https://doi.org/10.2352/ISSN.2470-1173.2017.5.SD&A-363

See-through projection 3D display using time-division multiplexing

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Abstract

We propose a large screen 3D display which enables multiple viewers to see 3D image superimposed on real objects behind the screen. In previous study, large screen 3D displays using multiple projectors are proposed, and multi projection 3D display with see-through property is also proposed. However, using many projectors makes installation and adjustment difficult. Our new 3D display exploiting time-division multiplexing is composed of single high-speed projector and an active see-through screen which has a see-through property and a motion mechanism for scanning light beam from the projector. The screen consists of multiple vertically-long half mirrors which swing around vertical axis direction. The half mirrors reflect light beam from the projector diffusely in vertical direction and specularly in horizontal direction. It is possible to display different images for multiple viewpoints by changing projection image corresponding to reflection direction. To confirm the principle of the proposed method, we conducted a computer simulation and confirmed that proposed system displays 3D image which has appropriate parallax.

Introduction

Applications using 3D display such as Virtual Reality (VR) and Augmented Reality (AR) have been attracted attention. Various types of 3D display have been developing according to applications. In AR application, 3D display is required see-through property because it displays 3D image superimposed on real-world environment. Typical examples of 3D display for AR application are “HoloLens” which is manufactured by Microsoft Company and “Meta2” which is manufactured by Meta Company. These displays are Head Mounted Display (HMD) type. Not only HMD type but also naked eye type see-through 3D display has been studied. Naked eye type 3D display suits to display 3D image for multiple viewers. If a naked-eye type see-through large screen 3D display is realized, it is useful for advertisement and exhibition application. In previous study, see-through multi-projection 3D display using transparent anisotropic diffuser (TAD) which is implemented by a metal-coated anisotropic diffuser and index matching oil is proposed [1]. TAD has see-through property and reflects light beam from projectors. Although screen size of this display is not large, multi-projection 3D display is suitable for large screen display. Large screen 3D displays using multiple projectors are proposed, but not see-through screen [2][3][4]. In these displays, large size imaging optics is used as a screen. Multi-projection 3D display is required many projectors to display 3D image which has smooth parallax. As number of projectors increase, it is difficult to install and adjust them. In contrast, a 3D display using only one high-speed projector is proposed[5]. A screen of this display has motion mechanism for scanning light beam from a high-speed projector. It is possible to display 3D image by changing projection image corresponding to scanning direction. This display is observable from 360 degree around vertical axis. Installation and adjustment is easy relative to multi-projection 3D display. Because the screen is rotated, it is difficult to enlarge screen size. In this study, we propose a see-through large screen 3D display which enables multiple viewers to see 3D image using single high-speed projector and active screen. The screen has the motion mechanism for scanning light beam from the projector. It is possible to display different images for multiple viewpoints by changing projection image corresponding to scanning direction. We confirmed the principle of the proposed method by computer simulation. Moreover we developed experimental display and confirmed its displays 3D image which has appropriate parallax.

Proposed method

Schematic image of the proposed display is shown in Figure 1. The proposed display consists of single high-speed projector and an active see-through screen which has see-through property and motion mechanism for scanning light beam from the high-speed projector. The screen consists of multiple vertically-long half mirrors, each of which swing. Moreover, the multiple half mirrors reflect light beam from the projector specularly in horizontal direction and diffusely in vertical direction. To display multi-view images, projection image are changed corresponding to scanning direction.

