Patterned Beam Splitter That Shows a Background Image Behind Aerial Image and Makes Light Source Unnoticeable

Takeru Nishiyama¹, Mayu Adachi¹, Masakazu Sanbe², Shiro Suyama¹, Hirotsugu Yamamoto¹

hirotsugu@yamamotolab.science
¹ Utsunomiya University, 7-2-1 Yoto, Utsunomiya, Tochigi, 321-0904 Japan
²ANOVA Co., Ltd, 115-4 Iyasakadaira, Rokkasho, Aomori, 039-3212 Japan
Keywords: Aerial Display, AIRR, Beam splitter

ABSTRACT

Aerial imaging by retro-reflection (AIRR) by use of a patterned beam splitter can show a background image behind the aerial image. This study makes it possible to add a background image to the aerial image without increasing the number of AIRR components, and also make the light source less noticeable.

1 Introduction

Aerial displays, which shows information images in mid-air, are expected to be applied to touchless terminals in combination with sensors [1] and as secure displays where the screen is not visible to anyone except the operator by adjusting the viewing angle [2].

On the other hand, in order to expand the field of applications of aerial displays, it is necessary not only to project information in mid-air but also to form an aerial image in front of a background image such as a wall. In addition, the presence of a background image makes it easier to perceive floating sensation of aerial images. The purpose of this study is to propose a method of adding background image to aerial images.

This paper deals with aerial imaging by retro-reflection (AIRR) [3]. As a method to produce a background image to the aerial image by AIRR, an optical see-through AIRR [4] has been proposed that allows the viewer to see the image on the back side of the enclosure by changing the arrangement of optical elements. Furthermore, as a method of displaying aerial images in front of a pattern, a decorative sheet printed with a pattern has been proposed to be added behind the aerial image [5]. However, it is important to reduce the number of components as much as possible in order to maintain the simplicity of the configuration, which is one of the advantages of the AIRR.

The AIRR has a beam splitter, such as glass or acrylic, behind the aerial image, which is usually invisible from the aerial image side. We consider that the configuration of the beam splitter makes it possible to add a background image to the aerial image without increasing the number of components, because beam splitter can be constructed by metal patterns and transparent parts.

In this paper, an aerial image is displayed over a specific background image by AIRR using a beam splitter with a patterned surface. When aerial images formed by AIRR using beam splitters with various patterns are captured, the patterns are visible as the background image of the aerial images.

2 Principles

2.1 Aerial Imaging by Retro-Reflection (AIRR)

Figure 1 shows the principle of AIRR, which consists of a light source, a beam splitter, and a retro-reflector. The light emitted from the light source impinges the beam splitter and is divided into reflected and transmitted light. After splitting, the reflected light impinges the retro-reflector. Light impinges the retro-reflector is reflected in the same direction as the incident light due to the optical property of the retro-reflector. Retroredected light impinges the beam splitter again. The light is split by a beam splitter again, the transmitted light intersects and forms an aerial image at a position that is plane-symmetrical to the light source with respect to the beam splitter.

![Fig. 1 Principle of AIRR](image)

2.2 AIRR With Beam Splitter With Non-Transmission Surface

In this study, a beam splitter with a patterned glass plate is used. Figure 2 shows the principle of AIRR using a processed beam splitter. The retro-reflected light impinges on the glass surface or processed surface. The
light that impinges the glass surface is transmitted and forms an aerial image. However, that impinges the processed area is not transmitted and does not contribute to the formation of the aerial image.

Therefore, when the pattern by processing is large, the aerial image is formed in an interrupted manner, while with a minute pattern, aerial image is visible without interruption.

![Fig. 2 Principle of AIRR when beam splitter has non transmission surfaces](image)

### 3 Experimental System

**3.1 Patterned Beam Splitters**

Five types of beam splitters in different patterns were used in the experiment. Figure 2 shows the surface structure of each beam splitter. (1) to (4) are structures with fine patterns added to the surface, and (5) is an overall view of the patterned beam splitter that are large enough to be seen by the naked eye. The surface structures from (1) to (4) were observed and photographed using a microscope (SMZ/25, Nikon Corporation) and a camera (DS-Fi3, Nikon), while (5) was photographed using a digital camera (DSC-RX100M4, Sony Corporation). Light striking the white areas in the image is transmitted, while light striking the black areas is not. The surface structures of (1) and (3) and (2) and (4) in the figure have the same pattern. However, the size of each pattern is different. The overall size of the beam splitter is 80 x 155 mm for (1) to (5) common. Even when a fine pattern is added to the surface, the beam splitter as a whole is able to perform the role of a beam splitter in AIRR, to split light into reflection and transmission.

