Evaluation of Response Time of AIRR with Immersive Aerial Interface by 3D Motion Capture

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ABSTRACT

The response time of immersive aerial interface was measured using a high-speed video camera. We have successfully reduced the time to almost enough level of 15 milliseconds. The delay time was within the range that the VR sickness may be suppressed.

1 Introduction

Aerial image display can show image in the air, so it is increasingly implemented to society with non-contact touch panels as measures against the coronavirus. It is also beginning to be used as digital signage, a form of expression that has an impact on a space. AIRR (aerial imaging by retro-reflection) has been proposed as a method forming an aerial image using retro-reflection [1]. AIRR consists of three components: a light source, a beam splitter, and a retro-reflector. Since it can be arranged freely, various studies have been conducted, such as Aerial depth-fused 3D display [2] and omnidirectional aerial display [3]. The AIRR tablet, AIRR that integrates the 3D high-speed hand tracking and gesture to enable highly flexible operation, has also been realized [4]. Tiling retro-reflection elements has an advantage of allowing the design of large aerial display. In previous research, we have proposed an optical design of life-sized devices to form an immersive aerial image using AIRR [5].

This system is installed with OptiTrack (NaturalPoint, Inc.), optical motion capture system that captures user movements and OmegaSpace (Solidray Co., Ltd.), to display interactive contents [6]. In an interactive system, we believe that by shortening the response time until the display content is updated in response to user movement, the user will not feel any difference in hand movements or changes in the content. If the response time is significantly delayed for user operation, it may cause VR sickness [7]. For example, when the response time between the user's physical input to the system and the visual feedback is over 24.3 milliseconds, it has a tendency the use performance begins to decrease [8]. Moreover, when the response time in a visual feedback system during path-steering tasks is over 64.3 milliseconds, it has a tendency that the user performance begins to decrease [9]. In this paper, we have measured the response time of large aerial image interface using two types of display content with different update speed. Then we have investigated changes in response time of the constructed system.

2 Principles

2.1 AIRR

Fig. 1 shows the principle of AIRR. The light emitted from the light source goes to the beam splitter, and it is split into transmitted and reflected light. The reflected light goes to retro-reflector. On the retro-reflector, the light is reflected to the direction it comes, it is again split into transmitted and reflected light by a beam splitter. The transmitted light forms an aerial image at plane symmetric position of the light source.

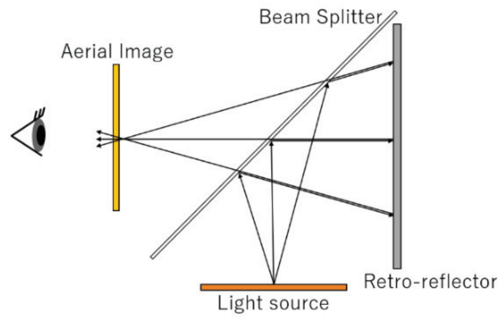


Fig. 1 Principle of aerial image by retro-reflection

2.2 Principle of Optical See-Through AIRR

Fig. 2 shows the principle of see-through AIRR used in this study. In this type, it is composed of the same elements as the conventional AIRR. However, the arrangement of the retro-reflector is different. The light emitted from the light source goes to the beam splitter and split into transmitted light shown by solid lines and reflected light shown by dotted lines. The transmitted light goes to retro-reflector, and it is reflected to the direction it comes, and then further reflected by the beam splitter. The light converges to the position of plane symmetry of the light source regarding the beam splitter. The reflected light forms a virtual image. The imaging position of the actual image observed from the front and the virtual image observed from the opposite side are almost the same position. Therefore, opposite user can also observe the operation that the front user performed by on the aerial image. An example of aerial image formed by see-though AIRR is shown in Fig. 3.

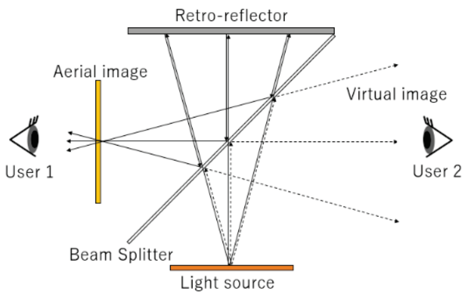


Fig. 2 Principle of optical see-through AIRR

Fig. 3 Aerial image formed with see-though AIRR

3 Experimental Setup

Fig. 4 shows the composition of a large aerial display using AIRR and response time measurement environment. The light from the light source follows optical path shown by a solid line and forms an aerial image at plane symmetric position. The image formation position is indicated by a dotted line. We have used the LED panel display and the LCD (predator X25, ASUSTeK Computer Inc.) as light sources. To measure the difference in response time due to the light source, the update speed of LED panel set to 60 frames/seconds and LCD set to 360 frames/seconds.

