Reduction of image distortion for vertically shifted viewpoints on Superimposed 3D Display Viewable from 360 Degrees

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ABSTRACT
In the previous superimposed 3D display viewable from 360 degrees, it has a problem that 3D images are distorted by vertical viewpoint shifts. In this paper, we propose a method to improve the distortion of 3D images tilt of the previous system.

1 Introduction
3D display is effective for use in advertising and exhibitions because they can attract people. For such purposes, it is desirable that 3D images can be seen by many people at the same time. A 360-degrees viewable 3D display is proposed to meet the above condition [1].

However, the 3D image cannot be superimposed onto real objects because the display area of the 3D image is occupied by the display unit.

A 3D display that can superimpose 3D image on real objects and be viewed from 360 degrees has been proposed. [2] The configuration of this system is shown in Fig. 1.

![Fig. 1 Configuration of the 3D display to be able to superimpose the 3D image onto real objects.](image)

The system is composed of a screen, a thin strip mirror and a high-speed projector. The mirror perpendicular to the screen surface rotates at high speed around a rotation axis. This rotation axis is perpendicular to the screen. The solid of revolution of the mirror is a hollow cylinder. Images corresponding to the mirror position is projected onto the screen and observers see a part of the images reflected through the mirror. Due to the afterimage effect, observers can observe 3D images inside the cylinder from all sides. Since the solid of revolution is a hollow cylinder, the display area is not occupied by the display unit.

Therefore, this display can superimpose 3D image onto a real object, because the real object can be placed inside the cylinder.

However, this display has a problem of distortion of the 3D image when the viewpoint positions are not at the assumed height.

Therefore, we propose a new optical system that the distortion is not caused when the viewpoint positions are not at the assumed height. Distortion is solved by changing the tilt angle of the mirror to the screen, in the proposed method.

We confirmed distortion ratio of vertical 3D image length by changing viewpoint height through simulation. We also confirm that the viewer can view the 3D image from all sides.

2 Principles

2.1 Superimposed 3D display viewable from 360 degrees using rotating mirrors [2]

Figure 2 shows that users observe what image when the mirror is at a certain position in the display proposed previously [2]. The observed area of the screen reflected by the mirror is different depending on the viewpoint as shown in Fig. 2.

![Fig. 2 Reflection of the screen.](image)

Thus, different images are observed for each viewpoint by projecting different images on the screen, taking the observer's position into account, as shown in Fig. 3. In addition, the observer can observe 3D images from all around due to the afterimage effect by projecting images on the screen according to the positions of the mirrors rotating at high speed. Thus, the observer can observe the appropriate parallax image according to the observation position.
2.2 Generation of image distortion due to changes in viewpoint position

This display has the problem that 3D images are easily distorted when the viewpoint positions are shifted vertically from the assumed height. This is because the image plane of the virtual image is a horizontal plane.

The projected image is created according to the assumed viewpoint. Therefore, the height of observed image is not distorted from the assumed viewpoint, as shown in Fig. 4. The height of observed image is extended when observed from a viewpoint above the assumed. Conversely, the height of observed image is shortened when observed from a viewpoint below the assumed.

This problem can be solved by making the virtual image of the projected image perpendicular plane to the screen shown in Fig. 5.

2.3 Superimposed 3D display viewable from 360 degrees using a tilting mirror

Configuration of proposed system is shown in Fig. 6. The proposed system is composed of a screen, a thin strip mirror and a high-speed projector as well as previous study. The thin strip mirror rotates at high speed and the high-speed projector projects image from below on the screen corresponding to the mirror position. The mirror is positioned that the angle between the screen and mirror is 45 degrees.

The solid of revolution is a hollow truncated cone when the mirror is rotated around the rotation axis. Hence, the 3D image is observed inside the truncated cone.

The virtual image plane and the screen plane are planar symmetry planes to the mirror. The mirror is perpendicular to the screen in the previous study. It is necessary that the mirror is tilted at 45 degrees to the screen in order to form the virtual image of the screen perpendicular to the screen as shown in Fig. 7. As a result, image distortion caused by vertical viewpoint movement can be reduced.
3 Simulation

3.1 Confirmation of the vertical distortion reduction in 3D image

Computer simulations were conducted to confirm that the 3D image is not distorted when the viewpoint is shifted vertically from assumed height. Figure 8 shows the configuration of the simulation to check distortion caused by vertical viewpoint shift. We prepared three viewpoints with different vertical positions to compare images distortion caused by vertical shifts from assumed viewpoint. We compared the mirror with a 45 degrees tilt (proposed method) and perpendicular (previous method) to the screen.

We used the checker board image to compare distortion between proposed method and previous method. The length of a side of the square was 20mm when it is observed from assumed viewpoint. The assumed viewpoint was positioned at a height of 100 mm from the screen. In addition, two viewpoints other than the assumed viewpoint were vertically positioned ±20mm. However, when the mirror is tilted by 45 degrees, the radius of rotation depends on the height from the screen, so the mirror rotation radius on the screen surface is defined as 50 mm.

