See-Through Aerial Concave Display by Use of Fresnel Lens and AIRR with Polarization Modulation

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Keywords: aerial display, polarization modulation, retro-reflector

ABSTRACT

This paper proposes an optical system for see-through aerial concave display. Due to aberration of Fresnel lens, a 2D image on a flat-panel display is converted to a convex image. Then, the convex image is converted to an aerial concave image with AIRR (Aerial Imaging by Retro-Reflection) in see-through structure.

1 INTRODUCTION

The purpose of this paper is to realize see-through aerial concave display. In the aerial display, it is reported that hollow face illusion [1] occurs on aerial depth-reversed images even binocular observation [2]. This feature is useful for aerial 3D perception for plural observers. When many people observe a single aerial image, every observer perceives as if the aerial image is directed to himself. Therefore, such an aerial depth-reversed image is applicable to one-to-many 3D signage without eye tracking and without eyewear.

This paper proposes a new optical system to form an aerial concave image in front of a background scenery. An aerial concave display is realized in two steps. Firstly, a convex image is formed by use of Fresnel lens. Secondly, the depth of the convex image is inverted. In the previous research, we have succeeded in forming an aerial convex image by use of aberration of Fresnel lens [3]. By using this formed convex image as the light-source display for aerial imaging by retro-reflection (AIRR) [4], we form an aerial convex image because AIRR can form the depth-inverted image of a light-source display. In order to increase visibility of the aerial image, we introduce polarization modulations for aerial image formation by use of Fresnel lens and AIRR. Furthermore, the proposed optical system is modified to realize see-through function.

2 PRINCIPLE

2.1 AIRR

Aerial imaging by retro-reflection (AIRR) is an aerial image formation technique which features a wide viewing angle, a large-size scalability, and a low cost. Fig. 1 shows the principle of AIRR. The AIRR setup consists of a light source, a beam splitter, and a retro-reflector. The light emitted from the light source is reflected by the beam splitter. The reflected light is retro-reflected and transmits the beam splitter. The transmitted light converges to form an aerial image. The aerial image is formed at the plane symmetrical position of the light source regarding the beam splitter.

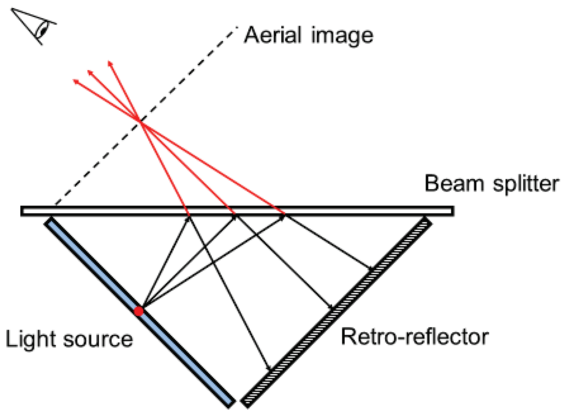


Fig. 1 Principle of AIRR.

2.2 Polarized AIRR

In order to increase luminance of the aerial image, we use polarized AIRR, which combines polarization modulation. Fig. 2 shows the principle of polarized AIRR. The device uses a light source, a reflective polarizer, a quarter-wave retarder, and a retro-reflector. By utilizing the characteristics of polarization, the light-use efficiency is increased. The aerial image formed with polarized AIRR becomes more clearly visible.

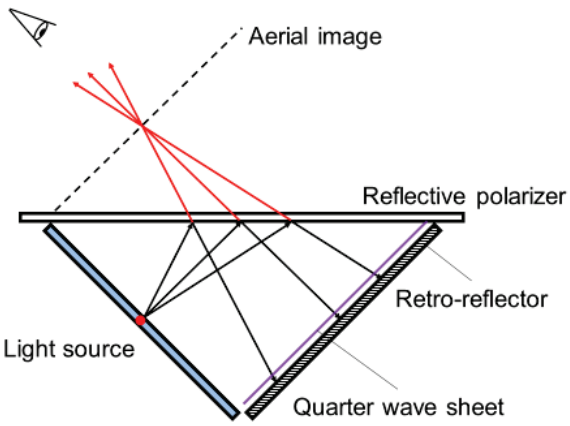


Fig. 2 Principle of polarized AIRR.

2.3 Aerial convex image by use of aberration of Fresnel lens

Fig. 3 shows the principle to form a convex aerial image caused by aberration of Fresnel lens. The device uses a light source, a Fresnel lens with a half-mirror coating, a reflective polarizer, and a quarter-wave retarder. Light rays emitted from the light source are refracted by the Fresnel lens. The refracted light is partially reflected by the reflective polarizer and the reflected light is partially reflected again by the half mirror coat deposited on the Fresnel lens. A convex aerial image is formed by aberration of Fresnel lens.

