An Active Barrier Autostereoscopic Display with Less Crosstalk

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ABSTRACT

We propose an autostereoscopic display system using a monochrome panel as an active parallax barrier. We confirm that placing a monochrome panel for barrier in front of the color imaging panel generates less crosstalk than placing it behind.

1 INTRODUCTION

2D head-up displays (HUDs) have already been commercialized and installed in high-end automobiles. In the future, 3D imaging in place of 2D can realize more informative visual assistance, such as an augmented reality system where information is attached to the 3D position of the objects in the real world. Of course, autostereoscopy is required for automobile HUDs, for wearing 3D glasses darkens the view of the scene. Though there have been some trials to realize 3D HUDs [1], the resolution of the image has been limited.

Parallax barrier is one of the simplest and the most well-known methods to realize stereoscopy without wearing special goggles. In the conventional parallax barrier systems, however, the viewing zone maintaining stereoscopy is narrow, and the resolution of the image is lower than that of the 2D displays.

In order to realize full resolution autostereoscopy, time-division multiplexing parallax barrier, which is attainable with thin optics, has been proposed [2, 3]. The whole information of the stereo pair is divided into two frames by resolution, where one frame shows half of the resolution of each view while the next frame shows the other half by shifting the phases of the barrier pattern and the image pattern. Time-division multiplexing parallax barrier realizes a full-resolution autostereoscopic image with the help of after-image effect.

In addition, head-tracking technology widens the viewing zone [4-7]. By monitoring the position of the viewer, the image or the barrier pattern is adjusted accordingly to move the viewing point so that it always follows the position of the viewer and keeps correct autostereoscopy.

To achieve high resolution of image and expansion of viewing zone free from crosstalk, Zhang et al. proposed time-division quadruplexing parallax barrier [8-11]. In the proposed system, the same image is delivered to 2 of the 4 viewpoints, which suppresses emergence of crosstalk when each of the viewer's eyes is positioned between the two viewpoints showing the same image. The theory on the viewing zone free from crosstalk has also been established [12,13].

When we apply an active parallax barrier to HUDs, diffraction and interference of light by the LCD panels are not negligible, for the pixel pitch of the display panels is fine. To keep the crosstalk level low, the effect of diffraction and interference has to be suppressed. In this paper we discuss an optical design to suppress this effect.

2 PREVIOUS WORK

Matsumoto et al. have proposed an autostereoscopic HUD based on parallax barriers using head-tracking (Fig. 1) [14]. In this system the 2D display panel is replaced by a 3D display using parallax barriers in the mirror-based optical system to generate a virtual image. When the observer moves in the horizontal direction, the reverse image is observed through the barrier slit. When the normal image and the reverse image are mixed, the sub-pixels of the left eye image and the right eye image are shifted to maintain stereoscopy.

In this system, however, the resolution of the image drops into half of the display panel because the barrier is static. Also the viewing zone in the depth direction is limited because the widths of the interleaved image and the barrier slit are both fixed.

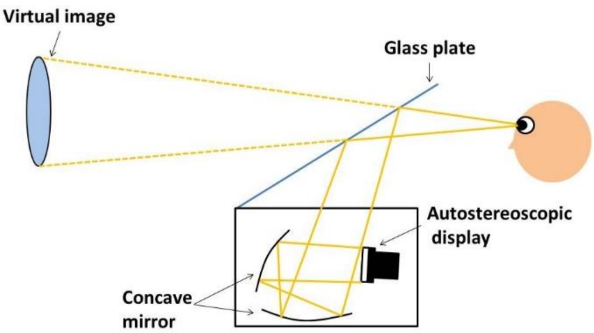

Fig. 1 Time-division quadruplexing parallax barrier.

Time-division multiplexing parallax barrier is an effective method to attain an autostereoscopic display without loss of resolution and to expand the viewing zone. We apply this method to realize a 3D HUD.

Fig. 2 shows the principle of time-division quadruplexing parallax barrier. Here 4 viewpoints and the corresponding images are denoted as A, B, C and D.

In this system a full resolution 4 view images are realized after 4 frames. When the refresh rate of the panel is 120 Hz, 30 Hz interlace image is reproduced.

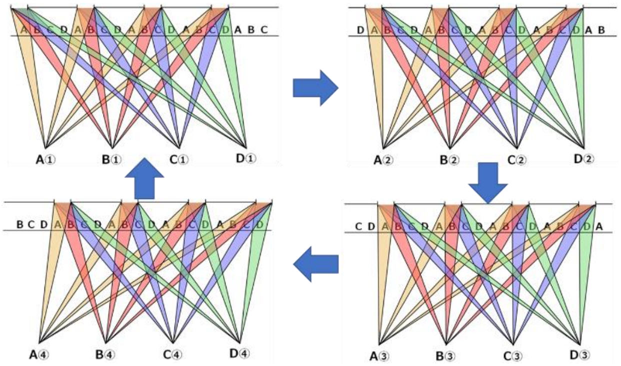

Fig. 2 Time-division quadruplexing parallax barrier.

