Monocular Perceived Depth Improvement Using Motion Parallax in Arc 3D Display and Dependence on Motion Cycle Time

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ABSTRACT

Saturation degradation of perceived depth of 50 mm by monocular motion parallax in head-tracking system can be successfully improved to large perceived depth of 180 mm by using Arc 3D display without delay time. Head motion cycle affects perceived depth and cycle time of 2 sec is the most stable.

1 INTRODUCTION

Many of practical 3D displays are stereoscopic or multi-view display by using only binocular disparity and vergence. However, not a few people have problems for perceiving depth only by binocular disparity. In order to solve this problem, 3D displays using monocular motion parallax have been proposed and developed by using head tracking [1] as shown in Fig. 1. One of problems in this head-tracking 3D display is degradation in perceived depth saturated around 50 mm (in left graph of Fig. 1) as designed depth increases, even when the delay time is as small as 33 ms [1].

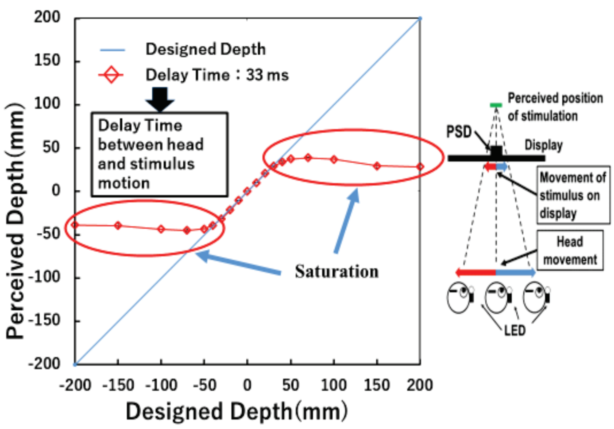


Fig. 1 Saturated perceived depth degradation by monocular motion parallax using head tracking with delay time of 33 ms

To solve this problem, smooth motion parallax and no delay time are important. Motion parallax is the change of the retinal image caused by moving observer's position. Sign and magnitude of perceived depth from motion parallax are determined by the geometric relationship between head and stimulus movements. As shown in Fig. 2, the observer can perceive depth from motion parallax in front of or behind of the display.

One of precious 3D displays having continuous motion parallax without delay time is Arc 3D display [2]. Figure 3 shows principle of Arc 3D display. Arc 3D display is composed of arc-shaped scratches, and only one bright spot appears in arc-shaped scratch according to one eye position. Different bright spot positions by both eyes and bright spot motion according to eye motion lead to binocular parallax and continuous motion parallax respectively. 3D image depth can be changed by arc radius change.

In our previous study [3], Arc 3D displays without delay time can improve depth saturation in head tracking system. However, since the head is moving freely, the motion speed is not constant, and perceived depth dependence on the cycle time of the head motion has not clarified yet [3].

In this study, we clarified the influence of the motion cycle time to perceived depth by monocular motion parallax in Arc 3D display.

