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Viewpoint Entropy for Material Appearance

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Abstract

In this paper, we proposed an evaluation model to quantify the viewing condition that enhances the material appearance of object without dependence on shape of object. The proposed model is based on viewpoint entropy which is used to find appropriate eye position. In order to establish this model, we first clarify the surface that have important information related to material appearance by measuring the gaze point with eye tracking equipment. Next, we added experimental results as a weight coefficient of material appearance into the conventional viewpoint entropy. We verified that our model is applicable to metal and ceramic objects by comparing the results between subjective evaluation and computational evaluation using the proposed model.

1. Introduction

Recently, a remarkable progress in the field of computer graphics (CG) provides useful applications as the industrial tool such as digital mock-up (DMU) [1]. In these applications, it is well known that material appearance is very important to design a final feature of industrial product. This material appearance consists of three factors, which are shape, lighting, and reflectance property. Owing to the effort of CG researcher for modeling above factors, it is easy to reproduce the realistic material appearance by using rendering engine [2].

In the rendering process, a decision of CG parameters based on the material property is very complicated problem to reproduce a realistic material appearance of object. Usually, these parameters are assigned by the measurement of optical behavior on the surface of object. Here, it is noted that the relationship between the CG parameters and sensitivity of human vision is ambiguous to reproduce the desired material appearance of material. Pellicini *et al*. executed a subjective evaluation to quantify the relationship between sensitivity of human vision and material properties [3]. They used specular reflectance and roughness as parameters under a unique condition for shape and lighting position. The result of this evaluation gives us a useful procedure that the sensitivity for material appearance can be defined as two dimensional spaces with image contrast and roughness axis. With the assistance of their definition, we can find the CG parameter consistent with the desired material appearance in their two dimensional space.

After setting the material properties to rendering engine, we adjust the viewing condition such as light position, intensity, and camera position because a poor setting of these conditions greatly reduces the material appearance. This adjustment is addressed as “Lighting design” in the field of photographic technique. Many technical textbooks with empirical skill for lighting condition exist as the conventional approach [4,5]. However, an automatic system with computational approach is not build to construct the best setting of light and camera position. The guideline of selection as well as Pellicini’s approach is also required in emphasizing the visual material appearance of material property by changing the light and camera position.

In this paper, therefore, we propose a specific method to quantify the viewing condition that enhances the material appearance of object without dependence on shape of object. Our system employs modified viewpoint entropy which includes information of important surface for material property. In order to establish this method, we first clarified important surface by exploring the surfaces with an eye tracking equipment during an evaluation test of material appearance. Next, we analyzed gaze points from eye trace and added as a weight coefficient of material appearance into the conventional equation of viewpoint entropy. Our challenge in this paper makes a basic procedure of setting about several lighting and camera positions, and the verification is performed by using more complicated shape.

2. Related Works

A variety of techniques for optimizing lighting have been developed in photographic field [6,7]. Almost these researches have a goal to enhance the shape of object by using shading and specular reflection. For emphasizing the material property, Adrien *et al*. proposed an automated system for optimizing and synthesizing environment maps [8]. They defined the linear or quadratic image quality metrics in terms of weighted light transport matrix and global illumination in environment map. In this definition, the weight had a selective function for importance of light direction in each material. A general optimization framework was proposed to solve the best utilization of environment map that maximizes image quality metrics. Unfortunately, their proposed method included an empirical factor which was weight function generated by special knowledge of photographer.

Vazquez *et al* proposed viewpoint entropy to automatically determine the best eye position on the basis of maximum entropy [9]. In this method, viewpoint entropy was used as probability distribution of visible area in the projected polygon of object. Viewpoint entropy is based on the Shanon entropy as shown in Eq.1.

$$I(S,p) = -\sum_{i=0}^{N_f} \frac{A_i}{A_t} \log \frac{A_i}{A_t} , \qquad (1)$$

where N_f is the number of surfaces in the scene, A_i is the projected area of surface i over the sphere around the object, A_0 represents the projected area of background in open scenes, and A_t is the total area of the sphere around the object. The best scene is defined that the entropy obtained by this equation is maximized. Although, this entropy operates similarly to weight function introduced by Adrien’s method, the Vazquez‘s method is superior in explicit solution based on the entropy theory. However, this viewpoint entropy is not applicable to the material appearance because their method only take account for the information of visibility of surface. For the evaluation of material property, the perceptual salience is more important than the visibility of surface. Therefore, we quantify the saliency of material appearance by measuring the gaze point with eye tracking equipment and associate viewpoint entropy with an important surface.

