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360-degree Glassless 3D Display and Its Simplification

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ABSTRACT

We research a method of high-quality 360-degree 3D display with a simple optical structure without 3D glasses. Our proposed method applies 3D visual perception, and a simple optical configuration is advantageous for image quality and structure. We have shown the feasibility of our method from projection verification using a prototype.

1 Introduction

The 360-degree 3D display without 3D glasses can display realistic objects as if they were on a table in real space. It is expected to have a wide range of applications such as live sports viewing, industrial product modeling, and remote education.

Autostereoscopic 3D display technologies with 360-degree motion parallax have been proposed. Kim et al. proposed a method capable of autostereoscopic viewing at 360 degrees by rotating a transmission-type screen at high speed [1]. However, since images are displayed by time division with systems using a rotating screen, it is hard to increase the frame rate and it is also difficult to enlarge the display surface because a high-speed rotation mechanism is required. Furthermore, a large rotation mechanism needs to be installed under the table, which limits the places where the table can be installed.

A display method that does not require a rotation mechanism was proposed by Yoshida [2]. The system uses 288 projectors placed at very small intervals (1.25 deg), projecting onto a special cone-shaped screen. Using multiple projectors to project viewpoint images in this way is advantageous in that the frame rate is not decreased. On the other hand, many projectors at very close intervals are needed to switch smoothly between video sources as the viewpoint moves, which increases equipment costs and the complexity of the content control system.

2 Reduce the number of viewpoint images and projectors

To reduce the number of viewpoint images and projectors, we have focused on a perceptual mechanism of the visual system called "Linear blending". In linear blending, the luminance of the image from adjacent viewpoints is composed based on the observer's viewing position, so that the intermediate viewpoints are perceived as being visually interpolated.

2.1 3D visual perception

Figure 1 shows the perceptual mechanism of the image projected in the human retina, which is the basis of this autostereoscopic 3D display [3]. When two images overlap with a slight horizontal offset, an image with double edges to the left and right is projected onto the human retina as shown in Fig. 1 (a). However, in the human visual system, if the distance between these two edges is less than the fusion limit angle [4], the edges are perceived as one edge instead of two, and the perceived position of the single edge varies as a smooth transition according to the luminance ratio of the two overlapping images as shown in Fig. 1 (b).