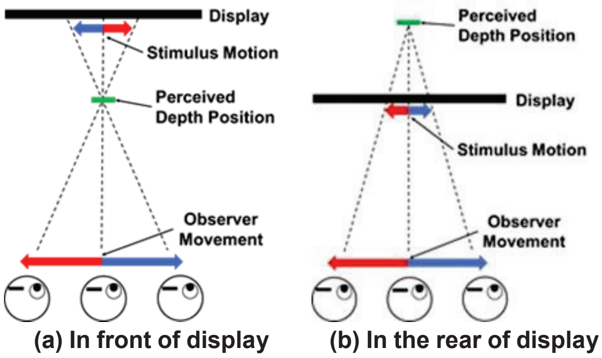


Fig. 2 Principle of motion parallax

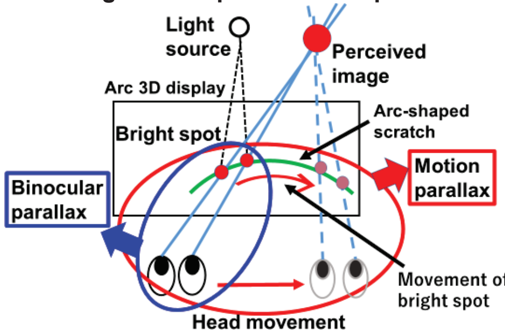


Fig. 3 Principle of Arc 3D display with smooth motion parallax

2 EXPERIMENT 1: INFLUENCE OF OBSERVATION DISTANCE

We have evaluated importance of observation distance of perceived depth in front of or behind Arc 3D display using motion pallrax.

2.1 Evaluation method for monocular perceived depth by changing observation distance

Perceived depths by monocular motion parallax were evaluated with one eye while subjects were moving their head. Designed depths were randomly changed by arc radius change. Table 1 shows the Arc 3D display designed depth and arc radius. Observation distance is 1 m or 2 m. The subject evaluated the perceived depth of Arc 3D image relative to reference by using interval between their thumb and index finger under 100 mm in left illustration or ruler over 100 mm in right illustration in Fig. 4. Three trials were measured at each randomly selected designed depth.

Table 1 Designed depths and arc-shaped radius of Arc 3D display

Designed Depth	Arc-shaped radius
30 mm	45 mm
50 mm	75 mm
70 mm	105 mm
100 mm	145 mm
150 mm	215 mm
200 mm	270 mm

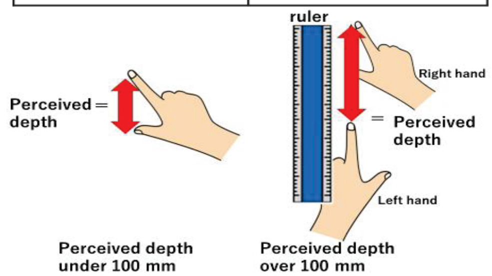


Fig. 4 Measuring method of perceived depth

2.2 Importance of observation distance when designed depth is in front of the Arc 3D display

Experimental apparatus is shown in Fig. 5. Designed depth was in front of Arc 3D display surface.

Figure 6 shows the perceived depths of 3 subjects by monocular motion parallax in Arc 3D display when the observation distance is (a) 1 m or (b) 2 m. When the perceived image is in front of the display surface at observation distance of 1 m in Fig. 5 (a), the perceived depth is saturated around 100 mm and decreased over 100 mm. However, when the observation distance is 2 m in Fig. 5 (b), the perceived depth can be enlarged over 100 mm, to about 140 mm. Thus, perceived depth can be increased more than twice or 3 times as compared to that by using head tracking.

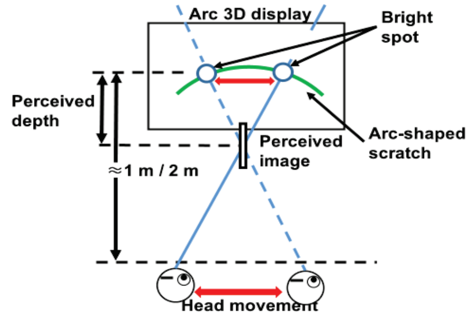
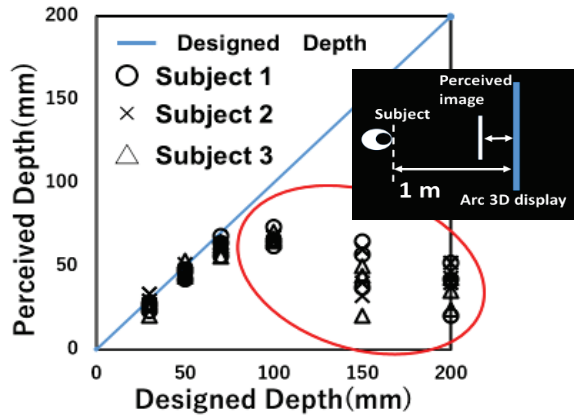
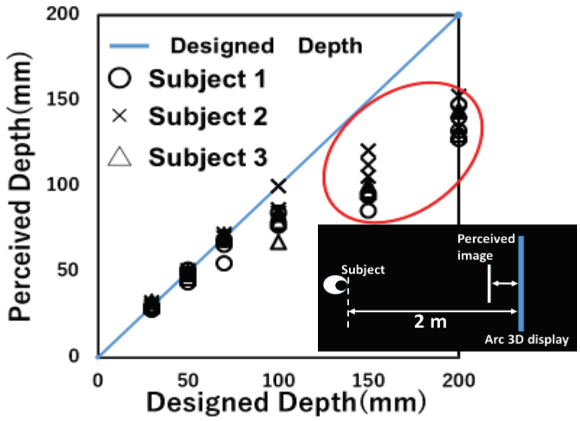


