Optical system that forms a mid-air image moving at high speed in the depth direction

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ABSTRACT

Mid-air imaging technology expresses how virtual images move about in the real world. A conventional mid-air image display using a retro-transmissive optical element moves a light source the distance a mid-air image is moved. In conventional mid-air image displays, the linear actuator that moves a display as a light source makes the system large. In order to solve this problem, we designed an optical system that realizes high-speed movement of mid-air images without a linear actuator. We propose an optical system that moves the virtual image of the light source at a high speed by generating the virtual image of the light source with a rotating mirror and light source by the motor.

Keywords: Augmented reality, mid-air imaging, high-speed movement in depth direction.

Index Terms: Hardware—Emerging technologies—Emerging optical and photonic technologies

1 INTRODUCTION

Mid-air imaging technology expresses how virtual images move about in the real world. Mid-air images are formed by reflecting incident light. The users sense the virtual images as real because mid-air images can be placed next to physical objects. Furthermore, the mid-air imaging display can move the position of the mid-air image in the horizontal, vertical, and the depth direction as seen by the user.

In a conventional mid-air image display using a retro-transmissive optical element, the light source is moved the distance that the mid-air image is moved[1]. In order to move a display as a light source, conventional mid-air image displays require a linear actuator, which makes their optical system large. This large size limits the installation space of the mid-air image display. Therefore, we propose an optical system that realizes high-speed movement of the mid-air image without a linear actuator.

Our contribution in this paper is to propose an optical system that realizes high-speed movement of the mid-air image in the depth direction.

2 RELATED WORK

Several mid-air imaging methods exist, such as aerial imaging by retro-reflection (AIRR) [2], a dihedral corner reflector array (DCRA)[3], and micro-mirror array plates (MMAPs). With these methods, the position at which a mid-air image can form depends on the position of the light source. The distance to where the mid-air image moves corresponds to the distance to where the light source moves. In our research, we used MMAPs that can be easily acquired.

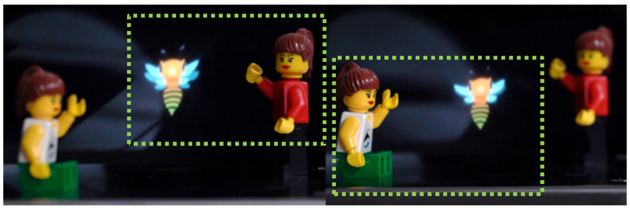

Figure 1: (left) Mid-air image formed at a 155-mm distance from MMAPs (A green rectangle shows a focus area is backward.) (right) Mid-air image formed at a 220-mm distance from MMAPs(A green rectangle shows a focus area is forward.)

In conventional mid-air imaging, the speed at which the light source moves depends on the speed at which mid-air imaging moves. Kim et al. [1] proposed MARIO, which offers an interaction experience with a CG character jumping onto stacked blocks on a table. The MMAPs were obliquely placed at a 45-degree angle from the ground, and the display as the light source was placed parallel to the ground under the MMAPs. The mid-air image was moved in the depth direction by moving the display in the vertical direction to the ground using a linear actuator. In the optical design, the CG character was moved in the horizontal direction and in the vertical direction seen by the user by changing the position of the image in the display. Therefore, it was possible to move the mid-air image in the horizontal direction and in the vertical direction as seen from the user at a high speed. However, when the mid-air image was moved in the depth direction, the linear actuator moved the light source. It was difficult to express how the CG character jumped between the blocks at high speed.

Katsumoto et al. [2] proposed the HoVerTable PONG, a mid-air imaging tabletop display system for playing face-to-face digital games. They implemented a PONG-like game, and the ball was shown as the mid-air image. The mid-air image was formed vertical to the table surface and moved about on the table. They used the MMAPs as imaging optics and the tabletop surface. To make the mid-air image stand on the tabletop surface, they placed a display with upright postures under the MMAPs. To move the mid-air image, an XY-table was placed under the optical device and it moved the display. Therefore, it was difficult to express the fast ball movement like in actual table tennis.

The research demonstrated that it is possible to move a mid-air image at a high speed in the depth direction by moving the virtual image of the light source at high speed.

3 PROPOSED METHOD

We propose an optical design that generates a virtual image of a light source using a mirror, rotates the mirror and the light source by a motor, and moves the virtual image of the light source at a high speed.

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3.1 Optical Design

Figure 2: shows the proposed optical design. We placed the MMAPs (Aska3D, Asukanet Co., Ltd.) obliquely at a 45 degree from the ground. In order to form the mid-air image (Mid-air image), we placed a display (iPod touch 5, Apple Inc.) as a light source with upright postures to the ground (Display), and we placed a mirror obliquely at a 45° angle from the ground (Mirror). In order to form the other mid-air image (Mid-air image'), we tilted the mirror by α rad from 45 degrees (Mirror') and simultaneously tilted the display by β rad (Display '). Due to the rotation of the display and the mirror, the virtual image of the light source could move in the vertical direction to the ground.

