# A New 3D Display Utilizing Occlusion Effect by Frames, Gap and Bend of Side-by-Side 2D Displays over Moving Stimuli

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## ABSTRACT

*Separating two side-by-side displays with frames and gap can improve virtual perceived depth of moving stimuli behind frames and/or gap by occlusion effect, rather than displays fastening together without them. Horizontal bend and/or vertical inclination in two 2D displays and curved moving stimuli can significantly enlarge virtual perceived depth.*


## 1 INTRODUCTION

Conventional 3D displays have problems that special equipments, such as 3D glasses, parallax barrier or lenticular lens, etc. are needed and that stereo-blind people cannot enjoy 3D perception by using binocular disparity. If depth perception can be obtained only by pictorial cues, such as occlusion effect, even stereo-blind people can also enjoy 3D perception. Occlusion effect is one of the strong pictorial cues: when the object A is partially hidden by another object B, the occluded object A is perceived behind another object B.

We have proposed a new simple 3D display utilizing occlusion effect [1] by frames and/or gap in two side-by-side 2D displays over moving stimuli. Figure 1 shows principle of our proposed method using occulusion effect. In our proposed 3D display, two 2D displays are arranged side by side with frames (bezel), gap, horizontal bend and vertical inclination. Moreover, horizontally moving stimuli are hidden behind their frames and/or gap and appear on another display. This results in virtual depth perception of moving stimuli behind the frames and/or gap by occlusion effect.

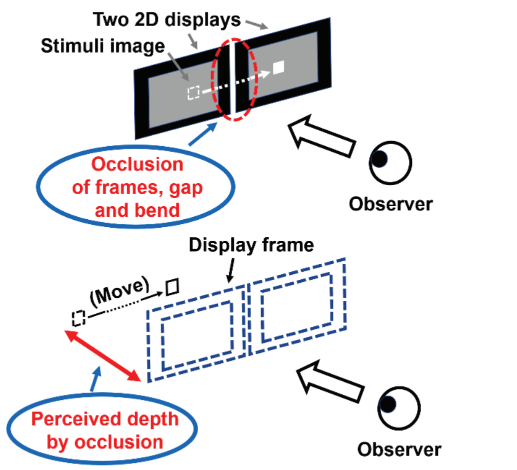



Fig. 1 Principle of our proposed 3D display

In previous studies [2], our proposed 3D display can successfully improve virtual perceived depth to about 1-3 cm as compared to single 2D display without occlusion effect. However, as depth improvement is small, it is necessary to search several conditions for increasing depth improvement.

In this study, we have proposed new arrangements of horizontal bend and vertical inclination in two side-by-side 2D displays and two stimulus movements of linear and curved reciprocating movements for perceived depth improvements.

## 2 EXPERIMENTAL METHOD FOR ESTIMATING PERCEIVED DEPTH IMPROVEMENT

### 2.1 Experimental system of our proposed 3D display

Figure 2 shows the experimental system of our proposed 3D display. Each screen size of display was 12.5 inches in height and 14.5 inches in width and frame widths was 3.0 cm. Two stimulus images in two displays were moved in synchronization. Observation distance from display frames was 90 cm.

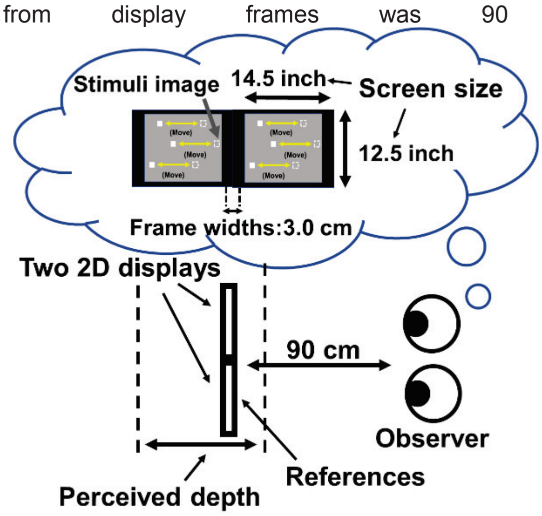



Fig. 2 Experimental system of our proposed 3D display

### 2.2 Arrangement of two side-by-side 2D displays

Figure 3 shows arrangement differences of two displays with frames, gap, horizontal bend and vertical inclination. Perceived depths behind display frames were evaluated with one eye in 5 conditions: (a) single 2D display, (b) occlusion frames between side-by-side 2D displays, (c) occlusion gap and frames between two 2D displays, (d) occlusion frames between two horizontal bend 2D displays, (e) occlusion frames and gap between two horizontal bend 2D displays and (f) occlusion frames, gap, horizontal bend and vertical inclination.