![Image of simulation configurations](image)

We confirmed that the vertical length of the square shrink and stretch in the previous method. A total of 360 projection images are created.

To verify the presence of parallax in the proposed display, we observed from nine viewpoints located at different horizontal positions as shown in Fig. 10.

These center row viewpoints are located at a height of 100 mm above the screen. The position of the mirror at 0 degrees is the reference position. 3D image can be observed this position. It is also observed from two positions rotated by ±45 degrees around the rotation axis from that position. The 3D image is also observed from these positions which are out of positions by ±20 mm off the assumed viewpoint height.

The observer observes the cube as a 3D image. The adjacent faces of cube are red, blue and green. The opposite sides are same color. A side of this cube is 20 mm long when it is observed from the assumed viewpoint. The object center passes through the rotation axis and it is positioned 25 mm above the screen.

![Image of simulation configurations](image)

3.2 Confirmation of the ability to observe a 3D image from 360 degrees

Simulations were conducted to confirm that the observers can observe the 3D image from all sides. 3DCG software was used for the simulation. Figure 9 shows the configuration during creation projected images. A projected image is created by rotating the cube every 1 degree. A total of 360 projection images are created.

To verify the presence of parallax in the proposed display, we observed from nine viewpoints located at different horizontal positions as shown in Fig. 10.

These center row viewpoints are located at a height of 100 mm above the screen. The position of the mirror at 0 degrees is the reference position. 3D image can be observed this position. It is also observed from two positions rotated by ±45 degrees around the rotation axis from that position. The 3D image is also observed from these positions which are out of positions by ±20 mm off the assumed viewpoint height.

The observer observes the cube as a 3D image. The adjacent faces of cube are red, blue and green. The opposite sides are same color. A side of this cube is 20 mm long when it is observed from the assumed viewpoint. The object center passes through the rotation axis and it is positioned 25 mm above the screen.

![Image of simulation configurations](image)

4 Results

4.1 Confirmation of the vertical distortion reduction in 3D image

We show simulation results as shown in Fig. 11. Figure 11(a) shows observed images when the mirror is tilted at 45 degrees (proposed method), and Fig. 11(b) shows observed images when the mirror is perpendicular to the screen (previous method). Center images are observed at the assumed viewpoint, left images are observed at the lower viewpoint position, and right images are observed at the higher viewpoint position.

We confirmed that the vertical length of the square shrink and stretch in the previous method. Additionally,
we confirmed that the vertical length of the square does not shrink and stretch in the proposed method. Hence, we verified that the vertical distortion of the image reflected in the mirror is reduced when the mirror is tilted at 45 degrees to the screen compared to the previous method.

Hence, we verified that the vertical distortion of the image reflected in the mirror is reduced when the mirror is tilted at 45 degrees to the screen compared to the previous method.

![Fig. 11 Simulated images for each viewpoint](image)

(a) Mirror is tilted 45 degrees (proposed method)  
(b) Mirror is perpendicular (previous method).

We show that the distortion ratio of vertical 3D image length by changing for each viewpoint height through simulation as shown in Fig.12. The distortion ratio indicates the degree of extension or shrinkage of the image height observed each viewpoint to image height of the assumed viewpoint(100mm).

In the previous study, we confirmed that the distortion ratio increases linearly with the shift of the viewpoint position from the assumed viewpoint. In the proposed method, we confirmed that the distortion ratio was less than 1% at viewpoint heights of 80 and 120 mm. Therefore, in the proposed method, the image distortion caused by shifting the viewpoint from the assumed viewpoint is very small compared to the previous method.

![Fig. 12 The change in image distortion ratio caused by vertical shifting from the assumed viewpoint.](image)

4.2 Confirmation of the ability to observe a 3D image from 360 degrees

Figure 13 shows the images at each viewpoint when the 3D image is observed from different horizontal viewpoints. The images in the center column shows the images observed at 0 degrees. The images in the left column shows the images observed at -45 degrees. The images in the right column shows the images observed at 45 degrees.

It can be confirmed that the parallax is caused by the horizontal shift of the viewpoint as shown in Fig. 12.

Therefore, a three-dimensional image can be observed from all sides by projecting images according to the position of the mirrors.

![Fig. 13 Observed images at each viewpoint.](image)

5 Conclusion

A 3D display that can be observed from 360° that can superimpose a 3D image on a real object was proposed. This system is able to reduce the image distortion that occurs outside of the assumed viewpoint by using rotating mirror.

We confirmed that the distortion ratio is reduced less than 1% by using a tilted mirror, whereas distortion ratio is 20% in previous method. We also confirmed that the 3D images can be seen from 360 degrees by projected images according to the position of the mirrors.

We are going to build up an experimental apparatus of this proposed system.

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References
