Change in Position of Multiple Aerial Images by Use of Non-Parallel Infinity Mirror

Kazunari Chiba[1], Masaki Yasugi[1,2], and Hirotsugu Yamamoto[1,2]

hirotsugu@yamamotolab.science
[1]Utsunomiya Univ., 7-1-2 Yoto, Utsunomiya City, Tochigi 321-0904, Japan.
[2]JST ACCEL, 7-1-2 Yoto, Utsunomiya City, Tochigi 321-0904, Japan.
Keywords: aerial image, AIRR, retro-reflector

ABSTRACT

By introducing an infinity mirror into AIRR (aerial imaging by retro-reflection), it is possible to form multiple aerial images from single light source. In this study, we report the change in the aerial imaging position when the mirrors are arranged non-parallel.

1 INTRODUCTION

An aerial image, which means a real image in mid-air with a sufficiently wide viewing angle, can be formed with aerial imaging by retro-reflection (AIRR) [1]. Aerial image has no physical restrictions and can be observed with naked eyes. There are various ways to use the aerial image, such as a secure aerial display [2] and an all-around display [3], and one of them is aerial guide such as indicating the position to put a user's hand. By using the aerial image as a guide, it is possible to prevent the spread of infectious diseases because we don't have to touch where others touched.

A technique for forming multiple aerial images from single light source by combining AIRR and infinity mirror has been reported [4]. This optical system is suitable for aerial guide because it is thin and can form multiple aerial images This paper reports on the change in the imaging position of the aerial image when the mirror were arranged non-parallel.

2 PRINCIPLE

2.1 AIRR (Aerial Imaging by Retro-Reflection)

We use the aerial imaging by retro-reflection (AIRR) [1] as a method of aerial imaging. The features of AIRR are low cost and wide viewing angle. Furthermore, the aerial image formed with AIRR is visible without glasses. There is no special hardware at the aerial image position.

The principle of AIRR is shown Fig. 1. Light from the light source goes to the beam splitter and splits in transmitted and reflected light. The reflected light heads for the retro-reflector. The retro-reflected light splits again on the beam splitter. The transmitted light converges to the position of plane-symmetry of the light source regarding the beam splitter. The aerial image can be observed at the position where the retro-reflector can be seen behind the aerial image.

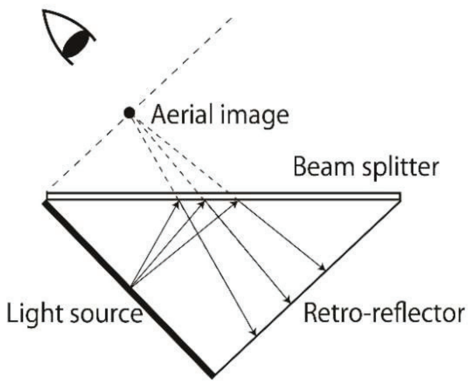


Fig. 1 Principle of AIRR.

2.2 Infinity mirror

Infinity mirror forms multiple virtual image from single light source by arranging mirrors in parallel and using multiple reflections.

The principle of infinity mirror is shown Fig. 2. The light source is located between a mirror and a half mirror. The virtual images are indicated by (a), (b) and (c) in the figure. Image (a) is the virtual image formed by the mirror directly reflecting the light of the light source. Image (b) is formed by the mirror reflecting the light once reflecting by the half mirror. Image (c) is formed by reflecting the light beam forming (a) again by the half mirror and reflecting it again by the mirror. Similarly, multiple reflections on a mirror and a half mirror form multiple virtual image from one light source. Fig. 3 shows multiple virtual image on the mirror.

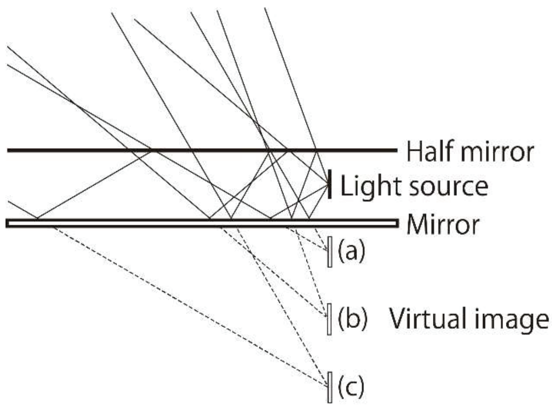


Fig. 2 Principle of infinity mirror.