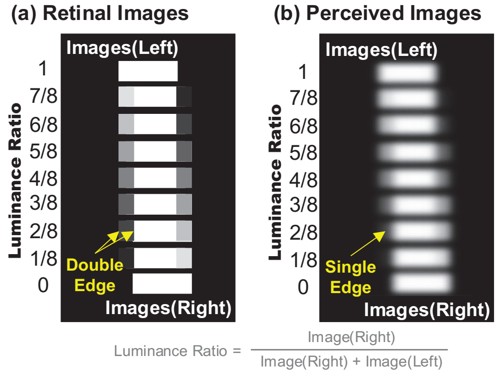

Fig. 1 Luminance Ratio and Edge Perception

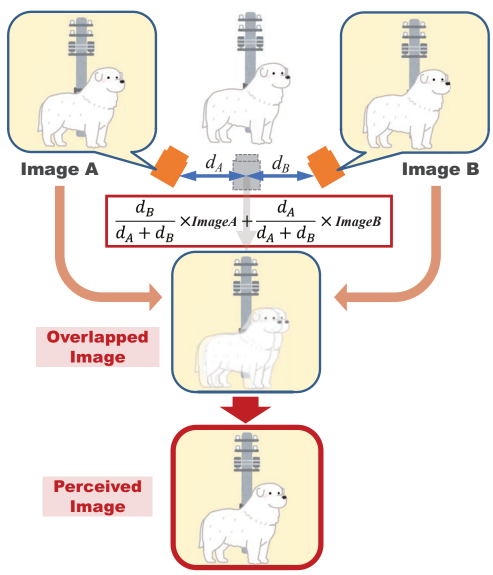

Fig. 2 Perception of Intermediate Viewpoint

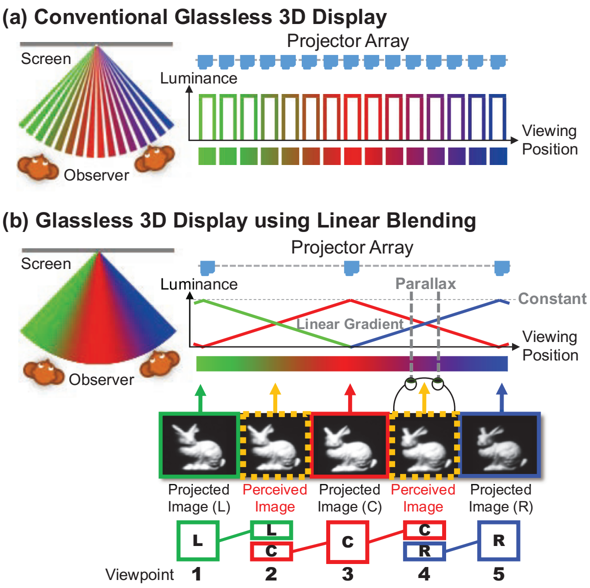

Fig. 3 Luminance Distribution using Optical Linear Blending

2.2 Overlapped adjacent images

To implement the linear blending mechanism, we require an optical hardware system whose luminance ratio changes according to the viewpoint position and viewpoint images with a disparity smaller than the fusion limit angle. Figure 2 shows a perception mechanism of intermediate viewpoint in the linear blending. By changing the composite luminance ratio of two adjacent viewpoint images according to the viewpoint of the observers, the observer can perceive 3D images by binocular disparity and smooth motion parallax, even when the projector intervals are wider than the space between the observers' eyes. Therefore, systems that use linear blending use fewer projectors by perceptual complementation of intermediate viewpoints.

The conventional method needs a closely spaced projector array to achieve binocular disparity and smooth motion parallax as shown in Fig. 3 (a), and the screen is designed to have a sharp luminance peak so that adjacent viewpoint images are not synthesized.

In contrast, linear blending does not require a closely spaced projector array as shown in Fig. 3 (b). The screen is designed to have a luminance distribution where the luminance peaks at the center position of the projector and decreases gradually as the distance from the center increases in the horizontal direction. Furthermore, since binocular disparity and transitions to adjacent viewpoint images are provided by the optical device configuration, the linear blending system projects a viewpoint image that corresponds to the projector position without a complex rendering process.

In linear blending, the total luminance of each light projected from adjacent projectors is always constant even if the viewing position changes. However, it has been confirmed that edge perception occurs even if the change is not a linear change in luminance but a non-linear change due to a general normal distribution (a general Gaussian distribution) by recent research using a general diffuser [5].

Applying this mechanism of luminance blending to multiple projector 360-degree 3D systems can significantly reduce the number of projectors required to display an intermediate viewpoint image.

3 360-degree tabletop type 3D screen system

To apply luminance blending to a 360-degree tabletop type 3D screen system and to reduce the number of required projectors, they proposed an optical configuration with a "spatial imaged iris plane screen" and a circular projector array [6]. We developed a prototype using 60 projectors, which enables observers to watch 3D images on a 1,200 mm diameter large display surface with a viewing area of 360 degrees as shown in Fig. 4. The interval between each projector is 6.0 degrees, about five times the conventional interval.

However, due to the structural characteristics of the screen, many various stray lights are generated, the image quality is significantly reduced, and many large 4K ultra-high-resolution projectors are used to improve the resolution. In addition, due to the restrictions of the laminated structure screen with a complicated structure, the projection angle on the screen cannot be large and a large-scale structure for projection is required above the observer, which is an important technical issue for practical use.