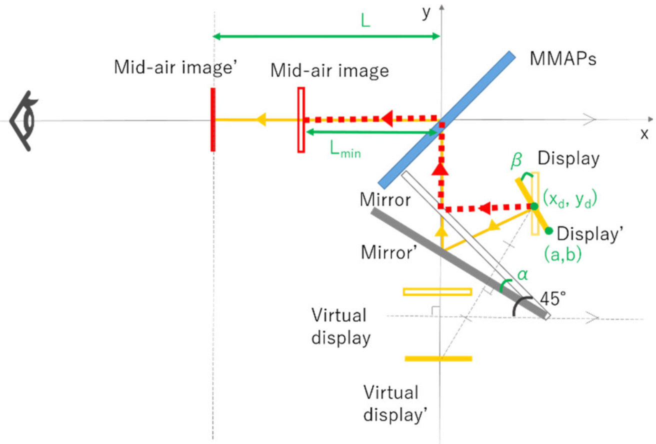

Figure 2: Proposed optical design (Red line shows light that forms mid-air image. Yellow line shows light that forms mid-air image'.)

3.2 Rotation angle of the light source and the mirror

Figure 2 indicates the rotation angle of the display and the mirror. As shown in Figure 2, the range of the distance between the mid-air image and the MMAPs is from L_{min} to L.

When moving the mid-air image to change the distance of the MMAPs from the mid-air image from L_{min} to L, we let α rad be the angle at which the mirror is tilted and let β rad be the angle at which the display is tilted. We also set the coordinates of the center position of the light source as (x_d, y_d). The mirror was tilted 45 degrees to the ground. The slope of Mirror' is the slope of the vertical bisector of the line segment connecting the center point of Display to the intersection of Virtual display' and a perpendicular line (y axis) toward the ground through the center of the MMAPs. The angle α at which the mirror was tilted is the angle between Mirror' and Mirror. We can derive α as equation(1). A certain point on the Virtual display' and the point of coordinate (a, b) on the light source are symmetrical with respect to Mirror'. When the mid-air image was moved so that the distance of the MMAPs from the mid-air image was changed from L_{min} to L, Display' is a line segment passing through the center position of the light source and the point (a, b) on the light source that moves line-symmetrically. The angle β at which the light source was tilted is the angle between Display' and Display. We can derive β as equation(2).

We set L to 220 mm and L_{min} to 155 mm. As a result of calculation, α was 0.32 rad and β was 0.64 rad. The moving time of the mid-air image was measured using the prototype device. The

$$\alpha = \tan^{-1}\left(\frac{y_d + L - x_d}{y_d + L + x_d}\right) \quad (1)$$

$$\beta = \tan^{-1}\left(\frac{a - x_d}{y_d - b}\right) \quad (2)$$

size of the prototype device is 275 mm in height, 290 mm in width and 225 mm in depth. It was confirmed that the mid-air image that is formed by the prototype device moves at maximum 879 mm/s. The maximum speed of the actuator used in MARIO[1] was 450 mm/s and they moved the mid-air image at 300m/s. We confirmed that it is possible to move the mid-air image at high-speed in the depth direction by the proposed optical design.

4 CONCLUSION

We proposed an optical system that moves the virtual image of a light source at a high speed to realize high-speed movement of a mid-air image in the depth direction. In a conventional mid-air image display that uses a retro-transmissive optical element, the light source is moved using a linear actuator the distance to which the mid-air image is moved. The linear actuator causes the optical system to be large and limits the installation space of the mid-air image display. By moving the virtual image of the light source at a high speed, it was possible to move the mid-air image at a high speed in the depth direction. The proposed optical design moved the virtual image of the light source at a high speed by generating a virtual image of a light source using a mirror and rotating the mirror and the light source by a motor. When letting the range of the distance between the mid-air image and the MMAPs be from L_{min} to L, we indicated the angle of rotation of the mirror and the display as the light source.

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REFERENCES

[1] Hanyuool Kim, Issei Takahashi, Hiroki Yamamoto, Satoshi Maekawa, and Takeshi Naemura. MARIO: Mid-air Augmented Reality Interaction with Objects. In *Entertainment Computing* Volume 5, Issue 4, Elsevier, pp. 233–241, December 2014.

[2] Hirotsugu Yamamoto, Yuka Tomiyama, and Shiro Suyama. Floating aerial LED signage based on aerial imaging by retro-reflection (AIRR). In *Optics Express* Vol. 22, Issue 22, pp. 26919–26924, 2014.

[3] Satoshi Maekawa, Kouichi Nitta, and Osamu Matoba. Transmissive optical imaging device with micromirror array. In *Optics East* 2006, Boston, Massachusetts, pp. 63920E–63920E, 2016.

[4] Hajime Katsumoto, Hajime Kajita, Naoya Koizumi, and Takeshi Naemura. HoVerTable PONG: Playing Face-to-face Game on Horizontal Tabletop with Moving Vertical Mid-air Image. In *ACE '16 Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology* Article No. 50, ACM, Osaka, Japan, 2016.

[5] Hajime Kajita, Naoya Koizumi, and Takeshi Naemura. SkyAnchor: Optical Design for Anchoring Mid-air Images onto Physical Objects. In *UIST '16 Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, ACM, Tokyo, Japan, pp. 415–423, 2016.