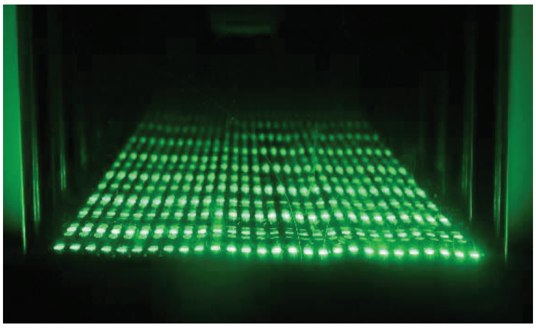


Fig. 3 Multiple virtual image on the mirror.

2.3 Infinity mirror with AIRR

Fig. 4 shows the optical system of forming multiple aerial images by use of infinity mirror and oblique retro-reflector. Since the reflectance of retro-reflector is higher near normal incidence [5], the retro-reflector is placed obliquely to improve the brightness of the aerial image.

Multiple reflections between mirror and the half mirror are performed, and the light transmitted through the half mirror reaches retro-reflector. After the retro-reflection, the light reflected on the half mirror converges in the mid-air. In addition, light rays transmitted through the half mirror before retro-reflection also converges to aerial image. Screen observation result of multiple aerial images is shown Fig. 5.

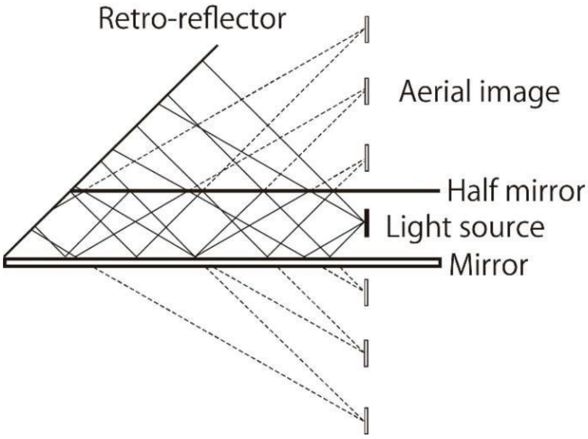


Fig. 4 Infinity mirror with AIRR.

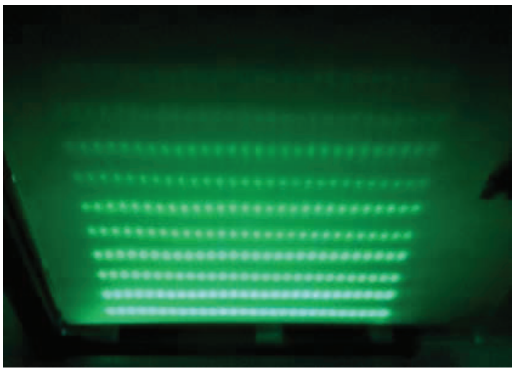


Fig. 5 Observation of multiple aerial images.

2.4 Multiple aerial images with non-parallel infinity mirror

In this experiment, we placed the half mirror diagonally and investigated how the imaging position of the aerial images changed. The principle of method is shown Fig. 6. By arranging the half mirror obliquely, the angle of multiple reflection is changed, and therefore the imaging position of the aerial image is curved.

Fig. 7 shows the geometrical parameter of this optical system. Assuming the left end of the mirror is the origin of the coordinates, the horizontal direction is the x-axis, and the vertical direction is the y-axis. When the x-coordinate of the *n*-th aerial image is x_n and the y-coordinate is y_n, the imaging position of the aerial image can be expressed by the following equation.

$$\begin{pmatrix} x_n \\ y_n \end{pmatrix} = \begin{pmatrix} L - 2d\sin\frac{n}{2}\varphi \\ (2n+1)d + nH \end{pmatrix} \quad (n = 1,2,3,\cdots) \qquad (1)$$

where L is the length of mirror; d is the distance between the light source and the mirror or the half mirror; H is the height of the light source; φ is the half mirror angle.

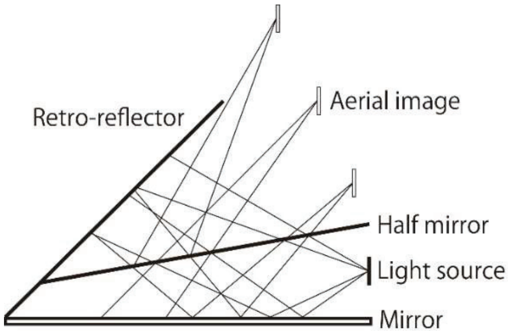


Fig. 6. Principle of curved multiple aerial images.

