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Original Paper

HoVerTable: Combining Dual-sided Vertical Mid-air Images with a Horizontal Tabletop Display

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Abstract – Tabletop displays serve as shared displays and co-located workspaces for multiple people. People often place physical objects such as mockup models on the table as an intuitive communication tool for tabletop displays. However, current tabletop displays have limitations in terms of image presentation: The display area is limited to horizontal surfaces, and the view-dependent appearance of the shared images is not provided. The goal of this paper is to solve these limitations by combining dual-sided vertical mid-air images and horizontal image projection to enhance visual presentation. For this purpose, our optical design employed a plate-shaped imaging optics as a tabletop surface and diffusion control film as a projection screen. The proposed system, "HoVerTable," provides both vertical and horizontal images to two users facing one another. In this paper, we describe the details of our optical design. A user study confirmed that providing text captions dependent on users' viewpoints is effective for text annotation in a shared tabletop environment. With HoVerTable, users can enjoy interactive applications such as a mixed reality showcase.

Keywords : Tabletop display, optical design, mid-air image, augmented and mixed reality, 2.5D display.

1. Introduction

Tabletop displays provide a co-located workspace for multi-user interactions. Practical applications have also been proposed to support co-operative work. With tabletop displays, people gather around and share ideas with others. In addition, horizontal displays on a tabletop not only display visual images but also support intuitive manipulation with multi-touch interactions.

However, we focused on the space "above" and "around" the tabletop surface in this study. For example, when a physical object is placed on a table, visual images will appear next to the object with floating in mid-air. We believe that such floating mid-air images (mid-air images) can provide a higher spatial connection to the object than horizontal images. Moreover, if different images can be provided to each user according to his/her perspective, visual representations around tabletop displays will be more effective when users share the same table. We expect such view-dependent appearance of visual images will be effective when we provide text messages to multiple users. The advantages of these visual representations will result in novel applications such as showcases and entertainment interactions.

Fig. 1 "HoVerTable" system

For these purposes, we previously developed a tabletop display called "HoVerTable", which stands for "**Ho**rizontal and **Ver**tical image presentation on a **Table**top display" [1]. HoVerTable was designed to satisfy the following three requirements:
(1) extending the display area of tabletop displays above the horizontal surfaces without the need for special glasses,
(2) providing view-dependent appearance of visual images to multiple users around a table, and
(3) achieving a mixed reality showcase with readable

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text annotation.

Figure 1 shows the HoVerTable system. Vertical floating images, the labels "Winglet" and "Cockpit," are formed in mid-air and superimposed onto a physical object, the airplane model. The images can be seen with the naked eye without the need for 3D glasses. The horizontal images on the tabletop surface are shared among all users around the table.

In this paper, we describe the optical design of HoVerTable that combines plate-shaped imaging optics and diffusion control film. The imaging optics form mid-air images in the vertical direction and used as the tabletop surface. The diffusion control film enables horizontal image projection on the imaging optics. This combined usage makes compact design of HoVerTable possible.

2. Related work

2.1 Extending display area of tabletop displays without need for special glasses

Tabletop displays display visual images to provide relevant information with physical objects [2] [3]. However, most tabletop displays can display visual images from only horizontal tabletop surfaces. Therefore, visual images cannot be shown immediately next to the physical objects. To overcome such limitations in the display area, vertical images have been added to tabletop displays.

In spatial augmented reality applications, wearable see-through displays, such as head-mounted displays (HMDs), can display visual images in a vertical direction and overlay them onto physical objects [4] [5]. However, wearable displays are cumbersome and may discourage face-to-face communication between users by hiding their facial expressions [6]. This does not accord with our philosophy regarding tabletop displays. We believe that glasses-free use and openness for face-to-face communication are the core values in tabletop displays.

For desktop environments, curved screens are used to extend the tabletop display area to the vertical direction [7] [8] [9]. Although curved screens can display horizontal and vertical images, they are only suitable for a single user and cannot support multi-user interactions due to their shape.

Physical displays, such as LCD displays [10] and upright screens [11] [12], are also placed on tabletop surfaces for vertical image presentation. However, these vertical images cannot be directly superimposed onto physical objects since they exist inside physical displays or on surfaces only.

Floating images formed using geometrical optics can be used to extend the display area to the vertical direction and enable glasses-free use since they can be viewed with the naked eye [13] [14] [15] [16]. Since the images have no physical shapes, they can be directly superimposed onto physical objects. However, these floating images are displayed without being combined with the horizontal images.

In HoVerTable, we aim to form a floating mid-air image on horizontal images by liberating the vertical images from physical displays or surfaces.

