Recent Developments and Applications of Aerial Display

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ABSTRACT

This paper introduces our developments on aerial display. Aerial imaging by retro-reflection (AIRR) features large-size scalability, wide viewing angle, and high-freedom in design. We have developed an omni-directional aerial display, a see-through aerial display, and a thin aerial display. Furthermore, AIRR have been utilized for aquatic display.

1 INTRODUCTION

Role of display drastically has changed in this century. 30 years ago, display is mainly used for showing image as a television terminal. Nowadays, displays plays a role in information communication technology. We expect that future information interface will have no weight like air and enable us to direct handling of the information in real space.

This paper introduces our developments on aerial displays, including an omni-directional aerial display, a see-through aerial display, and a thin aerial display with infinity mirror. Furthermore, we have realized the world-first aquatic display by utilizing the optical system for aerial display. Aquatic display is applicable to show fish visual stimuli for biology experiments.

Prospective applications of aerial displays include an aerial screen in a smart car, aerial signage, aerial interfaces for factories, entertainments, and museums. Touchless aerial interfaces are immune from hygiene issues on pressing a button to operate machines.

In Section 2, we explain the definition of aerial display in strict meaning, which is described in the technical report of the electrotechnical commission (IEC). Section 3 shows several types of optical systems to form aerial image in mid-air. Section 4 shows optical systems for aquatic display and typical results. In Section 5, applications of aerial displays are described.

2 DEFINITION OF AERIAL DISPLAY

In a wide sense meaning, aerial display refers display that show information in mid-air, where there is no hardware. Aerial display can be realized by use of a light-source display and some imaging optics. In the technical report of IEC, aerial display in strict meaning forms a real image in the mid-air by use of a light-source display and a passive optical component to converge diverging light from the light-source display [1]. Essentials of aerial display in strict meaning is shown in Fig. 1. The light-source display emits diverging light rays. A passive optical component changes the direction of each light ray so that light converges to the image position in the mid-air. Thus, the real image of the light source is formed because diverging plural rays emitted from a source position converge to the single position.

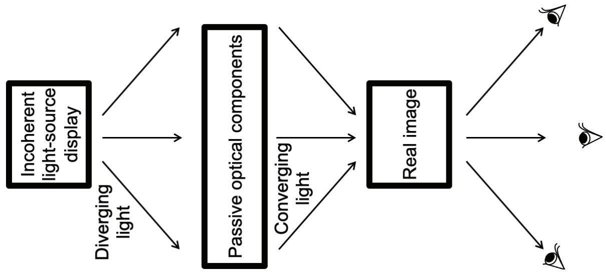

Fig. 1 Aerial display in strict meaning

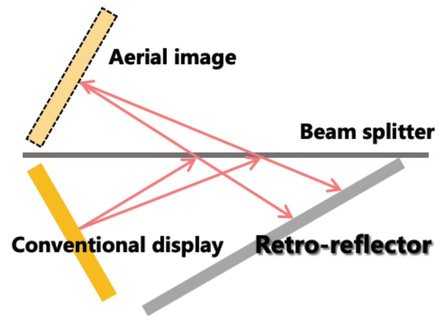

Fig. 2 Fundamental optical system for AIRR

The formed real image is visible over a wide range of angles when light rays from a wide range converge to the image position. When this converging angle is sufficiently wide, the formed real image is virtually a display in mid-air and maintains the visual 3D depth cues, including convergence, binocular parallax, accommodation, and smooth motion parallax.

3 OPTICAL SYSTEMS OF AERIAL DISPLAY

3.1 Aerial imaging by retro-reflection (AIRR)

Our basic optical method to form an aerial image employs a retro-reflector to converge light in the mid-air, called AIRR (aerial imaging by retro-reflection) [2]. The fundamental optical system for AIRR is shown in Fig. 2. Light emitted from the source display is reflected by a half mirror and impinges a retro-reflector. The retro-reflected light transmits the half mirror and converges in mid-air. The formed aerial image is plane-symmetrical of the source display with respect to the half mirror.

AIRR features a wide-viewing angle, a large-size scalability, a low cost with mass-productive optical components, and a high degree of freedom in optical design. The aerial image of a light-source display is formed at the plane-symmetrical position of the light-source display regarding the beam splitter. Unlike the conventional stereoscopic 3D display, the aerial image is the real image of the light-source display. Therefore, the reproduced 3D position is the same for everyone.

