Aerial-Imaging Steganography with AIRR by Use of Transparent Objects as Decoding-Keys

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Keywords: aerial imaging, steganography, retro-reflection, AIRR

ABSTRACT

A novel steganography technique is realized by utilizing aerial-imaging optical system based on aerial imaging by retro-reflection (AIRR). Transparent objects in a complex shape are placed in plane-symmetrically with respect to the beam splitter in AIRR. Transparent objects of various shapes were used to confirm the decoded aerial images.

1 Introduction

Three-dimensional (3D) displays have been investigated and developed for a wide variety of applications including advertisement, amusement, and medical tools [1]. In particular, the use of 3D display as a touchless interface is currently attracting attention from the perspective of preventing the spread of infectious diseases. Aerial imaging by retro-reflection (AIRR) [2] is one of such techniques. AIRR makes floating real images in the mid-air that can be seen by the naked eye.

Our previous study proposed a novel steganography that utilizes AIRR and two transparent spheres in the same size [3]. The proposed method used one of the transparent spheres as a key to form an aerial image that was formed with AIRR. In conventional AIRR configuration, the size of retro-reflector is required to be the same as or larger than the one of the light sources. In proposed method, the transparent sphere acts like a ball lens, focusing the light from the light source to the retro-reflector. This made it possible to reduce the area of retro-reflector required for aerial imaging [4]. Until now, we have used a transparent sphere for aerial-imaging steganography. However, if a transparent object that transmits and refracts light is arranged so that it is plane symmetrical with respect to the beam splitter, the principle suggests that steganography can be realized with a shape other than a sphere.

This paper proposes an aerial-imaging steganography that employs transparent objects with shapes other than spheres. We use four types of transparent objects: a rectangular prism, a cylinder, a PET bottle, and a vase with a wavy surface. For each transparent object, we experiment with two imaging patterns, near the light source and near the beam splitter. In the previous work, the light source, the transparent sphere, and the beam splitter were in contact with each other.

2 Steganography of Aerial Image Formed by AIRR with Dual Transparent Spheres

Figure 1 (a) shows the principle of AIRR. This setup consists of a light source, a beam splitter, and a retro-reflector. Rays from the light source are reflected by the beam splitter. The reflected rays are retro-reflected, that is, reflected reversely at the incident positions on the retro-reflector. The retro-reflected rays are converged to the position of the plane-symmetrical of the light source with respect to the beam splitter.

Figure 1 (b) shows the diagram of a concealing sphere under the beam splitter. Rays from the light source are refracted by the concealing sphere and do not converge to the aerial image positions. Consequently, no aerial image is formed.

Figure 1 (c) shows the diagram of the two same spheres (the concealing and decoding spheres) are placed plane-symmetrically regarding the beam splitter. Rays from the light source travel like Fig. 1 (b). In this case, retro-reflected rays are refracted again by the decoding sphere. Consequently, an aerial image is formed.

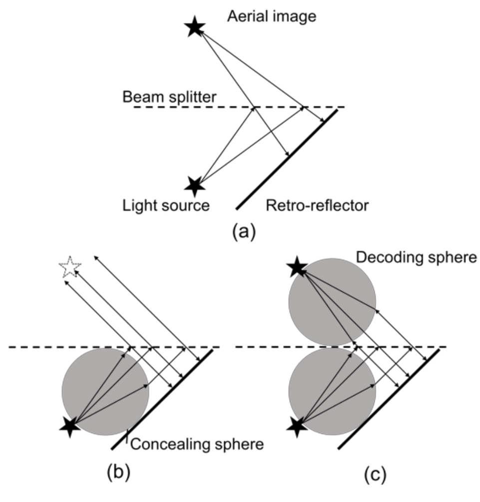


Fig. 1 Principle of aerial-imaging steganography with AIRR by use of dual transparent spheres.

