Depth Enhancement of Time Multiplexed Light Field Display by Multilayering Display Surface Using Two Lens Arrays

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ABSTRACT
One of the problems with light field displays is that the resolution of the displayed object decreases with distance from the display surface. To solve this problem, we propose a multilayer display using two lens arrays and a high-speed projector. The resolution improvement is confirmed by simulation.

1 Introduction
In recent years, the development of products utilizing VR, AR, and other technologies has made devices capable of observing stereoscopic images more accessible. The development of three-dimensional displays that can display stereoscopic images without special glasses is attracting attention in the digital signage field. In particular, the development of light field display, which is one type of display that can be observed by multiple people with the naked eye, is expected.

A light field display is a display that reproduces the rays emitted from an object. Real objects reflect ambient light on their surfaces, and people recognize objects when the reflected light enters their eyes. In a light field display, this reflected light is considered to be rays emitted from an object, and by reproducing these rays, a three-dimensional display is achieved. In order to reproduce the rays emitted from an object, a light field display has a structure that emits rays of different colors from the display surface in different directions.

One problem with light field displays is that when an object is displayed at a distance from the display surface, the resolution of the displayed object decreases as the object moves away from the display surface. This problem is caused by the structure of the light field display: As shown in Figure 1, the angular resolution of the rays that can be emitted by a light field display is determined by the structure of the light field display, which also determines the angle between the rays. Since rays are emitted in each direction from a point on the display surface, the distance between rays is proportional to the distance from the display surface. Therefore, if a point is displayed at a position far from the display surface, the accuracy of the position of that point is reduced. As a result, the resolution of areas far from the display surface is reduced.

To solve this problem, the purpose of this study is to improve the resolution of the display by increasing the number of layers on the display surface, even when the display target is large in the depth direction, it is possible to prevent the distance from the display surface and improve resolution. Previous studies to increase the depth resolution of light field displays by multilayering their display surfaces include methods such as preparing multiple display devices and multilayering their image surfaces [1,2], and using lenses [3] and mirrors [4] that respond differently depending on the polarization. Although multilayering is easy with these methods, luminance is easily reduced by half mirrors and other factors, resulting in low light source utilization efficiency. Polarization also makes it difficult to create more than three layers of multilayers.

In this study, two lens arrays and a high-speed projector are used to multilayer the display surface. This method is less likely to degrade luminance and can improve the resolution. Using this structure, simulations are performed to confirm that the resolution is improved at deep depth position.

2 Display principle of multilayer light field display
2.1 This study’s basic light field display principle
A light field display is a display that reproduces rays from an object. To reproduce the rays from an object, it is necessary that the display surface emits rays of different colors in different directions from the display surface. Therefore, in this study, a high-speed projector...
and lens array are combined to realize a light field display. The basic configuration of the light field display in this study is shown in Figure 2. The concave lens array is placed in front of the observer, and the high-speed projector projects images from behind the concave lens array. By refracting the ray coming from the projector with a concave lens, it appears to the observer as if ray is emitted from a light spot. The rays emitted from the light spot can change color in each direction. Here, by moving the lens array horizontally at high speed, the light spot moves and forms a light field display surface with an afterimage effect. By emitting rays from this light field display surface in accordance with the object, a three-dimensional display is achieved. In this study, the display surface is multilayered to improve the resolution from this basic method.

2.2 Multilayering methods

Two lens arrays are used to make the display surface multilayered. Figure 3 shows the structure of a light field display using two lens arrays. In the second lens array, lenses with different focal lengths and apertures are arranged side by side. The different focal lengths of the lenses change the depth position of the light spot as seen by the observer. This structure makes the display surface multilayered when the lens array is moved at high speed. The different apertures of the lenses then allow the same range of ray angles to be emitted from the light spot.

The first lens array consists of lenses with the same aperture and different focal lengths. All the lenses receive the same number of rays from the projector when the lens apertures remain the same in size. As a result, the same density of rays is emitted from each display surface and the same resolution at all layers. The focal length of the lenses is matched to the aperture of each lens in the second lens array.

This structure allows the light field display surface to be multilayered, and the viewing area and ray density of each layer can be the same. When moving the lens array, it is necessary to move it at the same speed and direction so that the positional relationship between the two lens arrays does not change.

2.3 Arrangement of lens array

For using two lens arrays, the efficient lens arrangement is considered. Figure 4 shows the square grid arrangement of the first lens array and the second lens array. The green and red lenses represent different focal lengths, so the light passing through the green lens of the first lens array is incident on the green lens of the second lens array, and the light passing through the red lens is incident on the red lens. The distance from the lens to the light spot is different for the red lens and the green lens. As these lenses move, each light spot forms a layer and a two-layer light field display can be realized.

By tilting and moving these lens arrays as shown in Figure 5, the light spots appearing by the lenses are arranged in two dimensions. These arranged light spots form the display surface. The tilt is set so that the lens with the same focal length changes by one step when it is moved by one cycle.
2.4 Structure of the proposed light field display

For a multilayer display surface, it is necessary to move the two lens arrays so that their positional relationship does not change. Therefore, the two lens arrays are arranged in a concentric cylindrical shape as shown in Figure 6. The image is then projected from the center by a high-speed projector. With this structure, the two lens arrays can be moved without changing their positional relationship by rotating them in the same direction at the same rotational speed.

3 Simulation

We confirm that the proposed method enables stereoscopic display and improves resolution by simulation. The method of image generation in the simulation is ray tracing. The structure devised is a concentric cylinder, however to confirm the effect of the multilayer display surface with two lens arrays, the lens array is assumed to be an ideal lens array with an infinite wide area and parallel light emitted from the projector.

Figure 7 shows the positional relationship between the lens array and the observer in the simulation, where the distance between the two lens arrays was set to 50mm and the observer was observed at a distance of 300mm from the second mirror array. In the simulation, the lens array was designed so that 28 lenses are aligned in one cycle and one cycle is formed when the lens array moves 300mm. As a result of setting the viewing angle to 45 degrees, the display surfaces were placed 7.58mm and 18.29mm away from the second lens array. The objects to be displayed were two cubes, 20mm on each side, tilted so that the diagonal of the cubes was parallel to the z-axis, and positioned so that the center of each of the three surfaces closest to the observer was located in the center of the two-layer display surfaces (Figures 8,9).

In the simulation, the viewpoint was shifted up, down, left, and right to be ±20 degrees from the normal of the second lens array surface, and images were taken from the observer’s viewpoint to confirm the three-dimensional display. In addition, in order to confirm that the resolution was increased by using two layers of display surfaces, a comparison was made by displaying the images with one layer. Three types of comparisons were made: one with the light field display surface in the center of the surface of the cube near the observer, one with the light field display surface in the center of the surface of the cube far from the observer, and one with the light field display surface in between the two.
4 Simulation results

Figure 10 shows the simulation results of the three-dimensional display confirmation. The simulation results show that the proposed display structure allows images to change depending on the observation position and enables three-dimensional display.

Figure 11 shows the simulation results of the resolution confirmation. The simulation results show that the closer to the display surface, the higher the resolution of the display object, confirming that the resolution of the display object improves when the display surface is multilayered. On the other hand, the number of pixels used per layer decreases due to multilayering, and pixel omissions appear.

5 Conclusions

The light field display with the structure proposed in this study allows the display surface to be multilayered and the resolution to be improved. Although a lens array was used in the simulations of this study, a mirror array can be used instead of a lens array if the properties of the proposed structure can be satisfied. This study is expected to improve the resolution and development of light field displays in the future.

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References