Importance of Continuous Motion Parallax in Monocular and Binocular 3D Perception

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ABSTRACT

Motion parallax is one of the cues of human depth perception. It provides sufficient depth information even in monocular viewing, and improves degradation of stereoscopic depth by visual acuity difference of both eyes. In this paper we demonstrate importance of continuous motion parallax in monocular and binocular depth perception.

1 INTRODUCTION

Motion parallax is one of depth cues of perception of three-dimensional (3D) world [1], however, most of 3D displays commercially available as of today are mainly based on binocular disparity and binocular vergence as physiological cues of depth perception. Motion parallax is not considered and cannot be provided in such type of displays. In our laboratory, we are studying contribution of motion parallax in monocular and binocular human depth perception for hyper-realistic 3D display technologies. In this paper we review our results in each of monocular and binocular depth perception from motion parallax.

2 INFLUENCE OF DELAY IN HEAD-TRACKING DISPLAY ON DEPTH PERCEPTION FROM MONOCULAR MOTION PARALLAX

Displaying motion parallax can be realized by multi-view display or head-tracking display. Head-tracking display detects change of observer's head position, calculates new object position on the screen, and depicts object images on the screen for synchronizing head movement and stimulus movement. This series of processes in the head-tracking system needs processing time and results in delay time between head movement and stimulus movement. Firstly, we evaluated influence of delay time on perceived depth from monocular motion parallax using a head-tracking apparatus.

2.1 Methods

The head-tracking apparatus used in our experiment is shown in Figure 1. A position sensitive device (PSD) detected the position of the LED light source attached to the observer's head. A computer calculated stimulus location on the display screen according to the head position signal from the PSD. Visual stimulus, which consisted of three green squares arranged vertically, was presented on a LCD located at 100 cm from the observer. Delay time of this system was 33 ms (two frames in 60 Hz refresh rate) at the shortest.

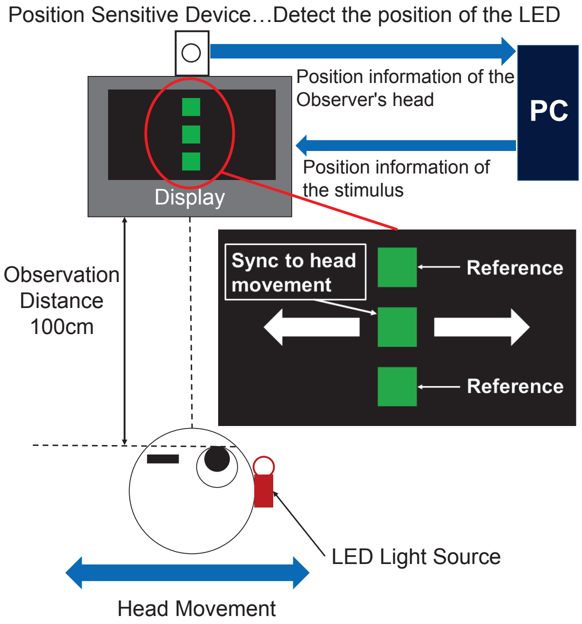


Fig. 1 Experimental apparatus using head tracking system

Subjects moved their head laterally and reciprocally with width of 12 cm and temporal cycle of 2 s. Only middle green square in the stimulus was moved synchronized with subjects' head movement. To vary motion parallax of the stimulus, the stimulus movement relative to the head movement was changed. Top and bottom green squares were always stable and were used as reference of perceived depth. Subjects observed stimulus with their preferred eye during their head movements. They reported perceived depth between middle square and reference (top and bottom squares) by using interval between their thumb and index finger. Prior to the experiment, subjects were trained and calibrated to indicate perceived depth by using their finger.

Delay times between subjects' head movement and stimulus movement were 33 ms, 95 ms, and 150 ms. Delay times of 95 ms and 150 ms were generated by computer program. These conditions were randomly selected and tested three times. For comparison, perceived depth for real object was also evaluated. Three subjects participated in this experiment.

2.2 Results and Discussion

Figure 2 shows perceived depth relative to designed depth specified by motion parallax for three delay times (33 ms, 95 ms, 150 ms) and for real object in one subject. Perceived depths are deviated greatly from line of designed depth with 150 ms delay time especially in large designed depth, and are gradually improved with decreasing delay time. The other two subjects show similar results. These results show degradation of perceived depth by increasing delay time between head and stimulus movements [2]. These results also indicate importance of reducing delay time to perceive designed depth in interactive systems using head-tracking.

