Tabletop Aerial DFD Display with AIRR

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Keywords: Aerial image, 3D display, AIRR, DFD display

ABSTRACT

This paper proposes a tabletop two-layered aerial display system with aerial imaging by retro-reflection (AIRR). Then, we have realized an aerial depth-fused 3D (DFD) display. We investigate the relationships between the two-layered-images distance and the observation distance. The result shows that the two-layered-images distance increases with the observation distance.

1 INTRODUCTION

Recently, aerial displays have attracted attention as one of the next-generation displays. Aerial display forms a floating information screen in the mid-air without special hardware on the aerial image position. Furthermore, the floating image is perceived without 3D glasses. In order to form such an aerial image, we have utilized retro-reflector for aerial imaging optics. Aerial imaging by retro-reflection (AIRR) [1] features a wide viewing angle, a large-size scalability, and a high degree of freedom in optical design. In the conventional AIRR, the formed aerial image is 2D, which doesn't give depth sensation by itself. In combination of AIRR and Depth-fused 3D (DFD) display [2], we developed an aerial DFD display by stacking two aerial display optics [3]. However, there are also some problems with this previous optical system. One problem is that the equipment is bulky. Since we use two AIRR setups to form two-layered aerial images, the equipment becomes large. Another problem is that the equipment blocks the view, because one of the two AIRR setups is installed vertically on the tabletop. Thus, the previous aerial DFD display was unsuitable as an inter-human interface.

The purpose of this paper is to propose a new optical system that forms two-layered aerial images on a tabletop, which solves the above-mentioned problems. Then, we demonstrate depth-fusion of the two aerial images, that is, we realize an aerial DFD display on a tabletop. By using a prototype aerial DFD display, we investigate the relationships between the luminance ratio and perceived depth of the aerial DFD display. Furthermore, we investigate the relationships between the viewing distance and the gap between two aerial images.

2 PRINCIPLE AND OPTICAL SYSTEM

2.1 Polarized AIRR

In this paper, we employ polarized AIRR (pAIRR) [4] system, which can improve brightness more than conventional AIRR by polarization modulation. Fig. 1 shows optical system of pAIRR. It consists of four components: a light source, a reflective polarizer, a quarter-wave retarder, and a retro-reflector. The reflective polarizer reflects only the s-polarization component of the incident light, and transmits the p-polarization component. The quarter-wave retarder delays incident light by a quarter wavelength. The retro-reflector reflects the incident light reversely to the original direction. The light from the light source is reflected by the reflective polarizer and reaches the retro-reflector. Since the light passes through the quarter-wave retarder twice, the polarization angle of the light is rotated by 90 degrees. Therefore, the retro-reflected light transmits through the reflective polarizer and forms the aerial image. The forming position of this aerial image is the plane-symmetrical position of the light source with respect to the reflective polarizer. Fig. 2 shows an aerial image with pAIRR. Because the light-use efficiency in pAIRR is better than the conventional AIRR, a bright aerial image is formed.

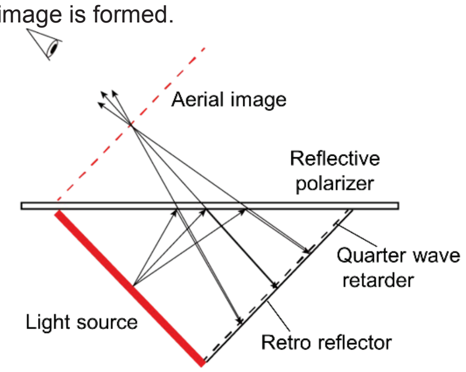
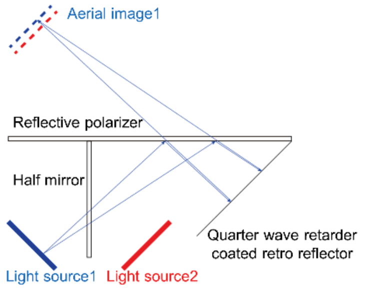


Fig. 1 Optical system of pAIRR (polarized aerial imaging by retro-reflection).