2.2 Providing view-dependent appearance of visual images

As a co-located workspace, tabletop displays help users around it share the same visual images. However, in some cases, visual images need to be selectively shared by changing their orientation or content according to users' viewpoints.

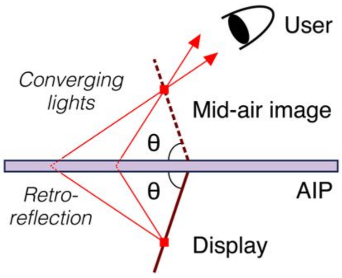
For selective sharing of horizontal tabletop surfaces, a parallax barrier mask [17] is used on an LCD display to separate visual images into two directions. Diffusion control films, such as Lumisty [18], are also used to provide visual images only at specific viewing angles by controlling diffusion directions [19] [20] [21].

Unlike these approaches, with HoVerTable, we aim to achieve this view-dependent property through vertical mid-air images. Mid-air imaging optics, such as Fresnel lenses, can control the viewing range of visual images with strong directivity [22]. Thus, HoVerTable forms dual-sided vertical mid-air images to provide view-dependent visual images to two users facing one another while sharing the same tabletop surface.

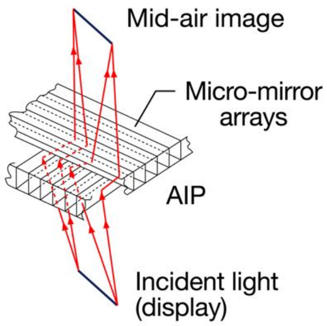
In short, HoVerTable uses a compact optical system that combines a horizontal tabletop and vertical mid-air images to support glasses-free use and provides view-dependent appearance of visual images.

3. System design

In our system design, we focused on combining vertical mid-air images and horizontal image projection. Vertical mid-air images are formed on the tabletop surface with dual sides to extend the display area above the tabletop surface and provide different visual images to multiple users around the tabletop

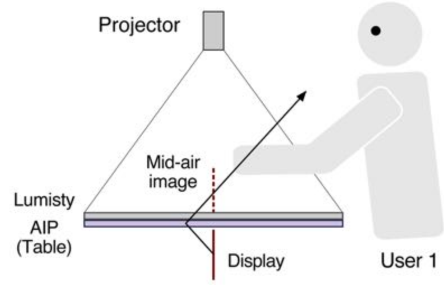


(a) Optical property

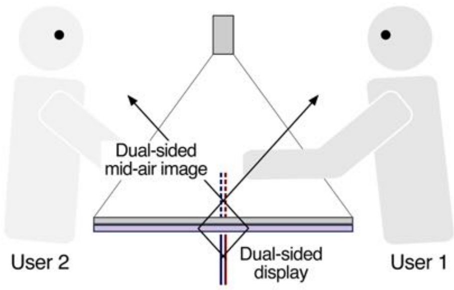


(b) Retro-reflection by AIP [23]

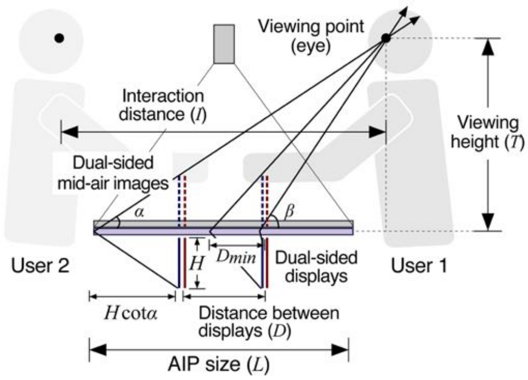
Fig. 2 Aerial imaging plate (AIP)



(a) A mid-air image formed above the table for User 1



(b) A dual-sided mid-air image for the users around the table (User 1 and 2)



(c) Optical design for two dual-sided mid-air images with design parameters

Fig. 3 Steps in optical design of HoVerTable

surface. Horizontal images are projected onto the tabletop surface and shared among these users.

3.1 Vertical mid-air images on tabletop surface

Requirements for vertical images

Since we consider text annotation as a main use of vertical mid-air images, the images need to have sufficient resolution and size for users to read. To superimpose visual images onto different positions, at least two sets of vertical images are formed on the tabletop surface. All the vertical images should provide enough viewing range to users sitting in front of the table.

