HaptoMIRAGE: An Active-shuttered Real Image Auto-stereoscopic Display

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ABSTRACT

HaptoMIRAGE is an auto-stereoscopic display that does not require the viewer to wear devices like 3D glasses. HaptoMIRAGE can project 3D images in mid-air. Auto-stereoscopic images are projected in mid-air, and a real object is placed near the image position, making it easy for the user to gaze at the image. Therefore, it is convenient to produce content such that real objects and 3D virtual objects are combined. Furthermore, multiple users can share the 3D view from their respective viewpoints.

1. INTRODUCTION

Our purpose is to implement a platform for storytelling, entertainment, and creative collaboration by superimposing auto-stereoscopic 3D images on real objects such that they can be observed by multiple users. If the 3D content is naturally manipulated by the user, it is necessary to meet the point that users can handle 3D image with real objects. Users should be able to close the 3D image and reach out with their hands to the 3D image. Therefore, the 3D image should be projected in mid-air. Furthermore, when we handle real objects, we usually share the objects with other people. Likewise, the 3D image should be visible to multiple users from their respective viewing positions because users usually view the objects from a free viewing angle.

To experience real objects and virtual objects combined in real space, it is imperative develop a 3D display technology that can project a 3D image in midair, wherein multiple users can view the 3D image from their respective viewing positions. In addition, it is also important to ensure that the users can experience the projected 3D image like a real object—by using their hands. The proposed 3D display enables users to reach out with their hands to the 3D image effortlessly, and puts real objects in close proximity to the 3D image.

2. RELATED WORKS

To superimpose 3D images on physical objects in mid-air, we require a 3D display technology that can project 3D images in mid-air. To address this requirement, a number of 3D display systems have been developed. For example, HoloAd [1], developed by InnoVision Labs, can superimpose 2D images on real objects, wherein multiple users can view and share the 2D computer graphic (CG) image and the real object. This system has been used at exhibitions and for some advertising stratagems. MRsionCase by Naemura et al. [2] is an advanced extension of HoloAd that enables viewing of the 2D image from approximately 360 degrees. These displays are visible to multiple users as 2D images spread over a wide area. However, this technology is limited in that users cannot reach and touch the CG image and the object with their hands. To address this issue, Naemura [3] proposed the Mid-air Augmented Reality Interaction with Objects (MARIO) that can project the CG image in midair, and users can touch and experience the real and CG objects.

The displays of the above approaches can project CG images in midair. However, if 3D actions, such as air drawing, are performed, users must be able to view the images in 3D. To address this requirement, light field display technology [4] is employed to enable users to observe the 3D image in a 360-degree field by projecting the light irradiated from the projector to a high-speed rotating mirror. This projector is arranged to correspond with the angle at which the mirror is positioned. An Auto-stereoscopic Projector Array Optimized for 3D Facial Display, developed by Nagano et al. [5], enables multiple users to view the 3D CG objects. This system projects a 3D image through the arrangement of several projectors. Although the system enables viewing of the 3D image, the 3D image projection point is at the point of the rotating mirror or screen; therefore, users cannot touch the 3D image or place physical objects in the scene. FLOATS [6], on the other hand, uses active shuttered auto-stereoscopic methods to enable users to reach their hand onto the 3D CG image. The active shuttered auto-stereoscopy method, which does not decrease resolution, provides the auto-stereoscopic image using a slit that aligns to the user's head. In this manner, the active shutter method provides only two auto-stereoscopic images, which correspond to each eye. In addition to enabling users to touch the 3D image, this technology does not require the preparation of the image for every viewpoint to cover 360 degrees for a panoramic view. This system only requires the preparation of 2 images corresponding to users active head position. Active shuttered method enables the use of minimal image data, such as two images for each corresponding eye thus addressing the limitation of tracking the user's head position. RePro3D [7] can project a multi-view 3D image on a diorama in real space by applying retro-refractive projection technology. The retro-refractive projection enables the user to view the CG image by aligning the image to the user's eye position. Therefore, the user can view the corresponding version of the image from each eye.

A 3D display for multiple users, fVisiOn [8] can project a 3D image in midair, and the 3D image can be viewed from a 130-degree wide-angle view. This system precisely accommodates the multiple user experience; nevertheless, it is limited in terms of projection space. Furthermore, it can only project the image on a table. Therefore, interaction with this system is restricted to the 3D image movement area and the positional relationship between real objects and the 3D drawing.