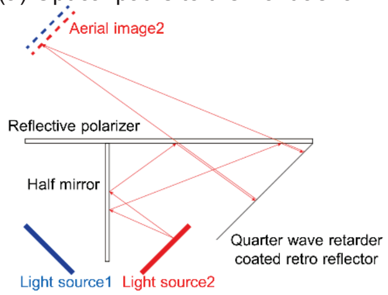
Fig. 2 Aerial image with pAIRR.

2.2 Two-layered aerial image

Fig. 3 shows an optical system that this paper proposes. Fig.3 (a) and (b) show optical paths to the front aerial image (blue image) and the rear aerial image (red image), respectively. We added a half mirror to the conventional AIRR to stack two images. The half mirror transmits light emitted from the light source 1 and reflects light emitted from the light source 2. Then, the aerial images are formed in the mid-air with AIRR. Fig. 4 shows our previously developed optical system for two-layered aerial display. Conventionally, two AIRR setups were combined to form two aerial images and they were set in an L-shape to stack the two images in layers. Therefore, the second part of the equipment was sticking out of the tabletop. On the contrary, in this work, all equipment is set under the tabletop. This means that the equipment has become smaller, and the opposite side of aerial images is also visible while a user views the aerial images. Furthermore, the conventional setups required two retro-reflectors. In this work, because we synthesize two images before the retro-reflection, we use only one retro-reflector. Table 1 shows the comparisons between the conventional method and our proposed method.



(a) Optical paths to the front aerial image.



(b) Optical paths to the rear aerial image.

Fig. 3 Optical system for two-layered aerial display.

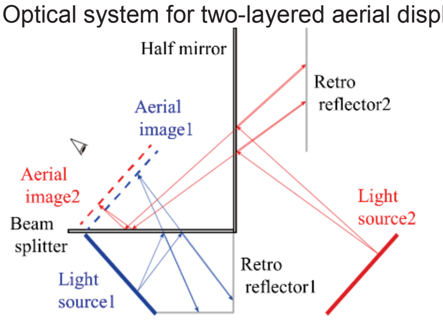


Fig. 4 Conventional optical system for two-layered aerial display.

Table 1 Comparisons of aerial DFD display optics.

	Conventional system	Proposed system
Size	Large	Small
Retro-reflector	Two pieces	One piece
Shape	Sticking out of the tabletop	Under the tabletop

2.3 DFD (Depth-Fused 3D) display

Fig. 5 shows conceptual diagram of DFD display. DFD display needs a front image and a rear image of which size and position are arranged so that the two images are overlapped from the central viewing position. The observer perceives the overlapped two images as an image that is located between the front and rear planes. The perceived depth is proportional to the luminance ratio between the front and the rear images.

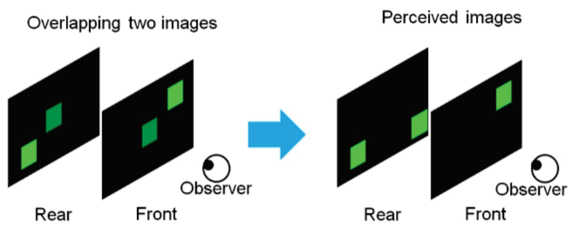


Fig. 5 Conceptual diagram of DFD display.

Fig. 6 shows a case of only a part is overlapping (this is not DFD display). The left side shows the two-layered images. The right side shows the retinal image that both eyes perceive. Let the edges of the front image be ‘A’ and ‘B’ and rear image be ‘C’ and ‘D’. In this case, the order of perceived edges is “CABD”, which is the same for the left eye and the right eye. Two images are perceived separately in front and rear by binocular parallax, since it is easy to associate the edges with the both eyes. The left side of Fig. 7 shows two-layer images which are displayed so as to overlap from the center of the observer’s both eyes. Under this DFD condition, the order of the perceived edges is “CADB” for the left eye and “ACBD” for the right eye. In this way, when images with different perceived edges order are recognized simultaneously, it becomes difficult to associate the left eye and right eye edges. Therefore, it is considered that the two-layered images are perceived as one image without being able to perceive the two images from the cue of binocular parallax. The right side of Fig. 7 shows the luminance of the retinal image when observing the two-layer images. In the human visual system, image processing is performed by separating into several spatial frequency bands. When it is difficult to match the edges of left eye and right eye, each edge is felt as one it is conceivable that edge matching is performed in a band. The luminance distributions of the front and rear images and the retinal image are also shown in Fig 7. When the low-pass filter is applied to the luminance distribution, the luminance is represented by a curve. Observers are considered to perceive the steepest part of this curve as an edge. When the luminance ratio of the front and rear images is changed, the position of this edge changes. Therefore, the parallax changes in both eyes. Thus, DFD display can represent continuous depth only by changing the luminance ratio continuously.