Optical principle

To form vertical mid-air images on a tabletop surface, we introduced a plate-shaped imaging optics called the aerial imaging plate (AIP) [23]. As shown in Fig. 2(a), when a display is placed below the AIP at an angle of θ, a mid-air image is formed on the AIP surface with the same angle (θ) by retro-reflection. Figure 2(b) illustrates the retro-reflection process inside the AIP. Since the AIP consists of two layers of micro-mirror arrays crossed at 90°, when light enters the AIP, it is reflected twice at the mirror arrays and converged at the same point symmetric to the AIP plane. This converged light forms an image in mid-air. Since the imaging process involves only linear reflections, the AIP can form distortion-free mid-air images, unlike Fresnel lenses and concave mirrors. However, the mirror arrays are discrete so that the resolution of the resulting images has limitations in principle. We compare the readability of text captions formed with the AIP to the horizontal projected images in Section 4.5.

Optical design: step-by-step

Figure 3 shows the optical design of HoVerTable with three steps. In the first step, a single-sided mid-air image is formed above the AIP surface for User 1 (Fig. 3(a)). To make the mid-air image stand on the tabletop surface, we placed a display with up-

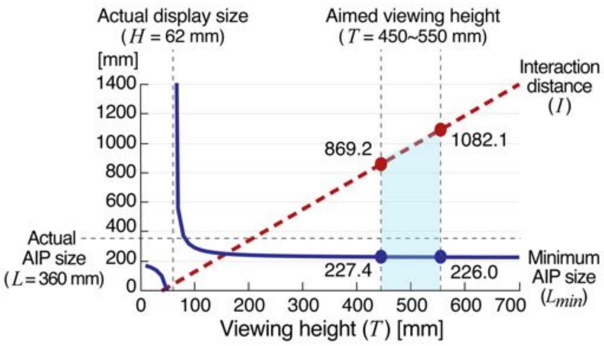


Fig. 4 Interaction distance (I) and minimum AIP size (L_{min}) from Eqs. (1) and (2) according to viewing height (T).

right postures under the AIP, as Markon et al. reported [16], which means θ=90° in Fig. 2(a). This enables us to use the AIP as imaging optics as well as the tabletop surface for a compact optical design. For horizontal image projection, a diffusive film (Lumisty) is placed on the AIP as a screen, and a projector is fixed above the table.

In the second step, we form a dual-sided mid-air image on the AIP surface to provide view-dependent appearance of visual images to two users around the AIP (Fig. 3(b)). Each user can view each side of the mid-air image.

In the final step, we add a dual-sided display to form two sets of dual-sided mid-air images on the AIP (Fig. 3(c)).

Parameter settings

For forming two sets of vertical images on the AIP, we defined design parameters for system implementation, as shown in Fig. 3(c).

The notation T is viewing height (vertical distance from the tabletop surface to a user's eye) and I is interaction distance (distance between the eyes of two users facing one another). The notation H is display height (the vertical size of mid-air image), D is the distance between displays, and L is AIP size. The notation α is the angle between the AIP surface and the end of the far vertical image, β is the angle formed by a user's eye, the bottom of the near vertical image, and the AIP. From an experiment, we found that the viewable range of a mid-air image is 30°–60°. Thus, α should be equal to or larger than 30°, and β should be equal to or less than 60°. From Fig. 3(c), we can derive I as Eq. (1).

$$I = T(\cot\alpha + \cot\beta) - H\cot\alpha \qquad (1)$$

When we form two sets of vertical images on the AIP, we need space between the displays to avoid occlusions. The minimum distance between displays (D_{min}) can be calculated from the homologous triangles in Fig. 3(c) as the following equation.

$$D_{min} = \frac{TH}{T-H}\cot\beta$$

To form a vertical image at a certain H, the AIP should be located $H\cot\alpha$ behind the image. The minimum size of the AIP (L_{min}) can be calculated by Eq. (2).

$$L_{min} = 2H\cot\alpha + D_{min} \qquad (2)$$

Figure 4 illustrates the I and minimum AIP size (L_{min}) from Eqs. (1) and (2) at T. The H is set to 62 mm with actual display size and the α and β are set to 35° and 55°, respectively. Actual AIP size (360 mm) is also plotted as a dashed line. For T, we mainly targeted the 450–550 mm range since we expect most users belong to this height range. In this range, the L_{min} should be 226–227.4 mm. The I is determined between 869.2 and 1082.1 mm. We consider this distance appropriate for face-to-face communication and direct access to the tabletop surface for two users. The D_{min} is also calculated as ranging from 48.9 to 50.3 mm. Based on these calculation results, we implemented the optical system of HoVerTable.