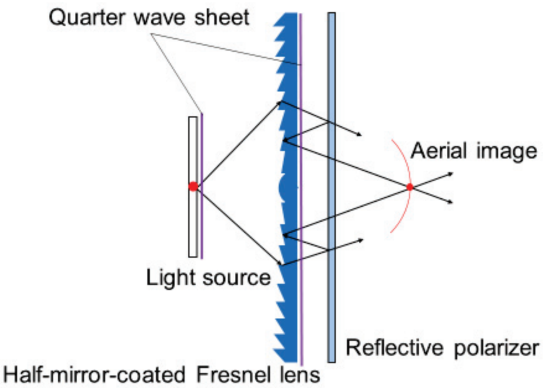


Fig. 3 Principle of forming an aerial convex image by use of aberration of Fresnel lens.

2.4 Aerial concave image

The principle to form an aerial concave image is shown in Fig. 4. Because the aerial image formed with AIRR is plane-symmetrical of the light-source display regarding the beam splitter, the convex image is converted to the concave image. In order increase the luminance of the aerial image, polarization modulation is introduced to the optical system, as shown in Fig. 5.

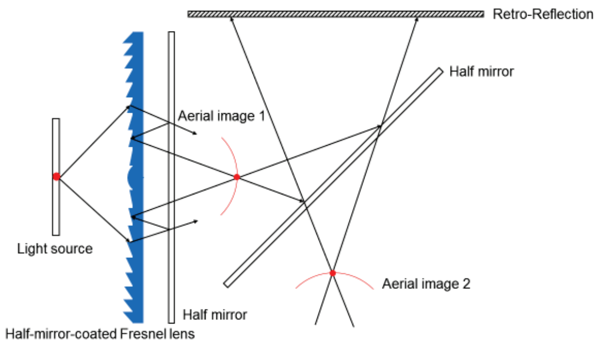


Fig. 4 Principle of proposed aerial display without polarization modulation.

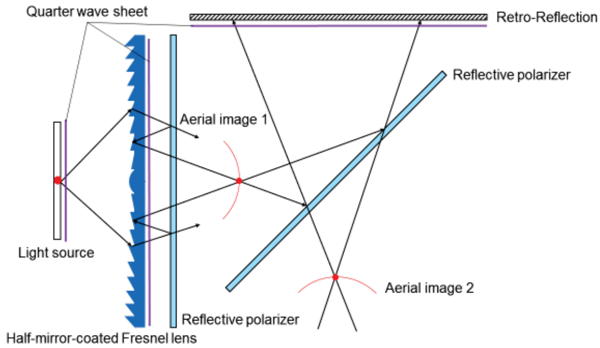


Fig. 5 Principle of aerial concave display in combination of Fresnel lens and polarized AIRR.

3 EXPERIMENTS

Experiments have been conducted by use of a concentric circle pattern A, as shown in Fig. 6.

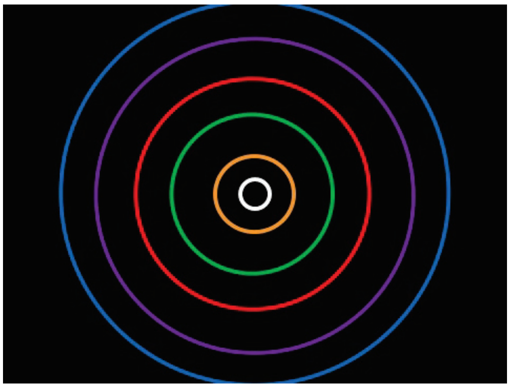


Fig. 6 Test pattern A.

Fig. 7 and Fig. 8 show viewed images of the aerial concave image. By introducing polarization modulation, the aerial image becomes bright. The brightness of the aerial image with the polarization modulation (Fig. 8) is much higher than that of the conventional AIRR (Fig. 7). Note that surface reflection on the retro-reflector is visible in Fig. 8.

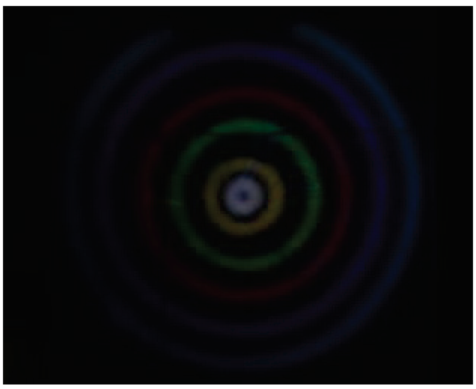


Fig. 7 Aerial cave image with conventional AIRR.