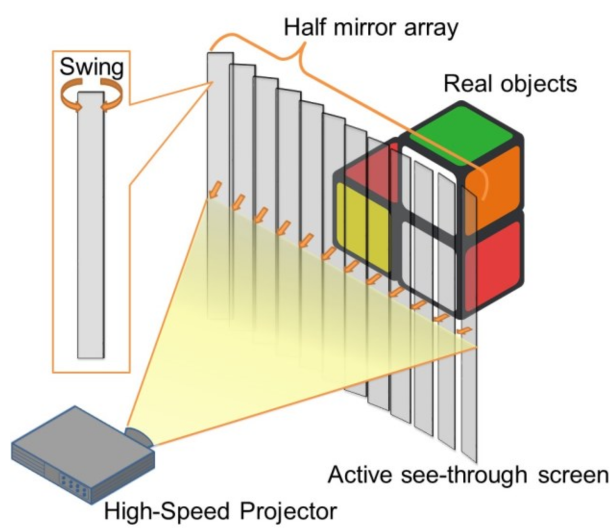


Figure.1 *Schematic image of the proposed display*

1. Active see-through screen

1.1 Mechanism and configuration

To display different image in horizontal direction, we exploit time-division multiplexing by using high-speed projector and the active see-through screen. It is necessary to change the screen normal direction at every position of the screen at high speed in order not be felt flicker by human eyes. If the screen is large in horizontal direction, it is difficult to swing the screen at high speed because moment of inertia is proportional to the square of radius gyration. Therefore, in the proposed display, the screen is split vertically. It is possible to reduce moment of inertia by swinging split screens individually synchronously. From the above, active see-through screen consists of vertically-long screen array which swing around vertical axis direction synchronously. We exploit lever crank mechanism as swinging mechanism.

1.2 Reflection and see-through properties

In horizontal direction, the screen reflects light beam from high-speed projector specularly to display different image for different viewpoints. In vertical direction, the screen reflects diffusely so that 3D image can be observed independently from viewing zone. Because we want to observe 3D image on the screen independent of viewing position in vertical direction. Moreover, the screen is required see-through property to superimpose on real objects behind the screen. In previous study, a screen that has properties mentioned above was produced by index matching oil and thin metal coating technique [1]. In the proposed display, each strip of screen is composed of array of horizontal metal wire that leave space between each wire in vertical direction. Surface of metal wires reflect light beam specularly. Since metal wires are apposed at intervals in vertical direction, when the screen is watched at a distance, light beam from behind the screen through the screen. Further, it looks like the screen reflects specularly in horizontal direction and almost diffusely in vertical direction due to curvature radius is small.

2. Design

At first, we decide screen size and number of splits. As mentioned in section 1.1, these parameters have relationship to moment of inertia. Although these parameters can be determined freely, it is preferred narrow each strip of screen width. Second, we decide projection and viewing parameters. Now, we explain to decide these parameter from the specifications of a high-speed projector. If you design specifications of a high-speed projector according to projection and viewing parameters, you need to reverse calculation process which is described later. A projected image size is determined to be equal to the screen size. Then, a projection distance is determined so that the projected image equal to the screen size. Let us consider the number of viewpoints, viewing zone angle and viewpoint pitch. Viewpoint pitch are determined to equally divide the viewing zone angle by the number of viewpoints. In the proposed display, since the projector is installed in front of screen, we can design viewing zone angle up to 180 degrees. Number of viewpoints is related to refresh interval of the projector and the swing speed of screen. Because projection images are changed corresponding to reflection direction, the swing speed have to be high enough in order not be felt flicker by human eyes. In swinging mechanism, the angular velocity is not constant. Minimum viewpoint pitch is determined by product of maximum angular velocity and refresh interval of projector. The number of viewpoints limited by minimum viewpoint pitch. Finally, we decide a range of swing. Schematic image about relationship between the range of swing and other parameters is shown in Figure 2. The range of swing is different for each screen. Now, we are focusing on the most left screen. θ_{Lmax} is the angle of the screen surface when the light beam from the projector is reflected at the most right point on the screen and then head to the most left viewpoint. Similarly, θ_{Rmax} is the angle of the screen surface when the light beam is reflected at the most left point on the screen and then head to the most right viewpoint. All viewpoints are received the light beam from the projector while the screen is swinging from θ_{Lmax} to θ_{Rmax}. Therefore, the range of swing of the screen is the difference between θ_{Lmax} and θ_{Rmax}. θ_{Lmax} and θ_{Rmax} are determined by using numerical calculation. It is necessary to repeat this process for all strip of screens.

