https://doi.org/10.2352/EI.2022.34.2.SDA-311

An Aerial Floating Naked-Eye 3D Display Using Crossed Mirror Arrays

Yoshihiro Sato, Yuto Osada, Yue Bao; Tokyo City University; Setagaya-ku, Tokyo, Japan

Abstract

As the method of displaying the stereoscopic image in the air, there is a conventional method of combining the integral 3D display and the aerial display such as crossed mirror arrays. In integral 3D display, the number of usable pixels is smaller than that of a naked-eye three-dimensional (3D) display because images from many viewpoints are contracted and arranged in a row. Therefore, the integral 3D display cannot be displayed with high resolution. In this study, we propose a system that can provided clearer stereoscopic images. The proposal system is an aerial floating naked-Eye 3D display without the framework of the display. The results of the experiment confirmed that the obtained aerial image could provide different parallax images depending on the observation position, and naked-eye stereoscopic viewing was possible by observing different images with the left and right eyes.

Introduction

The development of display technologies has been growing remarkably [1]. The resolution of two-dimensional (2D) displays, which have been the mainstream for several decades, has improved dramatically. 4K Ultra-high-definition and 8K Ultra-high-definition television [2], with resolutions four to sixteen times higher than full HD, are being utilized in households. As a result, the resolution of naked-eye three-dimensional (3D) displays, which need to display parallax images from multiple viewpoints simultaneously, has also improved dramatically.

When a user naturally observes the a naked-eye 3D display, the images corresponding to each of the left and right eyes can be obtained without any visual discomfort. In other words, if images with strong disparity are given to each eye, the discomfort is very high such that stereopsis cannot be achieved. This is because the angle of convergence between image obtained by the observer and image displayed 3D display does not match. [3]. This displayable depth of naked-eye type 3D displays is determined by the combination of the display and the lenticular lens. Because the parallax of the displayed image cannot be made stronger, it is difficult to provide images that have a more stereoscopic effect. Therefore, there are still some issues to be solved in the stereoscopic display of naked-eye type 3D displays.

In this study, we propose a system that can provided clearer stereoscopic images. The proposal system is an aerial floating naked-eye 3D display without the framework of the display.

As conventional aerial display methods, to combine integral method and crossed mirror arrays have been proposed [4–5]. However, because the integral method contracts and arranges images from many viewpoints, the number of usable pixels is smaller than in a naked-eye 3D display. Therefore, the integral 3D display cannot be displayed with high resolution. In addition, due to the principle of the crossed mirror array (CMA), the optimal viewing angle is narrowed. Therefore, it is unnecessary to have many viewpoint images [6]. Consequently, a clearer stereoscopic display is possible than the conventional method by combining the CMA and the naked-eye 3D display that has a high resolution given to disparity and same viewing angle of CMA.

Method

We explain the lenticular method used in naked-eye 3D displays and the CMA for aerial display.

A naked-eye 3D display comprises a display and lenticular lens. Each parallax image can be observed by changing the viewpoint position at the optimum viewing distance. Figure 1 shows an example of light rays leading from a parallax image indicating paths taken through the lens from various origin points. In Figure 1, the four parallax images enter each eye. In this case, a yellow image enters the right eye and a green image enters the left eye. By presenting each of these images to a different viewpoint, stereoscopic viewing is possible.

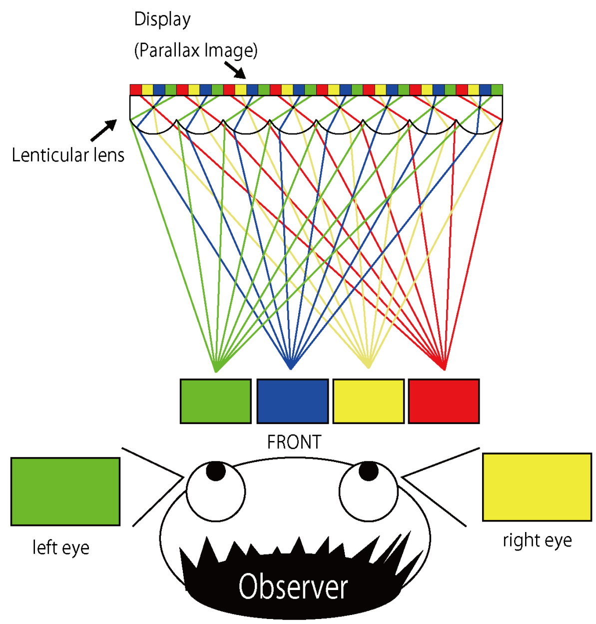


Figure 1. Example of how a parallax image is presented through the lens of a naked-eye 3D display using rays as paths.

