Enhancement of Gloss Perception by using Binocular Disparity

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Abstract

In this paper, we quantified the gloss perception by using binocular stereoscopic display. In our experiment, we evaluated gloss perception changing the disparity angle of surface and highlight to investigate the relationship between glossy appearance and the disparity angle. The magnitude estimation method is used to evaluate the sensibility of gloss appearance subjectively. As the result, the score of subjective evaluation on stereo display is stronger than on flat display, within the disparity angle range that is depth perceptible, and the score on stereo display and on flat display is same without the range. Additionally, we found that glossy contrast correlated highly with evaluation score regardless of the disparity angle and display method.

Introduction

Recently, computer-aided system such as CAD and CAE is becoming a major tool in the manufacturing processes[1]. These tools are capable of calculating the strength of structure and form deformation. A further development is digital mock-up that allows designers to select the material of product, and to simulate the appearance of final products[2]. Since a visual impression of final product gives influence to the commodity value, a digital mock-up may be high-end model of computer-aided system.

The appearance of digital mock-up is usually rendered by computer graphics (CG) on conventional display[3]-[6]. For making the digital mock-up look as much like real objects as possible, various reflection models are developed for accurate appearances such as color, shading, and specular reflection. Especially, specular reflection is generally called “gloss” or “highlight”, and it belongs to the most fundamental perceptual monocular cues of the overall the appearance of objects. Furthermore, gloss reflection has binocular cues which have the different disparity from the surface points as shown in Figure 1. Due to these cues, observers can recognize the material and surface condition by the strength of gloss reflection, whether an object has smooth or rough surface.

It seems that a stereoscopic display system is useful in order to express the natural appearance of digital mock-up. Fortunately, stereoscopic display system is already offered commercially, and we can easily achieve the 3D viewing which have binocular cue of gloss reflection[7]. However, it is not clear that 3D gloss appearance with binocular cure provide an effective enhancement and increasing authenticity for digital mock-up. Unless the great effect of installation can be expected, it is difficult to use the 3D stereoscopic system because the cost of instrument is expensive and calculation cost is high.

Therefore, in this paper, we quantified the gloss perception by using binocular stereoscopic display, and clarified the contribution of binocular cue for the appearance reproduction of digital mock-up. In order to evaluate the difference between monocular and binocular cues of gloss reflection, we compare the perceptional strength and authenticity of gloss with the magnitude subjective evaluation. The main parameters of this experiment are change of viewing dimension and distance. The use of evaluation samples which are varied the rate of contrast between diffuse reflection and gloss reflection will provide universal roles to enhance the 3D effect for appearance reproduction of digital mock-up.

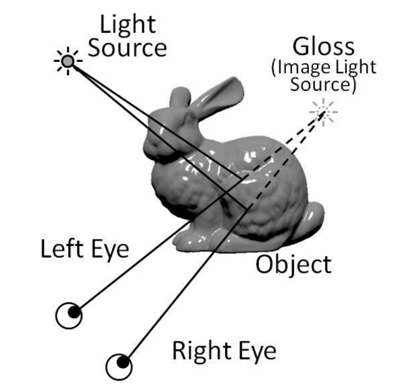

Figure 1. *Observation of 3D object and reflection light*

Related works

The reflected light from surface present various appearances which are related by the light source, shape, and reflectance of material. Among them, the gloss is the most noticeable appearance since it reflects the characteristic of light source and shape directly. Therefore, many researchers have been tried to reproduce the real appearance of gloss in the research field of CG and display system[8]-[11]. Here, it is well known that the gloss reflection has both monocular cues which are observed as highlight pattern on the surface and binocular cues which have the different disparity from the surface. Hence, the following related works are described about the monocular and binocular cues separately.

The gloss as the monocular cues is familiar with the highlight of image intensities. These intensities are generated by the image contrast between diffuse and specular reflection. Pellacini et al. tried to investigate the relationship between physical parameter and gloss perception[12]. They prepared some rendered images with changing the parameter of diffuse and specular reflectance by using Ward's model, and asked subjects to evaluate the strength and authenticity of gloss. Their

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experimental results showed that strength of gloss perception C was expressed the following equation.

$$C = \sqrt[3]{\rho_s + \rho_d/2} - \sqrt[3]{\rho_d/2} \qquad (1)$$

where, ρ_s indicate coefficient of specular reflection and ρ_d is coefficient of diffuse reflection. Though this investigation is performed by using 2D display and relative scaled images, gloss appearance enable to control the influence quantity as the monocular cue.