In the parallax barrier system, the size of barrier pattern should be magnified or reduced to reflect the similarity of triangles consisting of the light rays and the display planes when the viewer approaches or goes away from the display. Analog control of the barrier size, however, is impossible because the pixel size of the LCD panel is fixed. What is possible with the LCD panels to cope with this problem is to shift the positions of the slits discretely.

Shift of slit by pixel unit, however, is not fine enough to keep on presenting the image without crosstalk. To realize finer control of barrier slits, Okada et al. proposed shift of the slits by subpixel unit [10]. Subpixel shift is enabled when the slits are slanted by $\tan^{-1}$ 1/3. By inserting a lenticular lens that diffuses light only along the inclined slits as shown in Fig. 3, the moiré caused by the layered panels is erased without destroying stereoscopy.

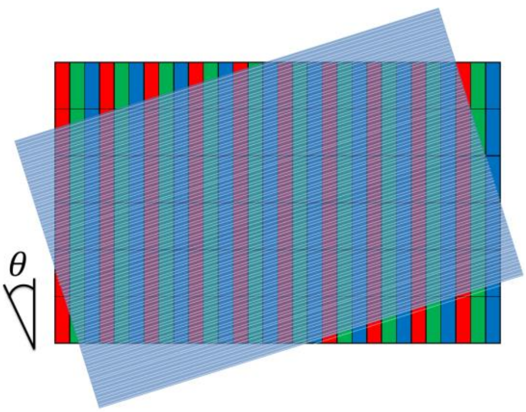

Fig. 3 Inclined directional diffusion.

Further fine shift of slit is realized by a slanted barrier slits whose inclination angle $\tan^{-1}$ 1/6 [15]. Here the directional diffuser is set so as to diffuse the light in the same direction as the inclined barrier slits. Also the right-eye image pattern and the left-eye image pattern are interleaved so that they are inclined in the same direction as the barrier slits as shown in Fig. 4.

In this system, the slit moves by 1/2 subpixel in the horizontal direction when the slit is shifted by 1 pixel in the vertical direction as shown in Fig. 5. When the minimum shift unit is half the original size, the viewing zone without crosstalk is expanded due to the fine tuning of the barrier pattern.

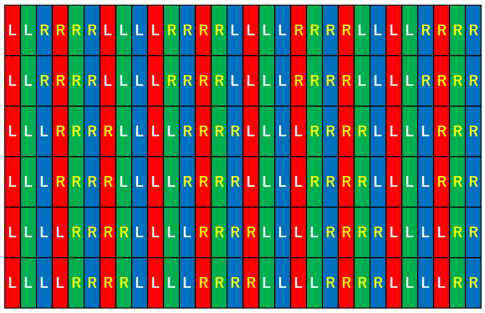

Fig. 4 Interleaved image pattern ($\theta = \tan^{-1}$ 1/6). Left-eye images are shown at subpixels L and Right eye-images are shown at subpixels R.

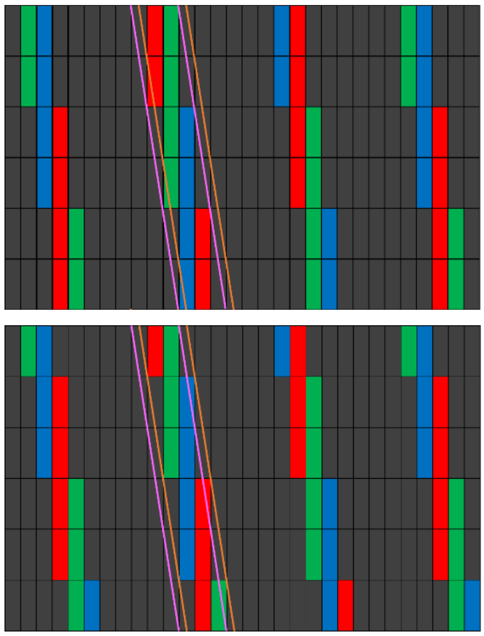

Fig. 5 Minimum barrier shift when $\theta = \tan^{-1}$ 1/6.

To commercialize this technology, use of a monochrome panel is desirable to show the barrier pattern, for the luminance of the image become three times brighter with the same backlight. In this case the diffuser is not needed to erase the moiré.

The authors have already applied the active barrier system composed of a monochrome LCD panel and a color LCD panel to the 3D HUD [16]. In that system the monochrome barrier is placed in front.

3 EXPERIMENTS

We made a prototype system using a pair of 3.1 [inch] monochrome panel and color panel whose pixel pitch *p* was 0.088 [mm]. In the parallax barrier system, the barrier can be placed in front or behind the image panel. We compare the images observed in both cases in Fig. 6. Here a black image is shown to the right eye position and a white image is shown to the left eye position.

As shown in the figure, the observed image becomes whiter, which means that the crosstalk is larger when the active barrier is placed behind, while the observed image is more black and the crosstalk is reduced when the active barrier is placed in front.

Fig. 6 The observed right-eye image when the dot matrix monochrome panel is behind the color imaging panel (top) and in front of the imaging panel (bottom).

