An Autostereoscopic Display with Time-Multiplexed Directional Backlight Using a Curved Lens Array

Garimagai Borjigin[1], **Hideki Kakeya**[1]

[1]Department of Intelligent Interaction Technologies, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 3058573, Japan

Keywords: Autostereoscopy, Curved Lens array, Crosstalk level, Time-division multiplexing, Directional light

ABSTRACT

We propose an autostereoscopic display with a curved directional backlight unit. The proposed backlight unit composed of a curved lens array and dot-matrix light sources suppresses the influence of filed curvature. Thus the crosstalk level is reduced without adding an additional layer of lens.

1 INTRODUCTION

Autostereoscopic displays have not been widely used yet due to the low image quality compared with the 3D displays with stereoscopic goggles. However, some applications such as medical displays for surgery or HUDs for automobile driving require autostereoscopy so that the vision of the surgeon or drivers may not be disturbed.

Conventional works on autostereoscopic display are mostly based either on parallax barrier or on lenticular lens. Both of these technologies have a drawback that the resolution of image they provide is lower than the original resolution of the LCD panel they use. For example, in a basic passive parallax barrier method aiming to generate a dual-view, the image resolution becomes half of the panel resolution.

Time-division multiplexing technology can realize a view having the resolution equal to that of the panel. The active parallax barrier is a typical way to implement this method [1-5]. Alternating the odd and even columns of the striped barrier and synchronizing it with the image on the display panel, the viewers can see a full resolution stereoscopic image. Another way to attain this goal is to use a time-multiplexed directional backlight. By delivering the directional light rays to each eye alternatively and synchronizing it with the alternating right-eye and left-eye images on the LCD panel, the full resolution stereoscopic image can be attained.

The use of lens is a common way to attain a directional backlight [6-8]. A display system composed of a large aperture convex lens and a dot-matrix light source can attain autostereoscopy with plural viewpoints [9]. However, the required optical distance is deep and the system becomes bulky. To reduce the thickness of display hardware, use of convex lens arrays has been proposed [10-13]. However, the image quality is poor because the distinct seam of lens array can be seen.

Ishizuka et al. have realized homogenous brightness of image by aligning the lenses so that the phase of lens arrangement in each raw may be different from one another [14]. The crosstalk level, however, is high due to the field curvature. Pursuing a lower crosstalk level, Ishizuka et al. have proposed a method to place a large aperture lens to reduce aberration [15]. However, two layers of Fresnel lenses used in this display system not only requires heavy optical calculation, but also produces stray light causing crosstalk.

As a solution to the crosstalk problem due to the stray light, a directional backlight system using a single layer of decentered lens array has been proposed to reduce the amount of crosstalk and optical calculation, but the crosstalk level is not low enough [16].

In this paper, we propose a further improved system using a curved lens array to achieve a lower crosstalk level. Furthermore, the optical calculation is light as well due to the single layer lens structure.

This paper is organized as follows. The conventional method is reviewed in Section 2 and the proposed method is described in Section 3. The experiment and its result are given in Section 4 and the paper is concluded in Section 5.

2 CONVENTIONAL RESEARCH

Time-division multiplexing autostereoscopic displays composed of a LCD and a synchronized directional backlight realize high-resolution 3D imaging without extra glasses.

The principle of the autostereoscopic display based on time-division multiplexing directional backlight is shown in Fig. 1. Dot matrix light sources are placed behind a lens array so that the interval may be the same as the focal distance of the elemental lenses, which realizes collimated directional light. By controlling the backlight to emit light at the position where the line connecting the observer's eye and the lens center intersects the backlight, directional light rays reach each eye. When the directional backlight to each eye alternates synchronously with the alternation of left-eye and right-eye images on the LCD panel, the viewer can see a stereoscopic image without wearing special glasses.

By increasing the number of light sources, multiple viewers can observe the stereoscopic image simultaneously.

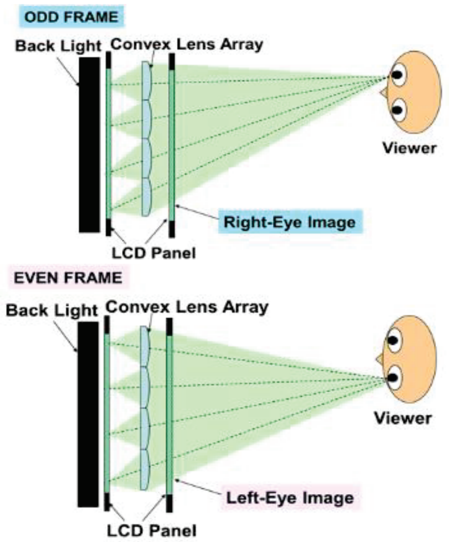

Fig. 1 The principle of basic time-multiplexed directional backlight autostereoscopic display

However, the poor image quality is the remaining problem of the system shown in Fig. 1. Because the lens array has distinct seams and the light going through the peripheral part of elemental lenses is weaker than the light going through the center of elemental lenses, the shape of the lens can be observed and the intensity of image is not uniform. To improve the image quality, Ishizuka et al. have placed a vertical diffuser behind the LCD panel while the small rectangle lenses are placed with stepwise phase shifts.

