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Projection type 3D display using spinning screen

Hiroki Hayakawa, Tomohiro Yendo; Nagaoka Univ. of Technology; 1603-1, Kamitomioka-machi, Nagaoka-city, Niigata-pref, 940-2188, JAPAN

Abstract

We propose 3D display that scans light rays from projector and enables stereoscopic display by arranging a number of long and thin mirror scanners with a gap and spinning each mirror scanner. This proposal aims at large-screen 3D display that allows multiple people to observe simultaneously with the naked eye. In previous study, multi-projection type 3D display was proposed as large-screen 3D display. However, many projectors make installation and adjustment complicated. Therefore, we have proposed 3D display that can display large screen with single projector in the past. However, there is a problem that the screen vibrates due to the screen swing mechanism, the scanning speed cannot be increased, and the displayed image appears to flicker. Our new proposed method can reduce the screen vibration by the spin mechanism, increase the scanning speed, and prevent the displayed image from flickering. Computer simulation was performed to confirm the principle of the proposed method, and it was confirmed that appropriate parallax could be presented. The necessary conditions and problems when manufacturing the actual machine were considered, and the prototype was designed.

Introduction

In recent years, video contents using stereoscopic display technology such as 3D movies, 3D TVs, and virtual reality (VR) headsets have begun to be used in various scenes. Augmented reality (AR), such as automotive head-up displays and smartphone application software typified by Pokémon GO, has also become pervasive. Recent developments in information technology and computer science have driven an increasing demand for 3D displays and various types of 3D display have been developing according to applications. For AR application see-through property is one of the most important feature. It is possible to display 3D image superimposed on real-world environment by using see-through 3D display. One of the promising application fields is exhibition especially advertisement on showcase and shop window. By replacing the area of the window with see-through 3D display, it is possible to more effective advertisement display such as additional information to exhibited real objects or emphasizing them. In a limited exhibition space, even if a real object that cannot be placed actually, 3D image can be displayed. In exhibition field, it is supposed that 3D display is watched by multiple viewers at the same time. Therefore, it is required that large screen 3D display enable to multiple viewers to see 3D image with naked-eye.

In previous study, there is multi-projection type as large screen 3D display. Inoue proposed 200-Inch Glasses-Free 3D Display System [1], which can be observed by multiple people simultaneously with the naked eye. The display reproduces an image of each viewpoint by using projector array, and displays stereoscopic image. However, since a large number of projectors are used, installation and adjustment are complicated, and the scale of the apparatus must be large. Also, since the image is projected from the back of the screen, it is not possible to superimpose the image on the real object. The other hand, Young proposed See-through multi-projection three-dimensional display using transparent anisotropic diffuser [2]. This display can superimpose the image on the real object by using transparent anisotropic diffuser. However, since a large number of projectors are used, installation and adjustment are complicated, and the scale of the apparatus must be large. To reduce the number of projectors, time-division multiplexing type 3D display was proposed. Jones proposed Rendering for an interactive 360 ° light field display [3]. This display is composed of single high-speed projector and rotating anisotropic diffuser. This display can display stereoscopic image by switching the projection image in accordance with the rotation of the screen. However, in this study, large-screen displays are difficult because the screen is rotating at high speed. From the above, previous research is not suitable for use in application examples of this study.

Our previous study

Previously we proposed large-screen 3D display consisting of single high-speed projector and mechanical active transparent screen [4]. Figure 1 shows the configuration of the display.