Table 1 is a summary of the above. Further, the values of our design are also described. When we analyzed range of swing for all screen using designed value, range of swing of all strip were almost same value. Thus, we unified them. In addition, we define θ_{Lmax} as initial screen angle.

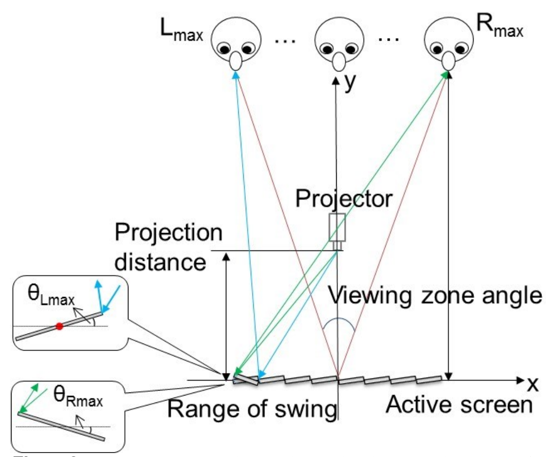


Figure2 *Schematic image about relationship between the range of swing and other parameters*

Table 1 Proposed display parameters

Screen size	H900×W900[mm]
Number of splits	15 [-]
Viewing distance	2160.39 [mm]
Number of viewpoints	31 [-]
Viewing zone angle	30 [deg]
Viewpoint pitch	1 [deg]
Angle of view of projector	23.5324 [deg]
Reflesh rate of projector	27000[Hz] (binary image)
Projection distance	2160.39 [mm]
Range of swing	16.8599 [deg]

3. Projection image creation method

The projection image creation method is shown in Figure 3. It is necessary to change the projection image more than the number of viewpoints in one cycle. Therefore, we prepare projection images more than the number of viewpoints. The projector changes the projection images to equalize each projection time. In the proposed display, the projector changes projection images every rotation angle 1 ° of the crank. Therefore, number of projection images are 360. Let us consider the projection image at a certain moment.

At first, we prepare the parallax image for all viewpoints (Figure 3(a)). The projection image is created using information of all screen angle value. The screen angle values are determined rotation angle of crank and initial screen angle defined in Section 2. Now, we focused on one of the all screens (Figure 3(b)). We determine the viewpoint which is nearest to the ray reflected at the screen. The area corresponding to the screen in the parallax image corresponding to the viewpoint is clipped and paste. Sometime, the viewpoint which is nearest to the ray reflected at the right end of the screen is different to the viewpoint which is nearest to the ray reflected at the left end (Figure 3(c)). In this case, we use images of both viewpoints for the screen. Border of the both image is the point at which the ray reflected goes to the intermediate point between both viewpoint (Figure 3(d)). We repeat to same process for all screens (Figure 3(e)).

