Aerial Imaging by Retro-Reflection with Transparent Retro-Reflector (AIRR with TRR)

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ABSTRACT

We propose a novel design of aerial displays. Our proposed design employs a transparent retro-reflector (TRR) for aerial imaging by retro-reflection (AIRR). AIRR with TRR can reduce a hardware space. Furthermore, AIRR with TRR can show images on TRR planes and can realize both a dual-view and dual-layered aerial display.

1. INTRODUCTION

Aerial displays with passive optical components have gained more attentions owing to the advent of 3D gesture sensing cameras [1-4]. The re-imaging optics present floating real images of conventional displays (e.g. LED, LCD and OLED) in a hand-reachable, real space and enable users to make intuitive interaction with digital information without suffering from visual fatigue by accommodation-vergence conflicts. To improve cost performance of re-imaging components with wider viewing angles in a larger scale, we have studied aerial imaging technique with retro-reflection to converge lights [5]. We have developed a prototype of an aerial LED signage [6] and have also improved brightness and resolution to realize LCD-based aerial tabletop displays [7]. In the previous approaches, however, we had critical constraints to limit viewing areas within a retro-reflector and had a difficulty to show another image on a retro-reflector area; because we cannot place a retro-reflector in the same space as a display (Fig.1). To solve this problem, we propose a novel design of aerial imaging technique.

In this paper, we present AIRR with a transparent retro-reflector (TRR). AIRR with TRR not only expands viewing space for aerial images (Fig.2) but also realizes a dual-view, double layered display in a built-in form.

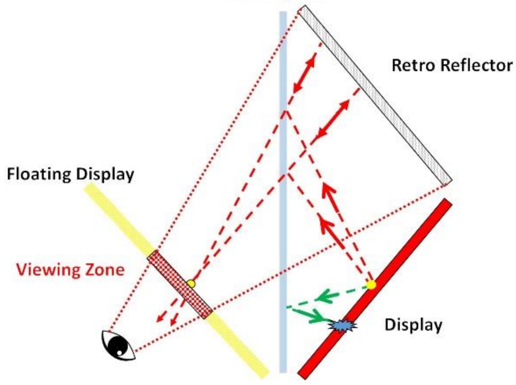

Fig. 1 Limitation of viewing zone with conventional AIRR.

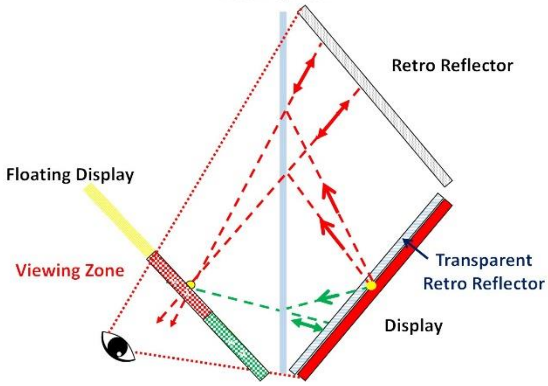

Fig. 2 Extended viewing zone of AIRR with TRR.

2. RELATED WORK

2.1 Transparent Retro-Reflector

Standard retro-reflectors are opaque with a single color (e.g. silver, black, red, green, and blue). The substrates are, in general, coated with high reflective materials and protective layers to gain sustainable retro-reflectivity in a harsh outdoor applications, such as traffic signs and adverting boards.

In previous studies, Nojima et al. [8], Nishimura et al. [9] and Kiyokawa et al. [10] have proposed various mechanically scanning approach to make virtual transparent retro-reflectors for application of see-through, bright projection screen. To realize a transparent retro-reflector with a persistence of vision, they have customized a high-speed-moving, piece-wise retro-reflective screens with opaque retro-reflectors: namely, a rotating propeller screen for a head up display and a shifting slit screen for a head mounted display. Although those approaches have enabled modulation of transparency with opaque retro-reflective screens, the mechanical system requires a large space and an effort to maintain the transparency.