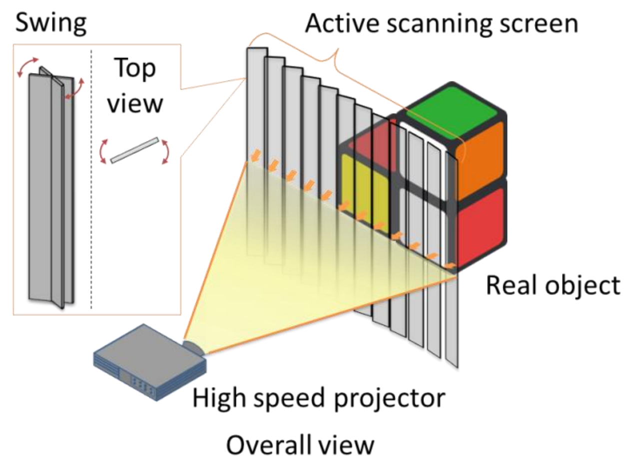


Figure 1. *Display configuration of our previous study*

The display has following features: large screen size, transparency, multiple viewers with the naked-eye, and small scale of the projection unit.

The screen scans direction of reflected light rays from the projector. The screen is consist of an array of vertically-long anisotropic mirror strips with transparency. The anisotropic mirror reflects light specularly in horizontal direction and diffusely in vertical direction. Each mirror strip rotates reciprocally around a vertical axis. Thus, the angle of the mirror changes, and the light rays from the projector is scanned in horizontal direction. By switching the projection image in accordance with the direction of light ray reflection, different images are displayed depending on the viewing position.

A prototype of the display uses lever crank mechanism, parallel crank mechanism, and one motor. Figure 2 shows the screen mechanism. The lever crank mechanism converts continuous rotation of the motor to the swinging motion, and then it is transmitted to all mirror strips by the parallel crank mechanism.

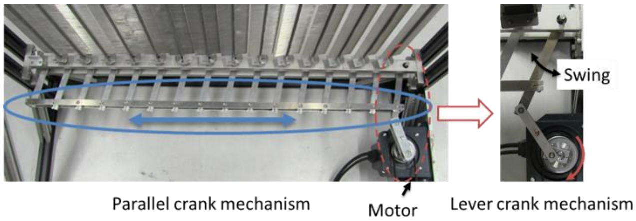


Figure 2. *Screen mechanism of our previous study*

Further, the anisotropic mirror is composed of an array of metal wires which arrangement has a gap so that the screen has transparency. The metal wire reflects light rays, and the gap allows light from behind the screen to pass through.

However, there are some problems in our prototype. First, the display image appears to flicker. This is because if the scanning speed of the light rays is increased, the screen vibrates and the mirrors come into contact with each other, so that the scanning speed cannot be increased. We consider that the screen is vibrating due to the movement of the large link of the parallel crank mechanism and the swinging motion of the mirror. Second, reciprocating motion such as swinging motion has a problem in energy efficiency due to repeated acceleration and stopping. Since kinetic energy increases in proportion to the square of the frequency, it is difficult to increase the frequency from the viewpoint of energy consumption. Third, since long and narrow plate-like mirrors are arranged, there is a problem that seams in image are formed between the mirrors. Fourth, since the horizontal metal wires are arranged vertically, there is a problem that the central fixing portion for fixing the wires does not have transparency. Fifth, there is a problem that the air resistance due to swinging motion of thin plate-like mirror.

Proposed method

In this study, we propose 3D display using single high-speed projector and a spinning mirror scanner array. Figure 3 shows the configuration of the display. The spinning mirror scanner array consists of many polygonal mirror scanners whose rotation axes are in vertical directions. Each scanner is extremely long in axial direction relative to its radial width. As each mirror scanner spins, the light rays from the projector is scanned. Therefore different images are displayed depending on the viewing position by switching the projection image in accordance with the reflection direction of the light rays. One side of the mirror scanner scans the light rays once. By setting the scanning speed of one side of the mirror scanner to 60 Hz, the image can be displayed without flickering.