3.2 Horizontal image projection

Requirements for horizontal screen

For horizontal images, we chose overhead projection from the top of the tabletop surface instead of rear projection to avoid cross contamination between the light sources, the projector and displays below the AIP. Since the AIP only passes the light from the projector, a diffusive screen is necessary on the AIP surface for horizontal image projection. In HoVerTable, a diffusive screen should satisfy two requirements: (1) penetrating light from the displays below the AIP as a transparent layer for clear vertical images, and (2) diffusing the projected light from the overhead projector for bright horizontal images.

Possible options for a horizontal screen

We surveyed two diffusive films as possible diffusive screens: Lumisty and a semi-transparent screen.

Lumisty (MFX-1515) is a film that diffuses the entering light at an incident angle between 75° and

Table 1 Expected optical property of visual images produced using diffusive films

	Vertical	Horizontal
No film (AIP only)	◎	-
Semi-transparent film	△	◎
Lumisty	○	○

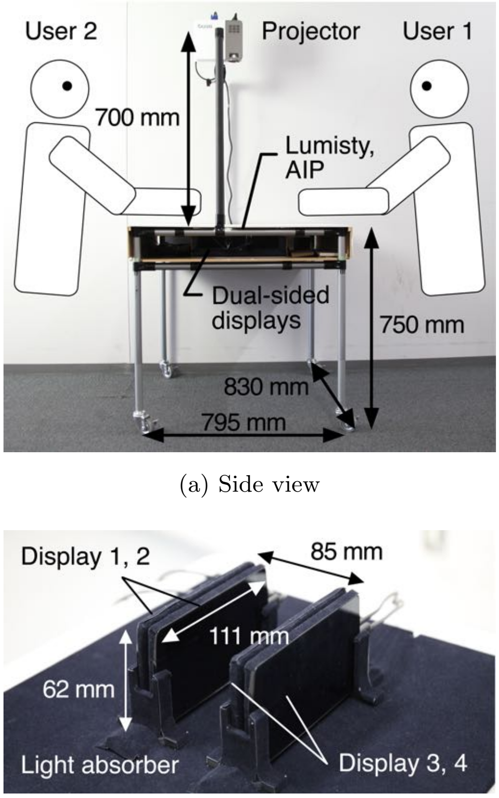
105° from the film surface. However, for the light coming from outside this range, Lumisty works as a transparent sheet. Due to this selective diffusion control by incident angles, we expected Lumisty would barely affect vertical images. Unlike the studies discussed in the Section 2, our use of Lumisty is for sharing horizontal images rather than providing view-dependent visual images.

We also considered a semi-transparent screen (CF-500-1525) [24] feasible for horizontal image projection due to its transparency and diffusiveness. Since this semi-transparent screen is mainly used for rear projection, it can be used for overhead projection. In addition, according to the catalogue specifications, the viewing angle is about 150° from the center of the screen. This viewing angle can cover the viewing angle of both vertical and horizontal images on HoVerTable. However, unlike Lumisty, this screen does not change its diffusion by incident angles; thus, vertical images may be blurred by diffusion.

Based on the optical properties of these films, we summarize our assumptions on the visual images in Table 1. For vertical images, we expect the AIP without any film will form the clearest images since the light is not affected by diffusive films and Lumisty will provide clearer images than semi-transparent film due to the selective diffusion control by incident angles. A semi-transparent film may provide a wider viewing range and brighter horizontal images because the diffusion does not depend on viewing angles. In Section 4, we describe the detailed results of visual images produced using diffusive films.

3.3 Implementation

Figure 5 shows the current implementation of HoVerTable. As shown in Fig. 5(a), HoVerTable consists of four parts: A projector, AIP with Lumisty film, and dual-sided displays. The size of HoVerTable is 830 (W)×795 (D)×750 mm (H). For horizontal image projection, we use a short-throw LED projector (BenQ GP20) which has the size of 387 (W)×247 (D)×111 mm (H) and 700 lm brightness.



(a) Side view

(b) Details of dual-sided displays

Fig. 5 Implemented HoVerTable system

The projector is fixed at 700 mm above the AIP, the lowest position where the projected image can cover the tabletop surface. The AIP is horizontally placed at the center of HoVerTable as a tabletop surface. The size of the AIP is 360 (W)×360 (D)×5 mm (H), which is larger than L_{min} (227.4 mm). A diffusive film (Lumisty) covers the AIP surface as a horizontal projection screen. Below the tabletop surface (the AIP), there are dual-sided displays.