3.2 Omni-directional aerial display

Omni-directional aerial display surrounds the central region with a cylindrical aerial image. Because the aerial image is formed at the plane-symmetrical position of a light-source display with respect to the beam splitter in AIRR, use of a cone-shaped beam splitter maps a 2D image on a flat-panel display to the cylindrical shape, as shown in Fig. 3. We have utilized this omni-directional display to investigate optomotor reaction of fish for the visual stimuli [3]. The omni-directional aerial display surrounds a cylindrical water tank. A medaka in the water tank followed to the rotating stripes shown on the surrounding aerial screen. We named this types of experiments VR biology.

3.3 See-through aerial display

Under the COVID-19, video conferences have become popular. Ordinary computer or smart phone equips a camera outside the display screen. This arrangement causes a gaze-mismatching problem. The beam splitter in AIRR can perform a kind of combiner and show an aerial image on a background scene [4]. As shown in Fig. 4, a user sees the opposite side through the aerial image. An operator, or a camera, in the opposite side can observe the user's gesture and the displayed image as a virtual image.

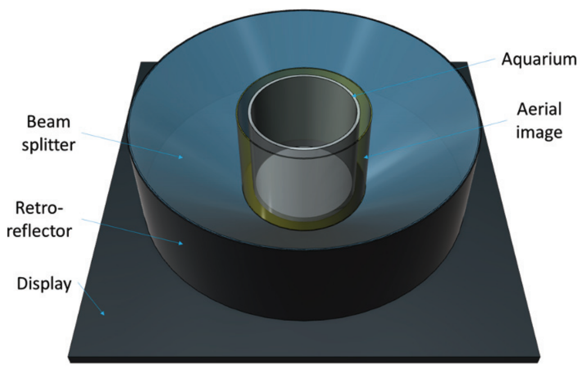

Fig. 3 Omni-directional aerial display for behavioral biology experiments of fish

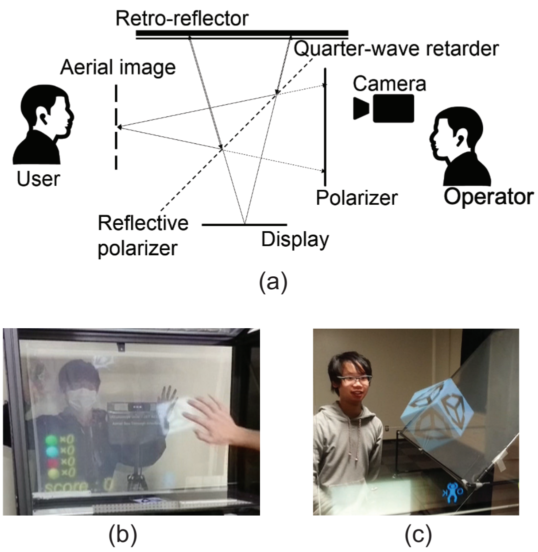

Fig. 4 (a) Optical system for see-through aerial interface and viewed images (b) from the user's side and (c) from the operator's side

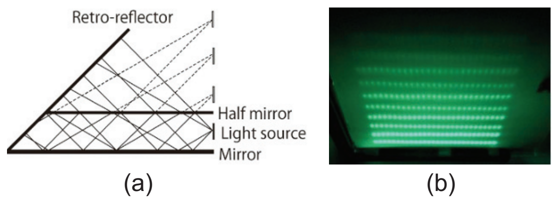

Fig. 5 (a) Optical system to form multiple aerial images with faced mirrors and AIRR and (b) formed multiple aerial images

3.4 Thin aerial display with infinity mirror

The volume of aerial display system sometimes limits its applications. To reduce the thickness, we have introduced faced mirrors to form multiple aerial images by use of a single light source [5]. The optical system and observation on a screen are shown in Fig. 5. A half mirror and a mirror are placed in parallel, which form multiple virtual images and sometimes called infinity mirror. By placing a retro-reflector, the multiple aerial images are formed in mid-air. We can form a light wall with a single ribbon LED tape.