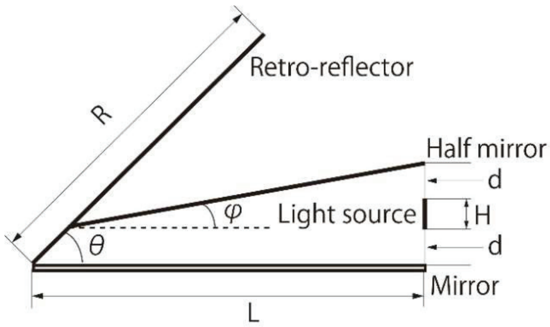
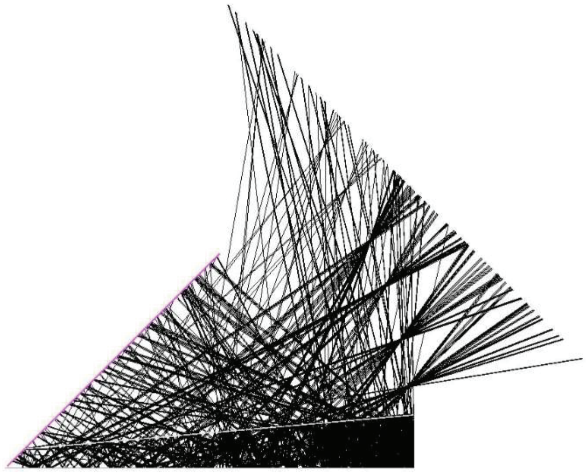
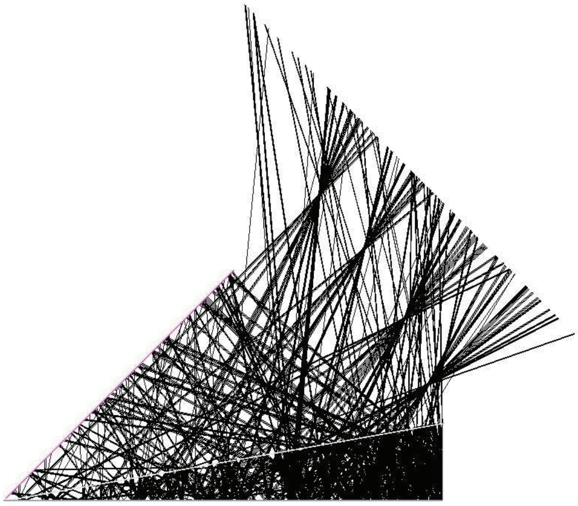


Fig. 7. Parameter of optical system.

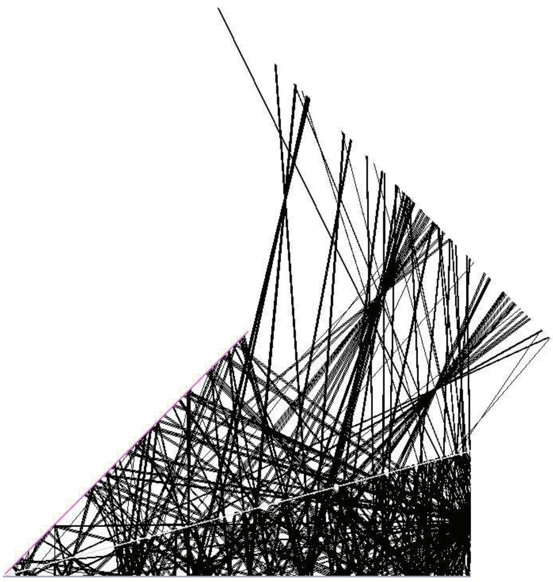
In order to confirm the feasibility of the proposed optical system, we have conducted optical ray-tracing simulations. and result of a simulation with LightTools is shown Fig. 8. It can be seen that the position where the light rays are converging draws a curve. Further, as φ increases, d inevitably increases, so that the imaging interval also increases.



