Ascertainment of perceptual classification for material appearance

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Abstract

In this paper, we investigated the reliability of reproduction with material appearance by using Ward's model through comparison with perceptual aspect. Four materials, aluminum, rubber, graphite, and ceramic, and three objects, were used in our experiment, and observer controlled two parameters of specular reflectance and roughness. Moreover, the three-dimensional display with eye-tracking control was developed for reproducing the object in order to improve accuracy. As the result of subjective evaluation, the discriminative combination of coefficient exists with each appearance of the material. There is a possibility that each parameter can control appearance of material, since the tendency to change an appearance exists according to the aspect of materials, respectively.

Introduction

Recently, the image quality of captured image by digital camera has been improved dramatically over the years. High resolution CMOS sensor can acquire detailed specifications of objects[1], and multiple exposure technique can record all range of radiance in natural world, which is called as high dynamic range images[2-4]. The next development based on these progresses of digital camera is expected that the captured images impress user greatly as authenticity of distinctive appearance.

For example, a picture for children is desired such as tenderness and moisturized skin, and the material appearance made of shiny metal and glasses has important characteristic such as blink reflection. The professional photographer expertly expresses these distinctive appearances by using contradistinctive arrangement between subject and background and/or emphasis the lighting effect. Unfortunately, the amateurs cannot perform such composition and emphasis, even if they obtain the highest class camera and environment. The superior assistant system is necessary to take excellent pictures for distinctive appearance.

One of the solutions for assistant system is an image processing which can emphasize the appearance. Enough resolution of captured image is capable of controlling remarkable appearance[5], and adequate depth of dynamic range is capable of transforming contrast of image[6]. The filtering process of smoothing and sharpness may be suitable for improving the feature of appearance. Here, it is noted that controlled quantity for controlling and transforming is important for the image processing to enhance the appearance. This quantity depends on the human sensibility for several appearances, such as gloss, reflection, and texture. Analysis of image contrast proposed by Pellacini et. al. can clarify the relationship between the physical dimensions of glossy reflectance and the perceptual dimensions of glossy appearance[7]. They proposed a new model of surface appearance that is based on quantitative studies of gloss perception, and this model can allow the prediction of gloss matches and quantification of gloss surface appearance. However, it is necessary to clarify a fitting correspondence of appearance between perceptual aspect and simulated model for the practical use. The selection of unsuitable dimensions also affects the reliability of model and reproduction.

Therefore, in this paper, we investigate the reliability of gloss reproduction by using CG model through comparison with perceptual aspect. Four materials, aluminum, rubber, graphite, and ceramic, were used in our experiment, and observer controlled two parameter of Ward's reflectance model. If the selection of model and parameters is correct, the result of subjectivity evaluation should be converged on the specific parameter. In order to improve accuracy, the three-dimensional display was developed for reproducing the object in our experiment. Moreover, the eye-tracking control was equipped in the experiment system for the compensation for difference of observer's position.

Related Works

The development of CG reflection model with specular has been accelerated during recent years. These progresses bring us that reproducing of the object in real world is almost possible by proposing various models, such as Phong, Torrance-Sparrow, Ward, and Lafortune[8]-[11]. For example, a reflection parameter for a simple object, an apple, etc., can be determined roughly. Now, the demand to these modeling is reproducing a complicated reflective phenomenon with fewer parameters.

In a same way, the synthetic model included material appearance is required as progress of a reflection model. Unfortunately, it is more difficult to establish the superior model since perceptually matching with human visual sensibility is necessary in addition to the matching with an optical property. With this matter, Pellacini et al. introduced perceptual dimensions for gloss to use in adjusting the parameters of a simple reflectance model[7]. Following that, Matusik et al. addressed the dimensionality of this approach by using samples of measured BRDF's and asking a user to classify their appearance according to a predetermined set of traits such as "roughness" and "greasiness"[12]. Their contribution can allow the prediction of appearance matching and quantification, however, there are not clearly definitions about classification of material appearance in the world. The user desires an appropriate selection of parameter in CG to reproduce the appearance which is matched to the specified material. We also have to clarify the emphasis parameter of material for the appearance improvement of a photograph.

For the some solution of this challenge, we consider that it becomes a cue or hint to review Pellacini's and others perceptual experiment. Since the perceptual dimensions proposed by them can express various appearances, it is possible to display a specific material under fixed condition of lighting environment. A possibility of novel appearance model can be explored by evaluating perceptual variation when the specific material is reproduced. Therefore, we examine the reliability of appearance reproduction by using perceptual model through comparison with various materials, such as aluminum, ceramic, rubber, and plastic. Furthermore, it should be implemented the experimental view as 3-dimensional display for a more precise verification, although Pellacini and Matusik performed the experiment by using 2-dimensional display[13][14]. Therefore, we employed a novel display system and evaluated the appearance of various material, as is expressed the following section.

