HoVerTable PONG: Playing Face-to-face Game on Horizontal Tabletop with Moving Vertical Mid-air Image

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Abstract

In face-to-face situations, tabletop displays have been used to share information among multiple users. The use of mid-air images is promising for using the space above a tabletop. However, in our previous research, the mid-air images on a tabletop were fixed in the depth direction. To design a digital PONG-like game, the mid-air image needs to move freely horizontally on the table.

On the basis of this previous research, we designed a mid-air imaging tabletop display system to show a moving vertical mid-air image. However, the optical design of the system causes through light when moving an image, which is undesirable. This is due to the behavior of the imaging device/aerial-imaging plate.

We propose an improved design of our mid-air imaging tabletop display system for playing face-to-face digital games. There were two requirements we had to meet to improve upon the previous system: moving a displayed dual-sided vertical mid-air image and blocking through light. To display a vertical mid-air image to two people, we use an optical imaging device and a dual-sided display, like the previous optical design. To move this image, an XY-table is placed

under the optical device. To block through light, we combine the use of view control film and the XY–table. This optical design enables us to play with a moving mid-air image. We implemented a PONG-like game with which users can manipulate and interact with moving mid-air images, as shown in Figure 1.

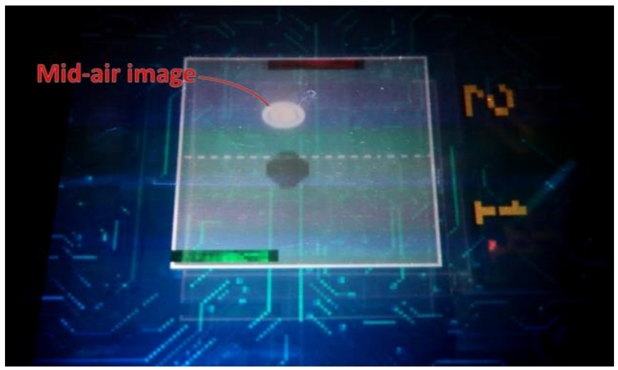

Figure 1: Game on HoVerTable PONG. Users operate each color bar and reflect white ball with character. Ball is shown as mid-air image and moves around on table.

Author Keywords
Tabletop Display; Mid-air Image; Face-to-face; Interaction; Entertainment

ACM Classification Keywords
H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities.

Introduction
Tabletop space is used to share information among multiple users, and tabletop displays are useful to share digital expressions among many users. To display and share digital data above the tabletop, the use of mid-air images is promising. Our previous design of our system called HoVerTable [1] enabled multiple users to see information on and above the tabletop by projection and dual-sided vertical mid-air images.

The tabletop space can also be used to play exciting face-to-face games. For example, one can play a real-life version of PONG using a pair of physical rectangular paddles and a physical square ball bouncing back and forth [2].

We improved upon the design of HoVerTable to implement a PONG-like game in mid-air space above the tabletop. To make it possible to play this game on the improved system, we had to meet two requirements: moving a dual-sided vertical mid-air image and blocking undesirable light.

We used an aerial-imaging plate (AIP) [3] and dual-sided display to form a dual-sided vertical mid-air image and projected the image on the tabletop. We implemented our improved design using an XY-table to move the mid-air image and view control films (VCFs) [4] to block undesirable light.

We implemented a PONG-like game as content. In Figure 1, the ball is a vertical mid-air image and the bar and field is a horizontal projected image. The system consists of only CG images.

Related Work
To have images stand out above a table surface, tabletop 3D displays are widely used. There are 3D displays with which we can see stereoscopic images without special glasses. However, users can see such images only from a specific point and cannot use these displays in face-to-face situations.

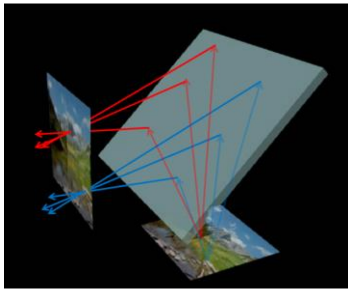

Figure 2: Aerial imaging using AIP. Mid-air image of display forms in plane-symmetric position.