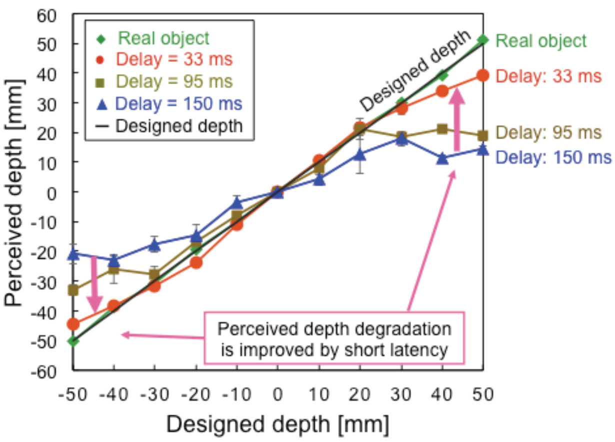


Fig. 2 Perceived depth from monocular motion parallax with various delay times

3 EFFECT OF VISUAL INFORMATION AT THE TIME OF CHANGING MOTION DIRECTION ON DEPTH FROM MONOCULAR MOTION PARALLAX

In the previous section, delay time between head and stimulus movements influence depth perception from monocular motion parallax. Because stimulus delay is significantly noticeable at the time of changing motion direction, we hypothesized that visual information at the time of changing head motion and stimulus motion plays important role in depth perception from monocular motion parallax. To test this hypothesis we compared perceived depths by motion parallax stimuli with and without motion direction change.

3.1 Methods

The head-tracking apparatus used in the previous section was also used in this experiment. Figure 3 shows experimental conditions for examining effect of displaying change of stimulus motion direction on depth perception from monocular motion parallax; (a) including change of motion direction, (b) not including change of motion direction. In Fig. 3(a), stimulus was presented only while subject's head was in either left or right of middle of horizontal head movement range. In Fig. 3(b), stimulus was presented only while subject's head was in either leftward or rightward movement. Stimulus duration was equal in both conditions because stimulus was presented for 50% of total trial time. For comparison purpose, perceived depth when stimulus is displayed throughout the trial was also evaluated. Subjects viewed stimulus with one eye while moving laterally and reciprocally with 10 cm width and temporal cycle of 2 s. They reported perceived depth between middle square and reference (top and bottom squares) by using interval between their thumb and index finger as in previous experiment.

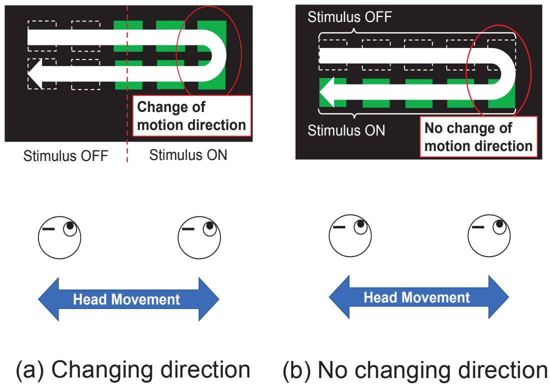


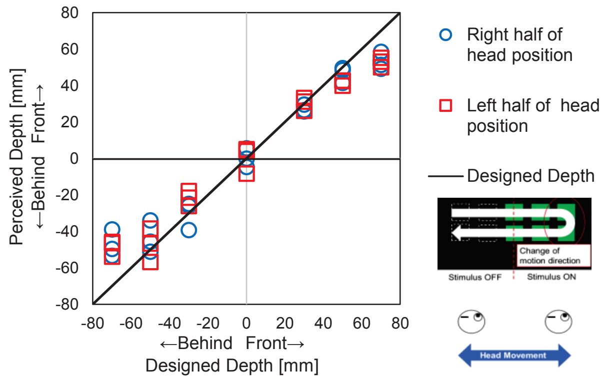
Fig. 3 Experimental conditions of moving stimulus

