Large stereoscopic LED display by use of parallax barrier of aperture grille type

(Invited Paper)

Hirotsugu Yamamoto[1,2*], Hayato Nishimura[1], Tetsuya Abe[1], and Yoshio Hayasaki[2]

[1]*Department of Optical Science and Technology, University of Tokushima, 2-1, Minamijosanjima, Tokushima City, Tokushima 7708506, Japan*

[2]*Center for Optical Research and Education, Utsunomiya University, 7-1-2, Yoto, Utsunomiya City, Tochigi 3218585, Japan*

[*]*Corresponding author: hirotsugu_yamamoto@cc.utsunomiya-u.ac.jp*

Received March 11, 2014; accepted April 4, 2014; posted online May 20, 2014

We propose a large parallax barrier by use of aperture grille. Main advantages of using aperture grille include no reflection and no absorption in apertures, as well as wide viewing angle. These advantages are investigated with theoretical calculations and experiments by use of several kinds of LED panels, such as a fine-pitch LED panel and a 140-inch large LED panel. Limitations of viewing angle by parallax barrier are analyzed in conventional black stripes on a transparent substrate type and in aperture grille type. Experimental results show use of aperture grille increases contrast and reduce reflection on the aperture surface.

OCIS codes: 120.2040, 330.1400.

doi: 10.3788/COL201412.060006.

1. Introduction

LED panels are used for digital signage. LED's durability[1] and high brightness are suitable for signage under broad daylight. LED digital signage becomes pervasive in public spaces such as stations, airports, exhibitions, stadiums, and downtowns. On the viewpoint of advertisers, it is important to attract more attentions of viewers to their signage.

Three-dimensional (3D) display is one of the prospective display methods to attract more audiences. We have been studying 3D display techniques for digital signage by use of several kinds of full-color LED panels. Glassless 3D display methods are suitable for use in the public spaces. Most of LED screens do not have as many pixels as high-definition televisions now. Under this restriction of pixels, we had set our first goal as a stereoscopic LED display because two perspective views are the minimum to provide depth perception based on binocular fusion. Parallax barrier[2,3] is suitable for large-scale screens in the public space because of its simple and scalable composition. Viewing zones of a stereoscopic LED display by use of a parallax barrier have been analyzed[4] and enlarged by the spaces between LED lamps[5]. We have investigated designed interpupillary distances of parallax barrier[6], a viewer's movements to the designed viewing zones[7]. We have also investigated variation of parallax barrier patterns: by rotating the parallax barrier, multiple images are provided according to the viewing distance[8]. Furthermore, we have discovered a new depth perception that was given by viewing LEDs through apertures[9].

Recently, new compositions of parallax barrier have been proposed: rotating parallax barrier with LED arrays provides omni-directional 3D display[10]; polarization-modulated parallax barrier enables frontal projection[11]; active anaglyph parallax barrier maintains resolution of each perspective image[12]. In this letter, we investigate composition of parallax barrier for a large LED letter. We compare the aperture grille type with the conventional type of parallax barrier, which is composed of black stripes painted on a transparent substrate. The design of aperture grille is described and is confirmed by making aperture grilles for a 4-mm-pitch LED panel, an 8-mm pitch LED panel, a 6-mm pitch LED panel in 140-inch size.

2. Design of parallax barrier for a large LED panel

Principle and compositions of parallax barrier are shown in Fig. 1. Stereoscopic images are column-sequentially interleaved and displayed on an LED panel. Both perspective images are separated by the opaque stripes, called parallax barrier. The stereoscopic display by use of

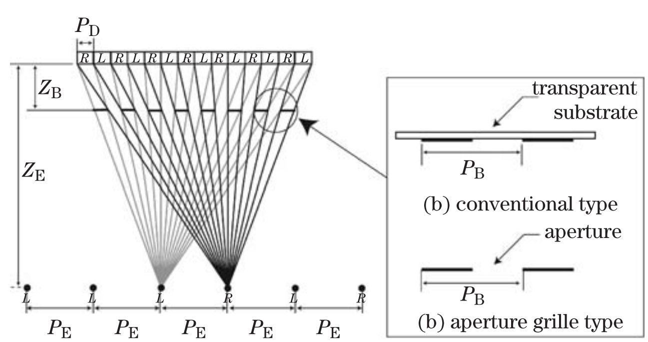


Fig. 1. Compositions of parallax barrier. (a) Conventional type is black stripes painted on a transparent substrate. (b) Aperture grille type is composed of opaque stripes.

a parallax barrier provides plural viewing positions which are located side by side at a certain viewing distance.