Figure 5(b) shows the details of the dual-sided displays. We use the display of a 5-inch smartphone device (Nexus 5) as the light source for vertical images. Each display forms a vertical mid-air image on the tabletop surface after passing through the AIP. A total of four layers of vertical images are formed, and each user can see the two image layers. The distance between the display sets was 85 mm, which is larger than D_{min}, to avoid occlusion between the display sets. The size and resolution of the display were 111×62 mm and 1920×1080 pixels, respectively. The space around the displays was covered with a light-absorbing sheet to prevent unnecessary reflections. All displays were connected to a computer via Wi-Fi as a sub-display through an Android application.

4. Results

4.1 Vertical floating images

Figure 6 shows the results of a vertical floating image on the HoVerTable. Each image was taken from the left (-50 mm), front, and right (+50 mm) of center with different Ts (T=450, 500, and 550 mm). For comparison, we horizontally placed a physical card on the table surface below the vertical mid-air image. We confirmed that HoVerTable can form a vertical mid-air image on the tabletop surface and users can see the image without the need for special glasses.

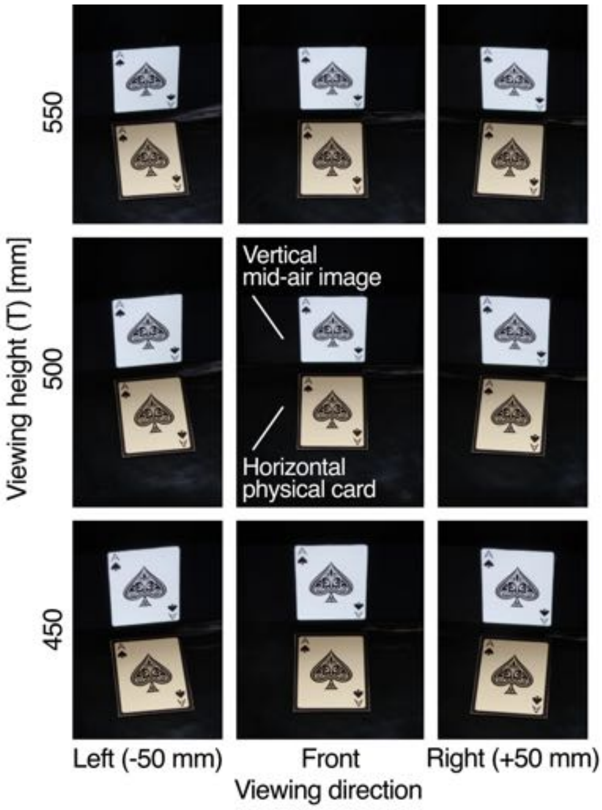
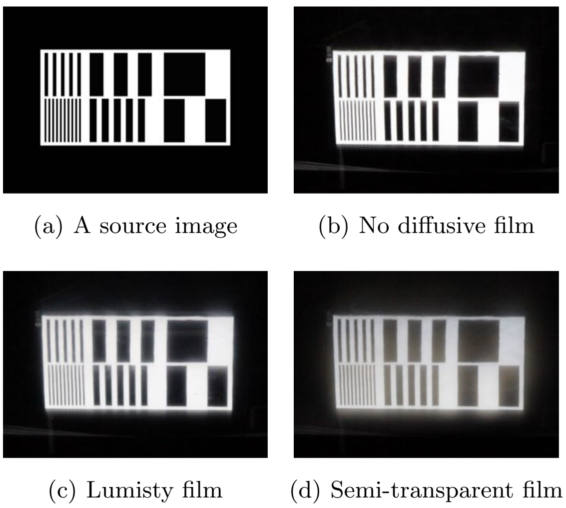


Fig. 6 Vertical mid-air image floating on physical card placed on table surface. Images were taken from left, front, and right with three different Ts.



(a) A source image (b) No diffusive film

(c) Lumisty film (d) Semi-transparent film

Fig. 7 Blur in mid-air images by diffusive films. These images were taken with same camera settings (1/15 sec, F6.3).

4.2 Diffusive films for horizontal image projection

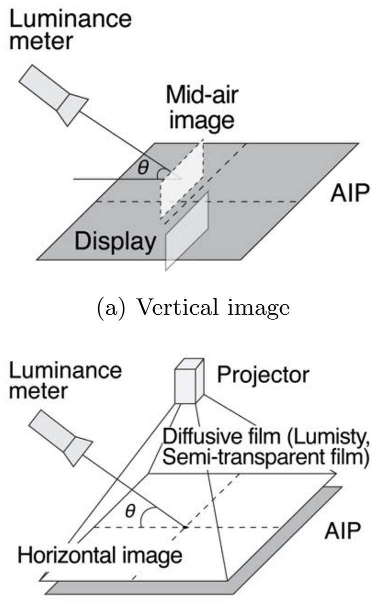
To investigate the effects of diffusive films on horizontal image projection, we examined the blur of vertical images and luminance of horizontal images.