3. Experiment to Find Important Surface

We can recognize the material of the object instantly and accurately at first glance. This material perception is provided by processing of visual information in the brain. However, it is difficult that how visual information is processed in the brain and what kind of visual information mainly contribute to material perception. Therefore, in this chapter, to quantify saliency of material appearance, we execute subjectivity experiment using eye tracking equipment and clarify the surface that have important information related to material appearance. Figure 1 shows a system of our experiment. The distance between display and the subject is 60cm. We use a 20.1-inch display (FlexScan S2001W, EIZO) and eye tracking equipment (Tobii X1 Light Eye Tracker). This eye tracking equipment can track gaze point at 30 frame/s. This experiment is performed in a dark room and evaluation time is unlimited.

We used CG objects in this experiment. The evaluation object is rendered by using Ward's reflection model. This model is denoted by Eq.2.

$$f = \frac{\rho_d}{\pi} + \frac{\rho_s}{4\pi\alpha^2\sqrt{\cos\theta_i \cos\theta_o}} \exp(-\frac{\tan^2\theta_h}{\alpha^2}) \qquad (2)$$

where f is the surface BRDF, θ_i is the incident angle, θ_o is the reflection angle of the light, and θ_h is the half-angle between the half-vector and the norm vector. Three parameters used by Ward's model are ρ_d, ρ_s, and 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 [10]. The materials of rendered CG are metal and ceramic, and the shape of reproduced CG are three types of blob. We set the three parameters ρ_d, ρ_s, and α empirically. Table 1 shows the parameters of each materials. Figure 2 shows six cases of CG used in this experiment.

Seventeen subjects participated in this experiment. All of them are 20s years old. Figure 3 shows the positional relationship among camera position, object position and light position of the rendered CG. Object position and camera position are fixed and the elevation angle of the light is 10 degree from the plane with center of object and camera position. Subjects can rotate the azimuth angle of the light position interactively around center of object by keyboard operation near the hand of subject.

Because setting of light position greatly impact on material appearance, the subjects were asked to find the best azimuth angle of light where enhance the material appearance by keyboard operation. While subjects operate the azimuth angle, the gaze point of subjects was measured by eye tracking equipment. To explore the surface that have important information, the gaze point was extracted at the moment when subject found the best azimuth angle. The reason why we extract such gaze point is that we assumed that subjects get information related to material appearance from such surface. Each subject evaluated the six cases of objects as shown in Figure 2. Figure 4 shows flow of this experiment.

Table1 Parameters of each materials

	specular reflectance ρ_s	diffuse reflectance ρ_d	roughness α
metal	0.9	0.07	0.4
ceramic	0.7	0.6	0.02

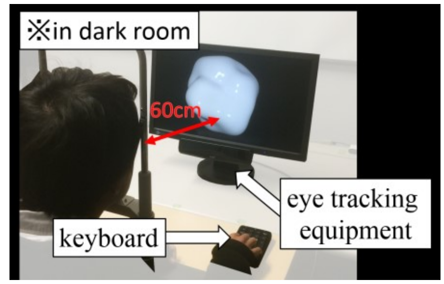
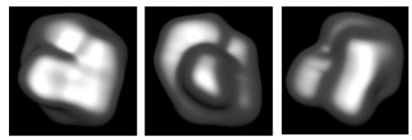
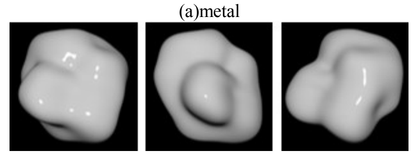