The horizontal pitch P_D of the LED panel and viewing conditions determine the parallax barrier. The pitch P_B of the parallax barrier and the distance Z_B between the parallax barrier are expressed by

$$P_B = P_D P_E/(P_D + P_E), \tag{1}$$

$$Z_B = P_D Z_E/(P_D + P_E), \tag{2}$$

where Z_E and P_E denote the viewing distance and the designed interpupillary distance, respectively.

As shown in Fig. 1(a), the conventional parallax barrier is composed of black stripes painted on a transparent substrate. In this letter, we investigated another composition of parallax barrier, called aperture grille. As shown in Fig. 1(b), aperture grille is composed of black opaque strips and aerial apertures. Note that there is no reflection on the apertures.

Limitation of viewing angle in the conventional parallax barrier is caused by optical refraction. Shift of an optical ray due to optical refraction is shown in Fig. 2. The shift S depends on the angle of incidence θ_A, the thickness T_B of the transparent substrate, and the refractive index of the transparent substrate. The shift is expressed by

$$S = T_B(\tan\theta_A - \tan\theta_B), \tag{3}$$

where θ_B denotes the angle of refraction of the incident ray.

The relationships between viewing angle and shift of optical ray due to refraction are shown in Fig. 3. The angle of refraction is calculated for an acrylic board of which refractive index is 1.49. When a thin substrate is used for installation, as used for conventional liquid-crystal displays, these shifts have almost no influence on the viewing angle. However, for large LED panels, relatively thick (about 4 mm) substrates are used to keep the flatness of the surface. Therefore, these ray shifts become an important factor to enrage viewing angle. Compensation of the light refraction by a transparent substrate is a problem for use of the conventional parallax barrier. One method to overcome this problem is to change the width and location of each black stripe based on the viewing angle and the refractive index of the transparent

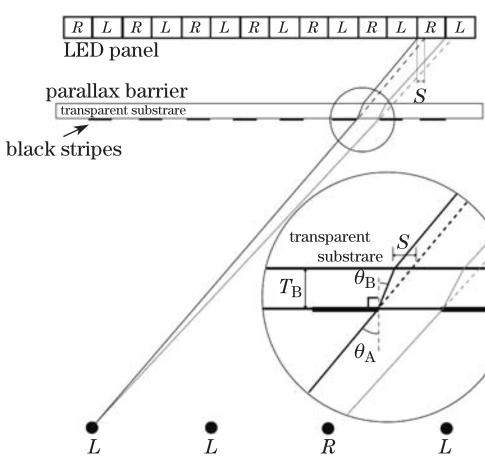


Fig. 2. Shift of optical rays due to optical refraction in the transparent substrate in case of parallax barrier of conventional type.

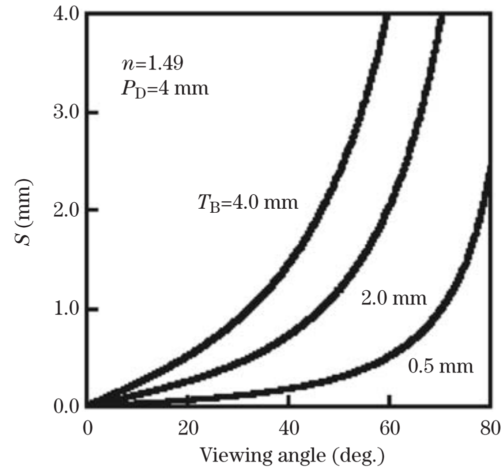


Fig. 3. Shift of optical ray increases with viewing angle.