3. ARIA METHODS

To enable the superimposition of a 3D image on real objects and to enable multiple users to manipulate the 3D image with real objects, we employed our Fuwa-Vision 3D display [9], which can project the 3D image in midair using the active-shuttered real image auto-stereoscopy (ARIA) method, which is similar to FLOATS, that provides auto-stereoscopic images to track user's eye position. This method produces an auto-stereoscopic image using an active shutter and transparent Liquid crystal display (LCD). It projects a real image in mid-air using a Fresnel lens.

Figure 1 illustrates the ARIA system overview. Each ARIA module consists of an LCD, a transparent LCD, and a Fresnel lens. The LCD provides the auto-stereoscopic image; the transparent LCD is used for the active shutter, and the Fresnel lens is used to project the real image in midair. These components work together using the ARIA method and 3D image auto-stereoscopy in mid-air. Although the displays can produce a 3D image in midair, the viewing angle is narrow—approximately 40 degrees; therefore, interaction by multiple users is not feasible.

Figure 2 illustrates the ARIA method principles. When the position of the convex lens is set at x = 0, the position of the active shutter, which is used by the transparent LCD for dynamic changing of the slit width and position, is set at $x = -S_3$. The position of the LCD is set at $x = -S_1$. The eye position of $x = S_4$ is the conjugate point from the active shutter across the lens. The slit changes so that the auto-stereoscopic image is projected to align with each eye; accordingly, it can provide the auto-stereoscopic image by time division. The 3D image projects at $x = S_2$; S_2 is determined by S_1 and the focal point of the lens.

To project the 3D image at a position that is precisely aligned to the user's eye position, the slit width and position must be determined to prevent vignetting and projecting of an auto-stereoscopic image that does not correspond to the user's eye position. As shown in Figure 2, the conjugate point of the eye position is (u, v), the position of the 3D object's upside and downside are ($-S_1$, i) and (S_3, s_y), respectively, and the position of the slit node end point is (S_3, s_y).

Therefore, s_y, as defined above, is defined by the formula as follows.

$$s_y = \left| i \frac{S_3 + u}{S_1 + u} \right| \quad (1)$$

$$s_y < \left| -S_3 \frac{i + v}{S_1 + u} \frac{S_1 v - iu}{S_1 + u} \right| \quad (2)$$

Eq. (2) indicates that the auto-stereoscopic image is not projected to correspond with the viewer's eye position. However, Eq. (1) represents the case in which the eye position is set on an optical axis. Therefore, if the eye position moves from the optical axis, Eq. (1) must likewise involve a derivative.

4. SYSTEM STRUCTURE

The detailed overview of the HaptoMIRAGE 3D display system is shown in Figure 3. The system consists of three ARIA units. Each unit is comprised of a Dell P2213 (22 inch, 1680x1050 pixels) for the LCD, a Samsung LTI220MT02 (22 inch, 1680x1050 pixels) for the transparent LCD, and two combined NTKJ CF400-0.3 Fresnel lenses (focal distance of 400 mm). As shown in Figure 2, the LCD is set at S_1 = 400 mm, and the transparent LCD is set at S_3 = 220 mm. The projecting point determines S_2 = 400 mm, and the user base position determines S_4 = 2000 mm.

To track the head position, a Kinect v2 motion tracking camera system is used. The active shutter follows the user's head and provides 60 frames per second images to the spot of user's eye. In this system, one ARIA unit uses one PC; therefore, this system employs three ARIA units that render the virtual image in mid-air. Thus, HaptoMIRAGE 3D display makes it possible to view the 3D image from a wide-view angle using three ARIA modules.

5. USER INTERACTION

HaptoMIRAGE enables the users to view 3D images and interact with real objects suspended in mid-air. These combined capabilities make possible the novel virtual reality field interactions that were formerly not possible. These interactions involve superimposing one's own operating onto physical objects and interacting with one's own operating with dynamic motion, such as changing the view point with multiple viewing angles, rotating the base to view different aspects. Moreover, 3D CG effects, such as rain, fire, and snow etc., can be superimposed on real objects—a feature that bridges real and virtual worlds. These interactions additionally include the mid-air superimposition of dynamic 3D CG content, such as character animations, collaborative drawing among multiple users, real-time drawing and discussion. These interactions are detailed in the following sections.