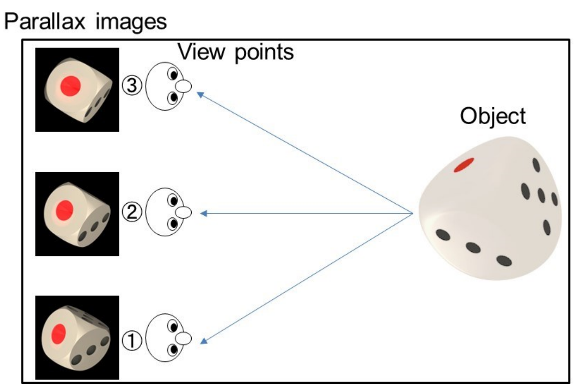


Figure3(a) *Projection image creation -parallax images-*

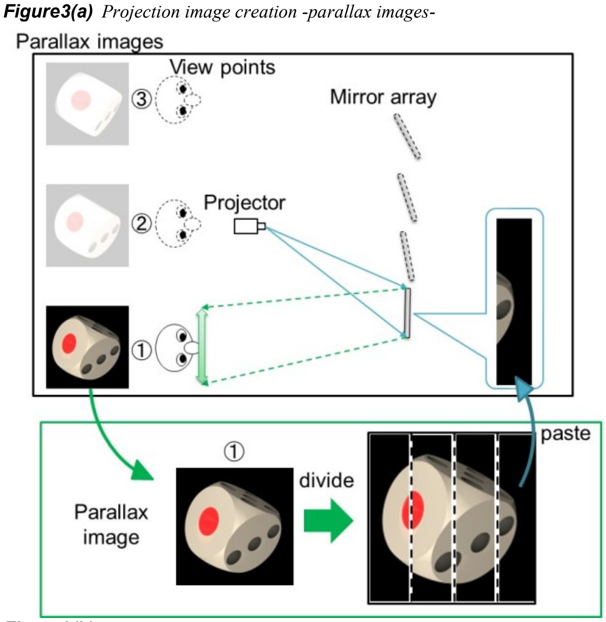


Figure3(b) *Projection image creation –use a parallax image-*

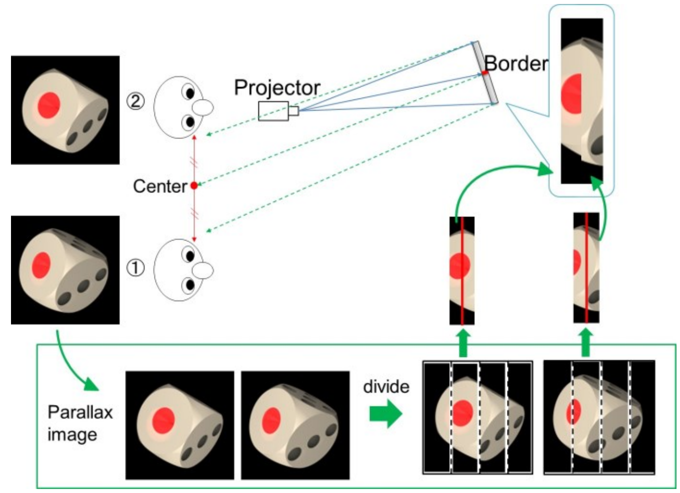


Figure3(c) *Projection image creation –use two parallax images-*

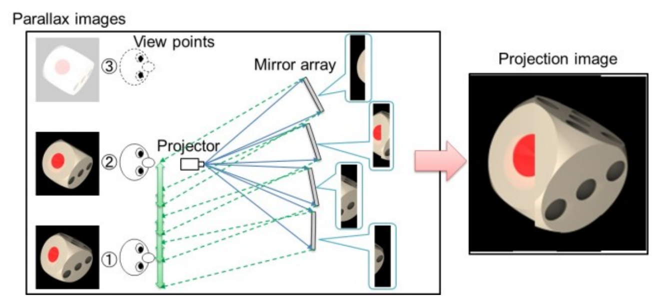


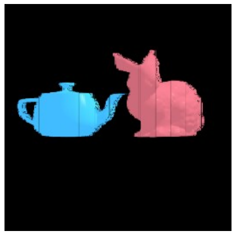
Figure3(d) *Projection image creation –projection image-*

Simulation

To confirm the principle of the proposed method, we conducted a computer simulation using ray tracing tool of POV-Ray. Simulation parameters are based on Table1. In the simulation, We simulated the image which is displayed on the virtual screen during one cycle of swing. 360° images are projected during one cycles. For each projection image, the observed image at the moment corresponding to is simulated. The simulated result are integrated for afterimage effect of human eye. In this simulation, transparency is not verified. Simulation results when the most right , middle and the most right viewpoint is simulated are shown in Figure 4, Figure 5 and Figure 6.

From these three results, it was able to confirm different images at different viewpoints. Therefore, we confirmed that our system displays 3D image which has appropriate parallax. There are some black line in there results. They are thought to be due to gap of each screen.