Blur in vertical mid-air images

We compared the effects of diffusive films on vertical images. The source and resulting vertical images are shown in Fig. 7. We made a vertical image of stripe patterns with different widths as a resolution test chart (Fig. 7(a)). As expected, the image formed without any diffusive film was the clearest (Fig. 7(b)). Lumisty caused a slight blur in the mid-air image (Fig. 7(c)), and the semi-transparent film caused a severe blur in the mid-air image (Fig. 7(d)). Thus, we concluded that Lumisty provides higher quality mid-air images than semi-transparent film.

Brightness of horizontal mid-air images

To examine the brightness of projected images, we measured their luminance. The experimental setup is shown in Fig. 8. We projected a white image onto



(a) Vertical image

(b) Horizontal image

Fig. 8 Measurement of image luminance on HoVerTable

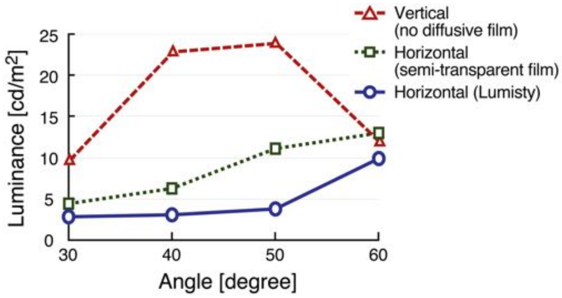


Fig. 9 Luminance of mid-air image and horizontal image projection on Lumisty and semi-transparent film

each film and measured the luminance at the center of the projected image from the angles of 30°–60° with a luminance meter (Minolta CS-100A). We also measured the luminance of a white vertical image for reference. Figure 9 shows the measured luminance of the vertical and horizontal images by viewing angle. The semi-transparent film provided brighter horizontal images than Lumisty from these viewing angles.

In the 30°–60° range, regarding the brightness of horizontal images, the semi-transparent film provided brighter images than Lumisty film. On the other hand, Lumisty provided clearer vertical images with less blur. The difference in image brightness was too small to sacrifice the clear images formed by Lumisty film. Therefore, we chose Lumisty film as the diffusive film for horizontal image projection with our emphasis on the combination of vertical and horizontal images.

Horizontal image projection

Figure 10 shows the effect of Lumisty film on horizontal image projection. Without Lumisty film, horizontal images cannot be clearly displayed due to the transparency of the AIP (Fig. 10(a)). On the other hand, when Lumisty film is placed on the AIP, a projected image (a green mat) can be displayed from the tabletop surface (Fig. 10(b). From these results, we confirmed that Lumisty film is effective as a projection screen on the AIP.

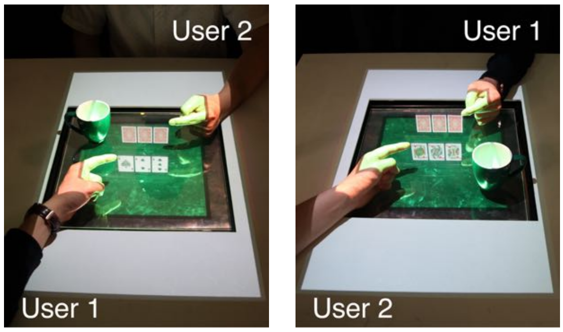
4.3 View-dependent appearance for two facing users

To provide view-dependent visual images from HoVerTable, we created mid-air images with two sides. Figure 11 shows the mid-air images viewed by two users facing one another, Users 1 and 2. From User 1's viewpoint, the cards with spades and the back of User 2's cards could be seen. On the other

(a) No Lumisty

(b) With Lumisty

Fig. 10 Effect of Lumisty film on horizontal image projection



(a) View from User 1 (b) User 2

Fig. 11 Dual-faced mid-air images can provide different visual images to two facing users.

hand, User 2 could see different cards and the back of User 1's cards. This result confirms that dual-sided mid-air images can provide view-dependent visual images in two directions.

From these results, we implement text annotation onto physical objects with HoVerTable. We chose vertical images for the text annotation instead of horizontal ones.