On the other hand, binocular characteristic of gloss was less familiar, until Blake et al. conducted that gloss appears to be located in a different depth plane than the surfaces [13]. Since the gloss appearance is generated by the direct reflection of light source at the object's surface, obviously, binocular disparity exist between surface and light source at the surface reflection points. Figure 2 shows geometric illustration when the gloss appearance is occurred. The disparity between surface and light source is calculated by α–β in this figure. Also, it is noted that the disparity between surface and light source is depend on the curvature of reflected surface. Therefore, gloss appearance varies rapidly when the eye position and/or object position is changed.

Gunnar et al. evaluated both perceived strength and perceived authenticity of gloss by using binocular stereoscopic display[14]. They used complex, three-dimensional curved surfaces, and reflection characteristics were varied using the Phong lighting model. As the results, they found that the presence of gloss disparity lead to an enhancement of both the authenticity and the strength of perceived glossiness. However, in order to clarify the contribution of binocular cue, it is necessary to evaluate only the influence of disparity which should be separated by the influence of image contrast. Fortunately, recent 3D stereoscopic display can switch 2D/3D for the various images, and amount of disparity and image contrast can change easily by using CG techniques. Therefore, in this research, we quantify the gloss perception of binocular effect for gloss appearance, which is independently varied disparity and image contrast.

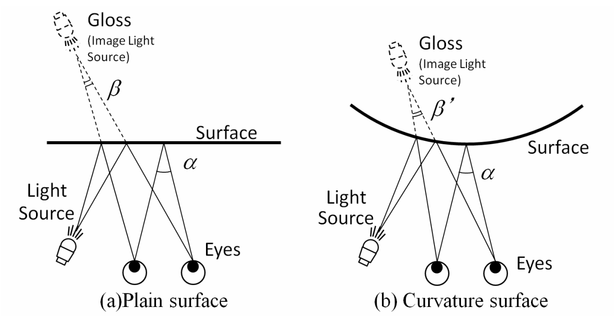

Figure 2. *Geometry and ray tracing of gloss position*

Method

Changing the contrast and disparity of gloss appearance, it is suitable to use computer-generated 3D object with CG technique. In this study, we adopt Ward's reflection model expressed by the following equation.

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

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. The Stanford Bunny which is a collection of 69,451 triangles is used as the test object. The various appearance of its bunny is rendered by changing the parameter of Ward' model. Here, we select diffuse and specular parameters as shown in Tabel 1, and final images for subjective evaluation are shown in Figure 3. Here, it is noted that the value of the spread of the specular lobe α is constant (=0.07) and each coefficient of diffuse reflection is matched to each Munsel value N2, N4, and N6, respectively. The rendering process is performed by OpenGL Shader Language library and programmed by Microsoft Visual C++.

In order to verify the effect of binocular stereoscopic depth cue, we should set the adequate disparity as the experimental condition. It is well-known that depth perception is attracted by binocular convergence at the fixation point. Here, the fusion range of any stereoscopic vision is limited around the fixation position. In the human visual system for example, the space around the current fixation point which can be fused, called Panum's area[15]. When there are two objects which have different disparity within Panum's area, we can recognize three dimension both objects. For our research, we should select two conditions of disparity angle to conform the effect of binocular 3D vision. However, it is difficult to measure accurate Panum's area. Pastoor et al. tried to find range of stereoscopic depth empirically[16]. Their results show that disparities of up to 35 arc min do not cause any discomfort and can execute unconscious and natural observation for stereoscopic display.

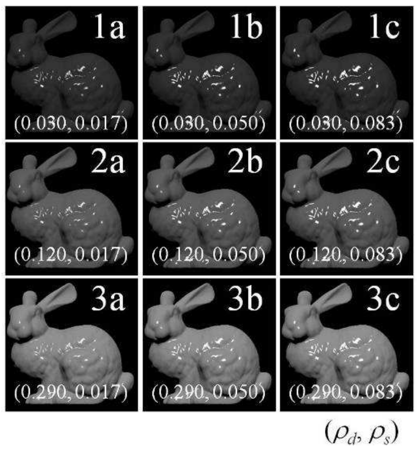

Figure 3. *Evaluation gloss images calculated by using Ward'model*

Table 1. *Diffuse and specular parameters for evaluation images*

No.	coff.	a	b	c
1	ρ_d	0.030	0.030	0.030
	ρ_s	0.017	0.050	0.083
2	ρ_d	0.120	0.120	0.120
	ρ_s	0.017	0.050	0.083
3	ρ_d	0.030	0.030	0.030
	ρ_s	0.017	0.050	0.083