A CMA can be used as a device for projecting aerial floating images. For example, it consists of multiple mirror arrays of thin glass with mirrored surfaces stacked orthogonally. Figure 2 shows an example of a CMA. Figure 3 illustrates the reflection of the CMA using a light ray to indicate light as it reflects from mirrors arranged at right angles creating a corner [7]. The reflected light is made parallel to the incident light by mirrors arranged at right angles. Because only the surface portions are mirrored, light can pass through the glass and resin portions. Therefore, light rays can be incident on the top and bottom. The light incident from below will form an image in the air with plane symmetry with respect to the CMA, allowing for aerial display.

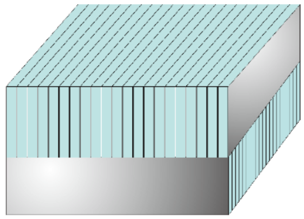


Figure 2. Structural drawing of a crossed mirror arrays.

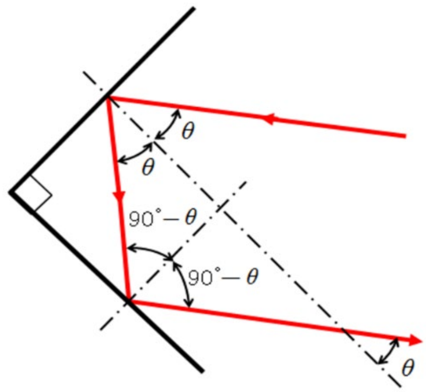


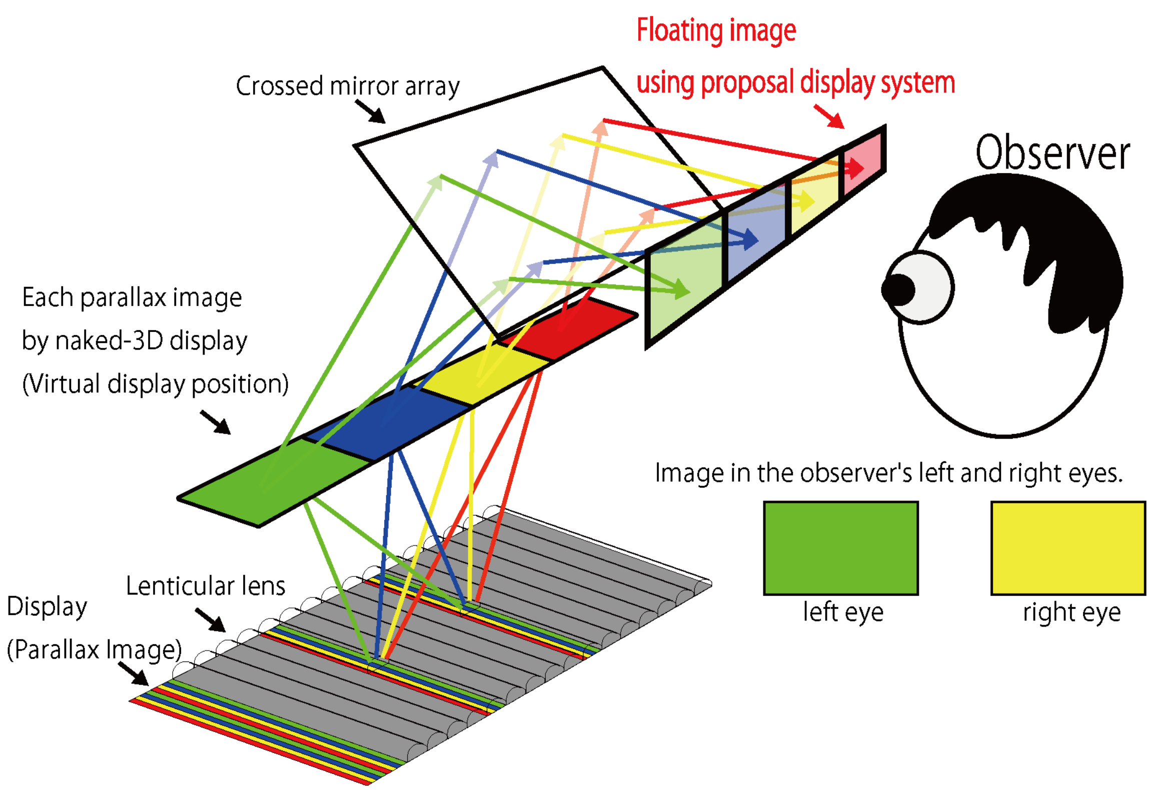
Figure 3. Example of incident and reflected light rays when mirrors are placed at right angles.

