Optical Design Suitable for Both Immersive Aerial Display System and Capturing User Motion

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ABSTRACT

We have developed an immersive aerial display system where life-sized aerial images surrounds a user. Our optical design features optical see-through structure that enables communication between the user and people outside the system. Furthermore, tracking of the user movements has been realized by use of near-infrared illumination and retro-reflective markers.

1 Introduction

The CAVE system, which projects images on a large screen that surrounds the user, can give the user a high immersive sense in the virtual reality space [1]. At the same time, there are some disadvantages caused by surrounding with a screen. For example, the experience a user obtains while surrounded by a screen is not shared with people outside the device. Also, when interacting with the images, the user may touch the screen, which can lead to user's injury or damage to the device. To solve the former problem, a method of surrounding the user with a transparent screen has been proposed [2]. However, this method cannot solve the latter problem as long as it surrounds the user by a wall.

As a way to solve these problems at the same time, we have proposed the use of aerial displays [3,4]. Aerial displays can form images in front of the user without a physical screen. Therefore, the user's oppressive feeling can be reduced, and there is no concern about collision between user and device. Another advantage is that a user can see the image floating in the air without wearing a special device such as an HMD. In previous research, we showed that aerial imaging by retro-reflection (AIRR [5]) is suitable for upsizing device, and that user and people outside the device can see each other through aerial images, by adopting an optical design called an optical see-through AIRR [4].

In this research, we assembled life-sized devices to form aerial images, by using the materials proposed in the previous research [3], and arranged it so as to surround the user. This enabled us to confirm that users and people outside the device could work while communicating. Furthermore, tracking of the user movements has been realized by use of near-infrared illumination, retro-reflective markers, and high-speed cameras. We show that the optical see-through type has an advantage when capturing the user's motion with this setting.

2 Principles

Fig. 1 shows the principle to form aerial floating image for life-sized devices. This arrangement is called wall-type AIRR. AIRR consists of three components: a light source, a beam splitter, and a retro-reflector. In wall-type, a retro-reflector stands vertically and a beam splitter is installed at an angle of 45 degrees. Part of the light emitted from the light source is reflected by the beam splitter, and heads toward the retro-reflector. On the retro-reflector, the light is reflected to the direction it comes, and heads toward the beam splitter. Part of the light passes through the beam splitter, which leads to the forming aerial image. In this type, the user (e.g. operator of aerial image) can see through the beam splitter, but not retro-reflector.

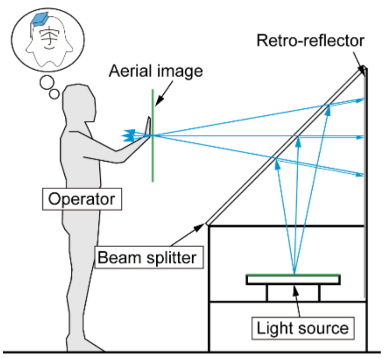


Fig. 1 Principle of wall-type AIRR

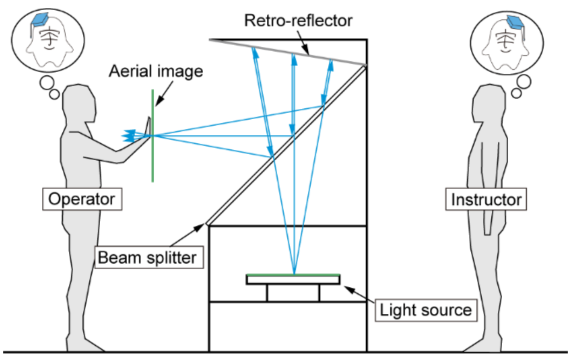
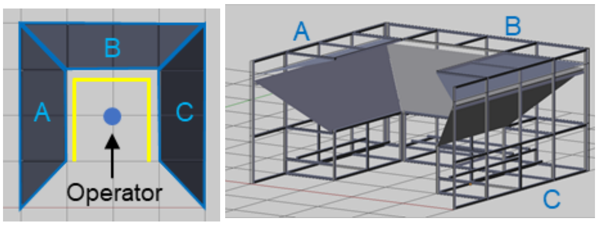


Fig. 2 Principle of optical see-through AIRR

Fig. 2 shows the principle of another arrangement for aerial imaging device. This type is called optical see-through AIRR [6]. In this type, retro-reflector is installed over the beam splitter. The retro-reflective sheet is not horizontal to prevent surface reflections of the sheet from entering the user's field of view [7]. The user and the people outside the device (e.g. instructor) can see each other through the beam splitter. The aerial image formed in front of the user is actual image, and at the same time, people outside the device can see the virtual image of aerial image.

3 Experiments

Fig. 3 shows the layout of our immersive aerial display system. This system consists of three optical see-through AIRR devices surrounding the operator. Three-dimensional computer graphics was used for the system layout, and the actual system was assembled based on this layout.



(a) (b)

Fig. 3 Layout of immersive aerial display system created with three-dimensional computer graphic model. (a) Viewed from above. Three large devices were arranged in a U shape. Yellow line indicates the position of aerial image forming. (b) Viewed from diagonally above.

Fig. 4 shows the photograph of assembled immersive system. The size of an aerial imaging device was 1.8 meters tall, 2 meters wide and had a depth of 1 meter. The whole system size was 4 meters square. As a beam splitter, 1 mm thick acrylic plate was used. The beam splitter was pulled from above and below so that it would not bend under its own weight. Retro-reflective sheets were developed to form aerial image (RF-Ax, Nippon Carbide Industries). As a light source, high luminance LED panels and LCD (PN-A601, Sharp Corporation, Japan) were used.

