Real-Object DFD Method Can Change Perceived Depths of Dark Real Object and Occluded Rear Real Object to in front and behind

Oku Iwamoto, Haruki Mizushina, Shiro Suyama

Tokushima University, 2-1 Minami-josanjima-cho, Tokushima-shi, Tokushima 770-8506, Japan
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ABSTRACT

Depth-fused 3D display can successfully change perceived depth of occluded rear real object from behind rear object to in front of front object by adding rear object image behind and in front of rear object. Moreover, perceived depth of dark real object can be changed by changing added front-display transmittance.

1 INTRODUCTION

If perceived depth of real objects can be changed, such as from the normal window to the bay window at the housing exhibition room, popping recommended products out of showcase and so on, 3D display will spread to various applications. However, stereoscopic display cannot directly change the perceived depth of real object, because it is necessary to adjust binocular disparity of both-eye images by using video see-through HMD (Head mounted display). In addition, as shown in Fig. 1, blank area between adjusted image position and original position of both eye images needs to be filled by extrapolated image from surrounding parts [1], resulting in visual discomfort.

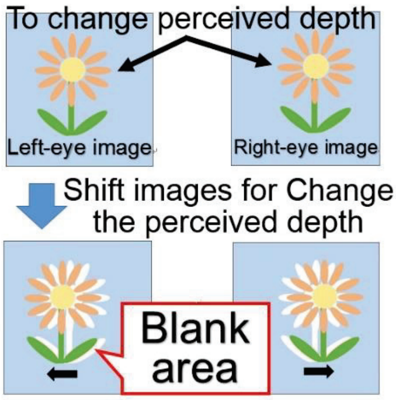


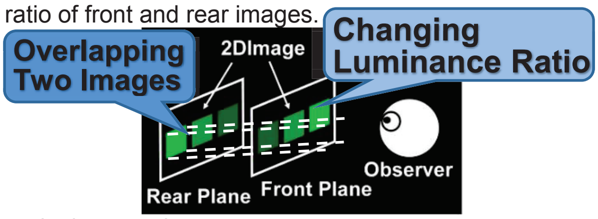
Fig. 1 Depth change in stereoscopic display by adjusting binocular disparity

On the other hand, since DFD (Depth-fused 3D) display [2] can change perceived depth by changing the luminance ratio of front and rear images, perceived depth change of real object can be easily achieved only by adding front (rear) image in front of (behind) real object.

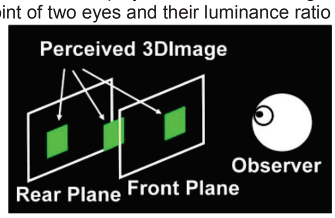
In this paper, we clarify that the perceived depth of real object can be changed by changing luminance ratio between added front (rear) image and rear (front) real object in real-object DFD display. We also estimate influence on perceived depth change by occlusions in real objects and possibility of perceived depth change of dark real object by changing transmittance of added front display.

2 PRINCIPLE OF LUMINANCE ADDITION DFD DISPLAY

In luminance addition DFD display as shown in Fig. 2, when front and rear images with different depths are arranged to overlap from the midpoint of observer's eyes, they are fused to one perceived depth. This one perceived depth can be changed by changing luminance ratio of front and rear images.



(a) Configuration of DFD display. Front and rear images are overlapped from midpoint of two eyes and their luminance ratio is changed.



(b) Perceived 3D image. Perceived depths are changed according to luminance ratio change.

Fig. 2 Principle of luminance addition DFD display

3 EXPERIMENT 1: INFLUENCE ON PERCEIVED DEPTE CHANGE OF REAL OBJECTS WITH OCCLUSIONS

First problem in perceived depth change of real object is occlusion effect. Occlusion is one of the powerful pictorial cues for judging whether front or rear object. Partially hidden object by other object is perceived as rear object even in 2D image. As it seems to be difficult to perceive the occluded object to front side, influence on perceived depth change by occlusions was estimated in real objects.

3.1 Perceived depths in DFD display

Figure 3 shows experimental setup for estimating influence of occlusion on perceived depth. Two real objects were used as stimulus in which rear real object was partially hidden. Added image of rear real-object photograph was arranged to overlap with rear real object and its luminance was randomly changed from 0 to 2.4 times to rear real object luminance. Subjects were let move reference to perceived depth position.