In a naked-eye 3D display, it is necessary to correctly observe the parallax image displayed on the display for naked-eye stereopsis. Therefore, it is necessary to be able to observe the correct parallax image even in the aerial image displayed by the CMA. In the proposed method, a virtual display is considered to exist at the optimum observation distance of the naked-eye 3D display, and an aerial naked-eye 3D display system is constructed by installing a virtual display and a CMA in a state that enables aerial display. Figure 4 shows a schematic of the proposed method.

The position that the image can be observed at the optimal viewing distance is called virtual display position (VDP). The image at VDP can be observed as aerial image by CMA. By observing each parallax displayed in the air, the observer can achieve a naked-eye stereopsis in air.

Experiments and results

The proposed system was used to confirm whether the parallax image displayed on the naked-eye 3D display was correctly observable in the air. The first step was to create a parallax image displayed in the naked-eye 3D display. The parallax image was generated by forming a 3D object and shooting the parallax image by moving four virtual cameras in parallel by using Unity. The background of each camera was changed to a different color to make it easier to check if it's a different parallax image. The parallax image displayed on the naked-eye 3D display is shown in Fig. 5. In this study, four parallaxes were used. The synthesized parallax image displayed on the naked-eye 3D display is shown in Fig. 6. An assembled view of the proposed device is shown in Fig. 7. The dimensions are shown in Fig. 7. The specifications of the naked-eye 3D display and the CMA used in the experiments are listed in Tables 1 and 2.



We verified whether there were four parallax images displayed in the air using a camera. The aerial image captured by using the camera is shown in Fig. 8. The results of the observation using a stereo camera(ZED Mini) with 65 milli meters between the cameras are shown in Fig. 9.

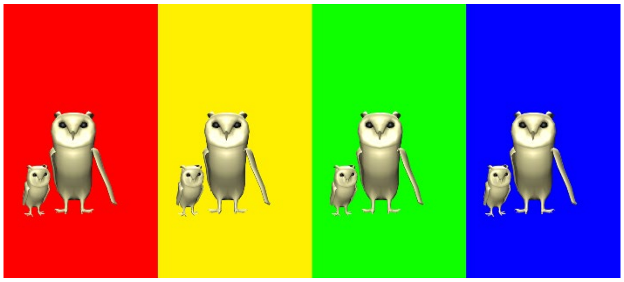


Figure 5. Parallax images generated by Unity from four viewpoints with varying background colors.