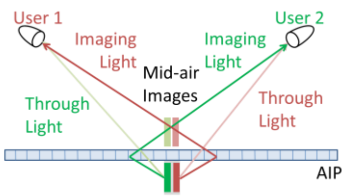

Figure 3: Dual-sided mid-air imaging system that consists of only dual-sided display and AIP. Users are supposed to see only imaging light, but undesirable light, through light, is also visible.

Images from certain 3D displays can be seen from 360 degrees. fVisiOn [5] is a tabletop 3D display with a special screen. The cone-shaped screen is set under the tabletop and many micro projectors surround it. As each projector projects a different image due to its location, users can see 3D image on the table from every side of the system. On the other hand, the display area is narrow and the image position is fixed.

Compared with 3D displays, the use of mid-air images is promising to show information above the tabletop in face-to-face situations. Our previous design of HoVerTable [1] was one solution. To use the space above the table efficiently and show different information depending on users' viewpoints, we used an AIP [3], a product of ASUKANET, and dual-sided displays to show dual-sided vertical mid-air images. Moreover, horizontal information is projected on the tabletop at the same time and enables combined expression of horizontal and vertical images. However, the mid-air images are fixed, and the display area of the images is narrow with this design. To implement an interactive game, we improved the system to be able to move a mid-air image.

Through Light Problem

Aerial imaging process with AIP

An AIP is a special mirror that forms a real image from a dual-sided display in a plane-symmetric position, as shown in Figure 2. We can see this collected light as a real mid-air image. When we use the AIP and dual-sided display, light ray from each side of the dual-sided display is reflected to form images. With our system, we assume that one user can see only one vertical mid-air image. In Figure 3, user 1 is supposed to see only the right side of the dual-sided display, and user 2 is supposed to see only the left side of it.

Undesirable light from under AIP

However, the previous optical design causes direct light rays from the dual-sided display through the AIP (through light), not only the light rays that forms the mid-air image (imaging light), especially when moving the image. This is due to the behavior of the imaging device/AIP, and the display placed under the AIP is visible. Figure 3 shows the paths of imaging light and through light of this system. For example, user 1 sees through light of the left screen, which is for the opposite mid-air image.

In fact, there are three types of light that pass through the AIP: imaging light, through light, and other light. They are classified by the number of reflections in the AIP, as shown in Figure 4. The Y-axis is the face-to-face direction of two users, and the Z-axis is the vertically upward direction. Imaging light is the purpose light, and through and other light are undesirable. We considered blocking only through light because such light comes from the dual-sided display under the table through the AIP and can been seen by users on the opposite side.

For this tabletop system, the more a mid-air image moves away from the center of the table, the stronger undesirable through light users see. We aim to move this vertical mid-air image; thus, we need to block through light wherever the image moves.

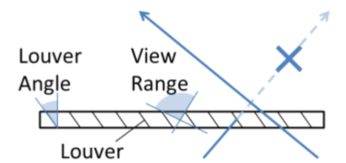

Figure 5: Structure of VCF. VCF has many louvers, which determines view angle. Light rays that hit louver cannot pass VCF.

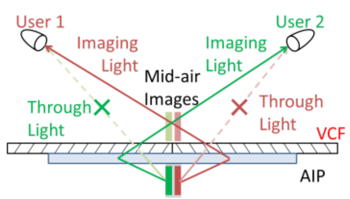

Figure 6: Optical design blocking only direct light rays from dual-sided display. Putting VCF on AIP enables selective passage of light rays: blocking through light and passing imaging light.