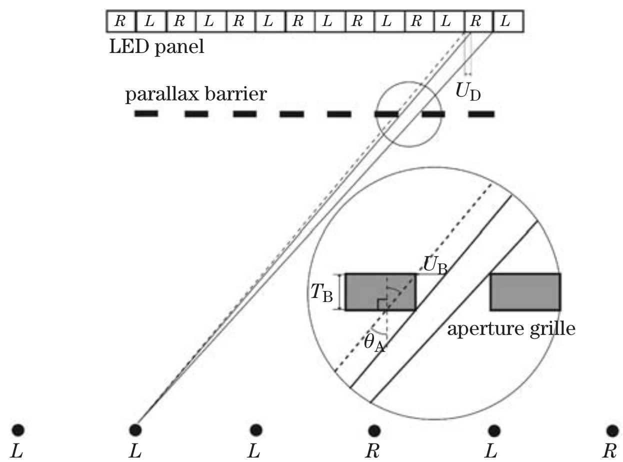


Fig. 4. Reduction of aperture width due to the thickness of the parallax barrier of aperture grille type.

substrate so that the refracted rays reach to their intended pixels. However, this method can be effective only for single observer. The other observers cannot observe the pixel originally intended because the change of the black stripes cause crosstalk at the side lobes. Because our goal is to realize stereoscopic LED signage for plural audiences, we fabricated uniform parallax barrier.

Viewing angle of aperture grille type is also limited by the thickness of opaque stripes. As shown in Fig. 4, apparent aperture width is reduced as viewing angle increases. This is like a kind of vignetting of vertical slits. The reduction width of an apparent aperture on the LED panel, which is denoted by U_D, is expressed by

$$U_D = Z_E(T_B \tan\theta_A)/(Z_E - Z_B), \tag{4}$$

where $\theta_A$is the angle of incidence. Z_E and Z_B denote the viewing distance and the distance between LED panel and aperture grille, respectively. T_B is the thickness of the aperture grille. Note that $Z_E/(Z_E - Z_B)=1+P_D/P_E$.

Relationships between the reduction width of an aperture and viewing angle is shown in Fig. 5. The curves are calculations for P_D=4 mm and P_E=65 mm. It seems a thick aperture grille causes large shift. Note that it is possible to eliminate the reduction of the apparent aperture width by tapering the opaque stripes.

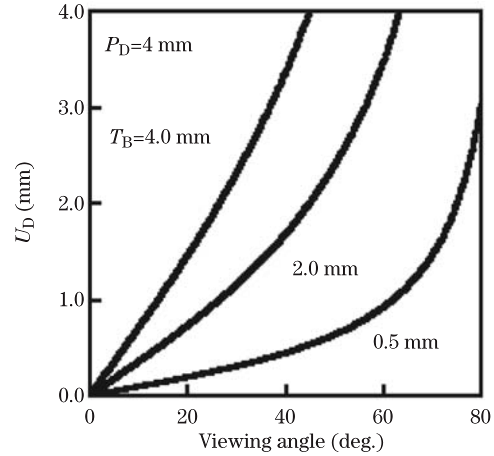


Fig. 5. Reduction width of an aperture increases with viewing angle.

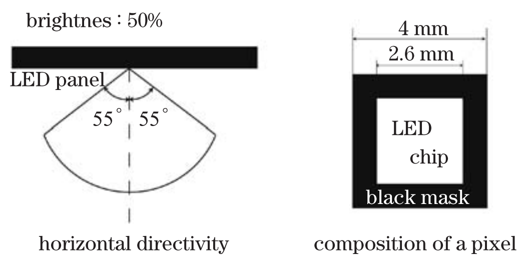


Fig. 6. Directivity and composition of a pixel of a 4-mm pitch LED panel.

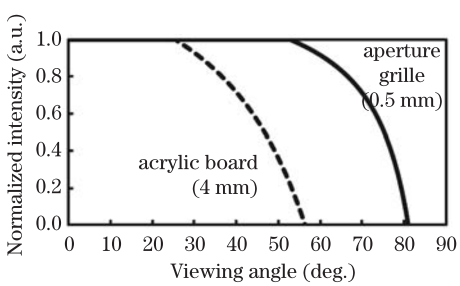


Fig. 7. Reduction of light emitting areas due to the optical refraction in the conventional type by use of 4-mm acrylic board (dashed curve) and the reduction of aperture width in aperture grille type by use of 0.5-mm opaque stripes (solid curve).