On the other hand, there are a couple of unique semi-transparent, retro-reflective prism sheets. They have

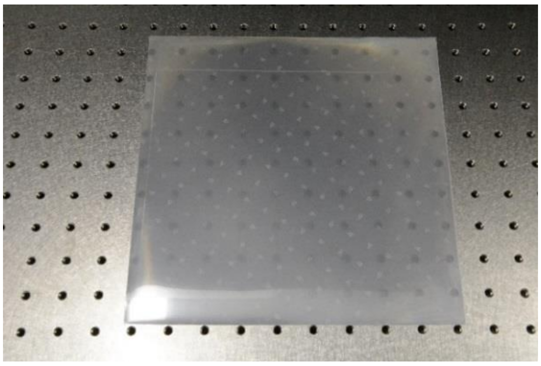

Fig. 3 Semi-transparent retro-reflective prism sheeting [11].

been used in a decoration purpose for clothing and also in a traffic sign with a texture image (e.g. 3M Scotchlite 6160R White High Gloss Trim [11]). As Fig. 3 shows, when the semi-transparent retro-reflective sheet is in contact with a background plane, the background plane's image becomes visible. We have utilized this contact-type, transparent retro-reflective sheet by directly placing it on top of the display surface and have explored the usage for AIRR.

2.2 Double Layered Display with Aerial Imaging

Chan et al. [12] have employed Fresnel lens to re-image a narrow-view floating display on top of the tabletop projection screen to provide both a privacy-protected screen and a public sharing screen. Martinez et al. [13] have deployed four fog screens on top of the tabletop projection screen to investigate mixed interaction of mid-air gesture and touch-screen input with multiple users. To facilitate implementation of a large scale and wide-view floating display on top of the tabletop screen, we have investigated spatial and temporal multiplexing methods by taking advantage of transparency of a beam splitter component in AIRR [14]. We have also investigated double LCD displays with AIRR to implement a double-layered floating display with a consideration of the depth reversing effect inherited in re-imaging principle of AIRR [15].

The focus of study in the aforementioned methods is limited to double layered displays and it is difficult to expand more layers, especially in the backside of the tabletop screen; this is because the backside has much less space than the front side and we also need to consider problems of occlusion and interference by additional layer of displays and projection screens. We have explored the simple solution with TRR to present an additional display layer in the back space.

3. AIRR with TRR

3.1 Viewing Space Improvement

As Fig.1 shows, AIRR only enables users to see a floating display within the limited area where the eyes can catch converging rays from a retro-reflector through a beam splitter; hence, the floating image is trimmed by a display region. To present a floating image in a display region, we need to place a transparent retro-reflector on top of the display without disturbing a display image. As a result, if the size of the display and the retro-reflector is the same and the joint angle is ninety degrees, which is a standard layout of AIRR, we can expect the viewing angle is improved by around twice of the conventional AIRR, as Fig.2 illustrates.

3.2 Compact Design of AIRR

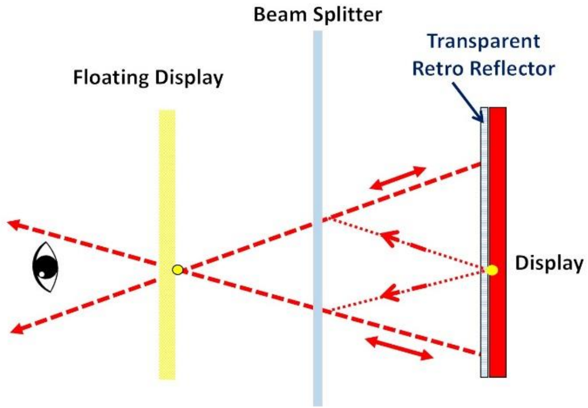

Fig. 4 Diagram of compact design of AIRR with TRR.

Placement of a transparent retro-reflector on top of the display can also save the necessary space for AIRR since we can integrate the separated space for a display and a retro-reflector into the same position, as Fig. 4 shows. This compact design can not only minimize the system design but also can increase brightness and sharpness by reducing the necessary optical path for the convergence of lights. We can hide a display source by utilizing reflective polarization film as a beam splitter in a crossed-Nicol alignment with respect to the display.