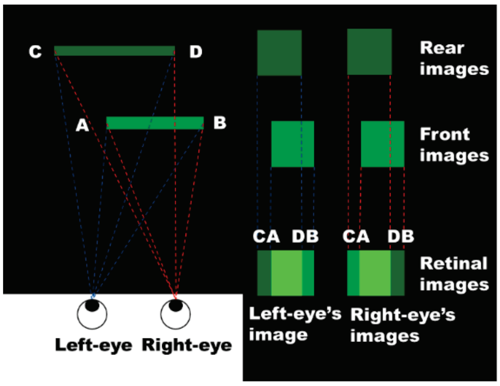


Fig. 6 Perceptual model of front and rear images with only a part overlapping.

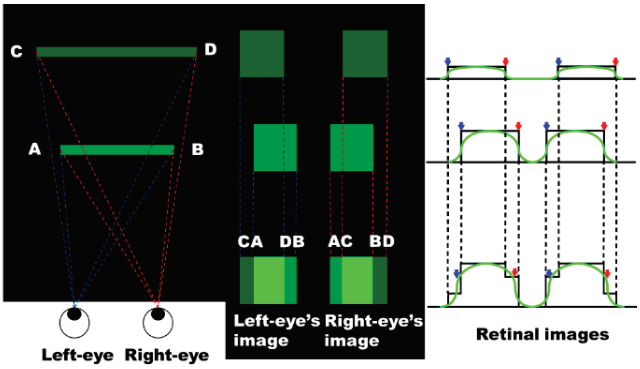


Fig. 7 Perceptual model of front and rear images completely overlapping.

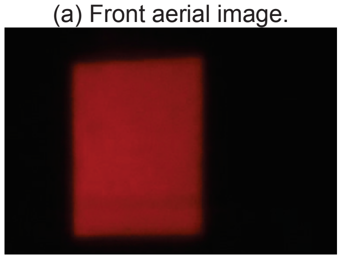
3 EXPERIMENTS

3.1 Two-layered aerial image

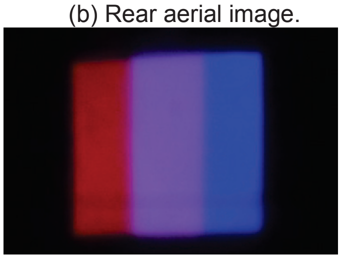
Fig. 8 shows two-layered aerial images that were formed in the proposed optical system. Blue and red squares are the front aerial image and the rear aerial image, respectively. As shown in Fig. 8 (c), the overlapped region looks purple.

Because the perceived depth in DFD display changes depending on the luminance ratio of the front image and the rear image, it is important to measure the luminance of each aerial image. Fig. 9 shows luminance of each aerial image for the pixel value in the light-source display. We used the same type display for each light source, but comparing the luminance of two aerial images, rear aerial image is obviously brighter than front aerial image. In this time, we used pAIRR to forming aerial images. Usually, polarization is almost maintained even if the light is reflected. However, in our developed optical system, the light from light source1 is transmitted through the half mirror, so the polarization is not maintained. For that reason, it is considered that there was a difference in the luminance of the two aerial images.

(a) Front aerial image.



(b) Rear aerial image.



(c) Overlapped aerial image.

Fig. 8 Two layered aerial images.

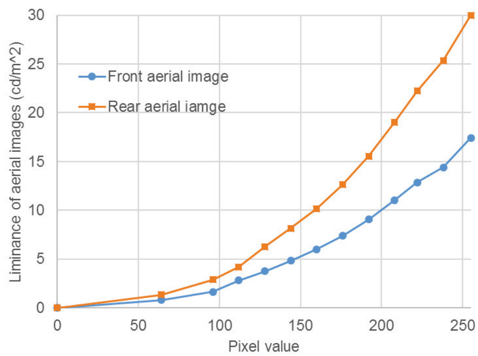


Fig. 9 Luminance of aerial images vs pixel value.