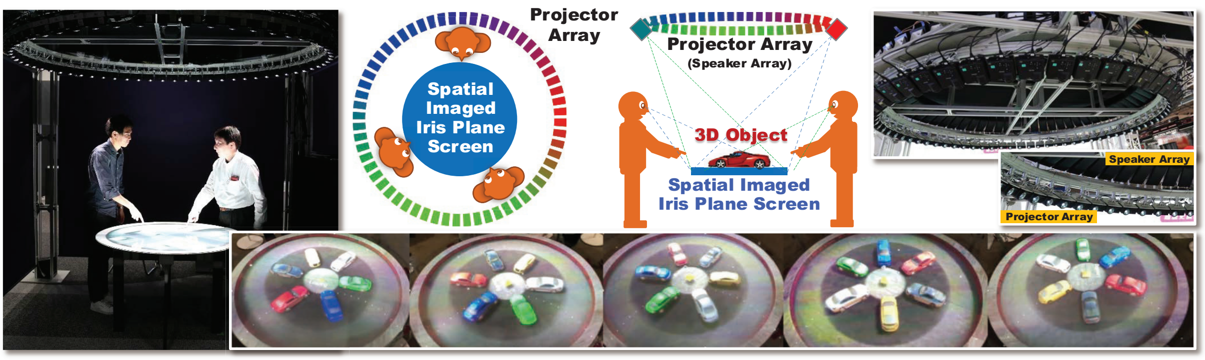

Fig. 4 360-degree Tabletop Type 3D Screen System

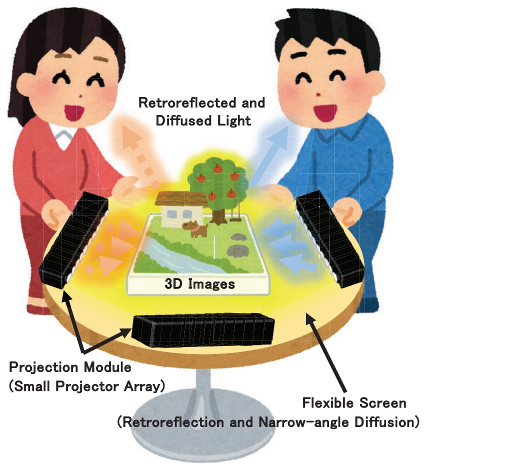

Fig. 5 360-degree Personal Glassless 3D Display

4 Simplified projection configuration

We proposed a method to realize a high-quality 3D display without 3D glasses as shown in Fig. 5 with a simple structure by applying retroreflection that is advantageous for image quality and structure. Then, the technical feasibility was shown by the basic verification using the actual prototype [7].

4.1 Proposed method

Figure 6 shows the optical configuration of our proposed method. The image from the small projector is projected on the screen on the table. The screen has not only retroreflective characteristics but also narrow-angle diffusion characteristics. The retroreflective material has a structure in which incident light is reflected in the incident direction by micromirrors or a micro glass bead as shown in Fig. 7. The image can be viewed only from a limited area in the observer's direction. In addition, by arranging multiple projectors in an array in the horizontal direction

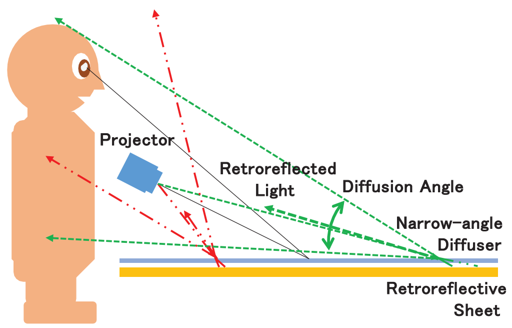

Fig. 6 Proposed Method

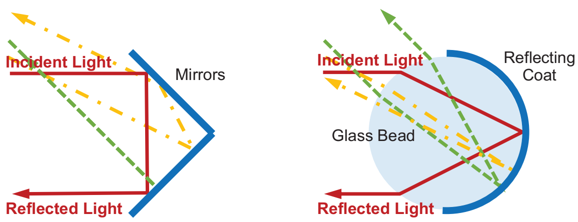

Fig. 7 Structure of Retroreflection

and using the luminance blending, the reaching area of light from adjacent projectors is designed to be twice the angle of the projector interval. As a result, even if the observer moves in the horizontal direction, the ratio of the luminance of the adjacent images gradually changes, and it is perceived that the image is smoothly transitioned to the image viewed from that direction. Despite the 3D display, it is possible to arrange projectors wider than the distance between both eyes, and the number of projectors is greatly reduced. Since it does not use any complicated optical configuration, it can project from a large angle close to the screen and can realize a compact 3D display with high image quality without stray light.

When these 3D display modules are arranged on the same table, many people can easily collaborate on work on the table even outside the viewing angle of one module unit.