3 Experiments

In this study, aerial imaging is performed using 5 types of objects as keys. Figure 2 shows the experimental configuration. The floating distance of the aerial image is 200mm. The light source the number 20 with a width of about 30 mm in green. The aerial images are observed when the light source and the key are in contact with each other and when the key and the beam splitter are in contact with each other on the floating distance. Note that the key object is filled with water during the experiment. This is to sufficiently refract the light that passes through the key object.

Figure 3 shows photographs of the transparent object used as a key of steganography in experiment. All transparent objects were filled with water during the experiment.

Figure 3 (a) shows a photograph of the rectangular prism used in this experiment. The rectangular prism is made of plastic with a length of about 60 mm. The prism has rounded corner.

Figure 3 (b) shows a photograph of the cylinder used in this experiment. The cylinder is made of glass with a diameter of about 85 mm.

Figure 3 (c) shows a photograph of the PET bottle used in this experiment. The body of the bottle is a prism with flat corners and a length of about 60 mm.

Figure 3 (d) shows a photograph of the vase with a wavy surface used in this experiment. The diameter of the widest part of the vase with a wavy surface is about 60mm. The floating height of the aerial image is adjusted to the height of the thickest part of the vase.

Figure 4, 5, 6, 7, and 8 show photographs of the experimental system for each transparent object. The quadrangular prism has two patterns, one with the corners facing the aerial image and the other with the faces facing the aerial image. In each figure, (a) the transparent object touches the beam splitter, and (b) the transparent object touches the light source. Because of the principle, the image formation position and size of the aerial image are the same.

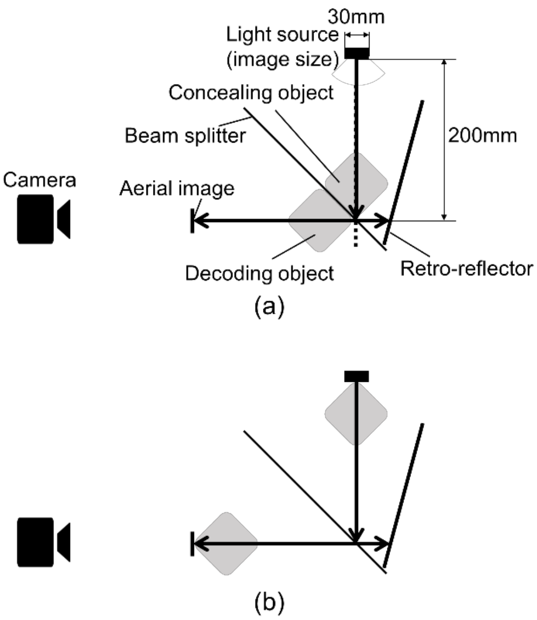


Fig. 2 Schematic structures of experimental setup. Transparent objects were placed (a) near the beam splitter and (b) near the light source.

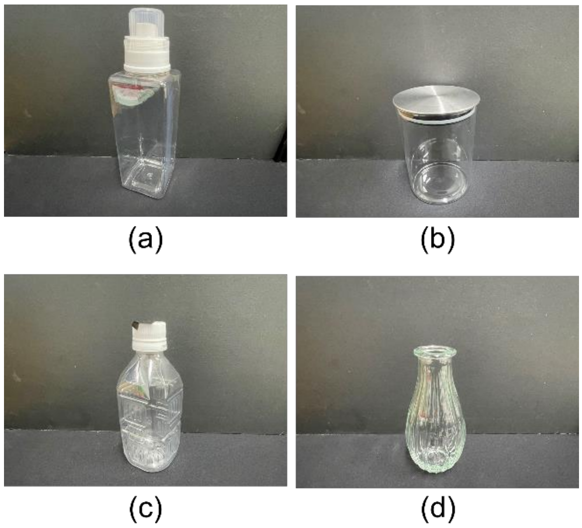


Fig. 3 Photographs of key objects used in the experiments: (a) rectangular prism, (b) cylinder, (c) PET bottle, and (d) wavy vase.