ρ_d : diffuse coefficient
ρ_s : specular coefficient

Therefore in this research, we decided that 35 arc min was the border between effective and ineffective range of binocular convergence. Our experiment is performed by the two cases, one case imposes the evaluation within 35 arc min and another case is more than 35 arc min.

Experiment

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 is maintained. The gravity of evaluation object has arranged at the center on a screen, and light source is placed at 3 m near side and 5.71 m height from the coordinate center.

In order to generate the different disparity for gloss appearance, it is simple way to shift the position of light source according to the desired disparity. However, the displacement of light source causes other changes such as shading and cast shadow. Therefore, we shift the observer position to generate the desired disparity in this experiment. Final observer positions to achieve the different disparity are 1.5 m and 3 m from the screen.

These distances were derived by preliminary simulation, which calculated the average disparity between surface of object and light source. Because its disparity depends on the curvature of object, the polygon data of Stanford Bunny was used as the target object in this simulation. As the result, 1.5m eye position from screen is possible to observe the gloss appearance which has about 80 arc min disparity, and gloss appearance at 3 m position has about 35 arc min disparity.

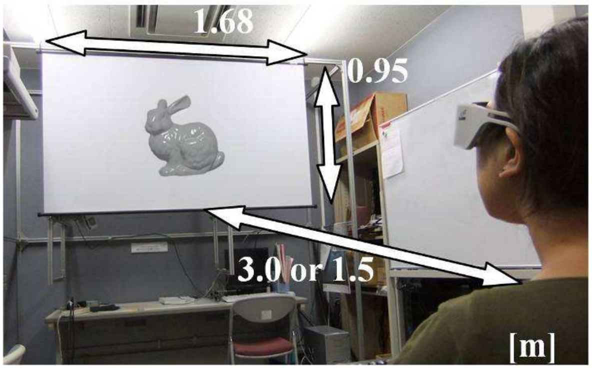

Figure 4. *Experimental environment (dark room)*

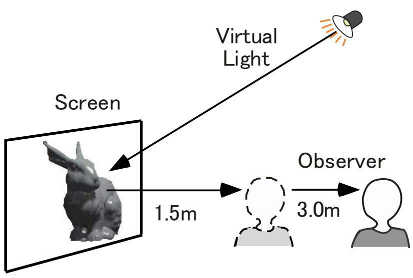

Figure 5. *Positions of observer, screen, and light source*

Magnitude Estimation is performed to verify the stereoscopic effect in gloss appearance[17,18]. This method is one of subjective evaluation which is possible to quantify the relationship between physical and psychophysical strength. Here, though there are many type of magnitude estimation method, we use standard stimuli in this evaluation. The rendered image in Figure3 2(b) with 2D observation is decided as the standard in this experiment. Subjects can observe this stimuli at the first time of evaluation process, and memorize this score as 100. Since then, various test stimuli shown in Figure 3 are displayed with random sampling, switching from 2D to 3D. We ask the score of magnitude 5 times with the interval for 30 minutes. Average and standard deviation of all the trails is employed as the final results. Twelve subjects take part in our experiment. All subjects were well experienced with psychophysical tasks and had normal of corrected to normal visual acuity.

Experimental results

At the first, subjects observed gloss appearance at the position of 3 m from screen. Figure 6 shows the result of average and standard deviation by all subjects. Here, vertical axis indicates the number of test image as shown in Figure 3, and horizontal axis indicates the score of magnitude evaluation. Error bars mean the standard deviation among the individual score, and each marker discriminate between 2D and 3D observation.

From this result, it is clear that gloss perception becomes strong according to the increase of speculer reflection light for gloss appearance. Increasing of diffuse light (1a->2a->3b) invoke the decrement of gloss perception because this change cause the decrement of image contrast between diffuse reflection light and specular reflection light. At paying attention to the difference between 2D and 3D, it is suggested that observation at 3 m has little difference between 2D and 3D, nevertheless subject can recognize the difference of contrast change in test images. This result derives some assertion that binocular cue from disparity between surface and light source is not effective at 3 m observation.