Figure 1 System of experiment



(a)metal



(b)ceramic

Figure 2 Sample of rendered images

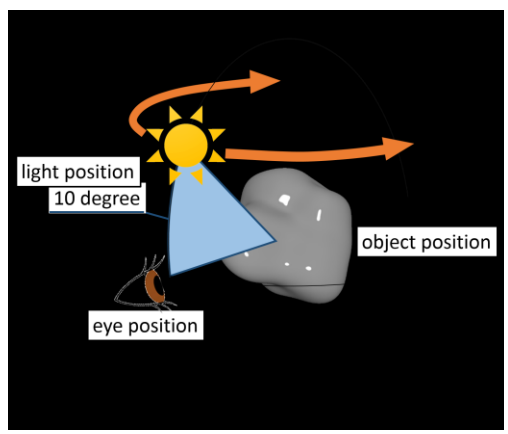


Figure 3 Positional relationship in CG

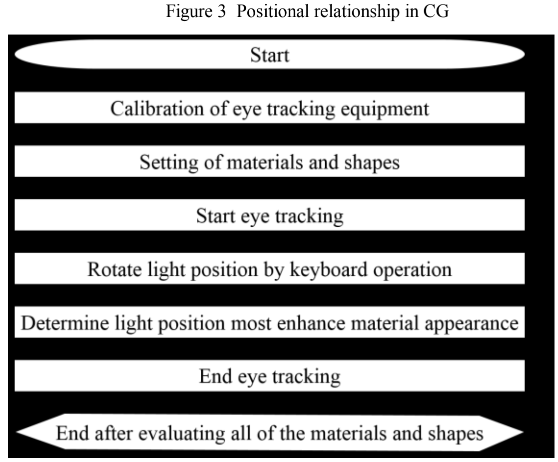
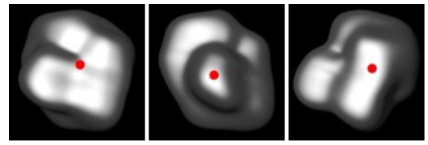


Figure 4 Flow of experiment

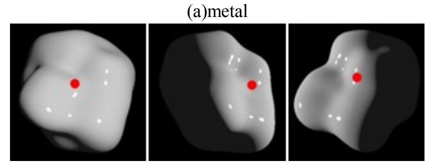
4 Results and Discussion in Finding the Important Surface

Figure 5 shows one example of results of this experiment. These figure are the best scene judged by a subject and point plotted in this figure represents the gaze point. Most of the gaze point of all subjects tended to concentrate on region of gloss regardless of metal or ceramic. Therefore, we assumed that there are similarities between incident direction and reflection direction of the light. To quantify results of this experiment, we used the half-angle. The half-angle represents the relationship among normal vector, camera position and light position. Figure 6 shows results of calculation in all of the gaze point. These figure are histogram of each material. Horizontal axis represents the half-angle, vertical axis represents the number of gaze point. The solid line represents transition of reflectance of each material.

As shown in Figure 6, we found that importance of the information related to material appearance is different in the change of half-angle. Furthermore, distribution of the histogram is different for each material. We assumed that this is affected by the size of gloss. The surface roughness of ceramics is 0.02, specular reflectance is rapidly decrease. Gloss appears in face on condition that the angle between half-angle is from 0 to 10 degree. The shape of histogram is also high on condition that the half-angle is from 0 to 10. On the other hand, the surface roughness of metal is 0.4, specular reflectance slowly decrease. The shape of histogram is multimodal. Region that the half-angle is from 10 to 20 corresponds to center of gloss, that is, contrast of gloss. Region that the half-angle is from 40 to 60 corresponds to edge of gloss, that is, sharpness of gloss. Therefore, in this case, we found that human get information related to material appearance from contrast and sharpness of gloss.

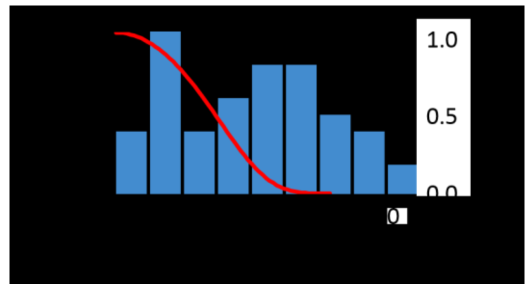


(a)metal

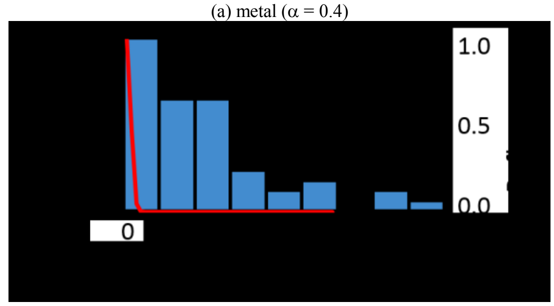


(b)ceramic

Figure 5 One example of experimental results



(a) metal (α = 0.4)