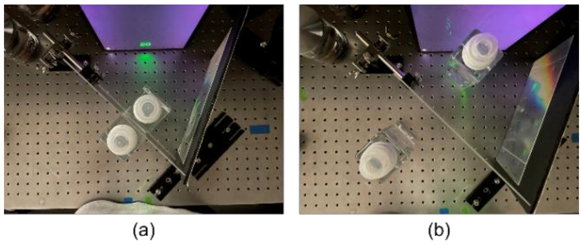


Fig. 4 A rectangular prism with its corners facing the aerial image. A Prism touches (a) the beam splitter and (b) the light source.

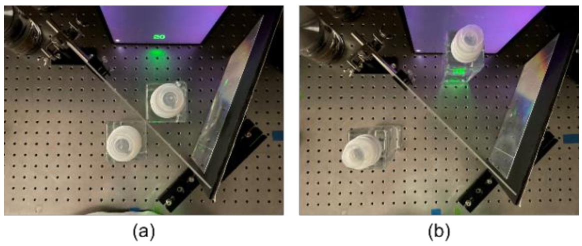


Fig. 5 A rectangular prism with its face facing the aerial image. A prism touches (a) the beam splitter and (b) the light source.

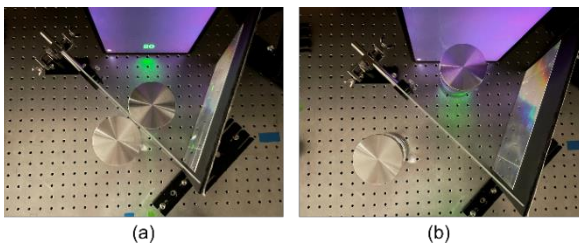
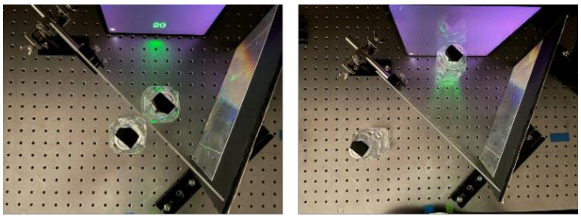
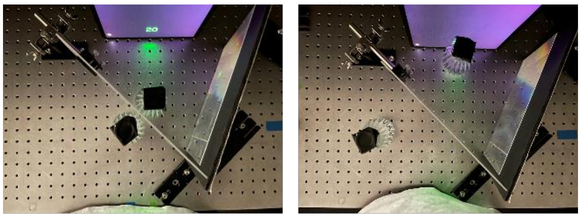


Fig. 6 A cylinder touches (a) the beam splitter and (b) the light source.



(a) (b)

Fig. 7 A PET bottle touches (a) the beam splitter and (b) the light source.



(a) (b)

Fig. 8 A vase with a wavy surface touches (a) the beam splitter and (b) the light source.

4 Results

Figure 9 shows the aerial image without the transparent object. The area enclosed by the red frame is the aerial image. As you can see, the number "20" is clearly visible.

Fig. 9 Aerial image without transparent objects (conventional AIRR).

4.1 Rectangular prism

4.1.1 With the corners facing forward

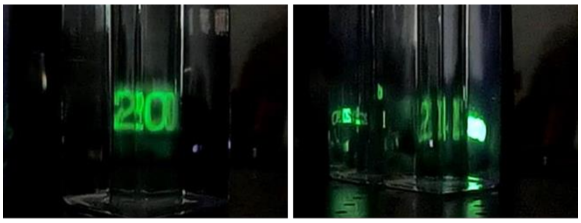
Figure 10 shows the results of using a rectangular prism with its corners facing forward as the key. When the key was placed in contact with the light source, the aerial image was visible. On the other hand, when the key was placed in contact with the beam splitter, it was not visible.

4.1.2 With the face facing forward

Figure 11 shows the results of using a rectangular prism with its face facing forward as the key. In this case, the aerial image was visible in each key arrangement. However, when the key was in contact with the beam splitter, the light directly reflected from the side of the rectangular prism showed up as noise.