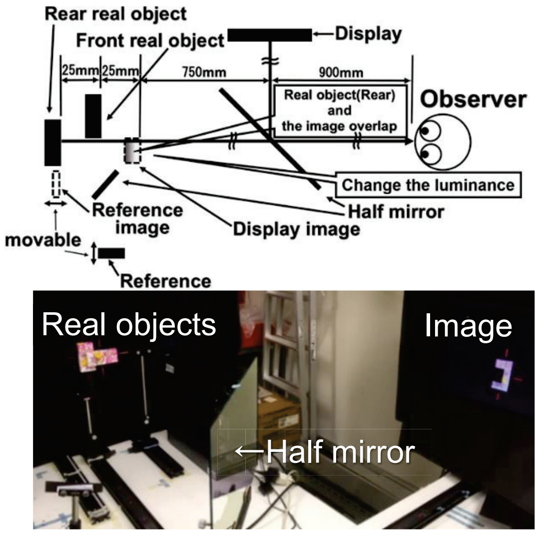


Fig. 3 Experimental system for estimating perceived depth change of occluded two real objects

As shown in Fig. 4 [3], perceived depth can be successfully changed from behind to in front of front real object by changing image luminance of added front image. Perceived depth of occluded rear real object can be easily changed in front of front real object without delay time when luminance magnification of added front image is 1.6 times or more. That is, perceived depths of rear and front real objects can be surprisingly reversed. Moreover, from subjects' interview, visual discomfort such as tired eyes is not reported.

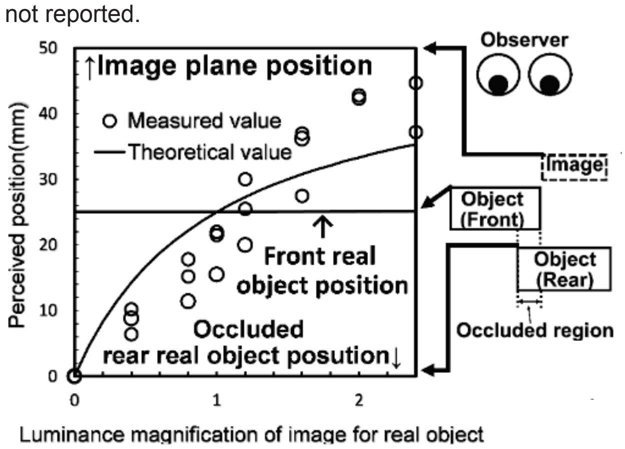


Fig. 4 Perceived depth change of rear occluded real object in front of front real object by using DFD display

3.2 Perceived depths in stereoscopic display

For comparison with DFD display, perceived depth change by stereoscopic display was also estimated using almost the same conditions. The required time for fusing stereoscopic images of single object and occluded object was estimated by using following time sequence as shown in Fig. 5. Stereoscopic images of single object and occluded object were shortly displayed between black images. Image display times were 0.5, 1.0, 1.5 seconds. Subjects were let mention whether images were fused or not and interviewed about fusion difficulty or stability. Figure 6 shows stimuli of stereoscopic images of single object and occluded object for estimating required time for fusing stereoscopic images.

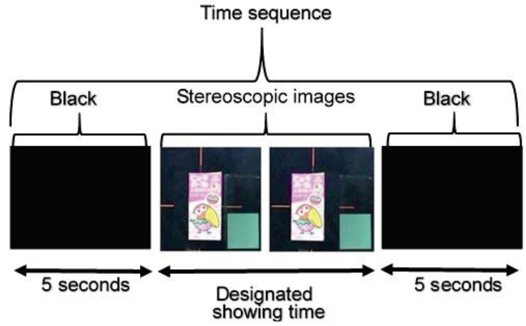
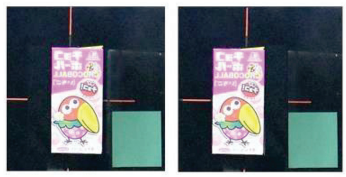
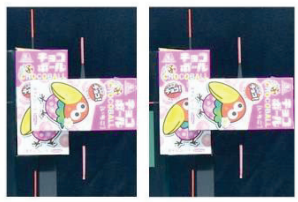


Fig. 5 Time sequence for estimating required time for fusing stereoscopic images



(a) Single object stereoscopic image



(b) Occluded object stereoscopic image

Fig. 6 Stimuli of stereoscopic image for estimating required time for fusing

Figure 7 shows required time for depths perceptions. There is a slight difference between single object and occluded objects for fusing time. Moreover, from subjects' interviews, the following instability differences from DFD display were reported.