In (b) and (c), the occlusion influences of frames and/or gap on perceived depths of moving stimuli hidden by frames and/or gap were evaluated. In (d), (e) and (f), the influences of horizontal bend and vertical inclination of two side-by-side 2D displays on perceived depths were evaluated.

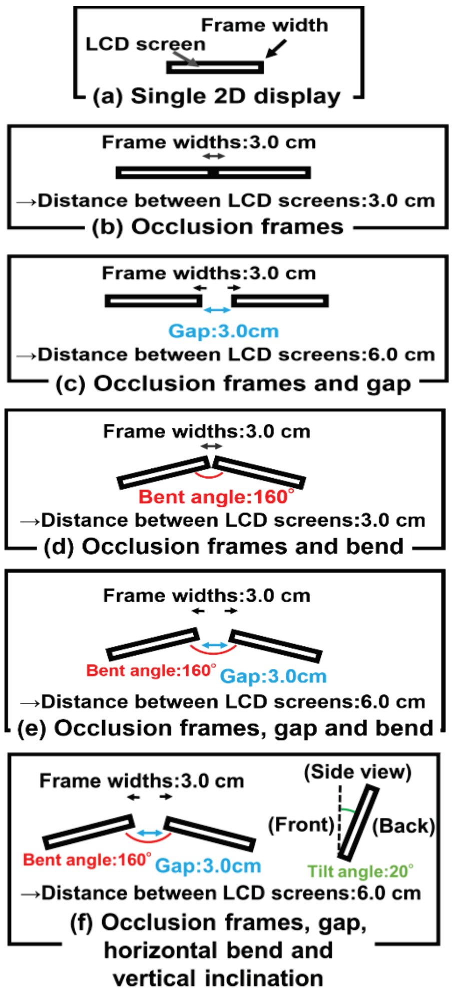



**Fig. 3 Top view of arrangement differences of two displays with frame, gap, bend and tilt**

### 2.3 Stimulus movements

Figure 4 shows linear and curved reciprocating movements of stimulus. Stimulus was composed of randomly arranged white squares. White squares move at constant speed to left and right on the two screens. Stimulus movements have 2 types: linear and curved reciprocating movements. Background was gray, and the number of squares was 31 on average per display. Moving speeds were 4.1 deg/s and 6.2 deg/s. A cycle of reciprocating movement was 4 sec. Radii of curved reciprocating movement were gradually changed from 145 cm at lower position to 167 cm at upper position.

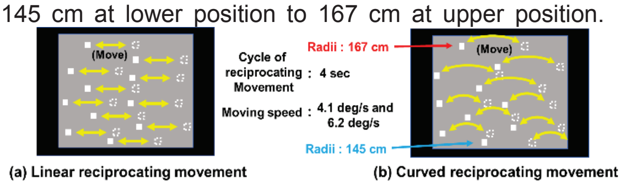
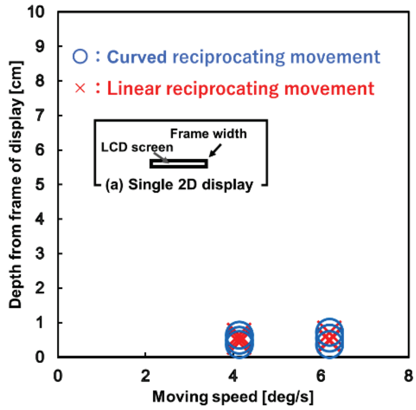


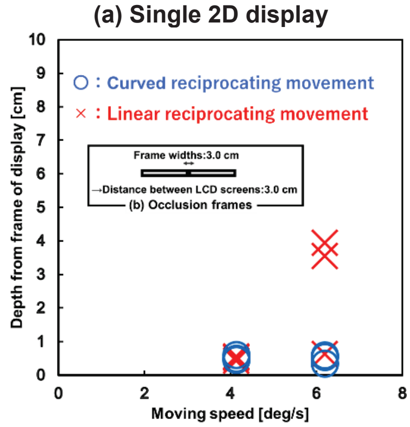

**Fig. 4 Linear and curved reciprocating movements of stimulus**

## 3 PERCEIVED DEPTHS FOR EACH ARRANGEMENT AND STIMULUS MOVEMENT

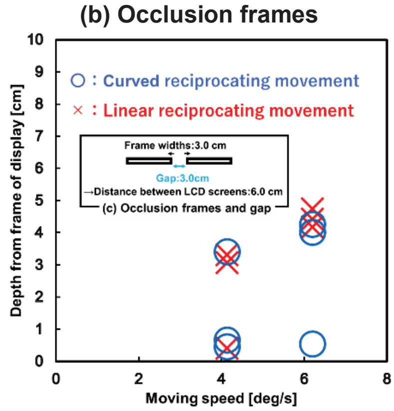
Figure 5 shows perceived depth dependences by various display arrangements and stimulus movements. Influences are discussed in following sections by each arrangements or stimulus movement.



