A 23-in. full-panel-resolution autostereoscopic LCD with a novel directional backlight system

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Abstract — An autostereoscopic display that shows stereoscopic images with full-panel resolution has been developed,1 but it has a problem in terms of unit size. To resolve this problem, a new directional backlight system was developed, and it was applied to a prototype autostereoscopic LCD. The backlight system has two light sources – one for the right eye and the another for the left eye – and an elliptically shaped mirror that controls the direction of light from the light sources. The LCD uses a field-sequential method which re-writes an image for one eye and one for the other eye at a frame rate of 120 Hz, and the light sources alternately blink in synchronization with each frame so that the LCD shows full-panel-resolution stereoscopic images without flicker. In this paper, the new backlight system is described. The backlight system is effective for large screen such as 23 in. on the diagonal. By using this backlight system, the prototype LCD achieved practible unit size, brightness over the entire screen, and cross-talk.

Keywords — Autostereoscopic displays, full-panel resolution, directional backlight.

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1 Introduction

Today, various methods for autostereoscopic display have been studied because it has an advantage in that special glasses are not required. These stereoscopic displays show two different images as a stereo pair for a scene by using either a spatial-multiplexing method or a field-sequential method.2,3 In spatial multiplexing, a parallax barrier or an array of small lenses, which separates an image into two views for the left and right eye of a user, is on the surface of display device. Because of such elements, it is difficult for spatial-multiplexing displays to show full-panel-resolution stereoscopic images. On the other hand, displays using the field-sequential method can show full-panel-resolution images because a pair of images are alternately shown, although an LCD is required to re-write images typically at a 120-Hz frame rate to show stereoscopic images without flicker.

In the field-sequential method for autostereoscopic displays, various structures to control the direction of light have been presented. Those structures characterize the image quality of those displays the most, so that the structure used to control the direction of light is the most important component for autostereoscopic displays. Directional backlight systems that have been previously presented can certainly control the direction of light and show full-panel-resolution stereoscopic images, although the screen sizes are relatively small. In this paper, a structure for the backlight system originally designed for our prototype is presented, and its optical characteristics are described.

2 Directional backlight

2.1 Background

Various structures used to control the direction of light have been presented. In such studies,2–5 they can certainly demonstrate full-panel-resolution stereoscopic images, but collimated or nearly collimated light sources are required. Thus, their applications are limited to relatively small-screen displays. That is to say, they are difficult to be applied to large-screen displays of over 20 in. on the diagonal. If a display is intended to be used at a desk, its preferable viewing distance for the display is usually 400–951 mm.6 When a display is used in a range of distances, light emitted from the display surface needs to horizontally diffused at an angle ranging from 4.57 to 1.93° from the center of the display and 35.6–13.2° from the far left and right of the display. If the light transmitted from an LCD is collimated, the light has to be diffused when it passes through the LCD because users will not see part of the image on the far left and right of the display unless the light is sufficiently diffused in the horizontal direction. This diffusion causes cross-talk which interferes with depth perception. To solve this problem, light emitted from a backlight system is required to focus on a left or right point given as one of user’s eyes.

Travis2 has previously presented such a structure for a backlight system. This backlight system has a convex lens directly behind the LCD and two light sources some distance away from the LCD as shown in Fig. 1. With such a structure, light from one light source is focused on a designed point by the convex lens so that the user can see the entire image shown on the LCD. If the screen size of the LCD
becomes larger, it is difficult to use only a single convex lens to achieve a sufficient brightness on the far left and right of the LCD where the gradient of the lens becomes large; therefore, most of the light from the light sources cannot transmit through the lens and reflects on the surface of the lens. Even with more than one convex lens, it is difficult to achieve a sufficient uniformity of luminance.

The biggest problem with the convex lens method is the large depth of the backlight system. In this method, the position of the light source is specified by the desired viewing distance from the surface of the LCD and screen size, i.e., the depth of the backlight system is specified to include them. For a structure to solve this problem by using the convex lens method, scanned-backlight structures has been presented. In these structures, light sources are located at the far left and right of the LCD, and an array of prisms and convex lenses control the direction of light. With such structures, the depth of the backlight system can be small, but it is also difficult to apply to large-screen displays because it uses the refraction of light, and the intensity of light is reduced at the left and right side of the screen where the angle of refraction is large.