Fig. 5 Experimental apparatus for evaluating depth perceived in front of Arc 3D display by motion parallax



(a) Perceived depth in front of display when observation distance is 1 m



(b) Perceived depth in front of display when observation distance is 2 m

Fig.6 Improvement of perceived depth in monocular motion parallax by using arc 3D display when the perceived depth is in front of the Arc 3D display

2.3 Importance of observation distance when designed depth is behind the Arc 3D display

Experimental apparatus is shown in Fig. 7. Designed depth was behind the surface of the arc 3D display.

Figure 8 shows the perceived depths of 3 subjects by monocular motion parallax in Arc 3D display when the observation distance is (a) 1 m or (b) 2 m. The perceived depth can be successfully improved from 50 mm in Fig.

1 to 100-150 mm in Figs. 8 (a) and (b) by using arc 3D display. When the perceived image is behind the Arc 3D display surface, the perceived depth dependencies are not affected by observation distance difference. Thus, perceived depth can be increased more than twice or 3 times as compared to that by using head tracking.

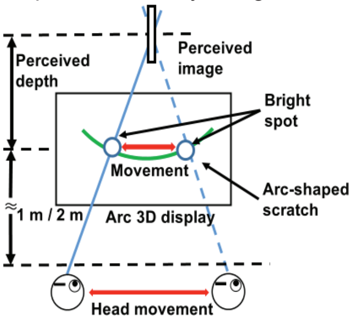
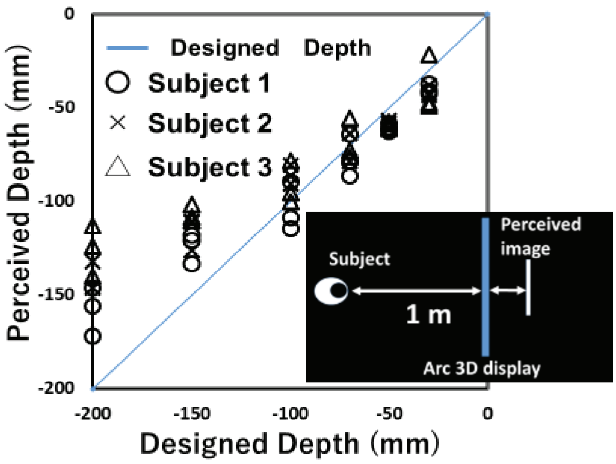
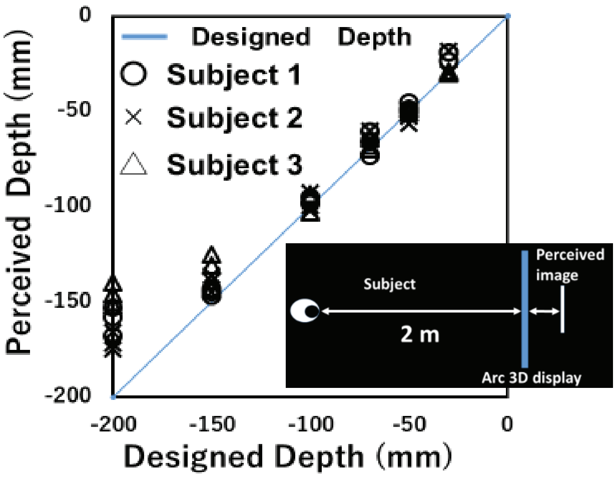