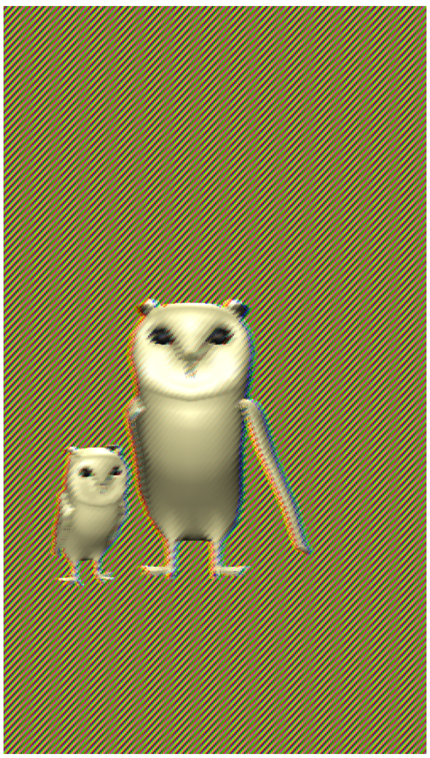


Figure 6. Display image synthesized from the parallax image in Fig. 5 for display on a naked-eye 3D display.

Table 1. Specifications of the naked-3D Display

Parameter	Value
Size [width x height]	336 x 596 [mm]
Resolution [width x height]	2160 x 3840 [pixels]
Number of parallax	4
Optimal visual distance	1200 [mm]

Table 2. Specifications of the crossed mirror arrays

Parameter	Value
Size [width x height]	200 x 200 [mm]
Mirror pitch	0.3 [mm]

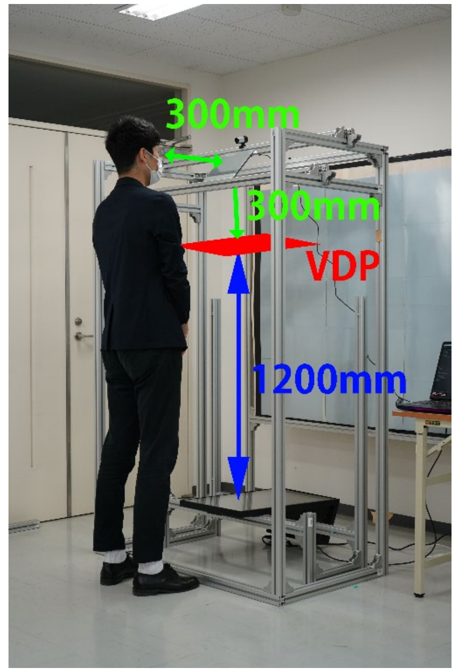


Figure 7. Experimental device and its dimensions.

Figure 8. Spectroscopic experimental results of a naked-eye 3D display imaged in the air.

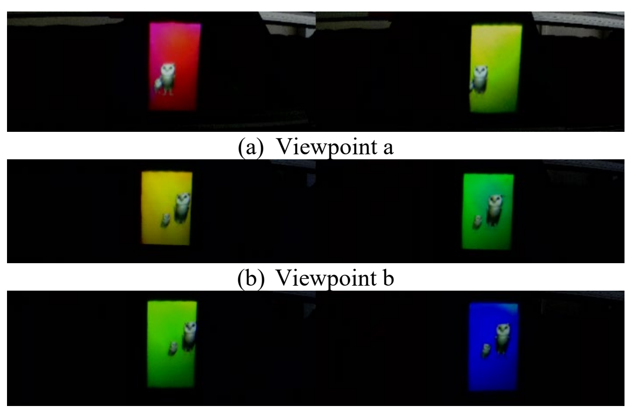


Figure 9. Results of a naked-eye 3D display shown in the air, captured by a stereo camera.

Discussion

From the images of the experimental results shown in Fig.8, it was confirmed that the parallax images of the naked-eye 3D display were visible as an aerial image. In Fig.9, It was also confirmed that stereoscopic viewing was possible by observing the disparity between the left and right eyes.

Figure 10 shows the results of an aerial display using the integral method, which has been reported recently [8]. Because the conventional method, the integral method, is a ray reproduction method, the observed image changes depending on the position of the observer. However, as shown in Fig. 10, although the image changes with the movement of the observation position, it is dimly lit. Additionally, the image from the other viewpoint is reflected and can be observed with blurred contours. Whereas, using the proposed method, it was confirmed that no crosstalk and no blurred contours, even when the viewpoint changes.