The problem of this system is the strong crosstalk due to the field curvature. In order to solve this problem, Ishizuka et al. have proposed a method to place a large aperture lens to reduce aberration. Yoshida et al. have added mirrors between the backlight and the lens array to prevent intrusion of light from adjacent segments. The structure of this advanced system is shown in Fig. 2.

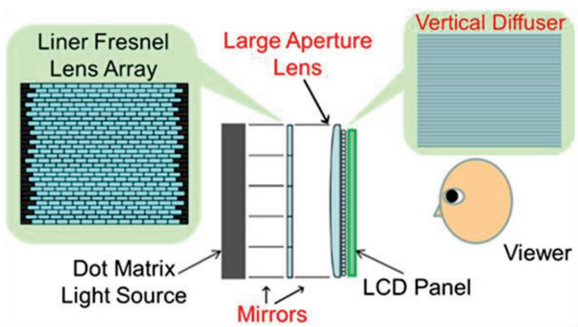

Fig. 2 The advanced system to reduce crosstalk level caused by field curvature

Two layers of Fresnel lenses used in the conventional system, however, not only requires heavy optical calculation, but also produces stray light, which causes crosstalk. The angle of prism becomes large and the groove becomes deeper in the area far from the lens center. As shown in Fig. 3, stray light going along an unplanned light path appears, which ends up with an optical noise. Additionally, the double layers of Fresnel lens increase the crosstalk level because of the reflection between them.

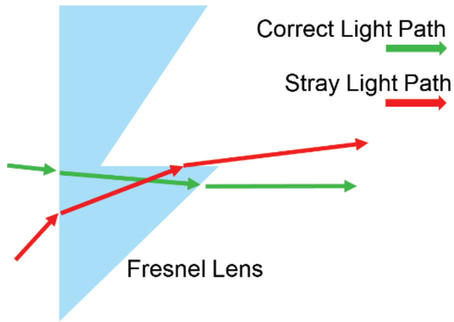

Fig. 3 The cause of stray light

To achieve a lower crosstalk level with a lighter optical calculation, Borjigin et al. have proposed a directional backlight system using a single layer of decentered lens array. As shown in the Fig. 4, they use a decentered lens array, where the geometrical center of the elemental lens becomes farther from the optical center as the location of the lens becomes farther from the center of the display. However, the crosstalk level is still high.

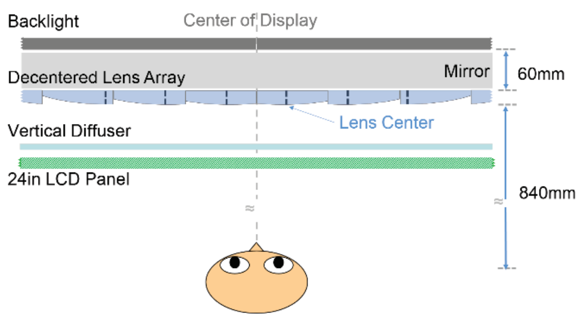

Fig. 4 The method using a decentered lens array

3 PROPOSED METHOD

Instead of arranging the lens array on a flat plane as the conventional methods do, we arrange the lens array in a curved shape as shown in Fig. 5.

Since the angles of incidence from the center of viewing zone to the peripheral lenses become larger in the conventional flat lens array, the luminous area to generate directional lights for the right and left eyes overlap due to the field curvature of lens. On the contrary, the angle of incidence is kept constant when the lenses are aligned in a curved shape. Therefore, the overlap of luminous area is avoided. Since the point of observation is on the center of the circular arc, lines connecting the point of observation and the center of lenses are orthogonal to the arc, which means that the angles of incidence to the lenses are all zero. Under this deal condition, the influence of field curvature is minimized.

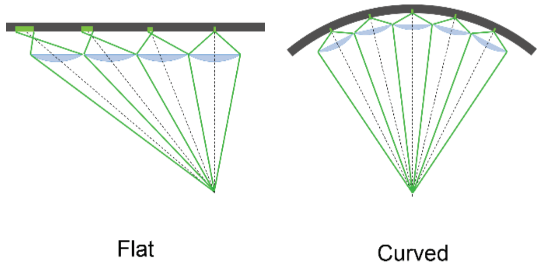

Fig. 5 Comparison between flat and curved arrangement of lens arrays

As shown in Fig. 6, the dot matrix light source is composed of a LED surface light source and a 27 inch LCD panel that has a R1800 curve. Since the backlight was on a circular arc with a radius of 1800 mm, we arrange the lenses on a circular arc sharing the same center of circle with the backlight so that the gap between the lens array and the LCD panel may be equal to the focal length.

