An Autostereoscopic Display with Time-Multiplexed Directional Backlight Using a Novel Linear Fresnel Lens Array

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ABSTRACT

We propose an autostereoscopic display with a directional backlight unit using a novel linear Fresnel lens array. In the proposed system, stereoscopy is maintained even when the observer tilts his head by applying the proposed backlight unit.

1 INTRODUCTION

Time-multiplexed directional backlight is a basic technology that can realize an autostereoscopic view having the resolution equal to that of the LCD panel. By delivering directional light rays to each eye alternatively and synchronizing it with the alternation of right-eye and left-eye images on the LCD panel, a full resolution stereoscopic image is attained.

The most popular way to realize a directional backlight is to use prisms or lenses [1-3]. An autostereoscopic display system consisting of a large aperture convex lens and a dot-matrix light source can realize plural viewpoints [4]. However, the required optical distance becomes deep and the system becomes bulky. To reduce the thickness of display hardware, use of an convex lens array has been proposed [5-8]. However, the image quality is poor because of the distinct seam of the lens array.

Ishizuka et al. have realized homogenous brightness of image by using vertical diffusers while aligning the lenses so that the phase of lens arrangement in each raw may be different from one another [9,10]. Additionally, some advanced versions of the system to lower crosstalk have been proposed [11-13]. However, the drawback of all the systems relying on vertical diffusers to attain homogenous backlight is the collapse of stereoscopy when the observer tilts his or her head.

In this paper, we propose a method to overcome this problem by using a novel Fresnel lens array, which does not require diffusers to realize homogenous light intensity.

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 the result are explained in Section 4 and the paper is concluded in Section 5.

2 CONVENTIONAL RESEARCH

An autostereoscopic display with full resolution of the display panel is realized by time-division multiplexing. Autostereoscopy is attained by time-division multiplexing directional backlight synchronized with the LCD panel to show two different images to each eye.

The basic principle of time-division multiplexing directional backlight composed of a lens array is shown in Fig. 1. The interval between the dot matrix light source and the lens array is equal to the focal length of the elemental lenses so that the collimated directional lights can be realized. By emitting light at the position where the line connecting the observer's eye and the lens center intersects the backlight surface, directional light rays are delivered to each eye of the observer. When the alternation of directional backlight to the left eye and the right eye synchronizes with that of the images on the LCD panel, autostereoscopy is attained.

In this system, more than one viewer can observe the stereoscopic image simultaneously by increasing the number of light sources on the LCD panel of the backlight unit.

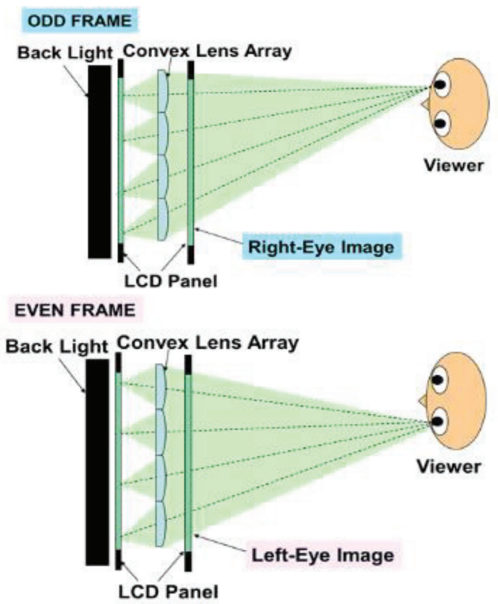

Fig. 1 Principle of the autostereoscopic display with time-multiplexed directional backlight.

In this system, however, the seam of the elemental lenses in the lens array are so distinct that the observer can see the shape of the lenses, which leads to poor image quality. In other words, the intensity of backlight is not uniform. The main problem is that the light going through the peripheral part of elemental lenses is weaker than that going through the center of lenses. 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 [9,10]. The basic configuration of the system is shown in Fig. 2. Mukai et al. have proposed a method to place a large aperture lens to reduce crosstalk caused by the field curvature. The mirrors between the backlight and the lens array have been added to prevent intrusion of light from adjacent segments for reducing the crosstalk [11]. Decentered lens array [12] and curved lens array [13] have also been tried, both of which reduces crosstalk caused by field curvature of the lenses.

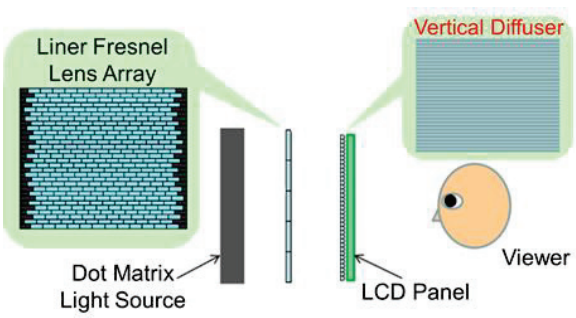

Fig. 2 Realization of uniform backlight.

However, the autostereoscopic system composed of a lens array and a vertical diffuser described above have viewing zones for each eye with vertically extended area because of the vertical diffusion, which disables stereoscopy when the head of the observer is tilted strongly.