Our group suggested a directional backlight system with an elliptically shaped mirror, which could be applied to a relatively large-screen display 21 in. on the diagonal. But even with this structure, the total size of the system was still too large because two display units are needed, although the cross-talk was small and the luminance uniformity was practicable. The details of this structure is described as well as our previous structure in this paper.

As one of the structures to solve all the problems described above, a backlight system with an elliptically shaped mirror shared by two light sources has been also suggested. In this paper, details on this structure is described here again as the latest structure, and then the results of the optical characteristics are presented because any experimental result has not been reported. With this structure, the total size of the system could be reduced by about half that of the previous structure.

On the other hand, the quickness of the LCs in changing images is also important for autostereoscopic displays using the field-sequential method because residual images cause cross-talk and cause users to combine two images into an image seen with depth. A residual image appears when LC’s response time is not sufficient. In our prototype, the timing for turning on and off the light sources is optimized by using an RIR evaluation method that was presented at IDW 2009, so that our prototype achieved practicable image quality in cross-talk.

2.2 Previous structure

Figure 2 shows a schematic view of the previous structure of the directional backlight system using an elliptically shaped mirror with one light source. This backlight system uses a characteristic ellipse, which has two focus points. Light passing one focus point condenses to another focus point. Therefore, when the elliptically shaped mirror is illuminated by a light source located at one focus point \( f_{\text{LCD}} \), light reflects on the surface of the ellipse and condenses to another focus point \( f_{\text{EYE}} \) where the viewing position for one eye of the user is determined.

But this structure has a problem with the total size of display system. In this structure, two individual LCD units with backlight systems are needed because it is impossible to arrange two individual backlight systems on one plane.

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This means that one LCD unit shows only one of a stereo-pair images so that two LCD units are needed to show a stereo-pair image that is combined with a half-silvered mirror into an image seen in depth as shown in Fig. 3. Thereby, the total size of the display system is too large compared to a 2-D display of the same screen size and is not suitable for practical use.

2.3 Latest structure
The biggest problem of the former structure is its large size. With our latest structure, this problem has been solved. For the previous structure, the region of light source could be expanded towards the outer display without any negative effect on the optical characteristics, and the user can see images with good luminance uniformity even at the outer side of the focus point; for example, the upper side in Fig. 2. That is to say, all of the light from the light sources does not have to pass the focus points $f_{\text{LCD}}$ and $f_{\text{EYE}}$. It means that an elliptically shaped mirror can be shared by two light sources located across focus point $f_{\text{LCD}}$ as shown in Fig. 4, which is a schematic view of our latest structure of the directional backlight system. With this structure, light from the light source for the left eye and one for the right eye are separated by a viewing distance ($f_{\text{EYE}}$) by reflectance on the surface of the ellipse.

In Fig. 4, a pair of light sources located across one focus point $f_{\text{LCD}}$ behind the LCD glass faces an elliptically shaped mirror. Those light sources have to be located on the upper side of the LCD and also the lower side of the LCD because they interfere with the light transmitted by the LCD if they are in the displaying area. Because of the location of the light sources, the integration of an anisotropic diffusion plate on the back surface of the LCD is required.

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The plate diffuses incident light in only the vertical direction. Without this vertical diffusion plate, light from the upper light sources cannot reach the user facing the display because light from the upper side travels not to the center at the viewing distance but to the lower side.

To show stereoscopic images that have full-panel resolution, stereo-pair images are alternately shown on the display at a frame rate of 120 Hz. The left and right pair of light sources turn on and off in synchronization with the LCD’s refresh timing. With this structure, the user can see full-panel-resolution stereoscopic images without flicker.

2.4 Results of optical simulation

Aiming at prototyping a display which has a 1920 x 1080 resolution (23-in. diagonal), an elliptically shaped mirror and light sources were designed, and the calculation of a light path was performed before prototyping. When designing a backlight system that includes the ellipse and location and size of the light sources, we considered the depth of the display to be balanced with the viewing distance from the surface of the display (the depth is as small as possible and the viewing distance becomes neither too large nor too short). After careful consideration, the viewing distance, width of the display, and depth were determined to be 890 mm, about 600 mm, and about 250 mm, respectively. A per-
perspective view of our prototype is shown in Fig. 5. Figure 6 is a photograph of the prototype.