Fig. 7 Experimental apparatus for evaluating depth perceived behind Arc 3D display by motion parallax



(a) Perceived depth behind display when observation distance is 1 m



(b) Perceived depth behind display when observation distance is 2 m

Fig.8 Improvement of perceived depth in monocular motion parallax by using arc 3D display when the perceived depth is in front of the Arc 3D display

3 EXPERIMENT 2: INFLUENCE OF THE MOTION CYCLE TIME TO PERCEIVED DEPTH BY MONOCULAR MOTION PARALLAX IN ARC 3D DISPLAY.

Arc 3D displays without delay time can improve depth saturation in head tracking system. However, since the head is moving freely, the motion speed is not constant, and perceived depth dependence on the cycle time of the head motion has not clarified yet. In experiment 2, we clarified the influence of the motion cycle time to perceived depth by monocular motion parallax in Arc 3D display.

3.1 Evaluation method of influence of cycle time to perceived depth

Experimental apparatus is shown in Fig. 9. An arc 3D display was placed 1 m in front of the subject, and the designed depth was behind the surface of the arc 3D display. In order to evaluate motion parallax only in the horizontal direction, horizontal slits were placed in front of the Arc 3D display and in front of the subject's eyes to limit vertical motion. Cycle times of head motion were 4 sec, 2 sec and 1.3 sec. The width of the head motion was 150 mm, and the click sound was made at the end of the motion to determine the motion cycle time. The subjects observed the stimulus with one eye and evaluated the perceived depth of the center stimulus relative to the arc display surface by using distance between their thumb and index finger under 100 mm or ruler over 100 mm in Fig. 4. Three trials were measured at each randomly selected designed depth. Table 1 shows the designed depth of the Arc 3D display and the radius of arc-shaped scratch.

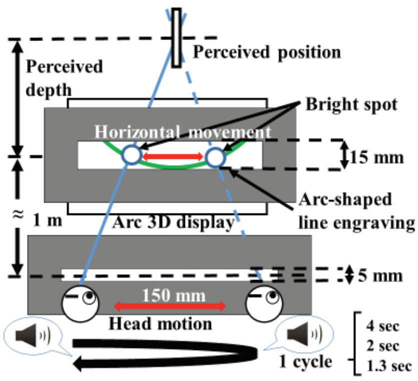


Fig. 9 Experimental apparatus for influence of cycle time to perceived depth by motion parallax

3.2 Influence of cycle time to perceived depth

Figure 10 shows the perceived depths of 3 subjects by monocular motion parallax in Arc 3D display when cycle time of head motion is changed.

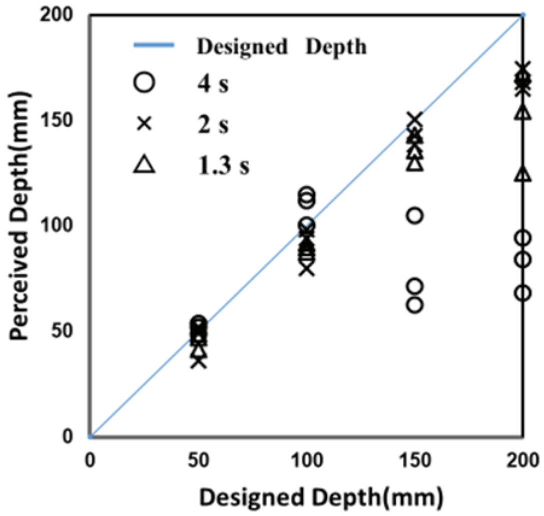
For all subjects in Figs. 10 (a), (b) and (c), when head motion cycle time is 4 sec, perceived depth increases along designed depth but has saturation tendency over

150 mm and large deviation. At head motion cycle time of 1.3 sec, perceived depth increases to almost the same depths as designed depths but is slightly degraded.