3.3 Dual-view and Double-layered Display

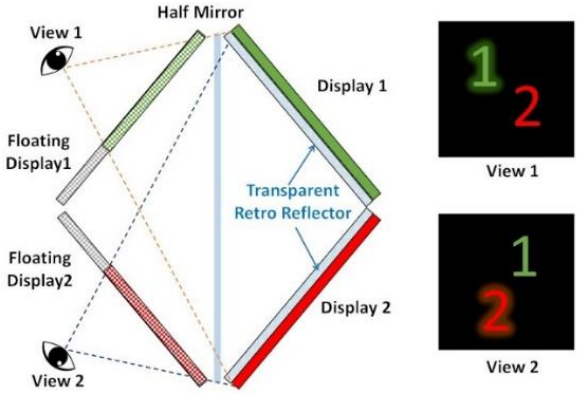

Fig. 5 Diagram of dual-view and double-layered display.

Deployment of two displays covered by TRR can realize dual-view and double-layered display, as Fig. 5 illustrates. User at view 1 can see a floating image of Display 1 (figure of green color "1") in a near plane and can concurrently see a background image of Display 2 (figure of red color "2") in a far plane. User standing at view 2 can see the reversed double layered images of view 1. We can present different contents of floating images and background images for viewer 1 and viewer 2 respectively by employing dual-view LCD displays with directional light control by lenticular lens. This layout is especially useful for a tabletop application for two users, sitting across the table from each other, to play games or to make a deal in business.

4. Experimental Results

4.1 Display setup for AIRR with TRR

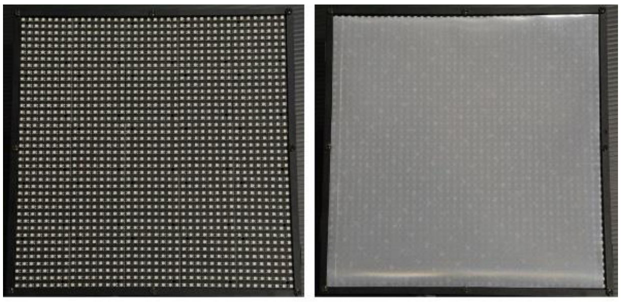

Fig. 6 (A) 40x40 LED panels. (B) TRR-covered 40x40 LED panels.

To verify our proposed methods, we have utilized 15-inch 40x40 LED panel (Fig.6 (A)) with a brightness of 2000 (cd/m^2) and have attached a 3M transparent retro-reflector [11] on top of the LED panel, as Fig. 6 (B) shows. We have deployed a standard half-mirror with 30% reflection rate as a beam splitter.

4.2 Compact self-reimaging

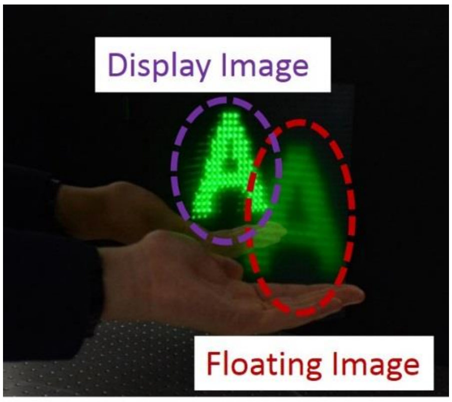

Fig. 7 Self re-imaging result of TRR-covered LED.

We have first setup the TRR-covered LED panel and a half mirror in the compact design as described in Fig. 4 to confirm self-reimaging ability of AIRR with TRR. As Fig. 7 shows, we have found a clear floating image of a letter "A" in front of a half mirror and have confirmed the attached TRR has not distorted the LED display image.

4.3 Comparison of viewing zone

To investigate improvement of viewing zone by TRR, we have compared visibility of a floating image, a red, capital letter "A", by AIRR and by AIRR with TRR as

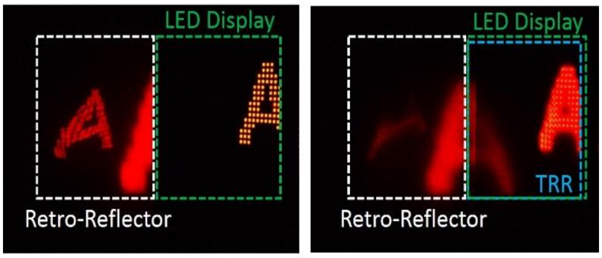

Fig. 8 (A) Floating image by AIRR. (B) Floating image by AIRR with TRR.

explained in Fig. 2. We have used a silver-color retro-reflective sheet (Reflexite, micro prism array type) as our opaque retro-reflector.