In an autostereoscopic display using a LCD panel as a parallax barrier, the front panel works as a diffraction grating because of the dot matrix aperture structure. When the color panel is in front, the subpixels of the same color work as a diffraction grating. Therefore, the distance between the neighboring slits *d* is the same as the pixel pitch of the panel *p*. On the other hand, when the monochrome panel is in front, all the subpixels work as a diffraction grating. Therefore, the distance between the neighboring slits *d* is the same as the subpixel pitch of the panel *p*/3.

It is known that the bright condition in diffraction grating is given by

$$d\sin\theta = m\lambda,\ (\ m=0,1,2,\cdots\ ) \qquad (1)$$

where θ is the angle of light rays, *m* is the order of the interference fringe, and λ is the wavelength of light rays. As explained above, *d* becomes smaller when the monochrome panel is in front, which makes θ larger and the interval of bright lines sparser. Therefore, the amount of light rays into the eye is reduced, which suppresses crosstalk.

In order to measure the degree of diffraction by the monochrome panel and the color panel, we first observed a red monochromatic point light source through each panel. The distance between the panel and the point light source *D* was 458 [mm]. The pixel pitch *p* of the monochrome and color panels was 0.088 [mm]. As shown in Fig. 7, when the light source was observed through the color panel, the interval between the 0-th and 1st order bright lines *s* was 3.5 [mm]. When the light source was observed through the monochrome panel, the interval between the 0-th and 1st order bright lines was 10.5 [mm]. From equation (1), the theoretical interval of *s* is given by

$$s = D\tan\theta = D\tan(\sin^{-1}\lambda/d) \fallingdotseq D\lambda/d. \qquad (2)$$

If we suppose the wavelength of the red LED is 680 nm, we obtain $s \fallingdotseq 3.54$ when we substitute $d = p = 0.088$. Also we obtain $s \fallingdotseq 10.6$ when we substitute $d = p/3 = 0.088/3$. Thus the values observed in the experiment are close to the theoretical value.

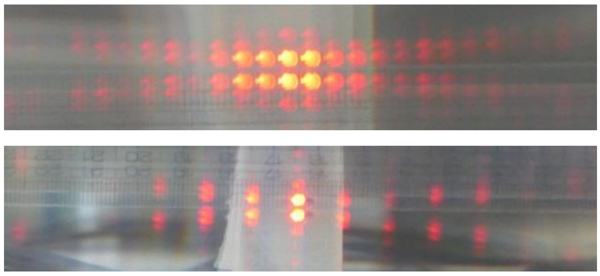

Fig. 7 Observed diffraction pattern of red light by a color panel (above) and a monochrome panel (bottom).

Next we observed a blue monochromatic point light source through each panel. The distance between the panel and the point light source was 395 [mm] this time. As shown in Fig. 8, when the light source was observed through the color panel, the interval between the 0-th and 1st order bright lines was 2.2 [mm]. When the light source was observed through the monochrome panel, the interval between the 0-th and 1st order bright lines was 6.7 [mm].

If we suppose the wavelength of the blue LED is 490 nm, we obtain $s \fallingdotseq 2.20$ when we substitute $d = p = 0.088$. Also we obtain $s \fallingdotseq 6.60$ when we substitute $d = p/3 = 0.088/3$. Thus the values observed in the experiment are again close to the theoretical value.

As the result of the experiment shows, the diffraction light becomes dense due to more frequent interference pattern when the light goes through the panel. This is the reason why the crosstalk becomes larger when the color panel is placed in front of the monochrome panel.

To reduce the crosstalk level, the monochrome panel for active barrier slits should be placed in front of the color imaging panel when the dot pitch of the panel is fine and the effect of diffraction is strong. Since diffuser is not needed when a monochrome panel is used for the barrier, the quality of image is maintained even when the imaging panel is behind the active barrier.

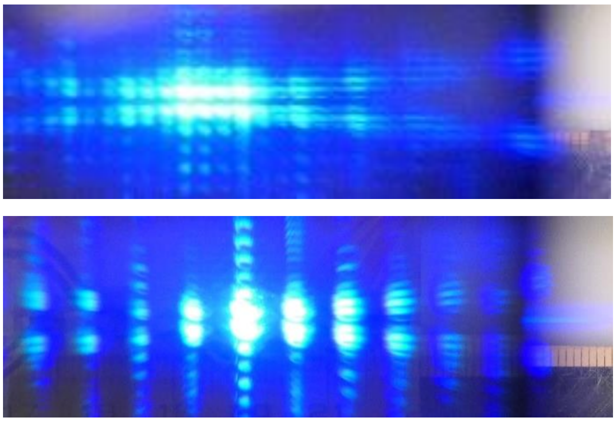

Fig. 8 Observed diffraction pattern of blue light by a color panel (above) and a monochrome panel (bottom).

4 CONCLUSION

In this paper, we have made a prototype autostereoscopic HUD display system using a monochrome panel as an active parallax barrier. We have found that placing monochrome panel for barrier in front of the color imaging panel generates less crosstalk than placing it behind. The mechanism of crosstalk reduction is confirmed by an experiment to see the effect of diffraction and interference caused by the dot pixel structure of LCD panels.

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