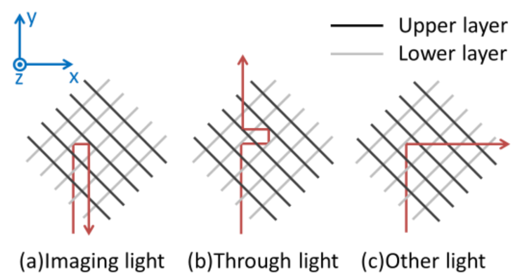

Figure 4: Optical paths of AIP. AIP has two-layered slit mirror arrays drawn as crossed lines in this figure, which causes these various light paths.

Proposal

We implemented the improved upon the design of HoVerTable to demonstrate that a mid-air image can move and users can interact with it. We also solved the through light problem.

Displaying and moving mid-air image

To display a moving mid-air image, we use an AIP for creating real images and an XY-table for moving it. We also use two thin LCD panels as the dual-sided display to display the image at the same position for users on each side of the table.

The AIP forms a real image from the dual-sided display in a plane-symmetric position; thus, two sides of a mid-air image can be shown depending on the view point. Furthermore, by moving the dual-sided display with an actuator, the dual-sided mid-air image horizontally follows the same position.

Blocking through light

We use VCFs [4], products of Shin-Etsu Polymer, to block through light. A VCF is an optical device that passes a specific range (view range) of light rays. As shown in Figure 5, a VCF has many partitions called louvers, and the view range is determined from the louver angle and distance between louvers. Light rays that hit the louver cannot pass through a VCF, and the light rays that pass between louvers are visible.

We placed two VCFs on the AIP across a mid-air image and blocked through light and passed only imaging light. Figure 6 shows this optical design. By installing each VCF in the proper direction, as shown in Figure 5, only through light is blocked by each VCF for both users. The effect of a VCF is shown in Figure 7. The upper square is imaging light and the lower square is through light. After the installation of the VCFs, only through light is blocked.

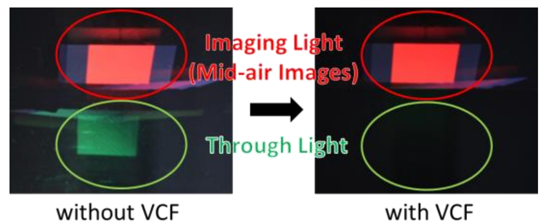

Figure 7: Effect of VCF. After installation of VCF, only through light is blocked.

We assumed a user's view point and calculated the proper combinations of louver angle θ_l and view range θ_r of a VCF. We also assumed that the view point is at a distance of 550 mm from the center of the table and 600 mm above the tabletop. The proper combinations are inside the black square in Figure 8. We use VCFs indicated as the red point in the figure, a θ_l of 18 degrees, and θ_r of 90 degrees because we can obtain only this VCF that has the proper θ_l and θ_r combinations.

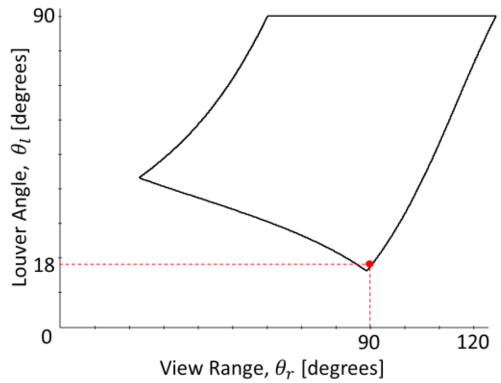

Figure 8: Required combination of louver angle and view range. When inside this square, user can view mid-air image without undesirable light. We use VCFs indicated as the red point, a θ_l of 18 degrees, and θ_r of 90 degrees.

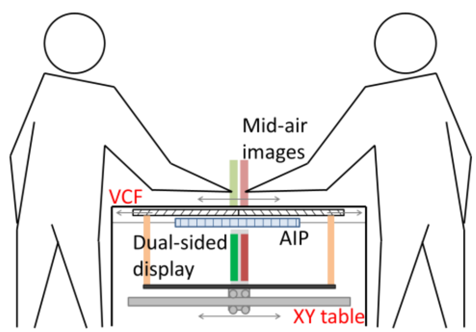

Figure 9: Optical and hardware design of proposed system. XY table is used as actuator to move mid-air images. VCFs and dual-sided display move coordinately, constantly blocking through light.