Fig. 5 shows the photograph of the operator surrounded by aerial images. This photo was taken from the outside of the immersive aerial display system. Even from outside the system, the aerial image behind and to the left of the operator can be seen as a real image, and the aerial image in front of the operator can be seen as a virtual image.

Fig. 6 shows photographs of the aerial image viewed from the operator side and viewed from the instructor side. The Operator and instructor can see each other, and can progress with the co-operative work such as manipulating aerial images while communicating.

Fig. 4 Assembled immersive system

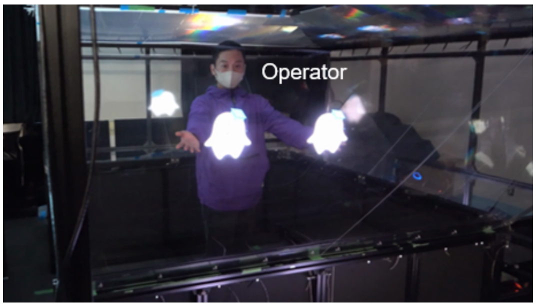
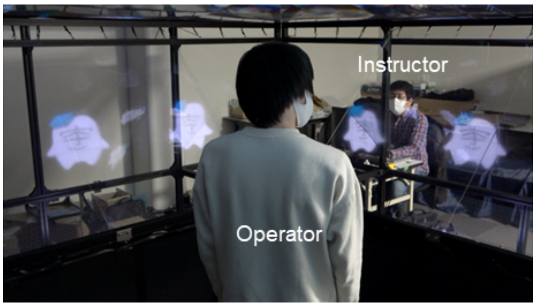
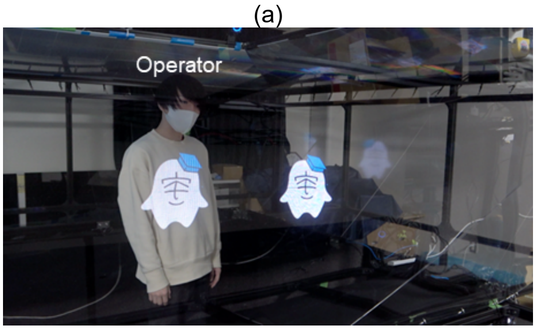


Fig. 5 Photograph of the operator surrounded by aerial images



(a)



(b)

Fig. 6 photographs of the aerial image viewed from (a) operator side and (b) instructor side.

Next, we installed a camera that captures the movement of the operator so that the aerial image formed by this system can be operated as a user interface. In this study, 4 cameras and motion capture system (OptiTrack, NaturalPoint, Inc.) were installed to track the operator in front of aerial images formed by B and C device in Fig. 3a. The cameras are equipped with infrared illumination. From the captured images, a central space of our immersive aerial display system was three-dimensionally constructed on the software. Fig. 7 shows the position of cameras constructed three-dimensionally.

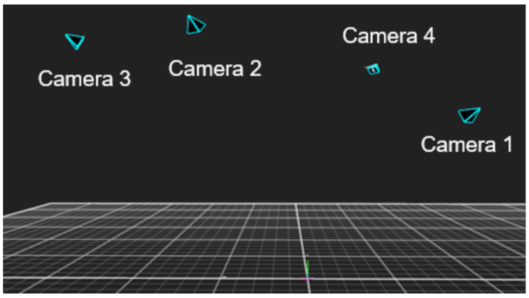


Fig. 7 Position of four cameras constructed three-dimensionally

Fig. 8 shows images captured by cameras. The white part of the image indicates the infrared illumination reflected by the retro-reflective sheet. This area is masked on the software. Thus the user's movement is not tracked in this area. On the other hand, the part surrounded by yellow line shows the area where the infrared illumination will be reflected by the retro-reflective sheet when the wall-type AIRR is adopted for this system. It can be seen that the optical see-through type has a wider area where the user's movement can be tracked, especially around the beam splitter.

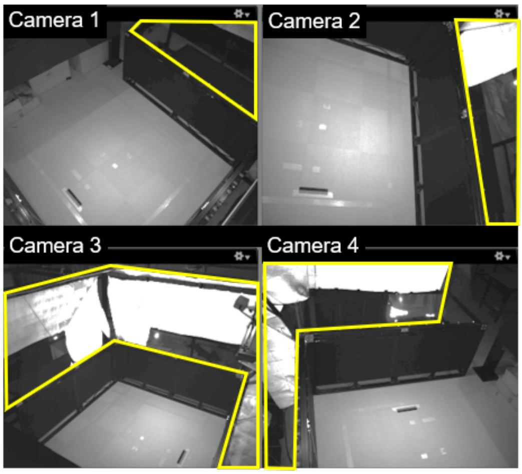


Fig. 8 Images captured by four cameras. In white area, infrared illumination was reflected by retro-reflector. Yellow area indicates the reflected area when wall-type AIRR is installed.

4 Conclusions

In this study, we actually assembled an immersive aerial display system, and showed that aerial images were formed around the user. Users and people outside the system were able to see each other, and to work while communicating. Furthermore, it was shown that the optical see-through type has an advantage when capturing the user's movement with an infrared camera, compared with wall-type AIRR.

References

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