- The occluded object stereoscopic image was fused, but the depth is not constant.
- The depth position of the occluded object stereoscopic image is constant, but it is difficult to maintain the fused state for a long time and the eyes become tired as compared to single object.

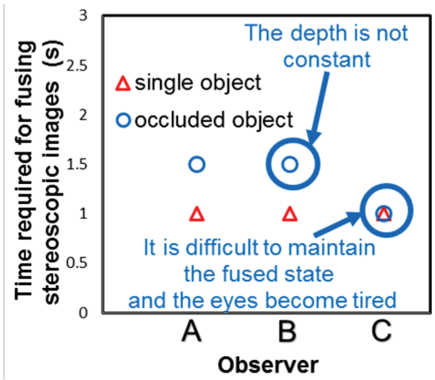


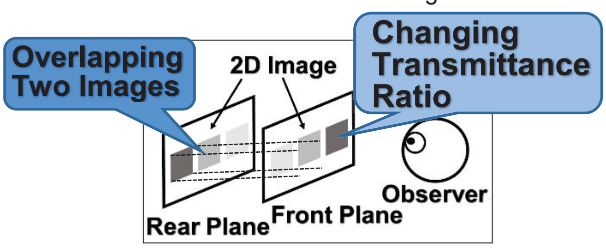
Fig. 7 Required time for fusing stereoscopic images of single object and occluded object. Interviews from subjects about fusion difficulty or stability are also shown

Thus, in stereoscopic display, subjects feel visual discomfort and fusion difficulty when the perceived depth of object occluded by front object is tried to change to the position in front of front object.

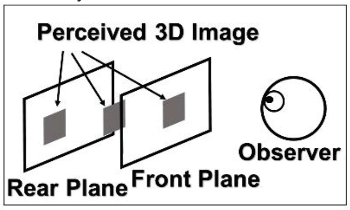
4 EXPERIMENT 2: POSSIBILITY OF PERCEIVED DEPTH CHANGE OF DARK REAL OBJECT

Second problem in perceived depth change in real object is dark real object. Perceived depth change of dark real object is difficult by using luminous addition between display image and real object because luminance of dark real object is very low.

Solution for this problem is luminance divided DFD display, by which perceived depth of dark real object can be changed. [4], This is easily constructed by putting transmittance changeable display (conventional LCD without backlight, OHP or so) in front of real object. Principle of luminance divided DFD display is shown in Fig. 8. When transmittance-changeable front and rear images are arranged to overlap from the midpoint of observer's eyes, they are fused to one perceived depth. This one perceived depth can be changed by changing transmittance ratio of front and rear images.



(a) Configuration of DFD display. Front and rear images are overlapped from midpoint of two eyes and their transmittance ratio is changed.



(b) Perceived 3D image. Perceived depths are changed according to transmittance ratio change.

Fig. 8 Principle of luminance divided DFD display

4.1 Perceived depth change in front of the object

Figure 9 shows experimental setup for perceived depth change of dark real object. For changing perceived depth of dark real object to front direction, OHP sheet with dark real object photograph was used as front added transmittance changeable display in front of dark real object. Its transmittance was randomly changed from about 30% to 100%. Subjects were let move reference to perceived depth position.

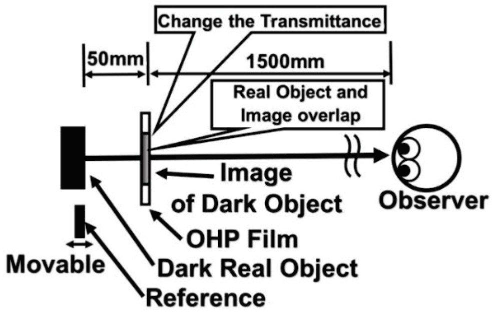


Fig. 9 Experimental system for estimating perceived depth change of dark real objects in front of dark real object position

Figure 10 shows perceived depth change of dark real object to front direction. Perceived depth can be successfully changed to near front position by changing transmittance of front OHP sheet.

However, from subjects' interview, perceived depth was sometimes hard to obtain when image optical-density ratio is very high.