4.4 User study

Goal

The readability of vertical images is critical for reliability of our usage example. Compared to horizontal images, vertical images have the advantage of good readability with higher brightness, as shown in Fig. 9. As we mentioned regarding the optical prop-

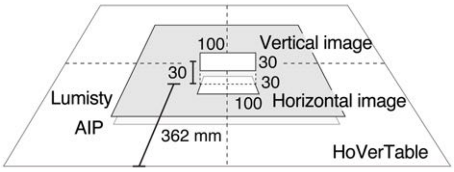


Fig. 12 Settings of vertical and horizontal images for user study

(a) Horizontal image with a correct orientation

(b) Horizontal image with an upside-down orientation

(c) Vertical image with a correct orientation

(d) Vertical image with a reflected orientation

Fig. 13 Example images used in user study. Images were taken with same camera parameter settings (1/20, F8).

erties of the AIP, however, there is a disadvantage in that the readability of vertical images is reduced: the mid-air images formed using the AIP have limitations in resolution due to its discrete mirror arrays. Moreover, HoVerTable can provide the view-dependent appearance of visual images to two users facing one another. We expect that text captions can be displayed with appropriate orientations to each user according to their viewing positions.

In particular, we investigated two assumptions through the user study: With HoVerTable, (1) text captions displayed in vertical images are as easy to read as horizontal projected images despite the differences in brightness and resolution, and (2) text captions with correct orientation from the user's viewpoint are easier for a user to read.

Settings and procedures

Figure 12 illustrates the settings of the horizontal and vertical images. Horizontal images were placed 362 mm from the end of the HoVerTable surface and vertical images were placed 30 mm above the center of horizontal images. The size of all visual images were 100 (W)×30 mm (H).

We used a 9-digit random number as the text caption. The reason we chose numbers is that they have only ten elements with a distinct orientation. Figure 13 shows the example images used in the user study. In each task, a 9-digit number randomly appeared on HoVerTable under one of the following four conditions: (a) a horizontal image with correct orientation, (b) horizontal image with upside-down orientation, (c) vertical image with correct orientation, and (d) vertical image with reflected orientation. When a number appeared on HoVerTable, participants were required to input the number using keypads.

An experimental set consisted of 20 input tasks, which included five tasks from each condition. We conducted three sets of experiments with each participant in total. In the first set, all participants were guided in a practice tutorial. After each set was completed, participants took at least a one-minute break. While participants observed the provided images, head movement was allowed for adjusting their viewpoint. We recorded the time taken for each task and the numbers input by the participants. For statistical analysis, we only used the time taken for the tasks with correct input.

Twelve participants (ten males, two females), who were recruited from our university, participated in the experiment. Their ages ranged from 23 to 38 (median=24). They had normal eyesight including some with corrected vision. The Ts of all participants were in the targeted range from 450–550 mm. The illuminance of the experiment room was set to 28.6 lux so that participants could see the vertical and horizontal images on HoVerTable and the keypads for the input task.

Results

Figure 14 shows the average input times for each condition of visual image presentation. For assumption (1), the average input time for vertical images was significantly shorter than that for horizontal images ($F(1, 11) = 14.51$, $p < .01$). This result confirms assumption (1) and indicates that vertical images on HoVerTable are easier to see than horizontal images despite the differences in brightness and resolution. We can suggest two possible explanations for this result: the differences in the brightness and effec-

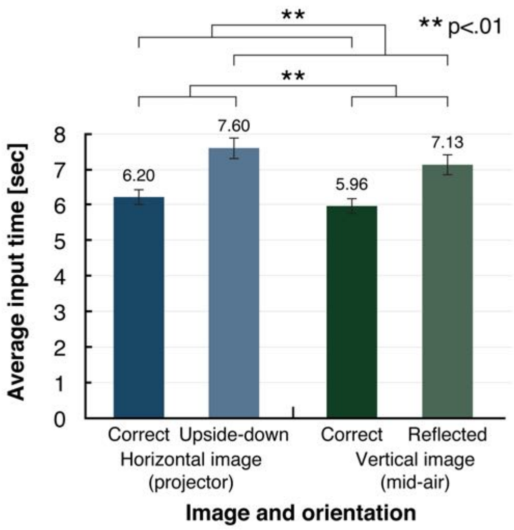


Fig. 14 Results of user study

tive size of the horizontal and vertical images. As we mentioned in Section 4.2, with HoVerTable, vertical images are brighter than horizontal ones: In the user study, the average luminance of the vertical images (7.42 Cd/m^2) was higher than that of the horizontal images (1.53 Cd/m^2). Moreover, participants' viewing angle was less than 45° so that vertical images had a larger effective size, the size viewed from a participant's perspective, than horizontal images, although their sizes were identical.