3. Use of fine (4-mm)-pitch LED panel for a stereoscopic display

We have developed a stereoscopic LED display by use of a fine pitch LED panel. The pitch of the LED panel is 4 mm. Each pixel is consisted of a light-emitting region of 2.6-mm width and surrounding black regions, as shown in Fig. 6. The brightness of LED decreases to 50% at 55 degrees to both sides in horizontal direction. Limits of viewing angle by use of the two types of parallax barrier have been analyzed for this fine-pitch LED panel. Figure 7 shows the relationships between the incident angle and the normalized intensity. In the case of black stripes on an acrylic board of 4-mm thickness, the intensity begins to decrease at 25 degrees and falls to zero at 57 degrees. On the contrary, in the case of an aperture grille of 0.5-mm thickness, the intensity keeps 1 up to 53 degrees. Then the intensity falls to zero at 81 degrees. The intensity at the horizontal directivity 55 degrees of the LED panel, the intensity is obtained only 0.08 in the black stripes on an acrylic board and 0.98 in the aperture grille. Furthermore, in the case of an aperture grille, it is possible to use sharp-edged strips to prevent the reduction of the apparent aperture width. Furthermore, the aperture grille prevents light reflection. Consequently, we have selected the aperture grille type for the parallax barrier for the fine-pitch and wide-viewing angle LED panel.

The aperture grille that we developed was installed in front of the LED panel in a gallery of our university. The LED display and the aperture grille are shown in Fig. 8. Right and left perspective images are interleaved and shown on the LED panel. The interleaved images are separated into the corresponding eyes by the aperture grille. Examples of viewed images are shown in Fig. 9. Seal and Chinese characters are represented in different depths. Plural viewers side by side enjoyed stereoscopic viewing at the same time.

4. Comparison of aperture grille and conventional painted parallax barrier by use of 8-mm LED panel

Fig. 8. Developed stereoscopic display by use of 4-mm pitch LED panel.

Fig. 9. Viewed images at a left eye position and at a right eye position. Note that there is a binocular disparity between the Chinese characters and the seal.

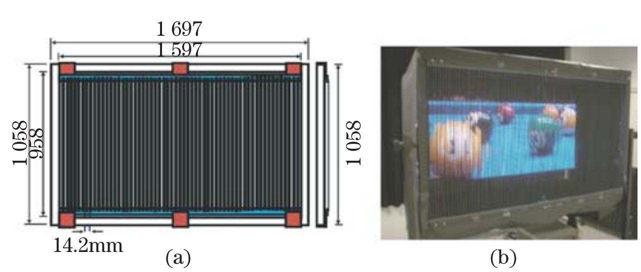
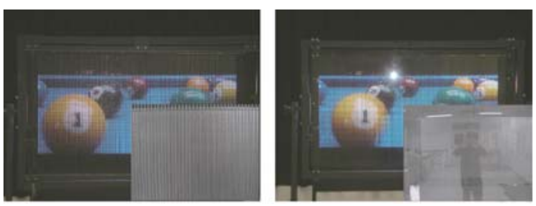


Fig. 10. (a) Shape and (b) photograph of developed parallax barrier of aperture grill type for an 8-mm LED panel.

In order to compare the optical intensity distributions, we made two types of parallax barriers for 8-mm pitch LED panel, which were installed in our experimental room. The developed aperture grille for 8-mm pitch LED panel is shown in Fig. 10.

4.1 Elimination of surface reflection by use of aperture grille type

Photograph of the stereoscopic LED displays and parallax barriers were taken with flashlight are shown in Fig. 11. Both parallax barriers separate the right and left perspective images. The photographs shown in the right bottom in both figures were taken of the surface of parallax barriers under the fluorescent lights when the LED panel was off. The reflections of the flashlight and the fluorescent lights were observed on surface of the acrylic board. On the aperture grille, however, no critical reflection of the flashlight and the fluorescent lights were observed. For outdoor installations of stereoscopic large display, the reflections of the sunlight may be observed in similar to the reflection of the flashlight. Furthermore, there are plenty of lights surrounding LED signage. These experimental results show that use of the aperture grille prevents light reflections on the surface of parallax barrier.