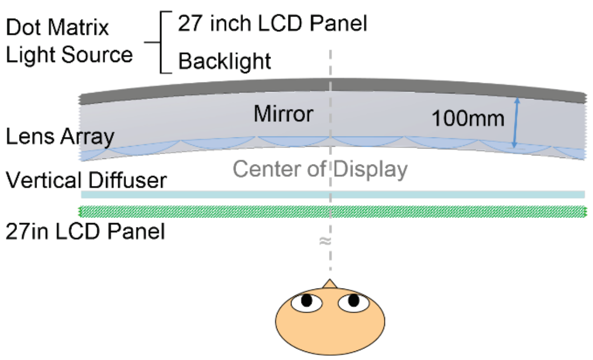

Fig. 6 Autostereoscopic display system based on the proposed method

As in the conventional research, we align the lens array with stepwise phase shifts, as shown in Fig. 7, and use a vertical diffuser to realize a uniformly bright image. Additionally, we also place a partial ring shaped mirror to separate the light sources for different steps of lenses.

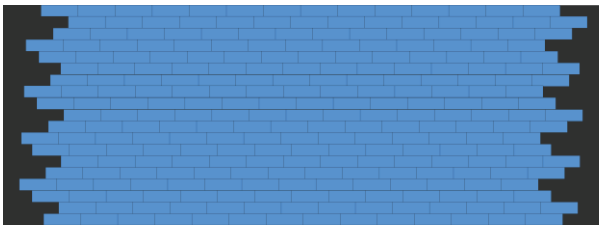

Fig. 7 Stepwise phase shifts of lenses

4 EXPERIMENT AND RESULT

We made a prototype display system based on the proposed method and evaluated its crosstalk level.

We cut the acrylic circle whose thickness was 15 mm into the shape of cylindrical lens and used it as the elemental lens as shown in Fig. 8. The lens was 48 mm in width and 15 mm in height and had 100 mm focal length.

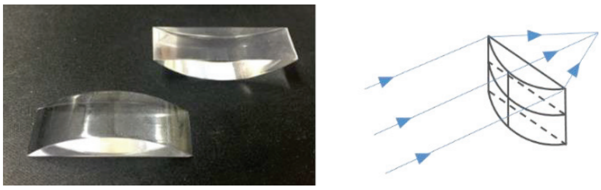

Fig. 8 Elemental lens

The prototype system is shown in Fig. 9. We used a pair of LCD panel of ASUS ROG SWIFT PG27V, which had the resolution of 2560 × 1440 and 144 Hz maximum refresh rate.

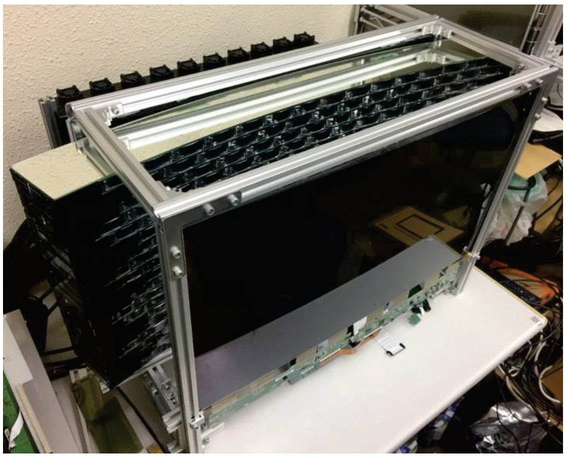

Fig. 9 Prototype system

To evaluate the crosstalk level, the luminance was measured under the following 3 conditions: View 0 (both the left-eye image and the right-eye image were black to measure the ambient luminance); View 1 (the left-eye image was white and the right-eye image was black); View 2 (the left-eye image was black and the right-eye image was white). The luminance was measured every time a luminance meter was moved by 1 cm in the fixed viewing zone. The distance of luminance meter moved from the original point is denoted as d. The result of the experiment is shown in Fig. 10.