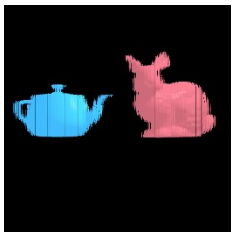
(a) Parallax image



(b) Observed image

Figure4 *Most left viewpoint*

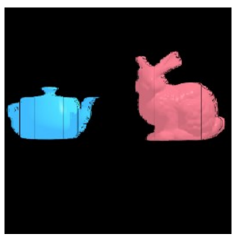
(a) Parallax image



(b) Observed image

Figure5 *Center viewpoint*

(a) Parallax image



(b) Observed image

Figure6 *Most right viewpoint*

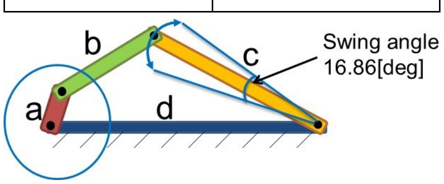
Experiments and results

Experimental apparatus

Experimental environment also based on Table 1. The length of each link was designed as shown in Table 2 in order to realize the designed range of swing with the lever crank mechanism. Power of swing is transmitted for all screens because the range of swing is unified. We replace the DLP part of the projector (TAXAN, TYPE:KG-PH1001) to the DLP (manufactured by ViALUX, TYPE: V4100) which operates at high speed.

Table 2 Link specifications

a link	15 [mm]
b link	80 [mm]
c link	140 [mm]
d link	200 [mm]



Screen

Schematic image of the screen is shown in Figure 7. The screen is required to reflect light beam from the projector specularly in horizontal direction and diffusely in vertical direction. Moreover the screen also is required see-through property. In the proposed display, the screen is produced by apposing metal wires that leave space between each other in vertical direction as mentioned in section 1.2. For the metal wires, stainless steel wires with 1 mm diameter are used. The screen that has aperture ratio of 50% is produced by apposing the wires at 2mm pitch in the vertical direction.

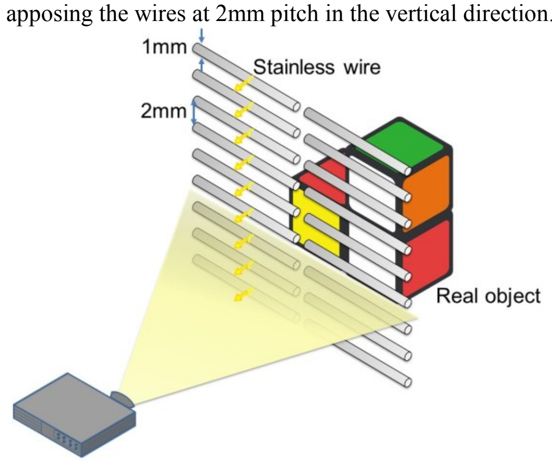
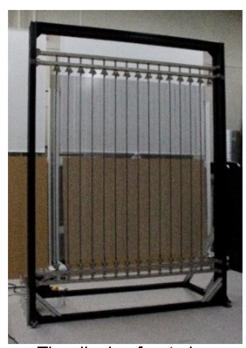


Figure 7 *Schematic image of the screen*

Figure 8 shows the experimental apparatus.



The display front view

The screen Enlarged view

The display rear view

Lever crank mechanism

Transmission part

Figure 8 *Experimental apparatus*

Experimental results

We displayed 3D image of the Stanford bunny which is floated 300mm behind the screen and placed a real object of kettle which located 600mm behind the screen. Figure 9 shows experimental results.

From the experimental results, it was possible to observed the different images at different viewpoint. Moreover, we confirmed the display has see-through property enough becasue the real object is observed from in front of the screen. The positional relationship with the kettle and the Stanford bunny is changed according to three viewpoints. Therefore, our proposed display display 3D images which has appropriate depth information.

Figure 9 *Experimental results*

Conclusion

In this paper, we propose a large size of see-through screen 3D display which enables multiple viewers to see 3D image using single high-speed projector and active see-through screen. We exploit time-division multiplexing by using high-speed projector and the active see-through screen. The screen consists of multiple vertically-long half mirrors which have motion mechanism for scanning light beam from the high-speed projector. We conducted a computer simulation and confirmation experiment. From the results, we confirmed that our proposed display has see-through property enough and displays 3D image which has appropriate parallax.

Acknowledgment

This work was supported by JSPS Grants-in-Aid for Scientific Research JP26280073, JP16K12475.

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Author Biography

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