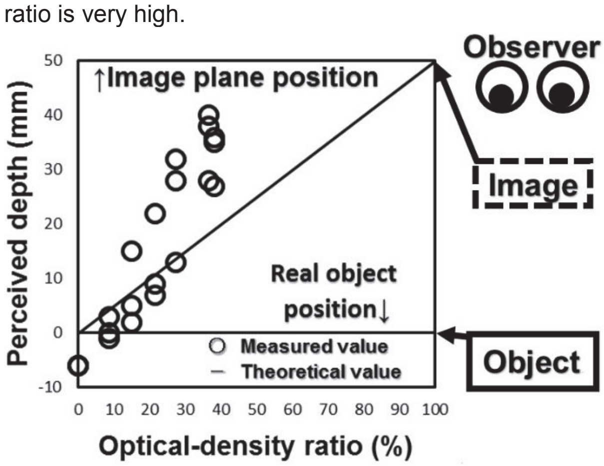


Fig. 10 Perceived depth change of dark real object in front of dark real object position by using luminance division DFD display

4.2 Perceived depth change behind the object

Third problem is how to change perceived depth of dark real object to behind real object. Second solution in section 4 is difficult to apply because luminance division displays cannot be put behind to real object because real object is not transparent. Another solution is protruding DFD display [5] by which perceived depth of dark real object can be changed even when added transmittance-changeable display is in front of dark real object. Principle of protruding DFD display is shown in Fig. 11. In both eyes, bright lines are observed between two dark vertical lines and right/left edges of 2D image because of parallax. This peculiar luminance arrangement of dark, bright and dark around edge region leads to perceived depth change behind rear plane.

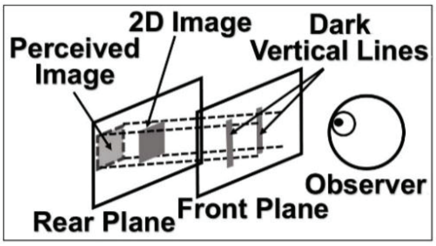


Fig. 11 Principle of protruding DFD display

Figure 12 shows experimental setup for changing perceived depth of dark real object to behind direction. Two dark vertical lines printed on OHP film was arranged to adjoin right and left edges of dark real object from one eye as shown in left illustration in Fig. 13. In both eyes, as shown in right illustration in Fig. 13, bright lines are observed between two dark vertical lines and right/left edges of dark real object because of parallax. Vertical line transmittance was randomly changed from about 30% to 100%. Subjects were let move reference to perceived depth position.

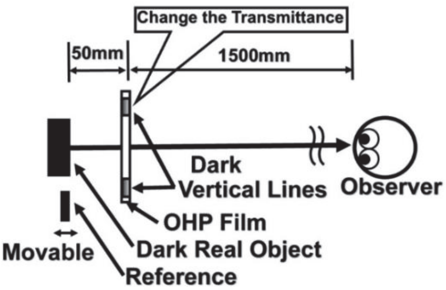


Fig. 12 Experimental system for estimating perceived depth change behind of dark real objects

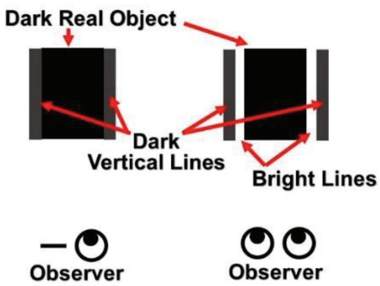


Fig. 13 How to overlap dark real object and dark vertical lines by single eye. Bright lines are observed by both eyes because of parallax

Figure 14 shows perceived depth change of dark real object to behind direction. Perceived depth of dark real object can be successfully changed to behind the dark real object by changing optical densities of two dark vertical lines in front of dark real object.

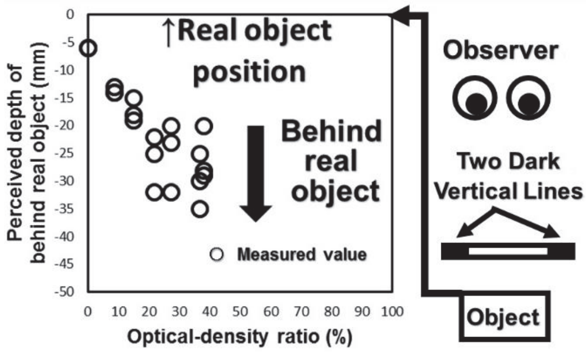


Fig.14 Perceived depth change of dark real object behind dark real object position by using protruding DFD image

5 CONCLUSIONS

DFD display can easily achieve to change perceived depths of real objects by adding front or rear image, even when real objects have occluded regions. Moreover, by using added transmittance changeable display, perceived depths of dark real objects can be easily changed to in front of and behind the real object. There is no visual discomfort with using DFD as compared to stereoscopic display.

Thus, we clarified the possibility of applying DFD display to changing the perceived depth of real objects.

ACKNOWLEDGMENT

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