We have installed 4 cameras that captures the movement of the marker held by a user. The marker is made of retro-reflective material, and the coordinates of the marker can be obtained in three-dimensions from the camera image. The marker size is 130 × 110 mm. Fig. 5 shows the marker used, the actual position of cameras and the position of cameras on the software. Fig. 6 shows images captured by four cameras.

We have added a high-speed video camera (acAC640-750um, Basler AG, resolution was 640 × 480 pixel, pixel size is 4.8 × 4.8 μm) and a lens (LM6NC1M1/2", Kowa optronics Co., Ltd., focal length is 6 mm, image size is 6.4 mm × 4.8 mm) to measure the response time.

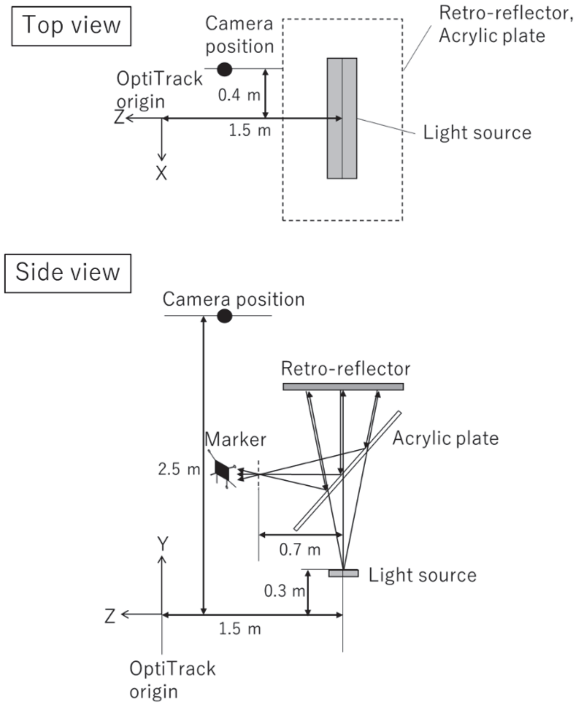
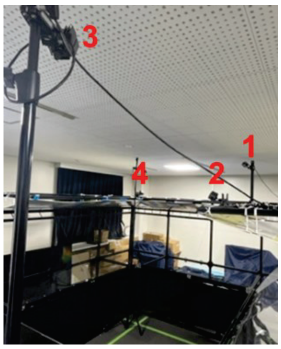
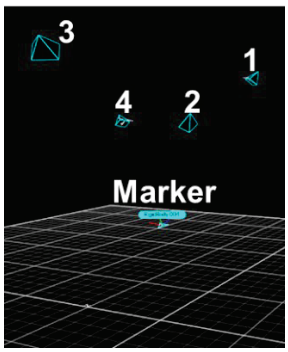


Fig. 4 Composition of a large aerial display with AIRR

(a)





(b) (c)

Fig. 5 Motion capture system: (a) marker with retro-reflective materials for tracking user movements, (b) the actual position of the cameras installed to capture the marker, and (c) the camera positions in the software screen installed to capture the marker

