Effects of Motion Parallax Smoothness and Head Moving Range on Reduction of The Cardboard Effect

Kosuke Takahashi[1], Haruki Mizushina[1], Shiro Suyama[2], Kenji Yamamoto[1]

[1]c612236011@tokushima-u.ac.jp
[1]Dept. of Optical Science and Technology, Tokushima University, 2-1 Minamijyousanjima, Tokushima, 770-8506, Japan
[2]Center for Optical Research and Education, Utsunomiya University, Utsunomiya 321-8585, Japan
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ABSTRACT

Smoother motion parallax and wider head movements contribute to reduce the cardboard effect in binocular stereoscopic display. The cardboard effect, a perceptual distortion in stereoscopic displays that makes objects appear flat, can be reduced by adding motion parallax.

1 INTRODUCTION

Among the various stereoscopic display technologies, the binocular stereoscopic display is one of the typical methods used for 3D movies, etc.[1] This method is relatively easy to achieve a 3D effect by presenting disparity images to the left and right eyes wearing 3D glasses. However, perceptual distortions specific to this method are known to be induced[2-4]. These distortions include the “puppet theater effect” and the “cardboard effect”, both of which do not occur in the real world and are unique to binocular stereoscopic display. It is important to reduce these distortions to maintain the reality of 3D images.

The cardboard effect is known as one of the common perceptual distortions often seen in binocular stereoscopic display systems[2-4]. The cardboard effect is a perceptual phenomenon in which, when viewing a stereo image consisting of a foreground object and background, the depth between the foreground object and background can be perceived, but the thickness of the foreground object itself cannot be accurately perceived, and is underestimated as thin, as if it were a stage scene. The most likely causes of this phenomenon are small disparity of the foreground object itself, a short viewing distance compared to the shooting distance, and discontinuous disparity between the background and the foreground. Since the shooting distance is often several meters to several tens of meters, whereas the viewing distance is often several tens of centimeters, the cardboard effect is expected to occur in most cases in stereoscopic images. These facts suggest that the cardboard effect is caused by incorrect depth scaling when there is a mismatch between binocular disparity and the perceived distance[5-7].

To reduce this cardboard effect, a previous study proposed a method to adding motion parallax caused by head movement to binocular disparity and reported that the cardboard effect was reduced by this method[8]. Motion parallax refers to the retinal image motion caused by the movement of the observer or the object and is one of the depth perception cues[9].

Our previous research showed that adding motion parallax reduces the cardboard effect that occurs in stereo images taken with various parameters[10]. However, in that research, to present smooth motion parallax, 150 images were used for each of the left and right eyes, and the head moving range was ±10 cm horizontally. The number of images corresponds to the number of cameras required, and it is difficult to prepare such many cameras and to arrange them closely together in practice. In addition, it is not realistic to move the head ±10 cm for practical use. Therefore, in this study we focused on the smoothness of motion parallax and the amount of information obtained from the head moving range.

Based on the above, this study clarifies the relationship between the smoothness of motion parallax and head moving range on reducing the cardboard effect by addition of motion parallax.

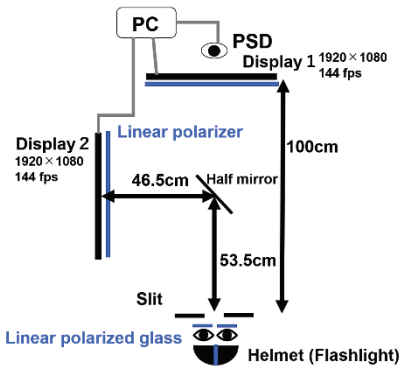
2 EXPERIMENTAL SYSTEM FOR EVALUATION OF REDUCING CARDBOARD EFFECT BY MOTION PARALLAX

2.1 EXPERIMENTAL SYSTEM

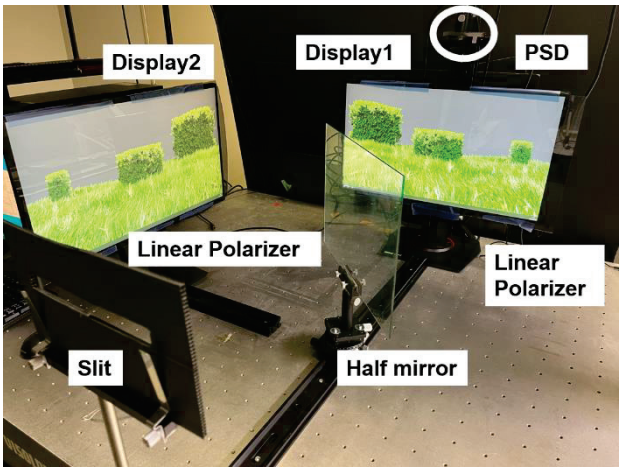
Fig. 1(a) shows an overview of the experimental apparatus using a binocular stereoscopic display system equipped with a head-tracking system. A polarization filter method was used to present binocular disparity. The subject's right eye received the image of Display 1, which presented only the image for the right eye, whereas the left eye received the image of Display 2, which presented only the image for the left eye. Display 1 for the right eye and the right eye of the linear polarized glasses worn by the subject were equipped with linear polarizer, while Display 2 for the left eye and the linear polarizer rotated 90 degrees were installed on the left eye of the linear polarized rotated 90 degrees glasses, so that only the respective images were delivered. By displaying images with disparity between Displays 1 and 2, the subject could obtain depth information by binocular disparity. The photo of experimental setup is shown in Fig. 1(b).