4.2 Cylinder

Figure 12 shows the results of using a cylinder as the key. In this case, the aerial image was visible in each key arrangement. However, because the cylinder used in the experiment was wide, we were able to see the difference in viewing angle. Figure 13 shows the results of observing the aerial image shifted to the right of the photograph. The viewing angle of the aerial image was wider when the key was closer to the light source.



(a) (b)

Fig. 10 Result of using a rectangular prism with its corners facing forward as the key. A prism touches (a) the beam splitter and (b) the light source.

(a) (b)

Fig. 11 Result of using a rectangular prism with its face facing forward as the key. A prism touches (a) the beam splitter and (b) the light source.

(a) (b)

Fig. 12 Result of using a cylinder as the key. A cylinder touches (a) the beam splitter and (b) the light source.

(a) (b)

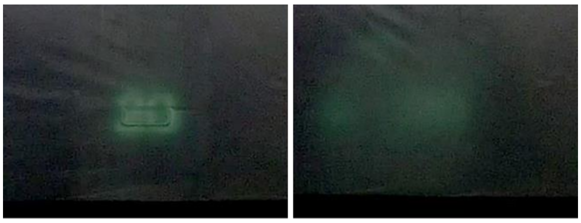
Fig. 13 Lateral viewing angle in a cylinder. (a) touches the beam splitter is wider than (b) touches the light source.

4.3 PET Bottle

Figure 14 shows the results of using a PET bottle as the key. The aerial image was visible when the light source was in contact with the key, but not when it was in contact with the beam splitter. In this case, the shape of the key made it difficult to see the aerial image. Figure 15 shows the result of projecting the image by placing a screen at the forming position of the aerial image. In Fig. 15 (a), the image was clearly visible, but in Fig. 15 (b) it was not.

(a) (b)

Fig. 14 Result of using a PET bottle as the key. A bottle touches (a) the beam splitter and (b) the light source.

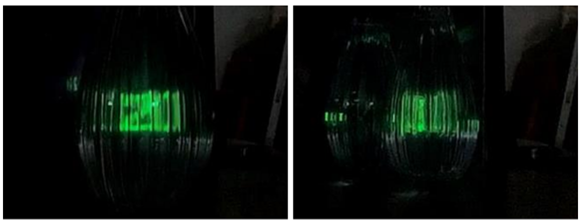


(a) (b)

Fig. 15 Result of placing the screen at the forming position of the aerial image with a PET bottle. A bottle touches (a) the beam splitter and (b) the light source.

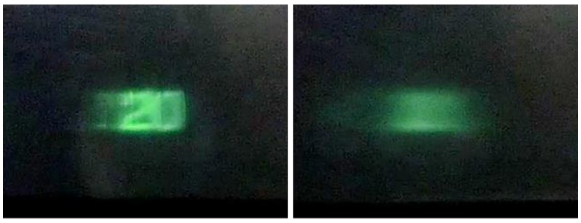
4.4 Vase with a Wavy Surface

Figure 16 shows the results of using a vase with a wavy surface as the key. The aerial image was barely faintly when the light source was in contact with the key, but not when it was in contact with the beam splitter. In this case, the image was also projected using a screen. Figure 17 shows the results. In Fig. 17 (a), the image was clearly projected, but in Fig. 17 (b), it was not.



(a) (b)

Fig. 16 Result of using a vase with a wavy surface as the key. A vase touches (a) the beam splitter and (b) the light source.



(a) (b)

Fig. 17 Result of placing the screen at the forming position of the aerial image with a vase. A vase touches (a) the beam splitter and (b) the light source.

5 Conclusion

The aerial images were formed using transparent objects of various shapes as keys. For all the transparent objects, the aerial images were visually observed when the light source and the object were in contact. For the rectangular prism with its corners facing the image, the PET bottle, and the vase, the AIRR principle suggests that the light transmitted through the objects did not enter the retro-reflector sufficiently to form an aerial image. For the visibility of the aerial image, such a surface geometry is not a suitable one for aerial-imaging steganography.

References

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