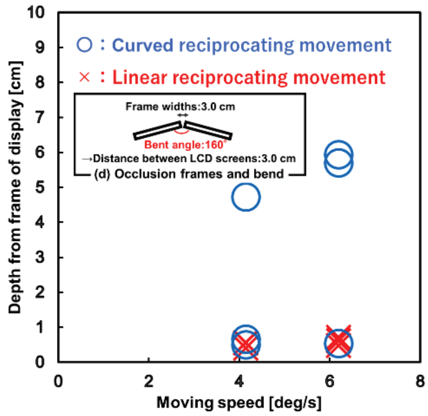

(a) Single 2D display



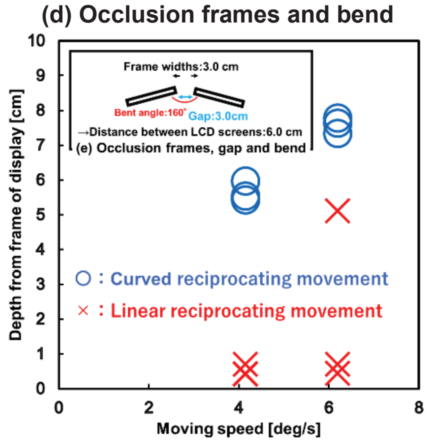

(b) Occlusion frames



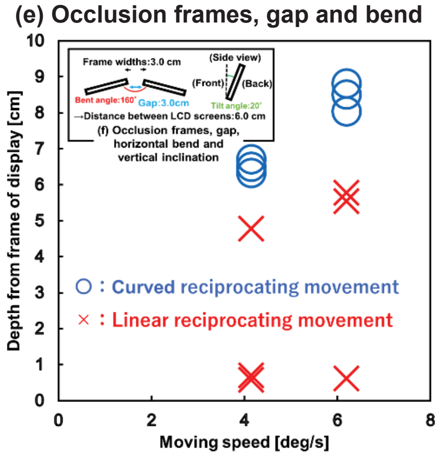

(c) Occlusion frames and gap




(d) Occlusion frames and bend




(e) Occlusion frames, gap and bend




(f) Occlusion frames, gap, horizontal bend and vertical inclination

**Fig. 5 Perceived depth differences by arrangements differences of two displays with linear and curved moving stimuli**

### 3.1 Overview of results

Figure 5 shows perceived depth differences by arrangements differences of two 2D displays with linear or curved moving stimuli. Perceived depths have separated tendencies of real depths around display surface and virtual depths behind the frame. This separation seems to be caused by fixation point difference of eye [3]. In the following sections, influences on virtual perceived depths by various display arrangements are discussed.

### 3.2 Influence of occlusion effect by frames and/or gap

When stimuli move across two side-by-side 2D displays, occlusion effect occurs by frames and/or gap, because stimuli disappear at frames and/or gap regions and are perceived to be hidden by them. This occlusion effect is expected to perceive depth behind them. Moreover, gap has two influences of extending the hidden distance and providing real depth cue by backyard viewing.

By occlusion effect by frames shown in Fig. 5(b), virtual perceived depths of 4 cm are observed by linear reciprocating movement in contrast that all perceived depths are stuck to display surface in Fig. 5(a) without occlusion. Moreover, in Fig. 5(c) with frames and gap, virtual perceived depths of 4 cm are also observed even at low moving speed in the same way as at high moving speed by both linear and curved reciprocating movements. These indicate that occlusion effect results in virtual perceived depths and is improved as occlusion region increases.

By comparing perceived depth separation in Figs. 5 (a), (b) and (c), when hidden width of frames and/or gap is increased, it becomes easy to perceive virtual depth and hard to perceive stuck real depth.

As shown in Fig. 5(c), virtual depth is perceived even when the backyard is visible from the gap of the display. It is probably caused by the hidden image reconstruction even at backyard-visible region. This indicates the possibility of improving virtual depth by providing real depth near two 2D displays.

### 3.3 Influence of moving speed

When object distance from observer is changed, object moving speed is changed geometrically like scene from train window. That is, near objects are expected to move faster than far objects. Following paragraphs describe perceived depth dependence on moving speed in Fig. 5.