Besides the directional backlight, a lens array can be used to attain autostereoscopy in various ways. For example, integral imaging uses a lens array to realize a multiview display. To obscure the distinct seam of lenses in the coarse integral volumetric imaging display [14-16], Kakeya has proposed a method to use a unique linear Fresnel lens array as shown in Fig. 3 [17]. As the figure shows, the small elemental prisms for the left lens and the right lens are interleaved in the connecting part of the lenses, which makes the seam of adjacent lenses less distinct. By using two layers of these lenses, a convex lens array with non-distinct seams is realized.

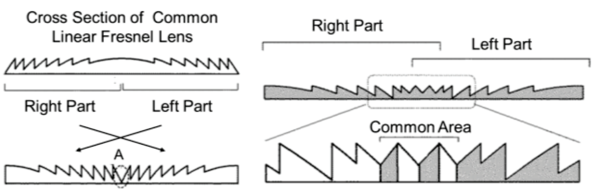

Fig. 3 Linear Fresnel lens with non-distinct seam.

3 PROPOSED METHOD

To overcome the drawback of the conventional systems described above, we propose a method to apply the linear Fresnel lens with non-distinct seams to realize a homogenous backlight.

The lenses we propose to use to realize a homogenous backlight is shown in Fig. 4. Though the basic principle of the lens to obscure the seam is the same as that in Fig. 3, the prisms are interleaved not only in the peripheral part of the elemental lenses, but also in the central part of the lenses. Thus the uniformity of luminance increases.

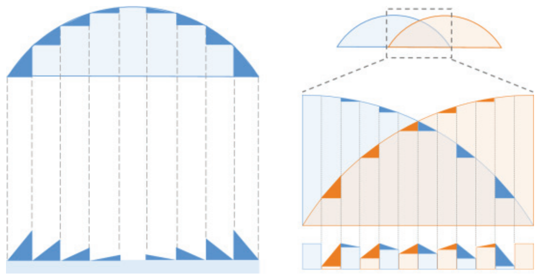

Fig. 4 Comparison between a normal linear Fresnel lens and the proposed linear Fresnel lens.

When the spherical lenses are aligned as shown in Fig .5 (b), which is equivalent to a pair of linear Fresnel lens array layered so that they are orthogonally aligned as shown in Fig. 5 (a), intensity of backlight is not homogenous as shown in Fig. 5 (c).

When the novel Fresnel lens array is applied, the elemental lenses are virtually overlapped because of the interleaved structure as shown in Fig. 5 (d) and (e). In this case the uniformity of backlight increases as shown in Fig. 5 (f). In this way, a homogenous backlight is attained without using a vertical diffuser.

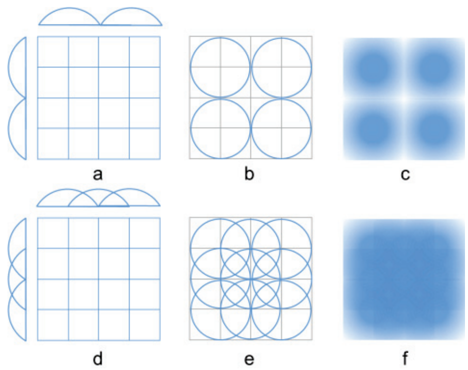

Fig. 5 Structure of lens array.

As shown in Fig. 6, we made a prototype of the autostereoscopic display using the lens array explained above. The dot matrix light source is composed of a LED surface light and a 27-inch LCD panel. The lens array composed of two layers of novel linear Fresnel lens is placed 100 mm away from the dot matrix light source so that the gap between them may be equal to the focal length. A 24-inch LCD panel for displaying the images for two eyes is placed between the lens array and the observer.

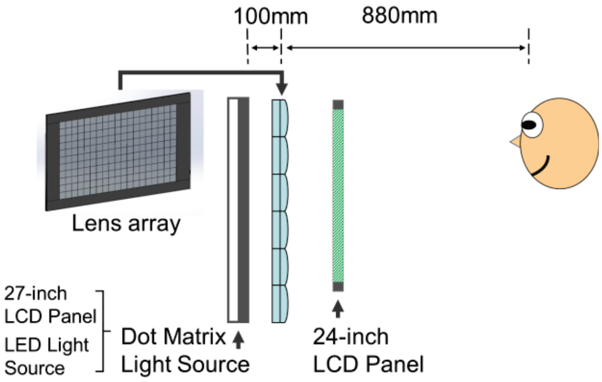

Fig. 6 Autostereoscopic display system based on the proposed method.

4 EXPERIMENT AND RESULT

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

The picture of the prototype system is shown in Fig. 7. The LCD panels we used had the resolution of 1920 × 1080 and 120 Hz maximum refresh rate. The elemental lenses were 30 mm in width and in height and had 100 mm focal length.