We select the data at $d = 8$ [cm] and $d = 15$ [cm] as the luminance for the left-eye position and the right-eye position respectively so that the crosstalk level may be minimized while maintaining the interval the same as the human interpupil distance. The observed crosstalk level is defined by

$$Crosstalk\ Level = \frac{1}{2}\left(\frac{L_{v2}-B_l}{L_{v1}-B_l} + \frac{R_{v1}-B_r}{R_{v2}-B_r}\right), \quad (1)$$

where L_{v1} and L_{v2} are the luminance at the left-eye position ($d = 8$) under View 1 and View 2 conditions, R_{v1}

and R_{v2} are the luminance at the right-eye position ($d = 15$) under View 1 and View 2, and B_l and B_r are the ambient luminance at the left-eye and the right-eye positions. By substituting the experimental data into the equation above, the crosstalk level is calculated as 5.2%. The crosstalk level in the conventional autostereoscopic systems using a directional backlight has been 9.5% [16] or higher, which means that the crosstalk level is reduced notably by the proposed method.

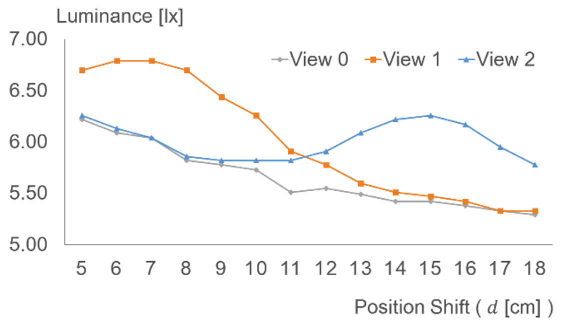

Fig. 10 Result of the experiment

5 CONCLUSIONS

In this paper, we have proposed a directional backlight system using a curved lens array, while the previous systems used a flat one. The proposed system can reduce the overlap of light rays to the left eye and to the right eye due to the field curvature of lens without adding an additional layer of lens, which causes crosstalk. A lower crosstalk level is confirmed in the experiment using a luminous meter. The crosstalk level in the conventional autostereoscopic systems using a directional backlight has been 9.5% or higher, while the crosstalk level of the proposed system is 5.2%. Thus the crosstalk level is reduced notably.

ACKNOWLEDGEMENT

This research is partially supported by the Grant-in-Aid for Scientific Research, JSPS, Japan, Grant number: 17H00750 and is partially supported by JST CREST Grant Number: JPMJCR18A2.

REFERENCES

[1] K. Perlin, et al., “An autostereoscopic display,” Computer Graphics, 319-326 (2000).
[2] H. J. Lee, et al., “A high resolution autostereoscopic display employing a time division parallax barrier,” SID06 Digest, 81-84 (2006).
[3] J. E. Gaudreau, “Full-resolution autostereoscopic display with all-electronic tracking system,” SPIE Proc. 8288-70 (2012).
[4] H. Kakeya, K. Okada, and H. Takahashi, "Time-Division Quadruplexing Parallax Barrier with Subpixel-Based Slit Control," ITE Trans. on MTA, 6(3), 237-246 (2018).
[5] H. Kakeya, A. Hayashishita, and M. Ominami, "Autostereoscopic Display Based on Time-Multiplexed Parallax Barrier with Adaptive Time-Division," Journal of the Society for Information Display, 26(10), 595-601 (2018).
[6] J. C. Schultz, et al., “Full Resolution Autostereoscopic 3D Display for Mobile Applications,” SID 09 Digest, 127-130 (2009)
[7] A. Travis, N. Emerton, T. Large, S. Bathiche, and B. Rihn, “Backlight for ViewSequential Autostereo 3D,” SID 10 Digest, 215–217 (2010).
[8] M. J. Sykora, “Optical characterization of autostereoscopic 3D displays,” SPIE Proc. 7863-29 (2011).
[9] T. Hattori, et al., “Advanced autostereoscopic display for G-7 pilot project,” SPIE Proc. 3639, 66-75 (1999).
[10] T. Hattori, “Stereoscopic Picture Display Device,” JP Patent 08-160355, A (1996).
[11] T. Hattori, “Stereoscopic Picture Display Device,” JP Patent 08-160356, A (1996).
[12] T. Hattori, “Stereoscopic Video Display Device,” JP Patent 08-160556, A (1996).
[13] T. Hattori, “Stereoscopic Video Display Device,” JP Patent 08-163603, A (1996).
[14] S. Ishizuka, et al., “Multi-Phase Convex Lens Array for Directional Backlights to Improve Luminance Distribution of Autostereoscopic Display,” IEICE Trans. Electron., Vol. E98-C(11), 1023-1027 (2015).
[15] T. Mukai and H. Kakeya, "Enhancement of viewing angle with homogenized brightness for autostereoscopic display with lens-based directional backlight," Proc. SPIE 9391, pp. 93911A.1-8 (2015).
[16] G. Borjigin and H. Kakeya, "An autostereoscopic display with time-multiplexed directional backlight using a decentered lens array," in Digital Holography and Three-Dimensional Imaging 2019, OSA Technical Digest, paper W2A.2 (2019).