3.2 Depth-fused distance vs observation distance

We have investigated a condition to realize aerial DFD display by use of the developed optical system. We have conducted a preliminary experiment to investigate the relationships between the viewing distance and the gap between the two-layered images. In Fig. 3, when the light source 2 approaches the half mirror, the aerial image 2 moves away from the observer (closes to the beam splitter). We have changed the gap between the two layers while the fixing viewing distance at 600 mm, 700 mm, 800 mm, 900 mm, and 1000 mm. The subjects responded when the two-layered images were perceived as two separated images at each observation distance. Three subjects examined three trials at each condition. Fig. 10 shows the experimental results. The horizontal axis is the distance between of the two aerial images (mm). The vertical axis is the response rate at which the subject answered that the two-layered images were separated. The points plotted are the average of three times experiments and the curves are sigmoidal fitting results. Table 2 shows the distance of two-layered images that were perceived as two separated images by each subject at each observation distance obtained by the sigmoidal fitting. As the observation distance increases, the distance that two-layered images are perceived as separated increases. Furthermore, the ratio of the two-layered images distance to the observation distance is shown at the bottom in each cell. Although there are individual differences, the two-layered images distance can be increased to about 3% of the observation distance.

4 CONCLUSION

We have proposed a new optical system that forms two-layered aerial images on a tabletop. Furthermore, we have investigated the relationships between the two-layered aerial images and the observation distance. The two-layered images distance can be increased to about 3% of the observation distance.

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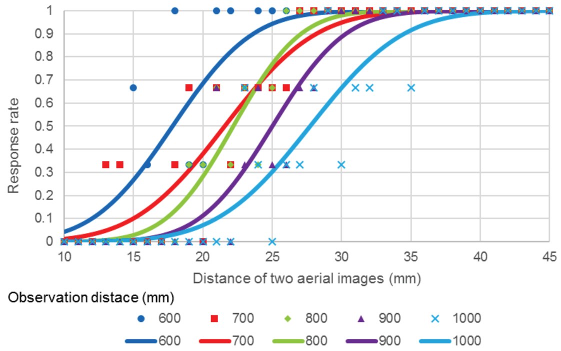
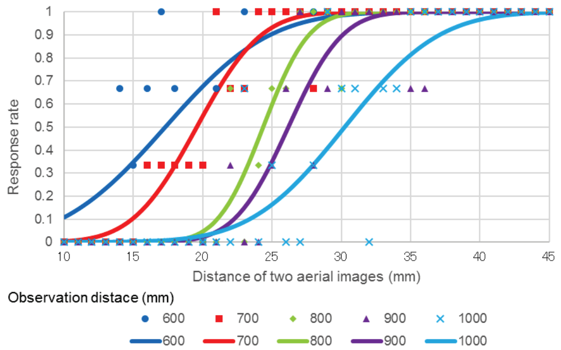
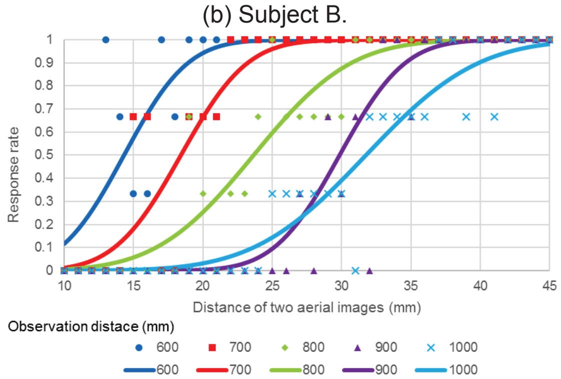


(a) Subject A.



(b) Subject B.



(c) Subject C.

Fig. 10 Experimental results on separation-perceived viewing distance.

Table 2 Distance perceived as two separated images vs observation distance.

	Observation distance (mm)	600	700	800	900	1000
Two images distance (mm) (/ observation distance)	Subject A	18 (0.030)	22 (0.031)	22 (0.028)	25 (0.028)	28 (0.028)
	Subject B	17 (0.029)	20 (0.028)	24 (0.030)	26 (0.029)	30 (0.030)
	Subject C	14 (0.024)	18 (0.026)	24 (0.030)	30 (0.033)	32 (0.032)