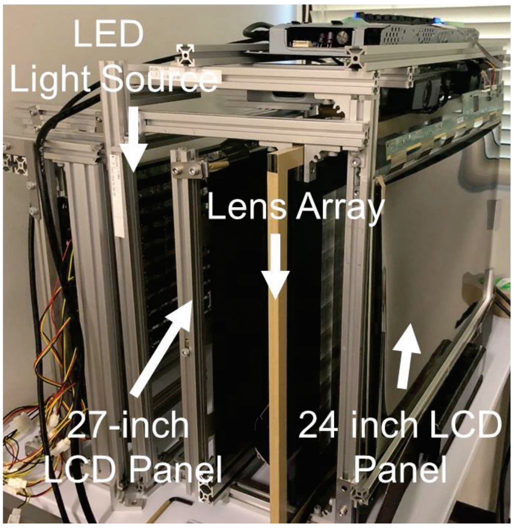

Fig. 7 Prototype system.

The results of observation are shown in Fig .8. Here a full red image was displayed for the left eye and a full green image was displayed for the right eye for testing. We can see that the central area of image is more uniform than the peripheral area. This is due to the field curvature of lenses. This problem is expected to overcome by applying the conventional method to reduce the effect of field curvature. Leakage of light between the elemental lenses is also visible because the lens units are assembled by hand.

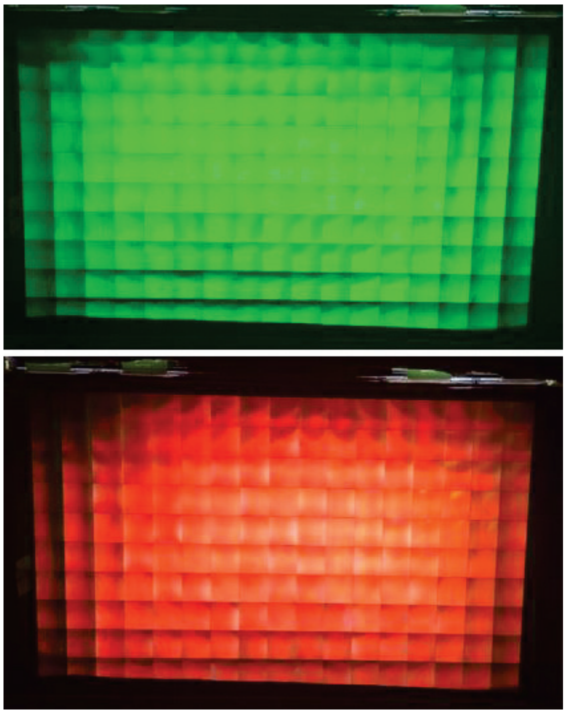

Fig. 8 Observation of test image with the prototype system.

We used a luminance meter (Kaise digital light meter KG-75) to measure the crosstalk level. 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). We set the original point of measurement in the center of the display panel, while the distance was 800 mm away from the panel. The luminance was measured every time a luminance meter was moved by 1 cm horizontally. The distance of luminance meter moved from the original point is denoted as *d*. The result of the experiment is shown in Fig. 9.

The suitable eye position for stereoscopy is decided so that the crosstalk may be minimized while the interpupil distance (PD) is restricted to 6 cm or 7 cm. We select the data at $d = -5$ cm and $d = 1$ cm as the luminance for the left-eye position and the right-eye position respectively so that the crosstalk level may be minimized when PD is 6 cm, while $d = -7$ cm and $d = 0$ cm are chosen when the PD is 7 cm. 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 under View 1 and View 2 conditions, R_{v1} and R_{v2} are the luminance at the right-eye position 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 5.8% (PD = 6 cm) and 5.4% (PD = 7 cm). The lowest crosstalk level in the conventional autostereoscopic systems with a directional backlight using a diffuser has been 4.6% - 5.8% [12], which means that the crosstalk level of the proposed method is on the same level as that in the previous research.

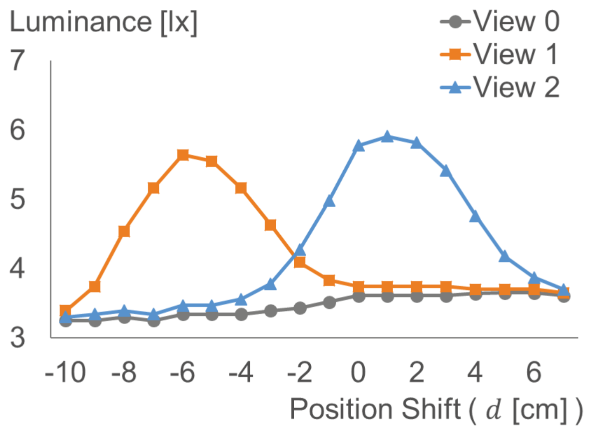

Fig. 9 Result of crosstalk measurement.

5 CONCLUSIONS

In this paper, we have proposed a method to realize a directional backlight by using a novel Fresnel lens array, which does not require diffusers to realize homogenous light intensity. The conventional systems that relies on vertical diffusers to attain homogenous backlight destroys stereoscopy when the observer tilts his or her head. With the proposed method, autostereoscopy is maintained even when the head is inclined by 90 degrees. To correct field curvature to attain homogenous light intensity in the peripheral part of the display is a future work to be accomplished.

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