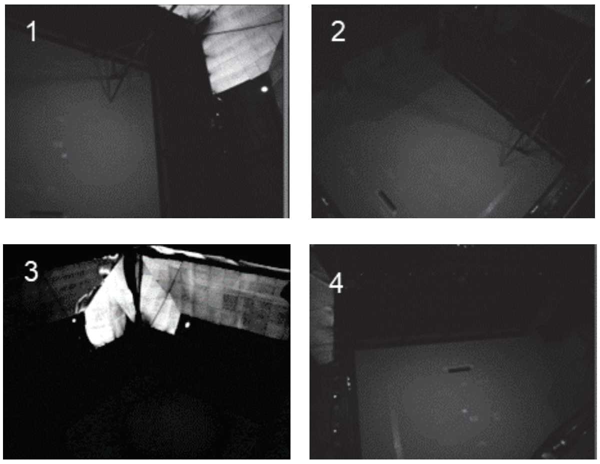


Fig. 6 Range and reflection from each camera

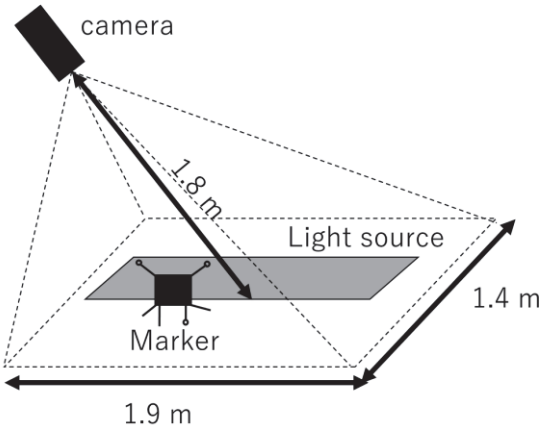


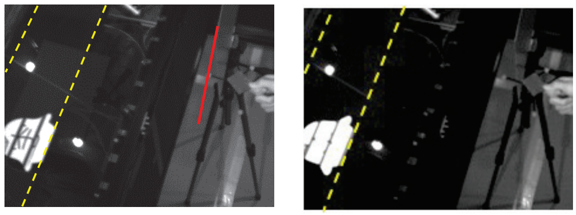
Fig. 7 Camera position and shooting range

Fig.7 shows the camera position and shooting range. It was set up 2.5 m above the floor and was adjusted to be able to record a hand and the light source at the same time. The shooting range was 1.9 × 1.4 m and the distance from the camera to the center of the shooting range was 1.8 m.

4 Response Time Measurement

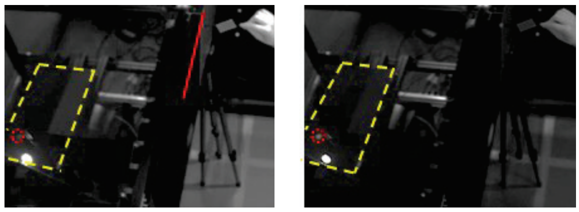
Display contents for time response measurement were created on OmegaSpace. The marker is moved perpendicular to the formed aerial image plane from the center of the aerial display system. Upon the contact of the marker with the image plane, then the color of the target object on the display changed. We have recorded the user moving the marker, extracted from the video the number of frames between the frame that the marker passed through the aerial imaging position and the frame in which the object color on the display changed. Then the time between these two frames was measured as the response time of the system.

Fig. 8 shows camera images when the LED panel was used and Fig. 9 shows camera image when the LCD was used. The frame rates of each image were 200 frame/seconds and 400 frame/seconds. In each figure, the red line indicates the position of the aerial image, and the yellow dotted line indicates the range of the light source. A screen was set up the position of the aerial image formation as the indicator of operation. Response time measured 5 times each with the LED panel and the LCD.



(a) (b)

Fig. 8 Captured images (a) at the moment of the contact of the marker with the image plane and (b) at the moment when the target object color the LED display changed



(a) (b)

Fig. 9 Captured images (a) at the moment of the contact of the marker with the image plane and (b) at the moment when the target indicated by the red dotted line object color the LCD display changed

When using the LED panel with the update speed of 60 frame/seconds, the response time measured by 200 frame/seconds was 36 milliseconds on the average. And the response time measured by 300 frames/seconds was 37 milliseconds on the average.

When using the LCD with update speed of 360 frame/seconds, the response time measured by 400 frame/seconds was 15 on the average.

5 Discussion

The response time measured in this study includes the update speed of the motion captured system as well as the update speed of the display panel. Comparing the two types of displays, the response time was reduced by 22 milliseconds for the faster frame rate display.

As a comparison to previous studies, the response time between the user's physical input to the system and the visual feedback is preferably within 24.3 milliseconds [8]. If the update speed of the display is 360 frame/seconds, the response time is less than this threshold, but if the update speed is 60 frame/seconds, the user's performance may begin to decrease. On the other hand, in the case of a visual feedback system during path-steering tasks, response time for both does not exceed 64.3 milliseconds [9], and it is considered that the user's performance is not affected by these delays. Based on the frame rate of 30 frame/seconds, which is the frame rate of general TV broadcasting, the response time of both images is within one frame, so there is little discomfort that users have.

6 Conclusion

The response time of a large aerial display interface combining AIRR with Optitrack and OmegaSpace was measured by a camera set up to capture both the hand movement and the light source.

We have shown that the response time of a large aerial display can reduce to almost enough level of 10 milliseconds by using a high frame rate display with 360 frame/seconds as a light source. If the display with a high frame rate is used as a light source can reduce response time and prevent the user performance degradation.

However, large aerial display uses the LED panel with update speed of 60 frame/seconds, which focus on brightness and size, which is important for aerial display. Subject of experiments would need to be conducted on the user performance degradation due to the response time of this LED panel. Depending on the results, the display update speed should be increased without reducing the brightness. Since it is true that there is a slight delay, compensation for the time delay using estimation remains for the future study.

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