Experimental system

In this section, we describe a novel 3D display system which uses our examination about reliability of appearance reproduction. Figure 4 shows our experimental system. The 3D projector is used to display test images with stereoscopic viewing. This projector has 1280×720 pixels and can provide the stereoscopic image with 120Hz refresh rate. Subjects can observe the stereoscopic image through the LCD shutter glasses which is synchronized to the left and right image, respectively. Here, the center of the coordinate system was matched to the center of screen so that the compatibility of the virtual and actual coordinate on a computer was maintained. The gravity of evaluation object had arranged at the center on a screen, and light source was placed at 3 m near side and 5.71 m height from the coordinate center.

On this occasion, our system employed real-time rendering with 3D position tracking to observe 3D reproduction naturally. Since two infrared LED were mounted on the both side of 3D shutter glasses, the observer's position can be detected by using an infrared camera setting up to the screen. This positioning information was used to the calibration of perspective distortion. Therefore, 3D object was reproduced correctly even if observer appreciated in arbitrary positions in our system. The effect of this calibration is shown in Figure 5.

The rendering process was described by OpenGL Shader Language library and programmed by Microsoft Visual C++. Changing the gloss and reflection appearance of object, we adopt Ward's reflection model expressed by the following equation.

$$\rho(\theta_i,\phi_i,\theta_o,\phi_o)=\frac{\rho_d}{\pi}+\rho_s\frac{1}{4\pi\alpha^2\sqrt{\cos\theta_i\cos\theta_o}}\exp\left(-\frac{\tan^2\delta}{\alpha^2}\right)\quad\cdots(1)$$

where, θ, ϕ denote the polar and azimuthal angles of the incident and reflected light directions, respectively. α denote spread of the specular lobe, and δ denote the halfway vector between the incident and reflected directions. In this experiment, the Sphere, Blob and Stanford bunny were used as the test object as shown in Figure 3. The various appearances of these objects were rendered by changing the parameter of Ward's model.

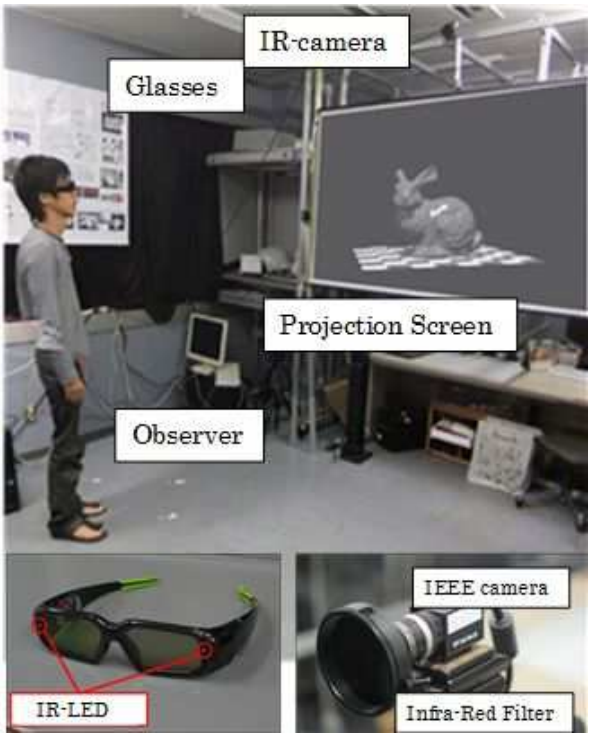
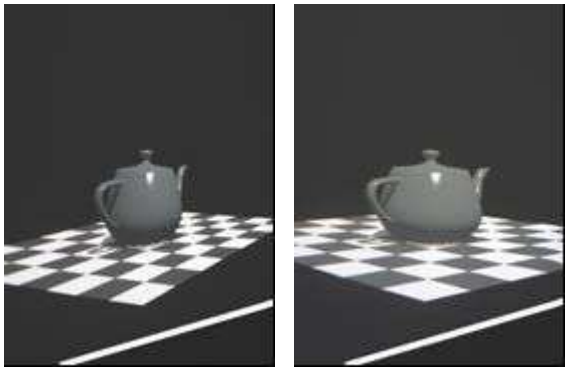