In order to compare of binocular effect each images, we sort out the experimental result by calculating the subtraction between 2D and 3D score. Figure 7 shows an organized result. At the case of 1a and 1b, a little difference exit, however, we evaluate that there are no significant difference.

Next, subjects observed gloss appearance at 1.5 m from screen. Figure 8 shows the result of average and standard deviation by all subjects, and Figure 9 shows the calculating result by subtracting 2D score from 3D score. It compares with the result of 3 m, it is clear that there is a noticeable difference between 2D and 3D score. It suggests that subjects can recognize the difference of disparity between surface and light source since the close observation attract the increase of disparity.

On the other hand, we focus on the decrease of image contrast score, namely monocular cue. Although there is no difference in order of the strength of the gloss perception, its scores, especially at the case of strong speculer, are decreasing clearly. This result evokes some assumption that gloss perception is realized by image contrast and disparity, and both cues are compensated each other.

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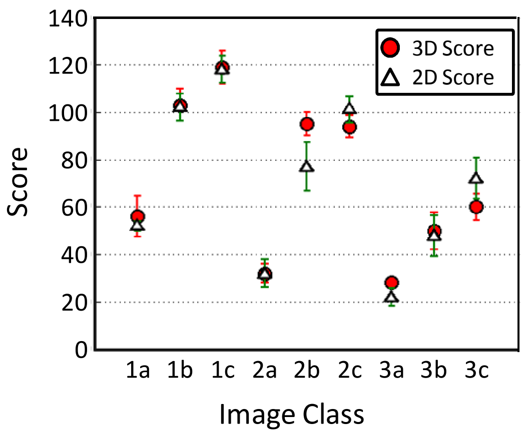


Figure 6. *Total result of subjective evaluation at the case of 3 m observation*

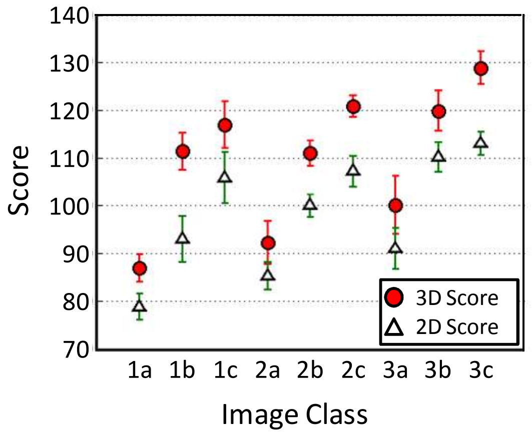


Figure 8. *Total result of subjective evaluation at the case of 1.5 m observation*

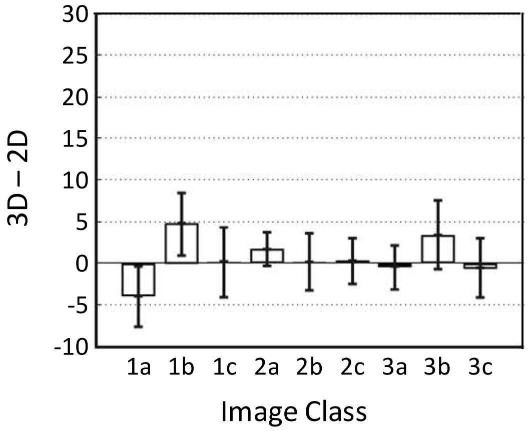


Figure 7. *Result of subtracting 2D from 3D score at the case of 3 m observation*