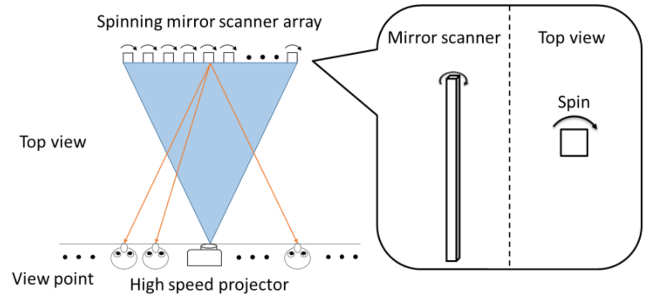


Figure 3. *Display configuration*

The screen needs to scan light rays in the horizontal direction and display images in the vertical direction regardless of the height of the viewpoint. Thus, each surface of the spinning mirror scanner array specularly reflects light rays horizontally and diffusely reflects light rays vertically. Further, the transparency of the screen is realized by finely arranging long and thin mirror scanners with a gap. The spinning mirror scanner array reflects light rays, and the gap transmits light rays from the back of the screen. Therefore, the screen can have transparency.

In the proposed screen, by spinning each mirror scanner, the use of the mirror's swinging motion and the parallel crank mechanism in the previous study can be stopped, and the problem of the screen vibrating is solved. In addition, the spinning motion in fixed direction eliminates repeated acceleration and stop, thereby improving energy efficiency. The proposed screen solves the problem of seams between the mirrors in the previous study because mirror scanners with very long and thin polygonal bars are arranged in small gaps. Also, since the mirror scanner is not made transparent but the screen is made transparent by the arrangement of the mirror scanner, it solves the problem that the fixed part of the wire in the previous study could not have transparency. And because the mirror scanner is very long and thin polygonal bar, we consider that the air resistance can be reduced compared to operating long and thin plate-like mirror as in the previous study.

Simulation

We verify whether the proposed method can display stereoscopically by simulation. Table 1 shows the simulation specifications. Figure 4 shows the simulation results. Image b is an image observed from the front of the screen. Images a and c are images observed when the viewpoint moves 15 ° left and right from the front of the screen. From the simulation results, it was confirmed that the appearance of the image was changed according to the observation position, and that the image could be displayed three-dimensionally.

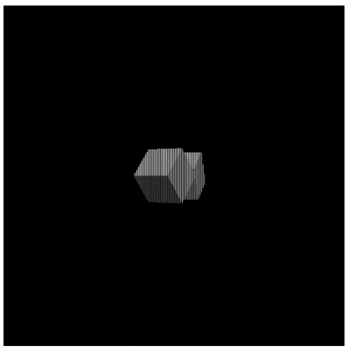
Prototype

Conditions and problems

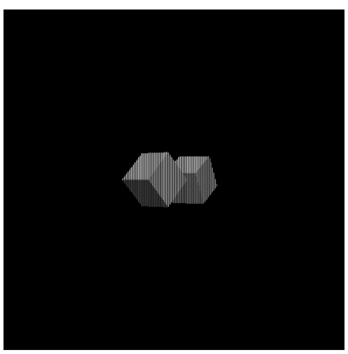
We considered some problems for design and manufacturing actual prototype. First, since the mirror scanner is long and thin, it may be twisted or warped when spun. Second, to arrange the mirror scanners in fine pitch, reduced size of the driving unit is needed. Third, it is necessary to mechanism to synchronize spinning of all mirror scanners.

Table 1 Simulation specifications

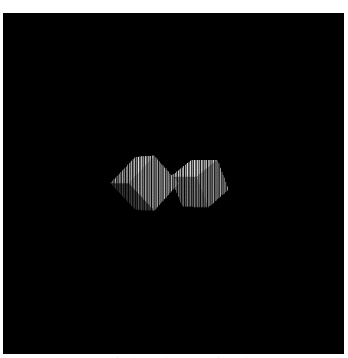
Viewing distance	2000 mm
Screen size	1000 × 1000 mm
Mirror scanner size	2 × 2 × 1000 mm
Mirror scanner pitch	4 mm
Number of mirror scanners	250