3.2 Results and Discussion

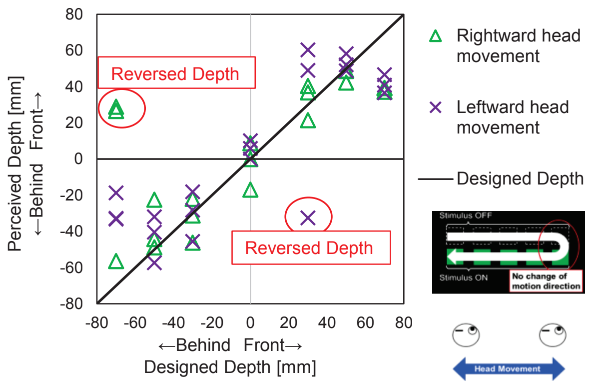
Figure 4 shows perceived depths of typical subject in each stimulus condition; (a) changing direction, (b) not changing direction, (c) displaying throughout the trial. Perceived depth in Fig. 4(a) is comparable to that in Fig. 4(c), which means small deviation from the line of designed depth specified by motion parallax with small variation. On the other hand, perceived depth in Fig. 4(b) is significantly deviated apart from the line of designed depth. In addition, perceived depth direction (near or far) sometimes reversed in Fig. 4(b). These results suggest that visual information at the time of changing head and stimulus motion direction contributes to stable and unambiguous depth perception in monocular motion parallax [3].

4 EFFECT OF CONTINUOUS MOTION PARALLAX IN BINOCULAR DEPTH PERCEPTION WITH UNBALANCE IN VISUAL ACUITY BETWEEN LEFT AND RIGHT EYES

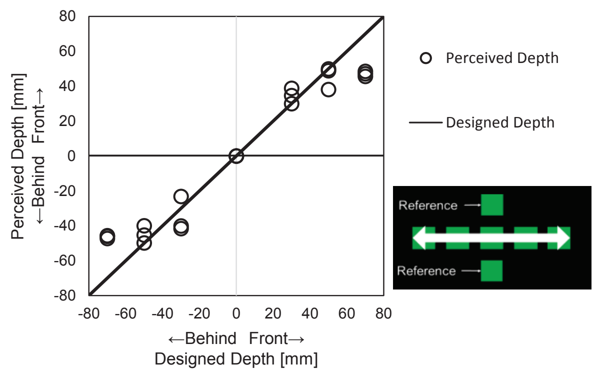
Contribution of motion parallax in monocular depth perception was examined in previous two experiments. We also evaluated effectiveness of motion parallax for improving perceived depth degradation by increasing visual acuity difference of left and right eyes. Anisometropia refers to large difference in visual acuity between left and right eyes. People with anisometropia are difficult to perceive depth only using binocular disparity. It has been reported that DFD (Depth-fused 3D) display [4] is less susceptible to visual acuity



(a) Changing direction



(b) No changing direction



(c) Displayed throughout the trial

Fig. 4 Perceived depth in stimulus conditions of (a) with change direction, (b) without change direction, and (c) displaying throughout trial

difference between both eyes in binocular depth perception [5]. DFD display has small, but smooth motion parallax and we hypothesized that smooth motion parallax supports binocular depth perception. In our study, we used arc 3D display instead of DFD display as a 3D display technique which has both binocular parallax and smooth motion parallax to evaluate our hypothesis.

4.1 Principle of Arc 3D display

Figure 5 shows principle of arc 3D display. When arc-shaped scratches are illuminated, directional scattering is caused at arc-shaped scratches. Because of this directional scattering, one bright spot can be observed from one viewing position. This phenomenon results in different bright spots for left and right eyes. These two bright spots at different locations generate binocular parallax. Moreover, these bright spots can move according to head and eye movement.

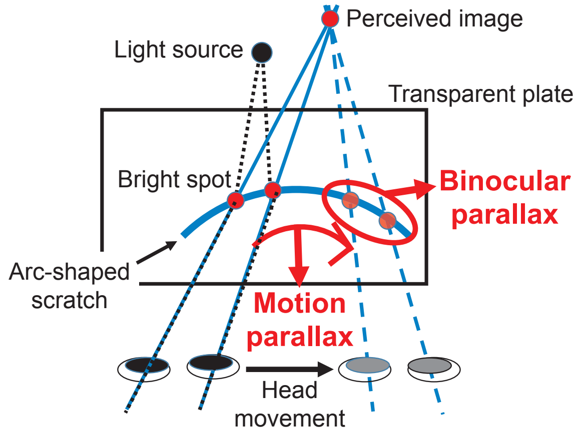


Fig. 5 Principle of arc 3D display

4.2 Methods

Figure 6 shows the apparatus to evaluate perceived depth of arc 3D display and stereoscopic display with large visual acuity difference between left and right eyes. Fig. 6(a) shows the apparatus used for evaluating depth perception of arc 3D display. Viewing distance was 300 mm and designed depth was 20 mm behind the arc 3D plate. Stimulus was a white rhombus with a side of 5 cm, which consists of a lot of arc-shaped scratches illuminated by a white light. Fig. 6(b) shows the apparatus used for evaluating depth perception to stereoscopic display. Viewing distance and designed depth were the same as those for arc 3D display. Stimulus was a photograph of the stimulus in arc 3D display with binocular disparity corresponded to depth of 20 mm. Observer's head was stabilized by a chin and forehead rest for both arc 3D and stereoscopic displays. For simulating anisometropia, visual acuity difference was induced by occlusion foil placed in front of one eye.

