combinations of objects illuminated by each light source. The viewing distance between observer and object is about 300 mm, and this experiment was performed by haploscopic matching technique.

Subjects were asked to judge the perceived difference about gloss appearance and material appearance by using the pair combinations of objects and light sources. Here, it is again noted that we pay attention to evaluate two parts of appearances, one is "gloss appearance" which is mainly observed the distribution of specular reflection, and the other is "material appearance" which is mainly observed all distribution of specular and diffuse reflection influenced roughness as whole appearance of object. These differences in gloss and material appearance are judged from 0 to 100, namely, 0 means small difference and 100 means large difference. This scale was used by Pellacini *et al*. to create a perceptually uniform gloss space [7]..

We prepared 28 pairs in the stimulus set, which consist of combinations from two kinds of material and four kinds of lighting shape. After these experiments, the scores evaluated by subjects were stored as 8 x 8 proximity matrix. All ten proximity matrices were analyzed by PROXSCAL MDS algorithm using the Euclidean non-metric stress formulation in IBM SPSS.

3.4 Transform MDS space into perceptually uniform gloss space

We analyzed the difference in gloss and material appearance by using MDS which is related to the perceptually uniform gloss space. Here, the perceptually uniform gloss space expressed by contrast gloss and DOI gloss is defined by the limited case which is evaluated by using area light source. Therefore, we transform the measured scores to the perceptually uniform gloss space based on the area light data in MDS space, as shown in Figure 5.

In order to project our scores in MDS space to the perceptually uniform gloss space, we have to acquire diffuse reflectance ρ_d, specular reflectance ρ_s, and specular lobe α for calculation of DOI gloss parameter d and contrast gloss parameter c. Therefore, we measured the BRDF of covering papers, high gloss sample and low gloss sample, by using gonio spectral photometer (GSP-2S, Murakami Color Research Laboratory) . By fitting Ward's reflection model to the measured BRDF, all parameter, ρ_d , ρ_s , α are obtained.

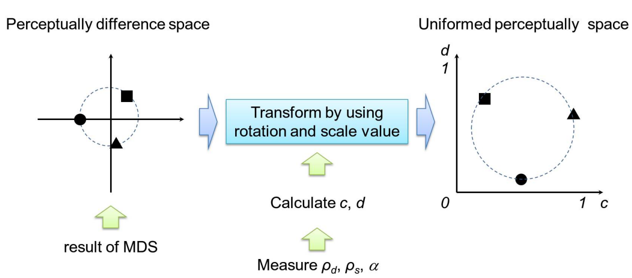


Figure 5. *Illustration of our transformation from MDS measured space to perceptually uniform gloss space. Each measured value are acquired by fitting measured BRDF of wrapped papers. The gloss parameters are calculated from Equation (3) and (4).*

At the next step, we calculate rotation and scale factor for projection to perceptually uniform gloss space, since our scores in MDS space are expressed in arbitrary units and directions. Therefore, we derive the transform equation as shown in Equation (5) and (6).

$$rad = \arctan\left(\frac{d_h - d_l}{c_h - c_l}\right) - \arctan\left(\frac{y_h}{x_h}\right), \quad (5)$$

$$s = \sqrt{\frac{(c_h - c_l)^2 + (d_h - d_l)^2}{x_l^2 + y_l^2}}\ , \quad (6)$$

where rad and s are rotation angle and scale factor, c_h and d_h are parameter on the perceptually uniform gloss space of high gloss sample, and c_l and d_l are parameter on the perceptually uniform gloss space of low gloss sample, which are calculated by Equation (3), (4). Here, x_h and y_h are anchoring score points measured by using area light source in high gloss sample, and x_l and y_l are anchoring score points measured by using area light source in low gloss sample. By rotating and scaling in each sample, our scores are accurately projected into the perceptually uniform gloss space.

4. Results

4.1 Gloss appearance evaluation

Figure 6 shows the result of gloss appearance evaluation in MDS space, and Figure 7 shows the projected result of gloss appearance evaluation in the perceptually uniform gloss space. Each point indicates an average value of 10 subjects. This projected result is useful to compare the result of perceptually appearance evaluation. Here, though the score of circular 40px and 80px slightly exceed the uniformed range by transforming the MDS space to the perceptually uniform gloss space, it is acceptable to compare the difference of each other.

For the difference of objects, a broadly-divided result indicates between high and low gloss paper. However, the difference of score between circular 120px by high gloss sample and circular 40px by low gloss sample is very contiguous in Figure 7. Both samples under the circular light are higher contrast than samples under the Area light. DOI gloss decrease with increasing radius of circular light in each of the samples.