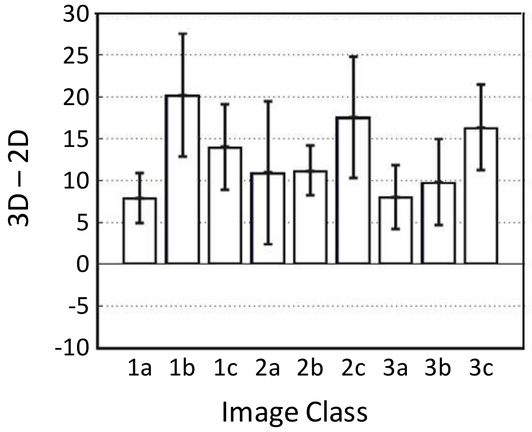
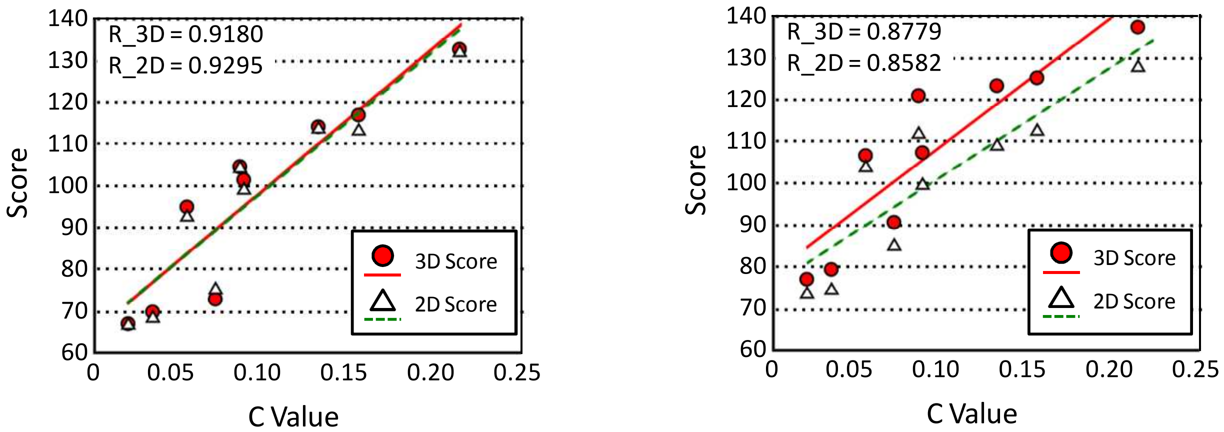


Figure 9. *Result of subtracting 2D from 3D score at the case of 1.5 m observation*



(a) At the case of 3 m observation

(b) At the case of 1.5 m observation

Figure 10. *Correlation between Pellacini's C value and evaluation score*

Discussion

In order to check each effect of disparity and image contrast, we organize the results of our experiments as shown in Figure 10. In this figure, the vertical axis is changed by C value which was proposed by Pellacini, denoted in Equation 1. At the position of 3 m observation shown in Figure 10(a), it is remarkable that the correlation value between C value and score is very high in all the tests, even if the gloss appearance was displayed by 2D or 3D. This result suggests that perception of gloss appearance is mainly depend on the image contrast, and disparity less than 35 arc min is ineffective between object surface and gloss reflectance which is originated by the position of light source. Therefore, stereoscopic display system is inadequate for the application observing from a distant place, for example, landscape simulation.

On the other hand, at the position of 1.5 m observation shown in Figure 10(b), the difference between 2D and 3D appears clearly. The effect of a stereoscopic display can be estimated at about 1.1 times for the gloss perception. Interestingly, the correlation with the value C is decreasing compared with 3 m position. This result suggests that perception of gloss appearance is affected by both image contrast and disparity of gloss. However, we have to analyze these results in detail, since the correlation value of 2D is decreasing compared with 3 m position.

Conclusion

In this research, we evaluate the contribution of binocular stereoscopic effect at gloss appearance with variation of disparity and image contrast. Especially, we pay attention to the disparity between surface and gloss appearance, and attempt the comparison experiments which include the two cases. One case impose the evaluation within 35 arc min disparity (distance is 3 m from screen) and another case is more than 35 arc min disparity (distance is 1.5 m from screen). From the result of 3m observation, it is difficult to distinguish the difference of gloss perception between 2D and 3D, nevertheless subject can recognize the difference of contrast change in test images. While on the other hand, there is a noticeable difference between 2D and 3D score at 1.5 m observation. It suggests that subjects can recognize the difference of disparity between surface and light source since the close observation attract the increase of disparity.

This time, we decided its border 35 arc min by using Pastoor's results. However, we should make clear this border value by the future work. The influences of disparity range have a possibility of clarifying the mechanism of our stereoscopic vision, also including relation with Panum's area. Another remarkable phenomenon is the decrease of image contrast score in a symmetric appearance of disparity effect. We also have to clarify whether the disparity effect in additionally or relatively by using 3D stereoscopic display.

Acknowledge

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