(b) ceramic (α = 0.01)

Figure 6 Histogram of gaze point

5. Viewpoint Entropy for Material Appearance

5.1 Theory

From the results of experiment in previous section, we quantify the saliency of material appearance. In this section, we associate viewpoint entropy with an important surface for material appearance. For applying viewpoint entropy to material evaluation, we added the weight coefficient that is obtained from normalization of the histogram shown in Figure 6 into conventional equation of viewpoint entropy. The sum of normalized histogram is 1. The proposed equation is denoted by Eq.3.

$$I(S,p) = -\sum_{i=0}^{N_f} w(\theta_i)\frac{A_i}{A_t}\log\frac{A_i}{A_t} \qquad (3)$$

where N_f is the number of surfaces of the scene, A_i is the projected area of surface i over the sphere around the object, A_t is the total area of the sphere around the object. θ_i represents the half-angle of surface i, and $w(\theta_i)$ is weight coefficient obtained by normalization of histogram in Figure 6. Table 2 shows relation between $w(\theta_i)$ and θ_i in each material. Furthermore, we define the entropy of shadow surface as 0 because there are no subjects who determine the azimuth angle of light position by looking at such surface. We use the weight coefficient in Table 2(a) in calculating the entropy of metal object, and use the weight coefficient in Table 2(b) in calculating the entropy of ceramic object. To verify the accuracy of the proposed method, we apply

Table 2(a) coefficient of metal

θ_i	$w(\theta_i)$
0~9	0.078
10~19	0.196
20~29	0.078
30~39	0.118
40~49	0.157
50~59	0.157
60~69	0.098
70~79	0.078
80~89	0.039

Table 2(b) coefficient of ceramic

θ_i	$w(\theta_i)$
0~9	0.333
10~19	0.216
20~29	0.216
30~39	0.078
40~49	0.039
50~59	0.059
60~69	0
70~79	0.039
80~89	0.021

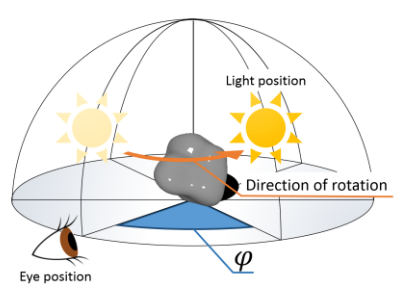


Figure 7 Direction of rotation of the light

the proposed method to the six types of ceramic and metal objects used in experiment of Section 3. We rotate the azimuth angle of light position in 1 degree increments around the object, and apply the proposed method in each angle. Figure 7 shows the direction of rotation of the light. Figure 8 shows one example of the results of applying the proposed method to ceramic object. The vertical axis represents entropy, the horizontal axis represents the azimuth angle φ of light position as shown in Figure 7. The 17 point plotted on the bottom of the graph represents the best azimuth angle of light where emphasize material appearance judged by 17 subjects. According to the comparing the results between subjective evaluation and computational evaluation, the high entropy obtained by our method corresponds to the results of experiment. Therefore, we can say that this method quantify the viewing condition that enhance material appearance. Moreover, the same result were obtained in other 5 blob objects.