4.2 Material appearance evaluation

Figure 8 shows the result of material appearance evaluation in MDS space, and Figure 9 shows the projected result of material appearance evaluation in the perceptually uniform gloss space.

A broadly-divided result also indicates between high and low gloss paper as same as "gloss appearance" for the difference of objects. Especially, the explicit distinction between high gloss sample and low gloss sample appeared in this result. The difference of score between area light and circular light is more distant than the difference of score between area lights. Moreover, it is very interesting that the results of each circular light is independent even if the scores of circular light in Figure 7 are in the same order as light size.

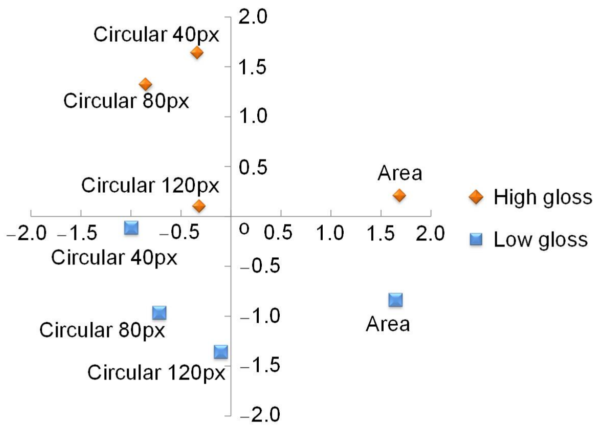


Figure 6. The difference in gloss perception. A description of each point is used lighting shape. An orange rhombus means the one object which wrapped by high gloss paper. A blue square means the other object which wrapped by low gloss paper.

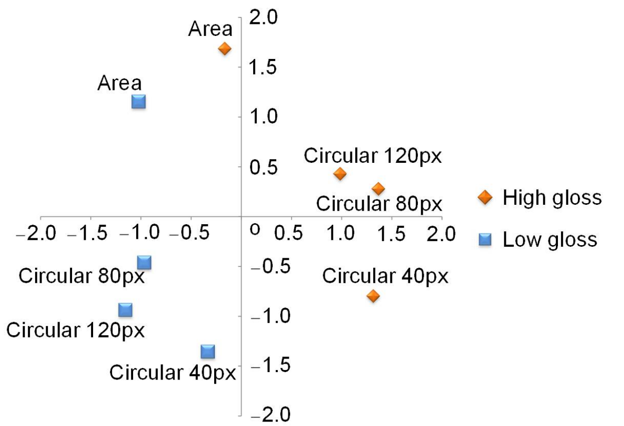


Figure 8. The difference in material perception. A description of each point is used lighting shape. An orange rhombus means the one object which wrapped by high gloss paper. A blue square means the other object which wrapped by low gloss paper.

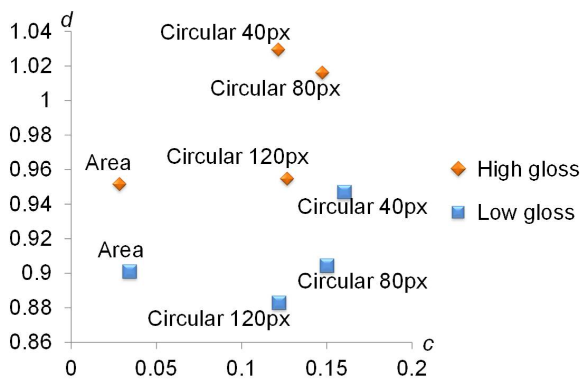


Figure 7. "Gloss appearance" on the perceptually uniform gloss space. This means the difference in gloss perception. A description of each point is used lighting shape. An orange rhombus means the one object which wrapped by high gloss paper. A blue square means the other object which wrapped by low gloss paper.

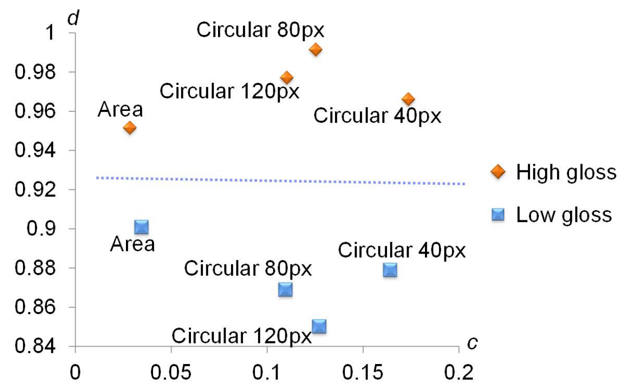


Figure 9. "Material appearance" on the perceptually uniform gloss space. A description of each point is used lighting shape. This means the difference in gloss perception. An orange rhombus means the one object which wrapped by high gloss paper. A blue square means the other object which wrapped by low gloss paper.