![Fig. 3 Surface structure of a patterned beam splitter](image)

**3.2 Experimental System to Form Aerial Images by Use of a Patterned Beam Splitter**

Figure 4 shows an overview of the experimental optics system used to capture aerial images when a special beam splitter is used. An image is formed in the air by AIRR with a light source placed below, and the image is captured by a camera (DSC-RX100M4, Sony Corporation). In order to take pictures under different illumination conditions, a solar simulator (HAL-320, Asahi Bunko Corporation) was placed behind the camera at a distance of 1 m from the position where the aerial image was formed, illuminating the ceiling above the optical system. The illuminance is measured with an illuminance meter before the image is taken. The light source was an 11 x 44 pixel LED name budgie, the retro-reflector was a prism-type retro-reflective sheet (RF-Ax, Nippon Carbide Industries).

When the retro-reflector is placed perpendicular to the light source, the light from the light source will be reflected when the aerial image is captured from the front, making it impossible to capture only the aerial image. To prevent this, retro-reflector is placed at a small angle in this system.
4 Aerial Image by AIRR Using a Pattern on the Surface of Beam Splitter

4.1 Beam Splitter Pattern Visible When the Image is not Displayed

As a preliminary step to taking aerial images, only the surface structure of the beam splitter was photographed when the light source was turned off. The illuminance at the time of imaging was 150 lux. Figure 5 shows images of each beam splitter. The numbers in the figure correspond to the patterns in Figs. 3 (1)-(4) are enlarged images of a part of the captured image, and (5) is the entire beam splitter. When Beam splitter in a bright environment like typical room, it appears to be a design glass.

![Fig. 5 Visibility with beam splitter in place at 150 lux. Note that the numbers under the photographs correspond to those in Fig. 3.](image)

4.2 Patterns on the Surface of the Beam Splitter When Aerial Image is Displayed

Aerial image was taken when using patterned beam splitters. Figure 6 shows an overall view of the aerial image when the beam splitter of Fig. 3(1) is used at an illuminance of 0 lux (A) and an overall view and partially enlarged view of the aerial image when the respective beam splitter is used at an illuminance of 30 lux (B). The numbers in the figures correspond to Fig. 3. When the pattern is large, the pattern can be seen even in dark surroundings, but when the pattern is minute, each pattern cannot be seen in a darkroom environment. In the presence of ambient light, the microscopic patterns could be observed simultaneously with the aerial image.

![Fig. 6 (A) Aerial image when using patterned beam splitter at 0 lux, (B) Aerial image and Magnified view when using patterned beam splitter at 30 lux](image)
4.3 Effect of Using Patterned Beam Splitter to Prevent Peeking at the Light Source

The use of a patterned beam splitter not only has the advantage of creating a background image in the aerial image but also has the effect of making it difficult to see the light source image inside the AIRR. Figure 7 shows the results of the experimental optics system with the beam splitter (A) without pattern, (B) Fig. 3(1), and (C) Fig. 3(5), taken from above. Illuminance at the time of photographing was 0 lux and the light source is taken through the beam splitter with the optics in Fig. 4. This means that the light source visible through the beam splitter is being photographed. Compared to the beam splitter with no pattern, the light source is blurred in the patterned beam splitter, and the image of the light source is barely visible when the pattern is of a size visible to the naked eye.

![Fig. 7 How the light source looks through the beam splitter](image)

(A) Light source is clearly visible
(B) Light source is little blurry
(C) Light source is very blurry

5 Discussion

In this experiment, the illumination was set to 30 lux to capture aerial images. However, in order to make it practical, it is necessary to verify the visibility under higher illuminance conditions in consideration of use outside. In addition, the solar simulator is illuminated on the ceiling to prevent outside light from impinging the beam splitter directly. In the future, it will be necessary to consider the effect of reflections on visibility when light other than light source impinges the beam splitter.

6 Conclusions

We proposed to use a patterned beam splitter on the AIRR. By using a beam splitter with a pattern, the aerial image appeared to be displayed on top of the background image when observed in a bright environment. In addition, the pattern of the beam splitter also made it difficult to see the light source inside the AIRR. This research makes it possible to display aerial images above specific background image without increasing the number of AIRR components.