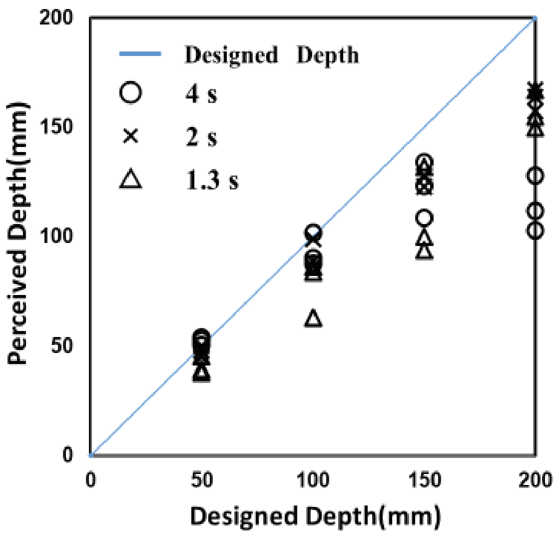
On the other hand, when head motion cycle time is 2 sec, the perceived depth increases to the almost same depths as designed depths, and degradation and deviation are very small.

Perceived depth degradations at head motion cycle time of 4 sec are different between subjects. Subject 1 has much saturation degradation in depth perception when designed depth exceeded 100 mm. Subjects 2 and 3 also have saturation degradation in depth perception, but the perceived depth is closer to designed depths than that of subject 1. On the other hand, perceived depth degradations at head motion cycles of 2 sec and 1.3 sec have not much difference between subjects.

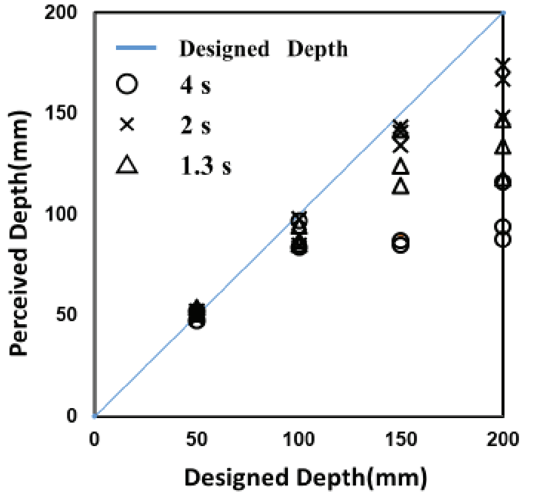
Thus, monocular perceived depth by motion parallax in Arc 3D display is affected by motion cycle time and the most stable motion cycle time is 2 sec.



(a) Subject 1



(b) Subject 2



(c) Subject 3

Fig. 10 Perceived depth dependences by monocular motion parallax at various cycle times of head motion

4 CONCLUSION

The effect of the perceived depth on the observation distance was examined to evaluate whether the perceived depth saturation was improved or not. When the perceived depth is in front of the arc 3D display, the perceived depth saturation is much improved by increasing the observation distance. When the perceived depth is behind the arc 3D display, the perceived depth can be improved at all observation distance.

We investigated the influence of the motion cycle time to perceived depth by monocular motion parallax in Arc 3D display. Depth perception is degraded when the motion speed is slow. By increasing motion speed, the depth perceived by the motion parallax is significantly improved.

This is very important result in developing new 3D display for people having problems for perceiving depth only by binocular disparity.

ACKNOWLEDGMENT

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