4.2 Prototype and experiment

We developed a prototype for the experiment. Figures 8 and 9 show the optical configuration and appearance. As a projection screen on the table surface, an aerial display reflector (Nippon Carbide RF-Ax) is used for retroreflective reflection, and non-glare low-reflection

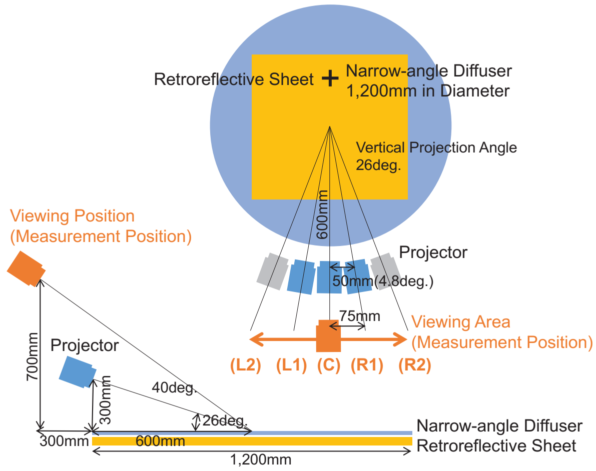

Fig. 8 Optical Configuration

Fig. 9 Prototype

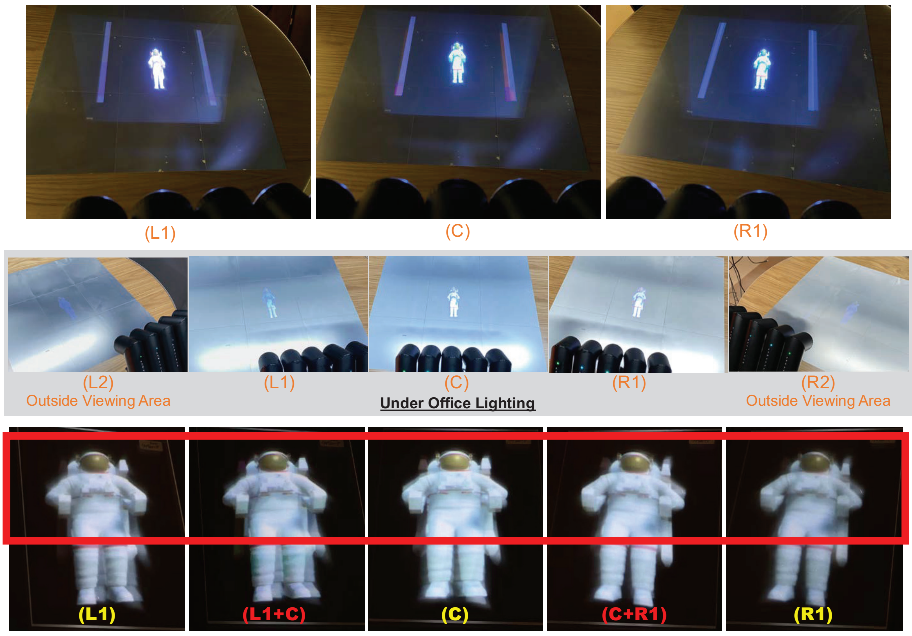

Fig. 10 Projected 3D Images

film (Tokyo Syscom AG800-G) is used for narrow-angle diffusion. Three small mobile projectors (FunLogy X-03) were arranged at an interval of 75 mm (4.8 degrees) which is larger than the distance between both eyes. The three viewpoint images were projected to screen as the overlapped image according to the mechanism of the luminance blending. In addition to the experiment under a dark room, we also evaluated as visual comparison under general office lighting (450 lx).

Figure 10 shows a photograph taken from a position moved to the left and right at the observation position. Despite the intervals between each projector is larger than the distance between both eyes, the observer perceived binocular disparity caused to the linear blending, and stereoscopic vision is possible regardless of the viewpoint position. It was also confirmed that stepless natural motion parallax causes even when the viewpoint moves in the left-right direction. Also, due to retroreflective and narrow-angle diffusion, most of the light projected from the projector returns to the observer's direction. Although the small mobile projector (100 ANSI lm), it was also confirmed that it has an image luminance of about 280 cd/m^2, which is sufficient for use under general office lighting.

5 Conclusions

We proposed 360-degree glassless 3D displays with a simple optical structure using a 3D visual perception of luminance blending. It demonstrated the feasibility of this method by developing prototypes.

In the future, we will develop a modularization of projectors and image control units and realize a 360-degree personal autostereoscopic 3D display system using the cooperation of multiple modules.

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