Fig. 8 shows the result by AIRR (A) and the result by AIRR with TRR (B). The central images are the expected floating images and the rest of images are reflected images by the half mirror and the opaque retro-reflector. As Fig. 8 (A) describes, the conventional design of AIRR has trimmed the letter "A" at the LED display region, indicated by the green rectangular area, and shows the left-half image in the retro-reflector area. On the other hand, AIRR with TRR has shown a complete floating image of the letter "A" thanks to TRR-covered LED panel (blue rectangular area), as Fig. 8(B) shows.

Since TRR likely transmits most of the light, the retro-reflective efficiency is, however, much lower than opaque one and results in a darker floating image; in Fig. 8(B), the right-half floating image of "A" is much darker than the left-half floating image. When we utilize a bright LED display, it is rather desirable to choose a TRR with lower transmission ratio and higher retro-reflectivity to realize a wide-view, bright floating display.

4.4 Double-layered Display

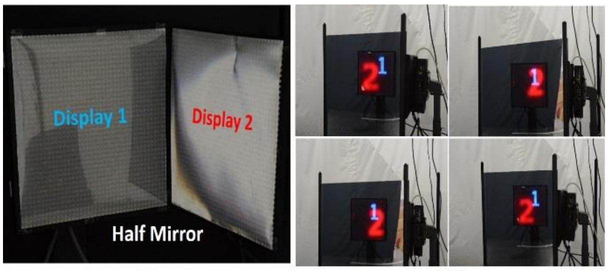

Fig. 9 (A) Two TRR-Covered LED panels placed at a right angle. (B) Double layered images from 4 different viewing positions.

To evaluate a double-layered display by AIRR with TRR, we have setup two TRR-covered LED panels at a right angle as Fig. 9 (A) shows. A half mirror has been placed to make a triangle with these two LED panels. As Fig. 9 (B) shows, we have found a clear floating image of the Display 2, the red number "2", in front of the Display 1 image, the blue number "1". The depth length is equal to the width of Display 2, around 26.9 cm. We have confirmed the large motion parallax effect with the proposed double-layered display as Fig. 9(B) shows.

4.5 Dual-view and Double-layered Display

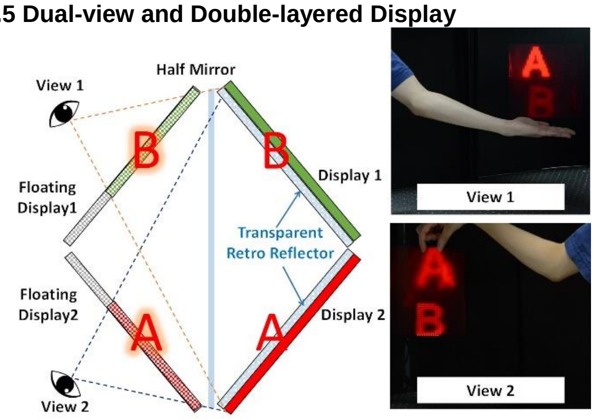

Fig. 10 Dual-view double-layered display by AIRR with TRR.

Finally, we have verified a design of dual-view, double-layered display as we introduced in Fig. 5. Fig.10 left figure shows our display setup and recorded viewing positions to confirm dual view image with a double depth layer. Display 1 shows a red letter “B” and Display 2 shows a red letter “A”. As Fig.10 right image shows, the recorded image at the view 1 position has shown a floating image of “B” in front of the LED image of “A,” while the recorded image at the view 2 has shown the depth reversed image. This result has confirmed AIRR with TRR is practical to design a dual-view, double-layered display.

As we have expected, in the viewing zones between the view 1 and the view 2, we have, however, seen both Display 1 image and Display 2 image in addition to a floating image. To overcome the cross-talk problem, our future vision is to control a directional light of LED with a lenticular array or a prism. We also plan to apply the proposed design to dual-view LCD displays with a reflective polarization film as a beam splitter to enhance brightness and to present different contents for multi users without crosstalk problem.

5. Conclusion

We have proposed various novel designs and applications of AIRR with a transparent retro-reflector (TRR). With implementations and demonstrations of prototype systems by TRR-covered LED panels, we have verified AIRR with TRR can compact the system, expand viewing space and furthermore realize a dual-view, double layered display. Since there are problems of low light efficiency and crosstalk with a current setup, we plan to improve the design with a focus of TRR optimization and directional light control of LED and LCD displays.

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