Next, the mechanism for adding motion parallax to the subject is shown in Fig. 1(c), where a helmet with an infrared light and a Position Sensitive Detector (PSD) were used. The PSD detected the position of the subject's head by sensing the position of an infrared light attached to the helmet. Motion parallax was displayed by switching images according to the detected position of the subject's head.

As stereoscopic images, scenes taken from a horizontal distance of 6.5 cm, which was almost the same as the distance between the eyes, were presented to the right and left eyes, respectively.



(a) Experimental system



(b) Actual experimental apparatus

(c) Helmet with infrared flashlight

Fig.1 Experimental apparatus

2.2 EXPERIMENTAL STIMULI

As the experimental stimulus in this experiment, we used hedges, which were objects whose depths were difficult to estimate only by pictorial cues. Hedges could be small, such as those in private gardens, or large, such as those on roadsides or in parks, and it was difficult to estimate their thickness in general. The experimental stimuli were created using CG software[11] and consisted of lawns with hedges on top, as shown in Fig. 2. CG data for the lawns and hedges were commercially available[12, 13]. The parameters were set at a shooting distance of 14 m and thickness of the center hedge was 4.2 m. Fig. 3 shows an example of experimental stimuli.

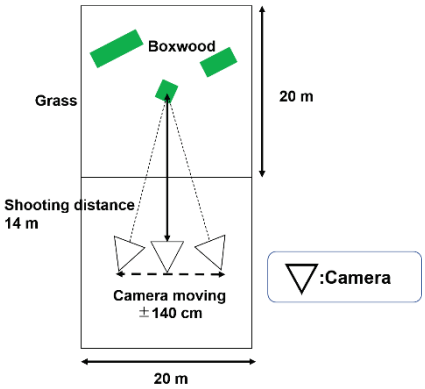


Fig. 2 Rendering system

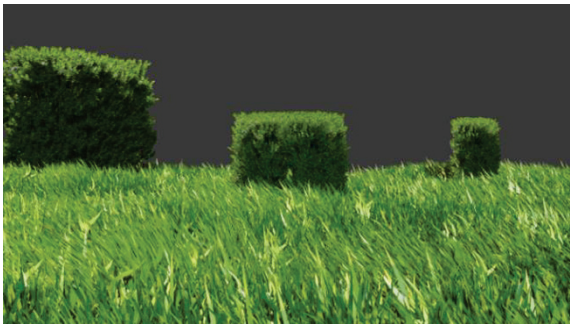


Fig. 3 Stimulus

3 EXPERIMENT 1 : SMOOTHNESS OF MOTION PARALLAX

3.1 METHOD

Five subjects who had normal stereo vision participated in this experiment. The subjects viewed the stereo images binocularly without moving their heads, or they viewed the stereo images binocularly while moving their heads back and forth horizontally in 2-second cycles. In the latter case, the motion parallax was represented by switching to images from adjacent camera positions each time subject's head moved 1.33 mm, 2.66 mm, 5 mm, 10 mm, 20 mm, 28.6 mm, 40 mm (hereafter referred to as "viewpoint interval").

After observing the stimulus, subjects responded to the perceived thickness of the center hedge while viewing the reference image shown in Fig. 4. The scale in Fig. 4 indicates the ratio of the length of the front side of the hedge to its thickness in the depth direction, and subjects responded to the ratio to one decimal place. The experiment consisted of 7 patterns of viewpoint interval with motion parallax and 1 pattern without motion parallax. 3 trials were made for each condition, for a total of 24 trials.