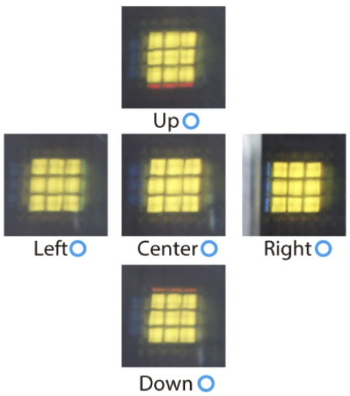


Figure 10. The 3D image with the optical tilt effect (Ref. [8], Fig. 14(b)).

Takaki et al. proposed an airborne multi-view system using a half-mirror[9]. They report that the resolution in pixels of the image displayed in 3D is 320×200 [9]. The resolution of the aerial 3D image can be improved beyond that of their method because our method provides a resolution of 540×3840.

In principle of the proposed method, it was necessary to observe the parallax image using parallel vision because the aerial display image is a VDP image. In the future, it will be necessary to change the display position of the parallax image to enable more natural stereopsis

Conclusion

The development of display technology has grown remarkably in recent years. As 2D displays, which have been the mainstream for several decades, have improved in both resolution and brightness, display technology has reached demand reality, and there has been considerable research on 3D and aerial displays. As the method of displaying the stereoscopic image in the air, there is a conventional method of combining the integral 3D display and the aerial display such as crossed mirror arrays. In integral 3D display, the number of usable pixels is smaller than that of a naked-eye three-dimensional (3D) display because images from many viewpoints are contracted and arranged in a row. Therefore, the stereoscopic image cannot be displayed with high resolution. In this study, we propose a system that can provided clearer stereoscopic images. The proposal system is an aerial floating naked-Eye 3D display without the framework of the display. The results of the experiment confirmed that the obtained aerial image could provide different parallax images depending on the observation position, and naked-eye stereoscopic viewing was possible by observing different images with the left and right eyes.

Acknowledgment

This work was supported by JST SPRING, Grant Number JPMJSP2118.

References

[1] M. Kimura, T. Ishinabe, S. Oka, T. Shimizu, H. Tsuji and, et al., Research Trend on Information Display, The Journal of the Institute of Image Information and Television Engineers, 75,2, pp. 226-238. (2021).

[3] J. Geng, Three-dimensional display technologies, Adv. Opt. Photon., 5, pp.456-535. (2013).

[4] J. Kim, S.W. Min, Y. Kim, and B. Lee, Analysis on viewing characteristics of an integral floating system, Appl. Opt., 47, D80-D86. (2008).

[5] S. Choi, S.Park, and S. W. Min, "Design of ghost-free floating 3D display with narrow thickness using offset lens and dihedral corner reflector arrays," Opt. Express, 28, pp. 15691-15705. (2020).

[6] Y. Maeda, D. Miyazaki, T. Mukai, and S. Maekawa, Volumetric display using rotating prism sheets arranged in a symmetrical configuration, Opt. Express, 21, 22, pp. 27074–27086. (2013).

[7] H. Kim and B. Lee, "Optimal design of retroreflection corner-cube sheets by geometric optics analysis," Optical Engineering, 46, 9, 094002. (2007).

[8] S. Choi, S. Park, and S.W. Min, "Design of ghost-free floating 3D display with narrow thickness using offset lens and dihedral corner reflector arrays," Optics Express, 28, 10, pp. 15691-15705. (2020)

[9] Y. Takaki, Y. Urano, S. Kashiwada, H. Ando, and K. Nakamura, "Super multi-view windshield display for long-distance image information presentation," Optics Express, 19, 2, pp.704–716. (2011).

Author Biography

Yoshihiro Sato received an M. E degree in computer science engineering from Tokyo City University, Tokyo, Japan, in 2018. He is currently a PHD student at Tokyo City University. His research interests include face recognition, defect detection, image processing, and 3D vision.

Yuto Osada received a Bachelor's degree in computer science engineering from Tokyo City University, Japan, in 2020. He is currently attending the master's course at Tokyo City University. His research interest is in aerial display.

Yue Bao received his Ph.D. degree from Kanazawa University, Japan, in 1996. He has been a professor at Tokyo City University since 2004. His research interest includes 3D display, image processing, and mobile robot.