***Figure 1**. Experimental system equipped with eye-tracking 3D rendering*



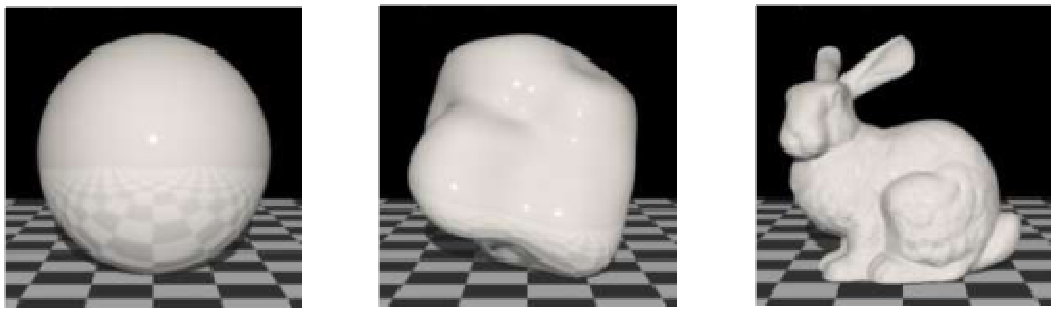
(a) without calibration ***(b) with calibration***

***Figure 2**. Comparison image with or without the perspective calibration*

Subjective evaluation of appearance

Subjective evaluation was performed to verify the discriminable ability in appearance of material. Four kinds of material as shown in Figure 4, such as aluminum, rubber, graphite, and ceramic, were selected and rendered in our experiment. Here, each value of diffuse reflectance ρ_d is decided empirically, and specular reflectance ρ_s and roughness α are controlled by subjects to match the appearance between rendered reproduction and real object.

For evaluating the appearance of material, the shape of a reproducing object is also an important factor. In this experiment, we used three kinds of shapes, such as sphere, blob and Stanford



(a) Sphere *(b) Blob* *(c) Stanford bunny*

***Figure 3**. Illustrations of rendering objects*

(a) Aluminum *(b) Rubber* *(c) Graphite* *(d) Ceramic*

***Figure 4**. Summary of subjective evaluation in case 2*

bunny as shown in Figure 3. Although each object had different complexity, the objective position was also important factor when the conventional 2D display was used. However, since our 3D position tracking system is enable to observe objects correctly even from arbitrary directions, the subject can evaluate intuitively.

Essentially, target appearance of subjective evaluation should use real object. Unfortunately, it is difficult to match the illumination condition between real and displayed object. Therefore, we show the sample pictures of Figure 4 at the beginning of the experiment. It is expected that this presentation is effective in suppressing the deviation as an evaluation result of the material. The matching task of appearance of material was performed 3 times with the interval for 30 minutes. Average and standard deviation of all the trails was employed as the final results. Nine subjects took part in our experiment. All subjects were well experienced with psychophysical tasks and had normal of corrected to normal visual acuity.

Experimental results and Discussion

Figure 5 shows the results of subjective evaluation which was performed by using four kinds of material and three kinds of shape. The x-axis indicates specular reflectance and y-axis indicates roughness. These coefficients are parameters which control the appearance of Ward's model. Across the all experiments, it is found that the almost same distribution is shown in every shape. And, the discriminative combination of coefficient exists with each appearance of the material. Especially about rubber, many subjects have selected the same coefficient of the material.

On the other hand, the result of aluminum indicates large deviation, since this object has various appearance of processed surface in the real world. However, we assumed that the tendency may exist between specular reflectance and roughness as the increasing ratio. According to this assumption, it is surmised that the appearance of graphite is located in the middle of rubber and aluminum.

Figure 6 shows the rendering results by using each material which was selected by each subject. A remarkable strange image is not found in each material. By the visual appearance, the reproduction of ceramic and rubber were realizable stably. On the other hand, appearance for aluminum and graphite indicate large deviation. Especially about graphite, we infer that little visual experience observed as a lump caused large deviation.

Thought this preliminary experiment, it is clear that some of the material with specific appearance can be characterized. However, it is difficult to become clear only by the coefficient of specular reflectance and roughness. In this experiment, although the diffuse reflectance was fixed for the simple evaluation, it has a possibility that complex appearance such as aluminum will be improved the characterizing. We assume that a possibility that each parameter can control appearance of material, since the tendency to change an appearance exists according to the aspect of materials, respectively.