System design

Figure 9 shows the optical and hardware design of our system. To block through light, VCFs always need to be placed just over the dual-sided display above the AIP. Accordingly, to keep the VCFs at the appropriate position to the moving dual-sided display, we constructed poles beside the AIP, then the actuator moves the dual-sided display and VCFs at the same time.

We also use a projector and transparent screen to project horizontal images on the tabletop. The shadow of a vertical mid-air image is also projected on the horizontal tabletop since the depth of mid-air images is difficult to perceive for users without it.

Application

We implemented an interactive PONG-like game on the improved system, as shown in Figure 1. In a face-to-face environment, users can move bars projected on the tabletop, and a ball is displayed as a mid-air image. Figure 10 illustrates the motion of a mid-air image, which is a CG image; therefore, various expressions, such as collision effect, are possible.

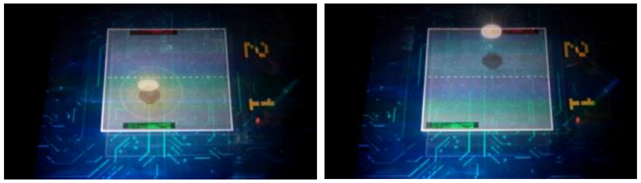

Figure 10: Motion of mid-air image. In left image, ball is in front and low position. In right image, ball is in back and high position.

Figure 11: Users playing our PONG-like game. Front user is trying to touch ball of mid-air image.

Results

The floating mid-air image could be moved over a wide area on the tabletop, i.e., about 20 (W) X 20 (D) X 10 cm (H). In addition, we could see this image from both sides of the table without through light.

Some users did not tend to touch the mid-air image initially. After they knew that there was no real object above the table; however, they eventually reached out and grabbed for the image, as shown in Figure 11.

Future Work

We improved upon the optical design of our HoVerTable system. However, several problems still exist in using this system.

The mid-air image is not bright enough to use the system in a bright room. Light from the display passes through various optical devices to form the image, which causes light attenuation. We need to use a brighter dual-sided display or low-attenuation-rate optical devices.

We can see the rectangle frame in a mid-air image because the LCD panels used as the dual-sided display have a backlight and the black area becomes less black. We need to use a display that displays complete black, such as an OEL display.

The vertical mid-air image is a plane, and some users pointed out that a stereoscopic mid-air image would be better. If we use stereoscopic displays as a dual-sided display, other problems, such as moire fringe, may occur; hence, it is difficult to display 3D mid-air images. If possible, we will consider displaying 3D mid-air images.

These problems should be solved to achieve better user experience.

Acknowledgements

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References

1. Hanyuool Kim, Hiroki Yamamoto, Naoya Koizumi, Satoshi Maekawa, Takeshi Naemura: “HoVerTable: Combining Dual-sided Vertical Mid-air Images”, The Transactions of Human Interface Society, vol. 17, no. 3, pp. 275 -- 286 (2015.8).
2. EL MEJOR 9,Table Pong Project, http://tablepongproject.com/ (2016.6.27 accessed)
3. Makoto Otsubo. 2014. U.S. Patent No. 8,702,252. Filed January 30, 2012, issued April 22, 2014.
4. Shin-Etsu Polymer Co., Ltd., VCF, http://www.shinpoly.co.jp/automotive/connector/view/vcf.html (2016.9.15 accessed)
5. Shunsuke Yoshida, “fVisiOn: interactive glasses-free tabletop 3D images floated by conical screen and modular projector arrays”, In SIGGRAPH Asia 2015 Emerging Technologies (SA '15). ACM, Article 12 , 3 pages (2015)