Figures 7(a)–7(c) are the result of the calculation of the light path of the directional backlight system. Figure 7(a) shows a top view when light from part of the light source for the right eye focuses just on the eye. Figure 7(b) shows light paths emitted from the left and right edges of the light source for the right eye. As shown in Fig. 7(b), light from the entire area of the light source for one eye does not reach the other side of user’s eye at the viewing distance, and a sufficient range of view for one eye can be obtained. Figure 7(c) shows a lateral view of the simulation results. In this figure, the red lines are light paths from the upper light source and blue lines are ones from the lower source. As shown in the figure, the diffusion plate behind the LCD spreads rays in the vertical direction.

2.5 Measurement of optical characteristics

At first, the luminance distribution for the viewing angle in the horizontal was measured. Figure 8 is a top view of this measurement. A luminance meter was set at the middle of viewing point and the luminance at the center of screen was measured by rotating the display unit in the horizontal plane. The result of this measurement is shown in Fig. 9. This figure shows that our latest backlight system can actually control the direction of light because the luminance value is high at the left-half side of the graph but small at the right-half side.

The luminance distribution on the display surface was measured by the method shown in Figs. 10(a) and 10(b). A luminance meter was placed at the point of the left eye (32 mm left from the center of the screen). For this measurement, the luminance meter was rotated in the vertical and horizontal directions, and 21 (seven points in horizontal direction, three points in vertical direction) were measured.
After measuring at the left-eye point, the luminance meter was moved to the point of right eye (64 mm towards the right). During this measurement, the light source for left eye blinked, and the one for right eye was in the disables state. An image shown on the display was a white still image. By performing this measurement, the actual luminance distribution seen by the user’s one eye and the luminance leakage to another eye are obtained.

The luminance distribution obtained by this measurement is shown in Fig. 11. The upper three lines are the results measured at left-eye point and the lower three lines are the results at the right-eye point. The luminance of left eye is larger than that of the right eye because the light sources for the left eye were in the enabled state and the other light sources were in the disabled state. A sufficiently bright image was gained especially around $x = 0$ mm, but they are still small at the left- or right-side parts. On the other hand, by paying attention to the difference between the upper three lines, the luminance at $y = 130$ is the highest and the smallest is at $y = 0$. This is because of the different incident angles of the rays to the vertical diffusion plate. When a ray from the upper light sources passes into the vertical diffusion plate, it is spread in vertical direction by the plate. If an incident angle is large, a ray has to be refracted mainly so that the intensity of the ray becomes small. The luminance at $y = 0$ is the lowest because the incident angle is the largest. The luminance being small at the center is certainly a problem; however, the value even at the center is large enough to see an image in a bright room.

A distribution of cross-talk ratio (ratio of leakage luminance to luminance in the enabled state) is shown in Fig. 12. The cross-talk ratio around the center is comparatively large and very little cross-talk images around the center may be seen, but it is sufficiently small. In fact, stereoscopic images could be seen across the entire area of the display.

This cross-talk mostly occurred because of the reflectance on the back surface of LCD where the reflectance ratio is about 12%. To reduce the cross-talk, the reflectance ratio on the LCD’s back surface has to be small enough.

### 3 Summary

Our prototype of an autostereoscopic display using ellipse-shaped mirror can successfully show stereoscopic images that have full-panel resolution. This display achieved a practicable unit size, brightness, and cross-talk ratio, although there needs to be improvement in the uniformity and cross-talk. As a next step, the two problems need to be solved at first, and then we are planning to prototype a smaller unit especially in depth by using newly designed mirror and light sources.

### Reference


Akinori Hayashi received his B.Sc. and M.Sc. degrees in engineering science from Osaka University, Japan, in 2000 and 2002, respectively. He joined Eizo NANAO Corporation in 2002. He has been working on the development of 3-D displays since 2006.