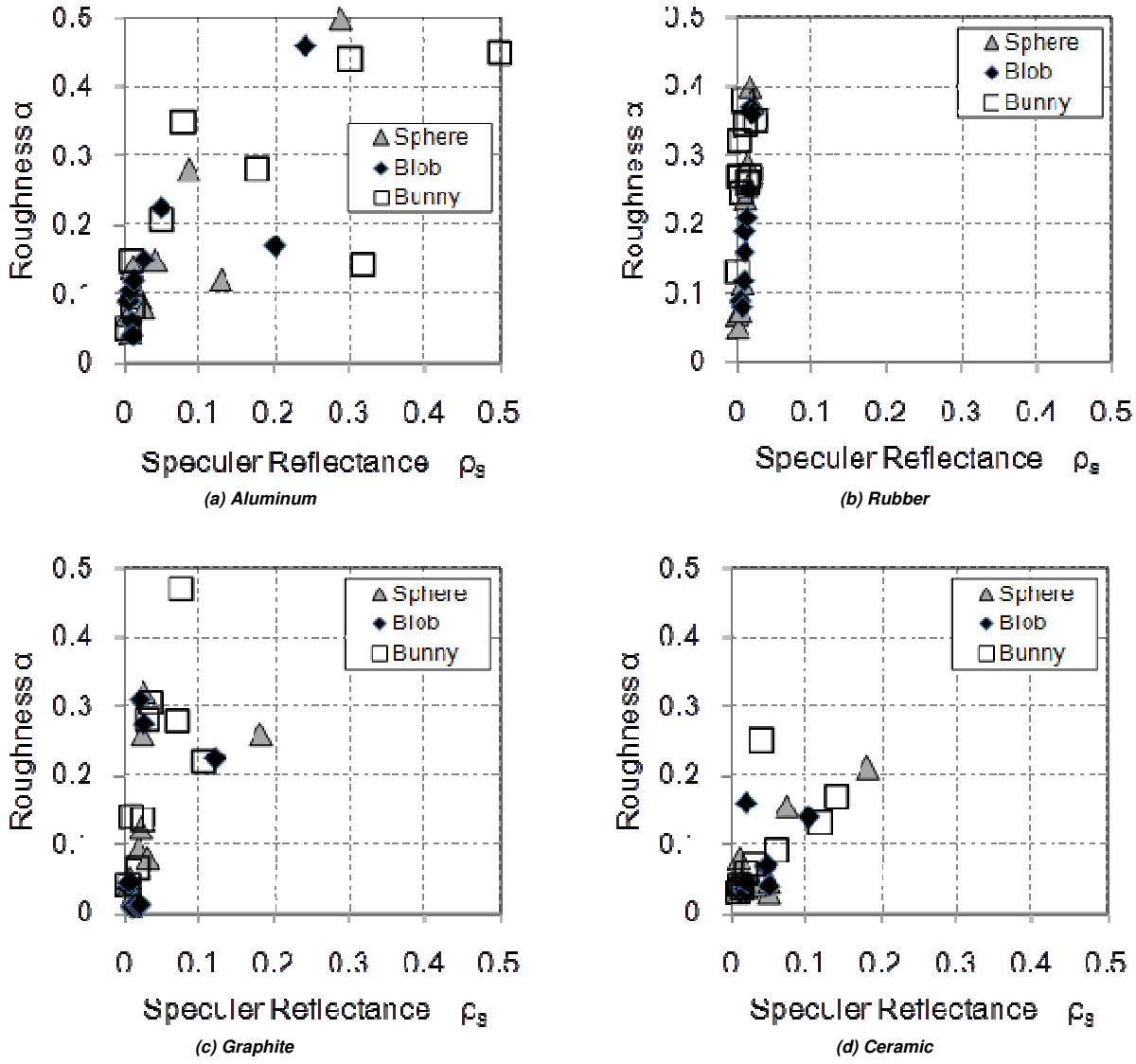


***Figure 5**. Results of subjective evaluation for each material*

Conclusion

In this paper, we investigated the reliability of gloss and reflection reproduction by using Ward's model through comparison with perceptual aspect. Four materials, aluminum, rubber, graphite, and ceramic, and three objects, were used in our experiment, and observer controlled two parameters of specular reflectance and roughness. Moreover, the three-dimensional display was used for reproducing the object in our experiment in order to improve accuracy. This system equipped the eye-tracking control for the compensation for difference of observer's position.