5. Discussion and Conclusion

Since the gloss appearance is mainly evaluated by the distribution of specular reflection, an effect of constancy about brightness is expected in gloss appearance evaluation. If gloss constancy is existed, the scores will make a group together in each gloss sample, and explicit distinction appear in Figure 7. However, it has no group at all about variation of light shape. Furthermore, it is difficult to discriminate each gloss sample because the difference of score between circular 120px by high gloss sample and circular 40px by low gloss sample is very contiguous.

Even if we could not find the effect of gloss constancy, we need to model the degree of constancy for industrial applications, such as digital mock-up and design simulator. We focus on the relationship between DOI gloss parameter d and radius of circular light sources as shown in Figure 10. This relationship is derived by using multiple regression analysis based on the following Equation (7).

$$d = 1.76 d_m - 1.76 r - 0.623 \,, \tag{7}$$

where d is estimated DOI gloss. d_m is calculated DOI gloss from covering paper. r is radius of circular light source. This result suggested that distinctness-of-image gloss parameter is decreased as the radius of circular light sources increase. Obviously, it is clear that the shape and size of light source give an influence to the gloss perception. Therefore, in this evaluation, we hardy find the effect of gloss constancy.

On the other hand, the material appearance was mainly observed all distribution of specular and diffuse reflection influenced roughness as whole appearance of object. In comparison to Figure 7, the result in Figure 9 shows that explicit distinction between high gloss sample and low gloss sample appears, even if there is some variability among the variation for light shape and size. Therefore, we also analyze the relationship between DOI gloss parameter d and radius of circular light sources as shown in Figure 11. This relationship is derived by using multiple regression analysis based on the following Equation (8).

$$d = 2.21 d_m - 0.24 r - 1.12 \,, \tag{8}$$

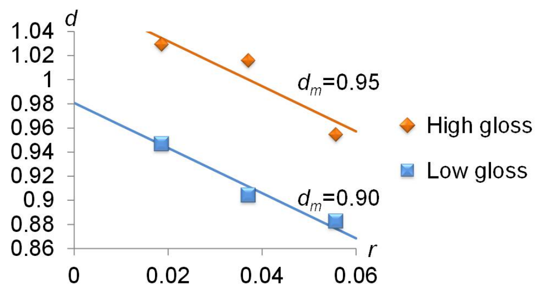


Figure 10. *Relationship DOI gloss and radius of circular light source in "gloss appearance". An orange rhombus means the one object which wrapped by high gloss paper. A blue square means the other object which wrapped by low gloss paper.d_m is calculated DOI gloss from wrapped paper.*

where d is estimated DOI gloss. d_m is calculated DOI gloss from covering paper. r is radius of circular light source. These results suggest that we can recognize the difference in material appearance of the two objects by using the axis d. Therefore, in this evaluation, we find the effect of material constancy.

In this paper, we verify the influence in gloss and material constancy under the artificial environment by changing the shape and size of light source. The present result about difference in gloss appearance suggests that sharpness of the gloss appearance is affected by shape and size of light source. Apparently, perception of gloss is decreased as the radius of circular light sources increase. Therefore, in this evaluation, we hardy find the effect of constancy for gloss appearance. The other evaluation is performed by observing the difference of material appearance. The subjects pay attention to the material property such as roughness and contrast between specular and diffuse reflection in this evaluation. An explicit distinction between high gloss sample and low gloss sample appears even if there is some variability among the variation for light shape and size. As a conclusion of this study, we suggest that constancy of gloss appearance only appears when we observe material property such as roughness and contrast as whole appearance of object.

Acknowledgments

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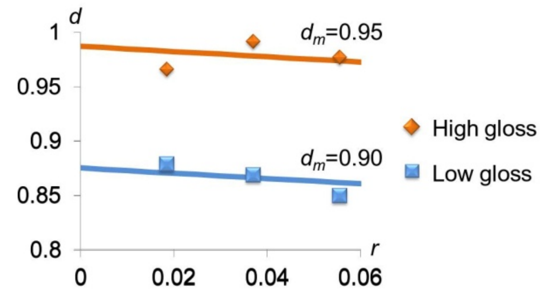

Figure 11. *Relationship DOI gloss and radius of circular light source in "material appearance". An orange rhombus means the one object which wrapped by high gloss paper. A blue square means the other object which wrapped by low gloss paper.dm is calculated DOI gloss from wrapped paper.*

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