$\varphi = 5°$



$\varphi = 10°$

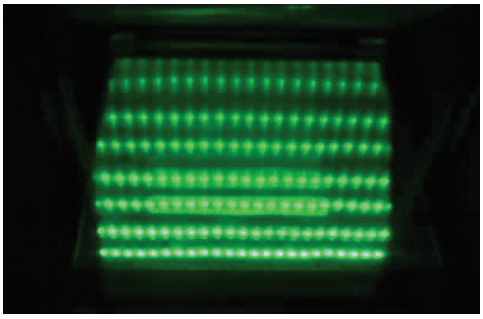


$\varphi = 15°$

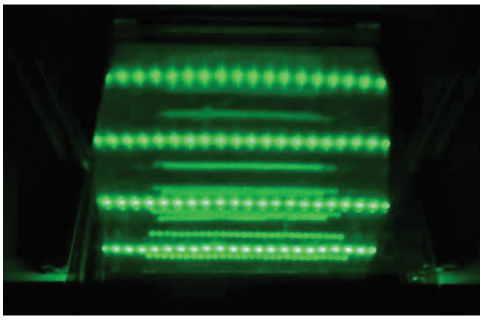
Fig. 8 Ray tracing results with optical simulation.

3 RESULTS

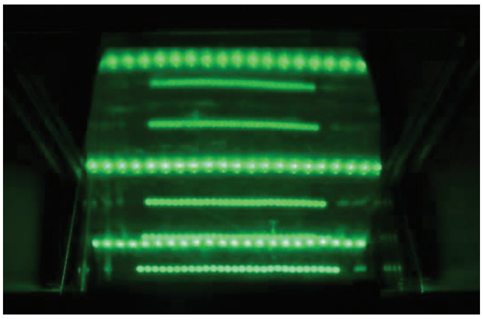
Multiple aerial images are formed by use of an LED tape as a light source. Results are shown in Fig. 9. The results were taken by dividing the angle into 3 stages of $5°, 10°, 15°$. Fig. 10 shows the results when viewed from a position deviated from the front. It can be seen that the imaging position of the aerial image changes so as to draw a curve.



$\varphi = 5°$

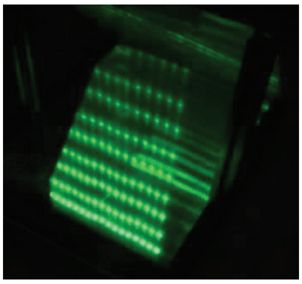


$\varphi = 10°$

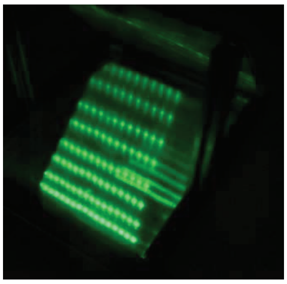


$\varphi = 15°$

Fig. 9 Aerial images with non-parallel infinity mirror.



$\varphi = 0°$



$\varphi = 5°$

Fig. 10 Comparison of multiple aerial images.

4 CONCLUSION

We confirmed that the imaging position of the aerial image changed by arranging the half mirror of the infinity mirror diagonally.

A part of this work was supported by JST/ACCEL (grant no. JPMJAC1601) and JSPS KAKENHI (19H04155, 20H05702).

REFERENCES

[1] H. Yamamoto, Y. Tomiyama, and S. Suyama, “Floating aerial LED signage based on aerial imaging by retro-reflection”, *Optics Express* ***22***, 26919-26924 (2014).

[2] K. Uchida, S. Ito, and H. Yamamoto, “Multifunctional aerial display through use of polarization-processing display”, *Optical Review* **24**, 72-79 (2017).

[3] E. Abe, M. Yasugi, H. Takeuchi, E. Watanabe, Y. Kamei, and H. Yamamoto, “Development of omnidirectional aerial display with aerial imaging by retro-reflection (AIRR) for behavioral biology experiments”, *Optical Review* **26**, 221-229 (2019)

[4] K. Chiba, M. Yasugi, and H. Yamamoto, “Multiple aerial imaging by use of infinity mirror and oblique retro-reflector”, *Japanese Journal of Applied Physics* **59**, SOOD08 (2020).

[5] K. Onuki, T. Okamoto, S. Onose, M. Nakajima, N. Kawagishi, and H. Yamamoto, “Comparisons of Retro-Reflectors for Polarization Modulation in the Aerial Imaging by Retro-Reflection”, IMID 2016 DIGEST, P2-60 (2016).

[6] N. Kurokawa and H. Yamamoto, “Forming multiple aerial images by use of parallel beam splitters with AIRR”, Proc. OSJ-OSA Joint Symposia 2016, 30pOD10 (2016).