For assumption (2), text annotation provided in the correct orientation to participants' viewing direction were associated with significantly shorter input times on average than those with upside-down and reflected orientations ($F(1, 11) = 25.65$, $p < .01$). This result confirms that providing view-dependent appearance with dual-sided vertical images is an effective method for text annotation with HoVerTable, as we expected. During the experiment, most participants commented that they found it difficult to differentiate the numbers "6" and "9" due to their reversed shapes.

5. Application

Based on the benefit of vertical and horizontal images, we implemented a usage example: A mixed reality (MR) showcase that superimposes text annotation onto a physical model, is shown in Fig. 1. When users place a physical object (an airplane model) on the HoVerTable, text labels are shown in mid-air and directly superimposed onto the model. Horizontal images are displayed from the tabletop surface to be shared among all users. Since the vertical images have two sides, different visual images can be displayed to each user. For example, English captions are provided to User 1 and Japanese ones to User 2 as shown in Figure 15.

(a) English captions for User 1

(b) Japanese captions for User 2

Fig. 15 MR showcase application for two facing users.

6. Discussion

The resulting images and user study results revealed limitations of HoVerTable.

The current implementation can support a usage scenario for only two users facing one another as a minimum configuration of multiple user interaction. However, many tabletop displays can support more than two users and various viewing positions. We need to increase the number of users and expand the viewing directions of vertical images by improving the optical design.

Since we focused on text annotation as a main function of vertical images, we conducted a user study on readability with numeric strings. However, the vertical and horizontal images on HoVerTable can display other kinds of visual information such as photos, figures, and illustrations. In the future, we plan to study the usability of HoVerTable with the view-dependent appearance of these images.

Although the use of the AIP as a tabletop surface has enabled a compact optical design, there is an occlusion problem when physical objects are placed on the AIP and block the light reflected by the AIP. This problem can be avoided by considering the shape and orientation of physical objects using object detection. Moreover, the position of vertical images is fixed in the current implementation. In the future, we move displays using mechanical actuators and enable dynamic visual expressions. We expect that changing the vertical image positions will also solve the occlusion problem.

The brightness of visual images needs further improvement. The vertical and horizontal images on HoVerTable exhibit low luminance compared to ordinary displays such as LCD monitors or projectors. Although the displays used for vertical images (Nexus 5) had a luminance of 429.6 Cd/m^2, the highest luminance of the resulting vertical images was 24.0 Cd/m^2. Horizontal projected images showed much lower luminance, with an average of 4.88 Cd/m^2 at viewing angles between 30° and 60°. To enable the use of HoVerTable under ordinary lighting conditions (e.g., office environment), we need to improve the brightness of the visual images. Changing the angle of the vertical images may be a solution. To provide bright vertical images, it is preferable for a vertical image to be perpendicular to a user's viewing angle. If the mid-air images were formed obliquely to the AIP surface instead of the upright postures, the vertical images would appear brighter.

7. Conclusion

We discussed the optical design of "HoVerTable" that combines vertical and horizontal images on the tabletop surface. Our optical design formed dual-sided vertical mid-air images using plate-shaped imaging optics (the AIP). Users could see the vertical mid-air images without the need for special glasses. For horizontal image projection, Lumisty was chosen as a diffusive screen due to less blur in vertical mid-air images. Dual-sided vertical images provided text annotation with correct orientation to two users facing one another. From these advantages, we implemented an MR showcase of superimposing text captions onto an airplane model. The user study on text readability confirmed the effectiveness of text annotation with vertical images or with a correct orientation for the MR showcase. However, the current implementation has several limitations due to

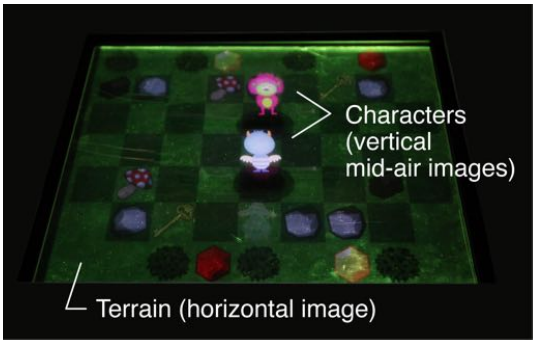


Fig. 16 Example of application for entertainment

the occlusion problem, fixed image positions, and low brightness. In the future, we plan to implement more usage examples with various visual images. A card battle game can be considered as an example of entertainment use, as shown in Fig. 16. Users can play a battle game with the characters summoned from the physical cards onto the table. We believe this combination of vertical and horizontal images with HoVerTable will enable new user experiences with tabletop displays.

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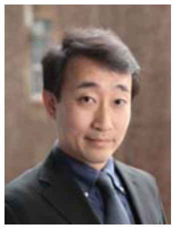

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