4.3 Results and Discussion

Figure 7 shows perceived depth change difference between arc 3D display and stereoscopic display when visual acuity difference between both eyes is increased. In stereoscopic display, perceived depth is quickly degraded when visual acuity of one eye is decreased to around 0.2 in subject A and 0.1 in subject B, and no depth is perceived at lower visual acuity. On the other hand, arc 3D display has little degradation even when

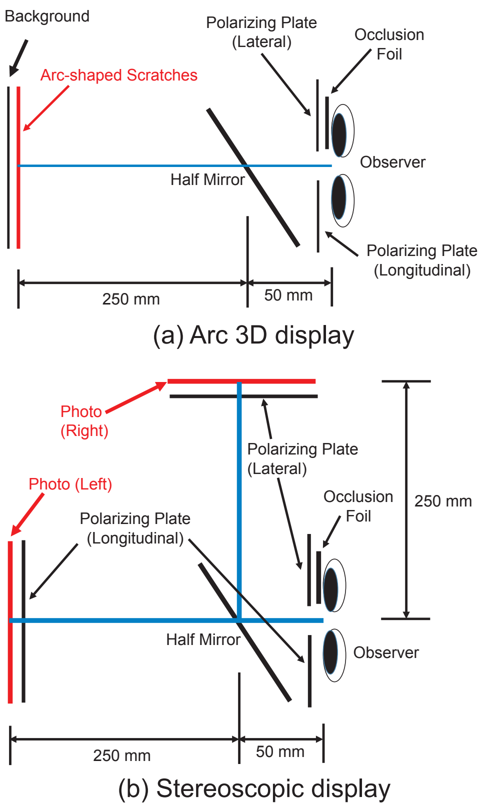


Fig. 6 Experimental apparatus to evaluate perceived depth of arc 3D and stereoscopic displays with visual acuity difference between both eyes

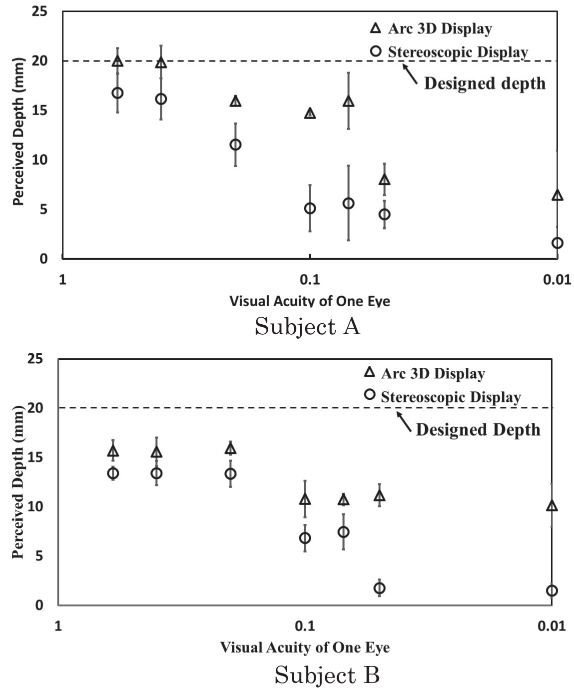


Fig. 7 Perceived depth change difference between arc 3D display and stereoscopic display

increasing visual acuity difference. As previously mentioned, critical difference between arc 3D and stereoscopic displays is existence of continuous motion parallax. This improvement of perceived depth degradation in arc 3D display has similar tendency as that of DFD display in previous study [5]. These results support our hypothesis and suggest that continuous motion parallax improves degradation of binocular depth perception in anisometropic situation [6].

5 CONCLUSIONS

In monocular motion parallax, decreasing delay time between head and stimulus movements and visual information at the time of changing motion direction are critical for depth perception. Even in binocular depth perception, motion parallax plays important role for supporting depth perception when visual acuity difference between both eyes is large. Although most of 3D displays commercially available cannot provide motion parallax, newly developing 3D displays would be better of considering motion parallax for human friendly display.

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