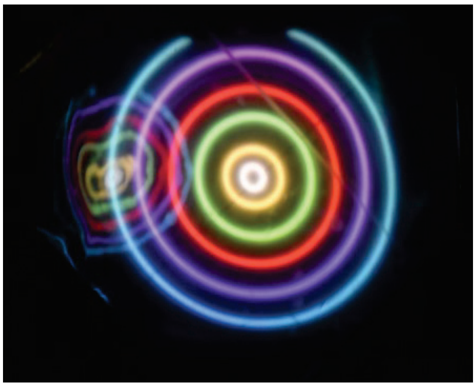
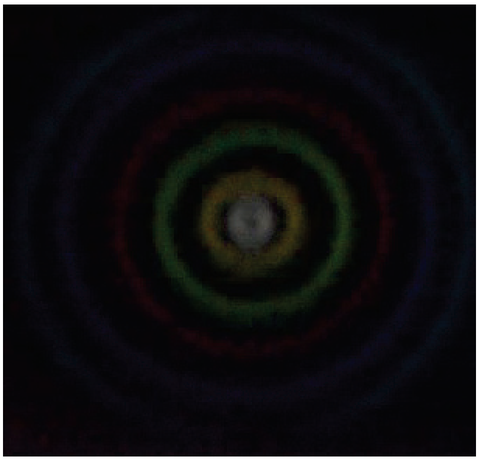
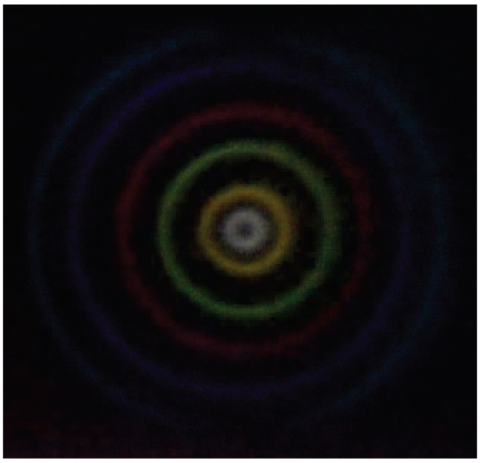


Fig. 8 Aerial cave image with polarized AIRR

Next, in order to check how much the aerial image is curved, a screen was placed around the aerial image and was moved back and forth. Screen observation results are shown in Fig. 9. The outer and inner circles were formed at different depths. Thus, we have confirmed the formed aerial image was concave.



(a)



(b)

Fig. 9 Aerial concave image with conventional AIRR observed on a screen that is placed (a) on the outer circle and (b) on the inner circle.

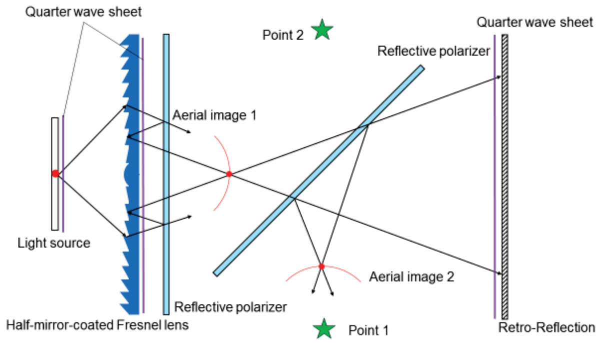


Fig. 10 Optical system for see-through aerial concave display.

Furthermore, the optical system is modified to realize see-through function, as shown in Fig. 10. A viewer at Point 1 can see the background through the formed aerial convex image. A viewer at Point 2 can see the view at Point 1 and can also recognize the displayed image as the virtual image. Viewed results at Point 1 and Point 2 are shown in Fig.11 and Fig. 12, respectively. In Fig. 11, the aerial image was visible in front of the background scene. In Fig. 12, a figure at Point 1 and the virtual image was visible. Thus, our design of the optical system to form aerial concave image with see-through function has been confirmed experimentally.

4 CONCLUSION

We have realized see-through aerial concave display by use of a flat-panel display as the light-source display. We used a half-mirror-coated Fresnel lens and AIRR to form an aerial concave image.

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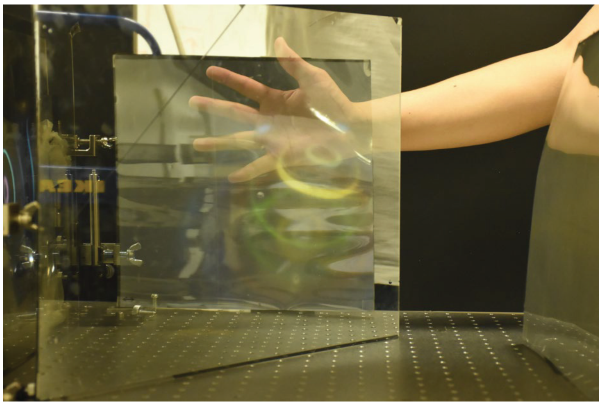
Fig. 11 A photograph taken at Point 1.

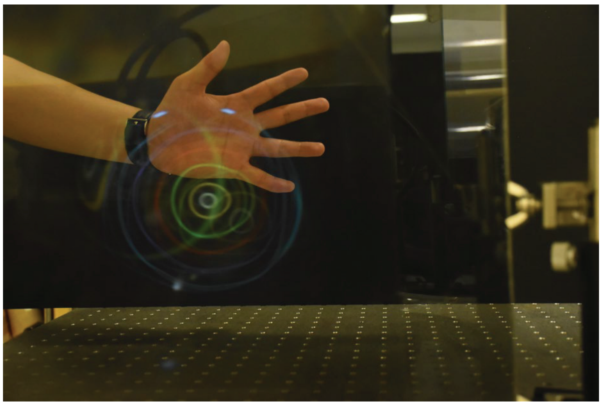
Fig. 12 A photograph taken at Point 2.