5.1 Interact with physical objects

As described earlier, HaptoMIRAGE can project a 3D image on physical objects. Therefore, we can use this system for exhibiting some artistic objects or commodities, such as toys, using a 3D image. Subsequently, we can also apply active effects, such as fire, rain, and snow to real objects in a virtually. Figure 4, for example, shows the 3D image of a car superimposed on a real stage-like platform. The user can rotate the 3D image by using the rotating stage and can place objects on the real stage.

As shown in the Figure 4 example, when the user rotates the stage using a motor to control the angle of rotation, the 3D image rotates correspondingly by tracking the stage rotation angle. This correlation enables the user to draw more complicated sketches in mid-air from different angles. Furthermore, users can superimpose their 3D sketch on real or CG objects. This capability makes it possible to expand the compatibility of creative exhibits/displays from the restrictive 2D format to 3D format with real objects, such as art exhibits, toys, and 3D CG.

5.2 Creating 3D objects in midair

Using the HaptoMIRAGE capability of superimposing a 3D image in mid-air, we implemented an air sketch application, as shown in Figure 5. Users can draw the illuminated lines in mid-air by using a pen shaped device. The device is equipped with a button that the user can press while drawing the illuminated lines. Thus, creative artwork, such as sketching, which is typically performed on the 2D field of an LCD or canvas, can be transformed from a 2D field to a 3D field. Furthermore, multiple users can collaboratively draw lines in the real environment and view it from various perspectives. Conversely, the user can create a sketch on a real object. When a prototype sketch is created with real objects, the user can then combine it with a 3D drawing or sketch.

6. DISCUSSION

HaptoMIRAGE system enables the projection of a 3D image in mid-air, and multiple users can interact with the 3D image in midair using their hands from respective viewing positions. HaptoMIRAGE has a lot of potential for mixed reality environments such as those described in chapter 5. HaptoMIRAGE is advantageous in certain aspects compared to other 3D displays systems.

Firstly, HaptoMIRAGE system enables users to view the 3D image naturally. Multiple users can view the 3D image from their respective positions, and they can see the 3D image at various angles. HaptoMIRAGE system does not require additional connecting equipment between the users and 3D image. Therefore, the users can experience a mixed reality environment without stress or interference from any obstacles. Furthermore, it is does not require the users to wear the any viewing glasses to see the 3D image. Users can see the 3D image just closing to HaptoMIRAGE system without wearing any devices. Secondly, the HaptoMIRAGE system can be constructed easily and is relatively cost effective compared with any other 3D mixed reality display system. HaptoMIRAGE system consists of three ARIA units, and the ARIA units comprise an LCD, transparent LCD, and Fresnel lens.

There are also certain drawbacks to using the HaptoMIRAGE system. Firstly, the 3D image cannot be projected in front of real objects. The 3D image is projected using lenses; therefore, if we place real objects in close proximity to the 3D image, users will see the 3D image behind the real objects. HaptoMIRAGE system is makes it plausible to interact with the 3D image using our hands or real objects; however, it is found wanting when placing real object near the 3D image. It is possible to place real objects in the proximity, but there are some limitations to the scale and placement position of the real objects. Secondly, HaptoMIRAGE system can project the 3D image for viewing for up to 3 users. This is because the ARIA units can project the 3D image for a single viewer because of the refresh rate limitation. The current system projects the auto-stereoscopic image to user's right and left eye to flip by 60Hz. The user's eyes can view the auto-stereoscopic image at 30Hz individually. It is possible for ARIA units to project the 3D image for more than two users, but whenever the number of users increases, the refresh rate for user's individual eye decreases. For increasing number of users, it is imperative to use higher refresh rate display units (including LCD, and transparent LCD) instead of the current LCDs used in this study.

7. CONCLUSION

In this study, we presented the use of an auto-stereoscopic display for seamless interaction with mixed reality environments. The proposed system can project a 3D image in mid-air with a 150-degree wide-angle view based on our proposed ARIA technology. Up to three users can observe the same image from different perspectives based on their relative position with respect to the projection. The 3D image can be superimposed on a real object, which allows the user to naturally interact with the mixed reality environment. Therefore, multiple users can experience coexisting Virtual and Real environment. Applications of the system include superimposing 3D images on objects in real environments like exhibitions and toys. In addition, users can draw auto-stereoscopic 3D illuminated lines in real environments. HaptoMIRAGE enables the users to bring virtual objects into the real world, while simultaneously interacting with multiple users. These capabilities can be applied to 3D modeling, collaborative drawing, idea sharing, and many more applications in the future.