From the result of subjective evaluation, the discriminative combination of coefficient exists with each appearance of the material. Especially about rubber, many subjects have selected the same coefficient of the material. On the other hand, the result of aluminum indicates large deviation, since this object has various appearance of processed surface in the real world. However, we assumed that the tendency may exist between speclur reflectance and roughness as the increasing ratio. According to this assumption, it is surmised that the appearance of graphite is located in the middle of rubber and aluminum. There is a possibility that each parameter can control appearance of material, since the tendency to change an appearance exists according to the aspect of materials, respectively. To use a diffuse reflection coefficient as a parameter or to improve the patterns of reflection images or backgrounds are future work in our research.

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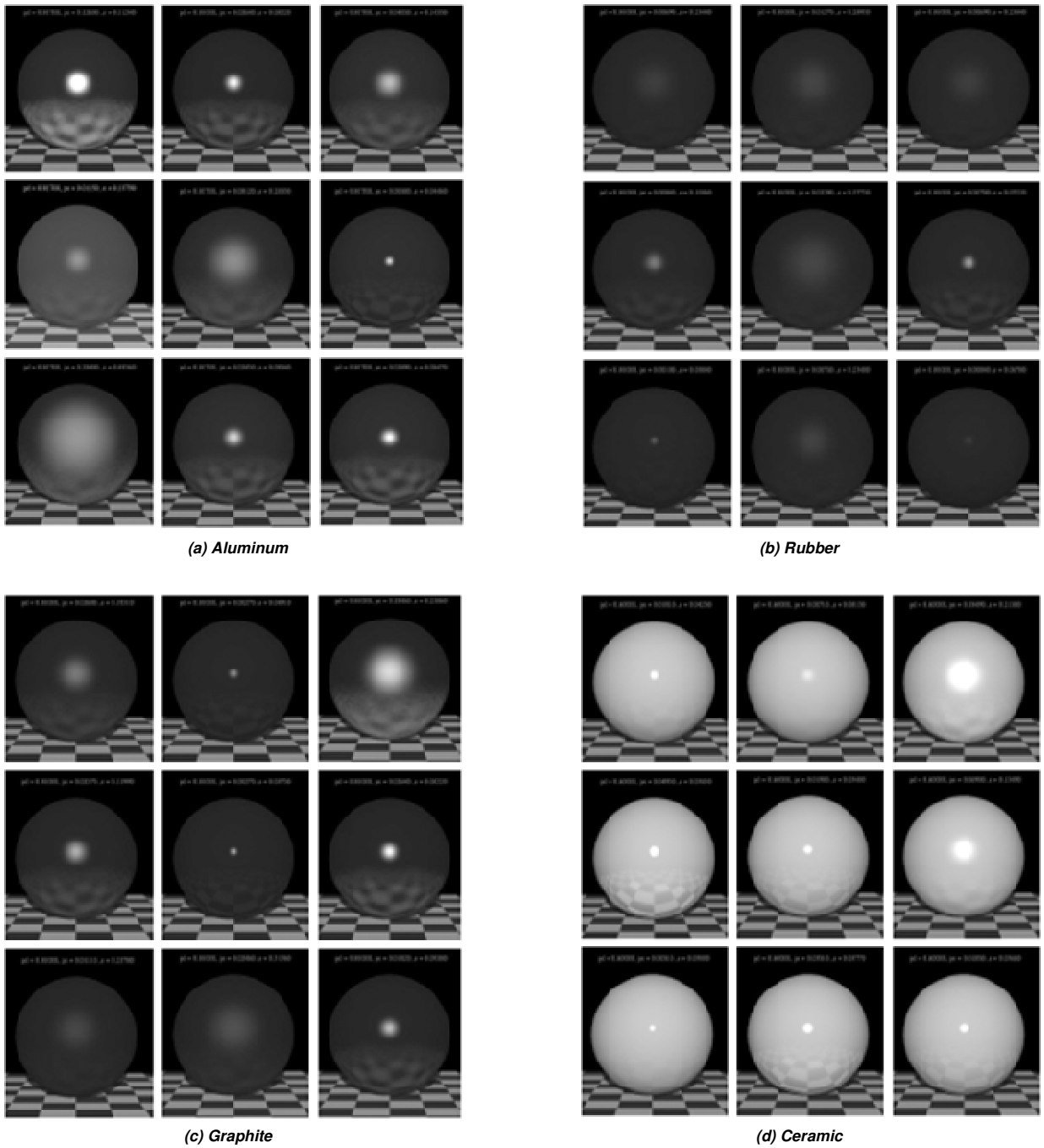

(a) Aluminum *(b) Rubber*

(c) Graphite *(d) Ceramic*

***Figure 6**. Rendering results of subjective evaluation for each material*

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Author Biography

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