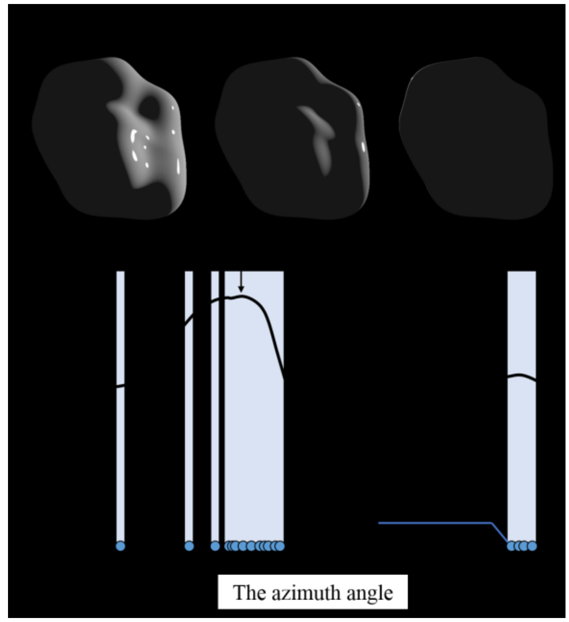


Figure 8 Results of applying the proposed method

5.2 Application

We applied the proposed method to complex shape. The material of the applied object are metal and ceramics, and the shape is Stanford Bunny. The CG objects are rendered in three camera position. The parameters of each material are the value in Table 1. Figure 9 shows the six cases of bunny objects only for verification of proposed method. We apply the proposed method to these six case of objects in the same way as the previous section. The weight coefficient in Table 2(a) is used in calculating the entropy of metal object, and the weight coefficient in Table 2(b) is used in calculating the entropy of ceramic object.

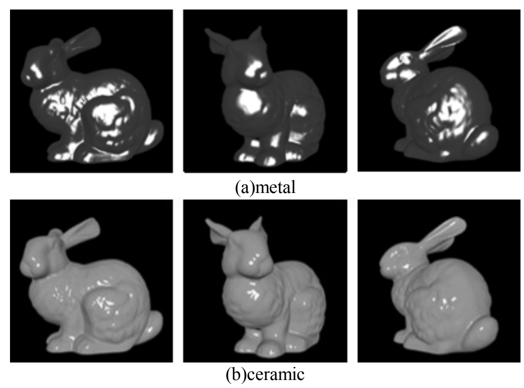


Figure 9 CG objects for only accuracy verification

Further, we performed experiment in the same way in Section 3 to these bunny objects. The experimental conditions are similar, and another 10 subjects participated in this experiment. Figure 10 shows one example of results of applying the proposed method to ceramic object and results of subjectivity evaluation experiment. The point plotted on the bottom of the graph represents the best azimuth angle of light where emphasize material appearance judged by 10 subjects. The horizontal axis similarly represents the azimuth angle φ of light position as shown in Figure 7. According to the comparison of these results, we found that the high entropy obtained by the proposed method can quantify the conditions that enhance material appearance without dependence on shape of object. The same results were obtained in other 5 bunny objects.

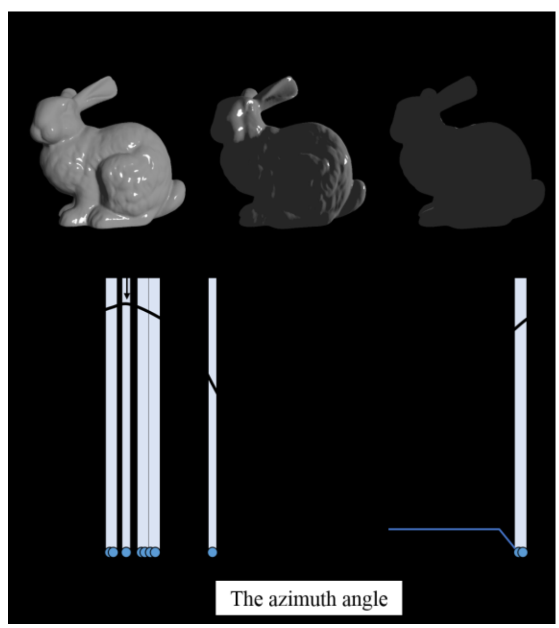


Figure 10 Results of applying the proposed method to complex object

6. Discussion and Conclusion

In this paper, we proposed an evaluation model to quantify the condition when the material appearance is emphasized. In order to establish our model, we first clarified important surface that have important information related to material appearance by the experiment using eye tracking equipment and associated viewpoint entropy with important surface. As a result of comparison between subjective evaluation and computational evaluation, we found that our method is applicable to metal and ceramic object without dependence on shape of object.

Although the material of rendered objects was limited to metal and ceramic in this experiment, various materials exist in the world. Therefore, it is necessary to clarify the surface that have important information related to material appearance for various materials. The surface having important information will be clarified by experiment for various materials to determine the appropriate weight coefficient of each material. In addition, we use the single point light in CG used in experiment. Therefore, it is necessary to validation under various light environment.

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