(a) Left viewpoint image



(b) Center viewpoint image



(c) Right viewpoint image

Figure 4. *Simulation result. (a), (b) and (c) are observed images from left, center and right viewpoint respectively. The viewpoint interval is 15 degree.*

Solutions

First, we considered the drive unit that spins the mirror scanner. The drive unit uses permanent magnet synchronous motor. The reason for using permanent magnet synchronous motor was that if power was transmitted from the motor using gears, a large number of small gears would be required, making it difficult to use due to mounting, friction, noise, etc. Since the permanent magnet synchronous motor is spun by magnetic force, there is no need to worry about friction and the like. Also, since the spin speed is determined by the frequency of the power supply, no feedback control is required. In addition, since there is no commutator or brush, maintenance is easy. In addition, we considered that even if a coil was not attached to each mirror scanner, it would be possible to spin multiple mirror scanners with one set of coils if there was no problem with the magnetic circuit.

Next, when spinning the mirror scanner, we considered the twist of the mirror scanner. We considered that by driving the mirror scanner from top and bottom and spinning it at a constant speed, it would be difficult to twist when spun.

Finally, we considered the warp of the mirror scanner as it was spun. We considered that by pulling the mirror scanner, the mirror scanner was stretched and could not be easily warp when spun.

Design

A prototype was designed based on the consider results. Figure 5 shows the configuration of the prototype. In this design, the magnetic poles of the electromagnet are arranged so that the two mirror scanners can be spun by one set of coils. Further, the spring was used as structure for pulling the mirror scanner. An acrylic square bar of 2 mm x 2 mm x 1000 mm was used for the mirror scanner. We considered using a mirror spray to make the acrylic surface look like a mirror to reflect the light rays from the projector with an acrylic square bar. And we considered to use lenticular lens to diffuse the light rays vertically. Therefore, by arranging those having this structure, we considered that the screen can be enlarged.

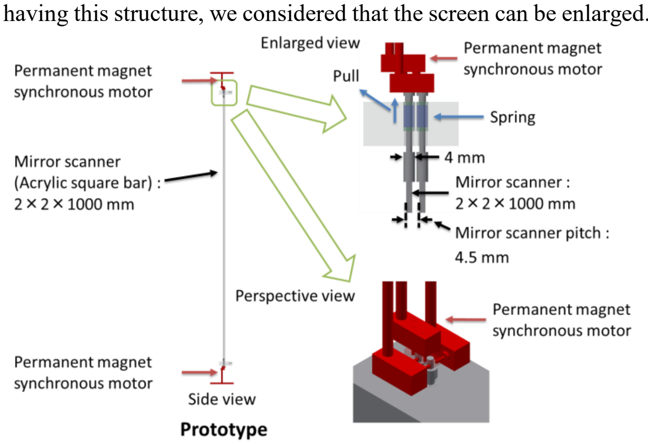


Figure 5. *Prototype configuration*

Conclusion

In this paper, we propose large-screen transparent 3D display that multiple people can observe with the naked eye simultaneously. The proposed method consists of single high-speed projector and a spinning mirror scanner array. A three-dimensional display is performed by scanning light rays from projector on the screen on which a number of long and thin mirror scanners are arranged, and switching projected images in time division. In the proposed method, the problems of our previous study was solved and the flicker of the displayed image was improved. Computer simulation was performed to confirm the principle of the proposed method, and it was confirmed that appropriate parallax could be presented. The necessary conditions and problems when manufacturing the actual machine were considered, and the prototype was designed.

Acknowledgements

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Author Biography

Hiroki Hayakawa was born in Niigata prefecture, Japan, in 1999. Hiroki Hayakawa received the B.E.degreein Department of Electrical, Electronics and Information Engineering from Nagaoka University of Technology, Niigata Japan, in 2018. He is now a master course student of Nagaoka University of Technology. His research interest includes stereoscopic image technology.