(a) (b)

Fig. 11. Photographs of the developed stereoscopic LED panel by use of (a) aperture grille and (b) black stripes on an acrylic board. Every photo was taken with flashlight. Inner photographs were taken of each parallax barrier with lighting up the experimental room.

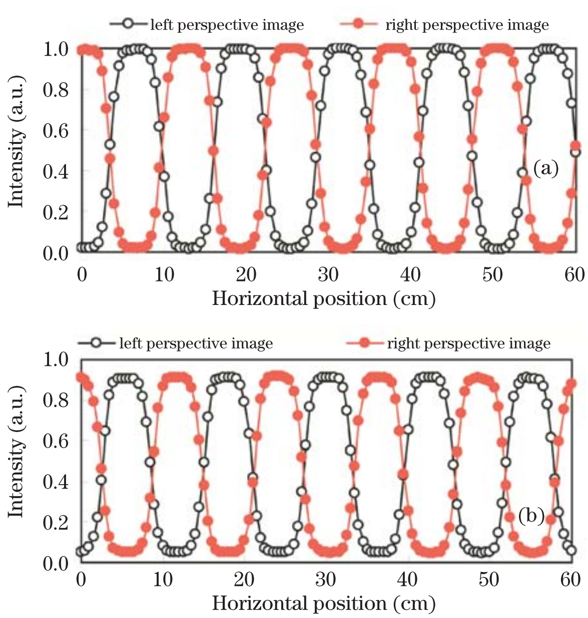


Fig. 12. Optical intensity distributions of the right and the left perspective images around the center of the viewing zones.

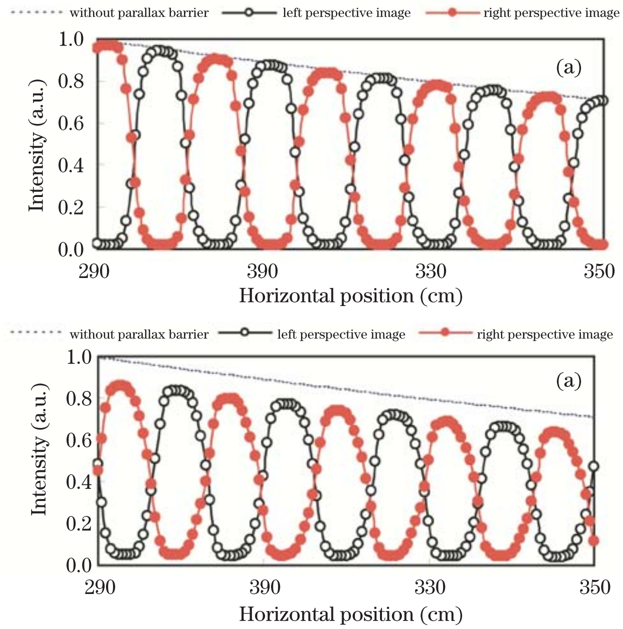


Fig. 13. Optical intensity distributions of the right and the left perspective images around 45° right toward the LED panel.

4.2 Comparisons of optical intensity distributions

We have compared viewing areas provided by the parallax barriers of the aperture grille and the conventional black masks painted on an acrylic board. Figure 12 shows the optical intensity distributions of stereoscopic test patterns. The viewing distance was set to 5 m. Two test patterns consisting of black and white stripes were displayed on the LED panels. One of the test patterns was for the right perspective image, which was the displayed pattern when the right perspective image was white and the left was black. The other test pattern was for the left perspective image. The obtained intensity is normalized so that the maximum of optical intensity in the case of using the aperture grille is set to be 1. In both cases of parallax barriers, the optical intensity distributions take the maximum and minimum value at intervals of 6.5 cm.

The peaks in the aperture grille type are higher than those in the conventional type. The bottoms in the case of the aperture grille type are lower than those in the conventional type. Contrast ratio, which is defined as the ratio of the maximum intensity over the minimum intensity, is obtained as 70 in the aperture grille type and 20 in the conventional type. Thus, use of the aperture grille increases the contrast of optical intensity of each perspective image.