4 AQUATIC DISPLAY

Aquatic displays can be formed with the following three types of optical systems, as shown in Fig. 6. In Type I, we place a beam splitter above the water surface to reflect lights from the light source and transmit the retro-reflected lights. Type II uses the water surface as a beam splitter because the intersection between water and air causes reflection and refraction. Type III uses the bottom of the water tank as a beam splitter. Preliminary experimental results are shown in Fig. 7. Aquatic display of Type III forms a clearer and stable image inside water.

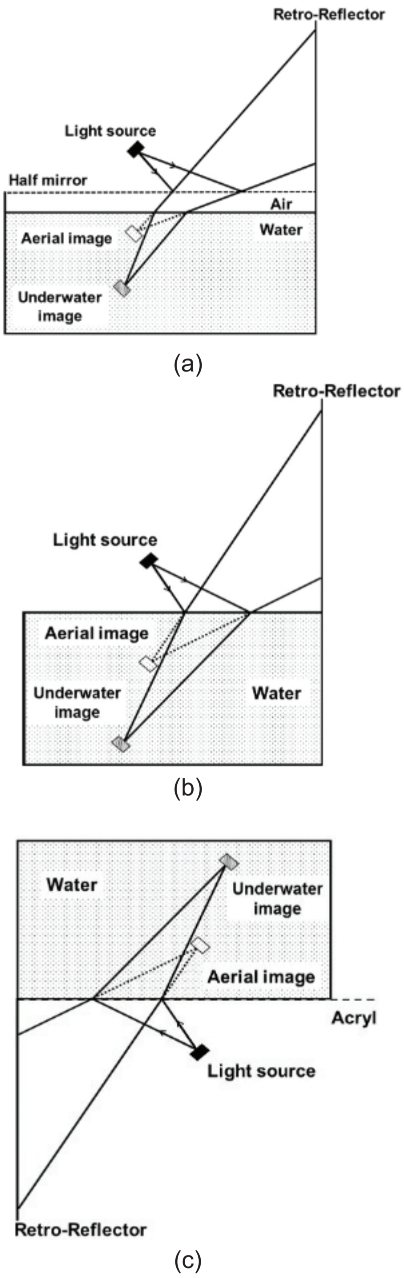

Fig. 6 Optical systems for aquatic display of (a) Type I, (b) Type II, and (c) Type III

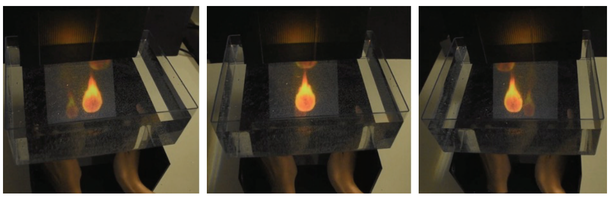

Fig. 7 Observation of an aquatic display of Type III viewed from the left to the right

Furthermore, a medaka reacted to a biological motion image that was shown in water. Thus, the proposed display is useful for behavioral biology experiments.

5 APPLICATIONS OF AERIAL DISPLAY

Applications of aerial display include an interface in automobile, amusement, signage, and touchless interface. To prevent spreading of COVID-19, aerial display is expected to realize touchless aerial interface. For the use of ATM and other security terminals, secure aerial display has been realized [6]. Transparent aerial gate was demonstrated at CEATEC [7]. We have shown an aerial agent on the center console in a concept car, which was exhibited at Tokyo Motor Show 2017 and CES 2018 [8]. In combination of two AIRR optical systems, aerial depth-fused 3D (DFD) was realized [9]. Multiple aerial signs can show different information depending the direction in a crossroad [10].

One of the issues is to develop an image quality evaluation method. We have measured contrast-transfer function (CTF) of aerial display [11]. However, CTF depends on the performance of the light-source display as well as the aerial imaging optics. To discuss the imaging quality, we have proposed measurement method of modulation-transfer function (MTF) of aerial imaging optics [12, 13]. By introducing Radon transformation in slanted knife edge method, we have succeeded in obtaining MTF curves that clearly show difference of aerial imaging performance [14]. In order to make the aerial display technology for social implementation, we have engaging in standardization of measurement method of image quality, aerial screen size, directivity, and so on at IEC/TC110/WG6.

6 CONCLUSION

We have developed several types of aerial displays with AIRR, including omni-directional aerial display and aquatic display. There are a wide variety of prospective applications of aerial display. International standard for aerial display is undergoing.

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