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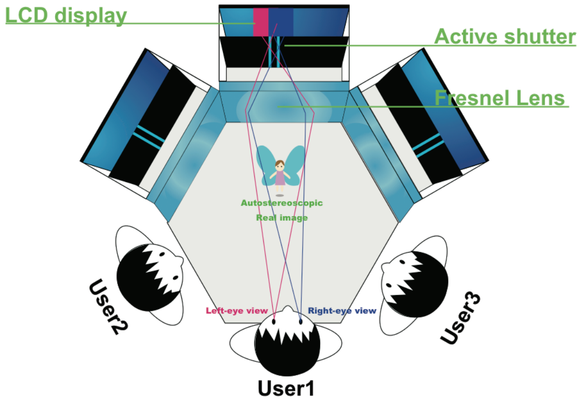

Fig. 1 HaptoMIRAGE system overview
HaptoMIRAGE consist of three units: LCD, Active Shutter, and Fresnel lens.

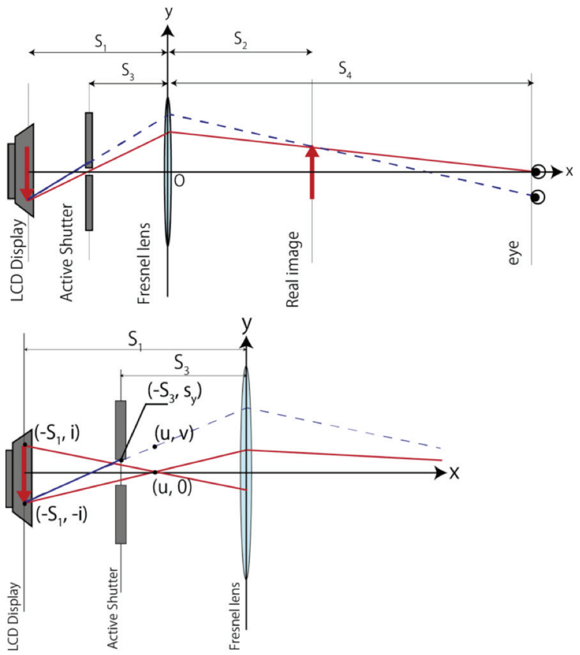

Fig. 2 The principles of Active Shuttered Real Image Auto-stereoscopy methods.
First image shows how to decide the slit position correspond to user’s eye position.

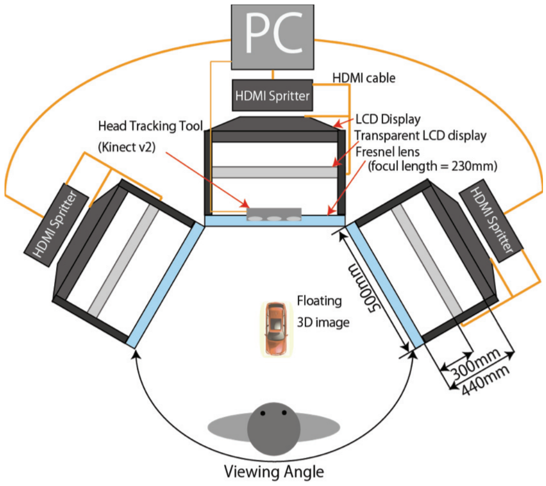

Fig3. System construction of HaptoMIRAGE system
HaptoMIRAGE system is operated using one PC, and is connected to three ARIA units.

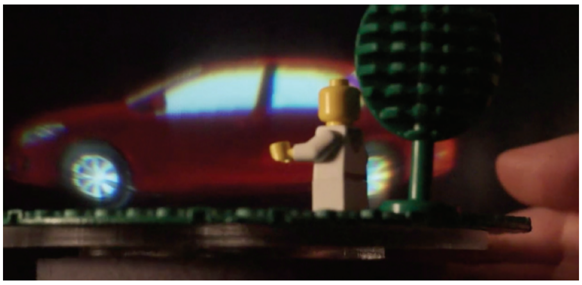

Fig5. Interaction with physical objects
Rotating the 3D image by rotating the physical stage.

Fig6. Creating 3D image in midair
Real time illuminated lines drawn in mid-air.