We have compared viewing areas of side lobes at the position of 45 degrees. Experimental results are shown in Fig. 13. The intensity is normalized so that the maximum intensity obtained without parallax barrier is set to be 1. Peaks in the optical intensity distribution in the aperture grille type were as high as the optical intensity obtained without parallax barrier. On the other hand, peaks in the optical intensity distribution in the conventional type decreased to 86%.

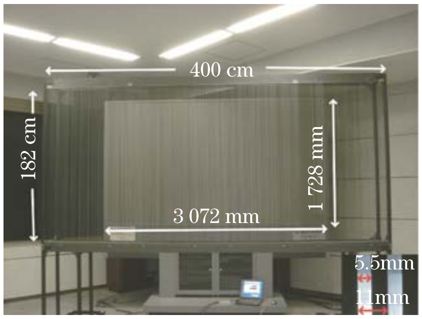


Fig. 14. Photograph of developed large aperture grille for 140-inch LED panel.

L *R*

Fig. 15. Viewed images at a left eye position and at a right eye position.

Fig. 16. Plural viewers enjoy the stereoscopic images at the same time.

5. Development of a 140-inch stereoscopic display

We have made a large parallax barrier by use of an aperture grille. 140-inch LED panel that have 512×288 pixels has been utilized for stereoscopic display. The pitch of the LED panel was 6.0 mm. The pitch of the aperture grille was 11 mm. The vertical length of each opaque stripe was 182 cm. The frame size of the aperture grille was 4 × 2 (m). The viewing distance was 15 m. The LED panel and the aperture grille are shown in Fig. 14. Viewed images are shown in Fig. 15. The aperture grille separated interleaved stereoscopic images. Plural viewers at least within the range of 16 m in the width at the same time as shown in Fig. 16. The width is limited by the size of the lecture hall where the 140-inch LED display was installed.

6. Conclusion

We have designed aperture grille to implement large stereoscopic LED displays. The design was confirmed by implementations of stereoscopic displays by use of 4-mm pitch, 6-mm pitch, and 8-mm pitch LED panels. Advantages of aperture grille, wide viewing angle, high contrast, and low surface reflections have been investigated in theoretical calculations and experimental results.

References

1. N. Narendran and Y. Gu, J. Display Tech. **1,** 167(2005).
2. H. E. Ives, J. Opt. Soc. Am. **20,** 585 (1930).
3. S. H. Kaplan, J. SMPTE **59,** 11 (1952).
4. H. Yamamoto, S. Muguruma, T. Sato, K. Ono, Y. Hayasaki, Y. Nagai, Y. Shimizu, and N. Nishida, IEICE Trans. Electron. **E83-C,** 1632 (2000).
5. H. Yamamoto, M. Kouno, Y. Hayasaki, S. Muguruma, Y. Nagai, Y. Shimizu, and N. Nishida, Appl. Opt. **41,** 6907 (2002).
6. H. Yamamoto, T. Sato, S. Muguruma, Y. Hayasaki, Y. Nagai, Y. Shimizu, and N. Nishida, Opt. Rev. **9,** 244 (2002).
7. S. Matsumoto, H. Yamamoto, Y.Hayasaki, and N. Nishida, IEICE Trans. Electron. **E87-C,** 1982 (2004).
8. H. Yamamoto, T. Kimura, S. Matsumoto, and S. Suyama, J. Display Tech. **6,** 359 (2010).
9. H. Yamamoto, H. Nishimura, K. Uchida, K. Ono, Y. Hayasaki, and S. Suyama, J. Soc. Inf. Display **17,** 1031 (2009).
10. K. Tanaka, J. Hayashi, M. Inami, and S. Tachi,in *Proceeding of the IEEE Vritual Reality 2004* 59 (2004).
11. Y. Kim, K. Hong, J. Yeom, J. Hong, J.-H. Jung, Y. W. Lee, J.-H. Park, and B. Lee, Opt. Express **20,** 20130 (2012).
12. Q. Zhang and H. Kakeya, Proc. SPIE **8648,** 86481R (2013).