Virtual perceived depth enlarged from 0.5 cm in (a) single 2D display to large depths of 3.5-8.5 cm in (b)-(e) occlusion frames, gap and/or bend. As moving speed increases, virtual perceived depths can be increased as about 1-3 cm at all these display arrangements.

These results are contrary to expectation, that is, perceived depth increased as stimuli moving speed increases. The reason is considered as follows. In these experiments, subjects' head is fixed. In this head fixing condition, Kanayama reported that the relationship between stimuli speed and their perceived depths have various types of dependences [4]. This indicates that perceived depths are not affected so much by stimuli speed itself. On the contrary, increasing number of stimulus getting into display frames as stimuli speed increases can much affects virtual perceived depths. This result in enlargement of occlusion effects.

### 3.4 Influence of curved reciprocating movement

When observer watches moving many objects on broad ground, the higher the object positions are, the deeper they are perceived. Moreover, when these objects move on the curve, far objects have larger radii than near objects. This leads to the assumption that curved reciprocating movement provides farther perceived depths.

Curved reciprocating movement stimuli can improve occlusion effect as shown in Figs. 5(c), (d) and (e). Perceived depth improvements of 3-4 cm, 4-6 cm and 6-8 cm can be achieved accompanied with frames and gap in Fig. 5(c) and with horizontal bend in Figs. 5(d) and (e) in contrast to sticking perceived depths to display surface in Figs. 5(a) and (b). This indicate that curved reciprocating movement stimuli can improve virtual perceived depths accompanied with occlusion frames, gap and/or bend.

### 3.5 Influence of horizontal bend

By using horizontally bent displays, even straightly moving stimuli seem to have similar movement as curved reciprocating movement for observer. As curved reciprocating movement provides farther perceived depths, moving stimuli on horizontally bent displays are also expected to increase virtual perceived depths.

Occlusion effect can be improved by horizontal bend in two side-by-side 2D displays as shown in Figs. 5(d) and (e). In Fig. 5(d) with frames and bend, virtual perceived depths are increased to 4.5-6 cm from that of 4 cm in Fig. 5(b) without bend. In Fig. 5(e) with frames, gap and bend, virtual perceived depths are increased to 5-8 cm from that of 3.5-4 cm in Fig. 5(c) without bend. These indicate that horizontal bend in two side-by-side 2D displays can significantly enlarge virtual perceived depth.

### 3.6 Influence of combination of curved reciprocating movement with frames, gap and horizontal bend

As several conditions increase perceived depth, perceived depths are expected to have further increase by combining these conditions. In Fig. 5(e), perceived depth by curved reciprocating movement with frames, gap and horizontal bend can be improved to no sticking to display surface and to large depth of 6-8 cm, in contrast to some sticking data in other conditions.

### 3.7 Influence of vertical inclination

By using pictorial cue of height which is derived from viewing ground or floor, the higher the object positions are, the deeper they are perceived. This suggests that inclined top of display over there enlarges this height effect of pictorial cue.

Occlusion effect can be improved by vertical inclination in two side-by-side 2D displays as shown in Fig. 5(f). In Fig. 5(f) with frames, gap, horizontal bend and vertical inclination, virtual perceived depths are increased to 8-9 cm from that of 7-8 cm in Fig. 5(e) without vertical inclination. This indicates that vertical inclination in two side-by-side 2D displays can significantly enlarge virtual perceived depth.

Thus, our proposed 3D display composed of two side-by-side displays with frames, and gap can successfully improve virtual perceived depth by occlusion effect to large level, rather than displays fastening together without frame nor gap. Moreover, horizontal bend and/or vertical inclination in two side-by-side 2D displays and curved moving stimuli can significantly enlarge virtual perceived depth.

## 4 CONCLUSION

We have proposed a new pictorial 3D display composed of occlusion effect, horizontal bend and vertical inclination arrangements in two side-by-side 2D displays and two stimulus movements of linear and curved reciprocating movements.

We clarified that separating two side-by-side displays with frames and/or gap can improve virtual perceived depth of moving stimuli behind frames and/or gap by occlusion effect rather than those fastening together without them. Moreover, horizontal bend and/or vertical inclination in two side-by-side 2D displays and curved moving stimuli can significantly enlarge virtual perceived depth.

Thus, our proposed pictorial 3D display without special equipments is promising for delighting most people including even stereo-blind people, since these virtual depths can be perceived by monocular cues for depth perception.

**ACKNOWLEDGMENT**

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