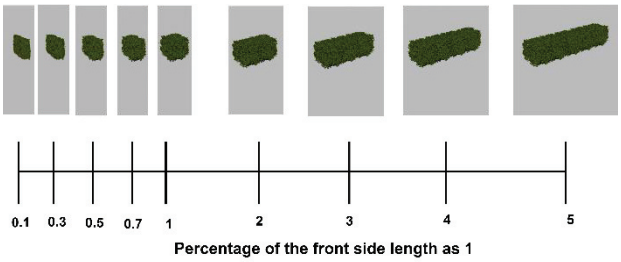


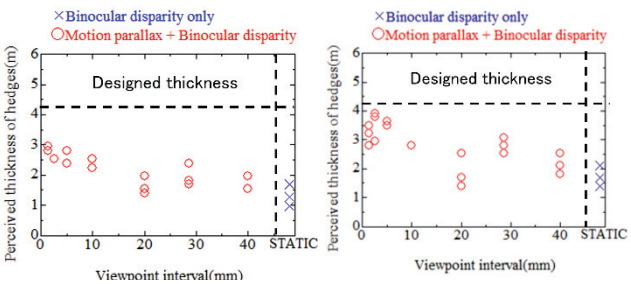
Fig.4 Reference image

3.2 RESULTS AND DISCUSSION

Fig.5 shows the evaluation results for two out of five subjects. The horizontal axis indicates the viewpoint interval (smoothness of motion parallax) and the vertical axis indicates the thickness of the hedge as perceived by the subjects. For the plot points, binocular disparity only (×), binocular disparity + motion disparity (○).

The horizontal dotted line on the graph represents the thickness of the designed hedge. The closer the plot point is to 0, the thinner the perceived thickness is, and the closer to the dotted line, the closer to the designed thickness is. In the binocular disparity only case (×), both subjects perceived the hedge thickness as thinner than the designed because the evaluated values were close to 0. This suggests that in the case of binocular disparity only, a cardboard effect occurred. On the other hand, when motion parallax was given (○), the values were relatively close to the dotted line, suggesting that motion parallax reduced the cardboard effect. Both subjects also perceived the thickness of the hedge to be thinner as the viewpoint interval became wider (less smooth) with respect to the smoothness of the motion parallax.

Analysis of variance from the results showed significant effect among each condition for both subjects. $F(7,16) = 13.502$ $p < 0.001$ (Fig.5(a)), $F(7, 16) = 11.532$ $p < 0.001$ (Fig.5(b)).



(a) Subject 1 **(b) Subject 2**

Fig. 5 Effect by smoothness of motion parallax

4 EXPERIMENT 2 : HEAD MOVING RANGE

4.1 METHOD

To investigate the effect of the range of head moving on the reduction of the cardboard effect by motion parallax, slit width were varied to limit the subject's head moving range. Five widths of head moving range were examined: 0 cm, 1 cm, 3.25 cm, 5.5 cm, 7.75 cm, and 10 cm. The actual slit size was calculated by adding 6.5 cm, the interpupillary distance, to each length. The viewpoint interval was constant at 1.33 mm in all conditions.

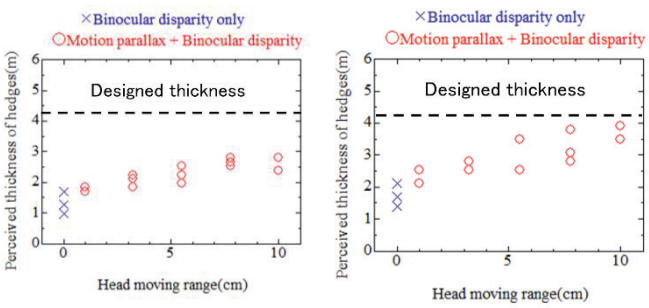
The experiment consisted of 6 patterns of head moving range with 3 trials were made for each, resulting a total of 18 trials.

4.2 RESULTS AND DISCUSSION

Fig.6 shows the evaluation results for two out of five subjects. The horizontal axis indicates the head moving range and the vertical axis indicates the thickness of the hedge as perceived by the subjects.

The result for both subjects shows that the larger the head moving range, the more the hedge was perceived at the designed thickness. This suggests that the smaller the head moving range, the smaller the reducing cardboard effect, and the larger the head moving range, the larger the reduction effect.

Analysis of variance from the results showed significant effect among each condition for both subjects. $F(5, 12) = 13.482$, $p < 0.001$ (Fig.6(b)), $F(5, 12) = 10.563$, $p < 0.001$ (Fig.6(b)).



(a) Subject 1 **(b) Subject 2**

Fig.6 Effect on head moving range

4 CONCLUSIONS

We evaluated the effects of the smoothness of motion parallax and the head moving range on the reduction of the cardboard effect by adding motion parallax. In experiment 1, the results indicated that the smoother the motion parallax the more the cardboard effect is reduced. In experiment 2, the results indicated that the wider the head moving range the more the cardboard effect is reduced.

Acknowledgements

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