3D display with uniform resolution and low crosstalk based on two parallax interleaved barriers

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The resolution of the parallax image is inversely proportional to the view number in the horizontal direction for the traditional autostereoscopic display based on a parallax barrier. To balance the resolution in the vertical and horizontal directions, two parallax interleaved barriers are designed. The liquid crystal display panel provides the synthetic image with square pixel units, and the pixels in a unit are distributed to different horizontal views. Two parallax interleaved barriers work together to modulate pixels in vertical and horizontal directions. 3D display with uniform resolution and low crosstalk is demonstrated.

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A great progress has been made for glasses-free 3D display and several techniques were demonstrated[1–7]. A parallax barrier based 3D display is a low-cost method to provide multi-views to the observers[8–10]. Many methods can be used for changing the pixels' arrangement to decrease the aliasing in the boundary[11–13]. However, the non-uniform of the vertical and horizontal resolutions cannot be solved. For the traditional parallax barrier 3D display systems, the pixels of parallax images are coded in the horizontal direction, which will cause the non-uniform of the vertical and horizontal resolutions, and the display quality is degraded and observers often experience with the discomfort. To provide multi-view autostereoscopic display with uniform resolution, dual parallax barriers were used simultaneously to modulate the pixels in the horizontal and vertical directions[14]. The synthetic image arranged the pixels of parallax images on the basis of square pixel units. The viewers can perceive the stereoscopic image with uniform resolution. However, the brightness distribution curve of a single parallax image[14] exhibited sidelobes near the peaks. It means that obvious ghost images of one view can be seen at the other viewing position, which caused crosstalk into the 3D display system. Here, we demonstrate a 3D display based on two parallax interleaved barriers, which not only provides 3D display with uniform resolution but also has few sidelobes and little crosstalk.

The uniform resolution 3D display consists of a backlight panel, a flat-panel display, and two parallax interleaved barriers. Figure 1 shows the configuration of the system architecture. Parallax interleaved barrier 1 locates in the middle of backlight panel and flat-panel display. Parallax interleaved barrier 2 locates in front of the flat-panel display. The 3D view zones are formed at the optimal observing plane. Here, as an example, a four-view 3D display system is demonstrated.

The structures of parallax interleaved barriers 1 and 2 are designed as shown in Fig. 2, which consist of different kinds of interleaved barrier units. They are used

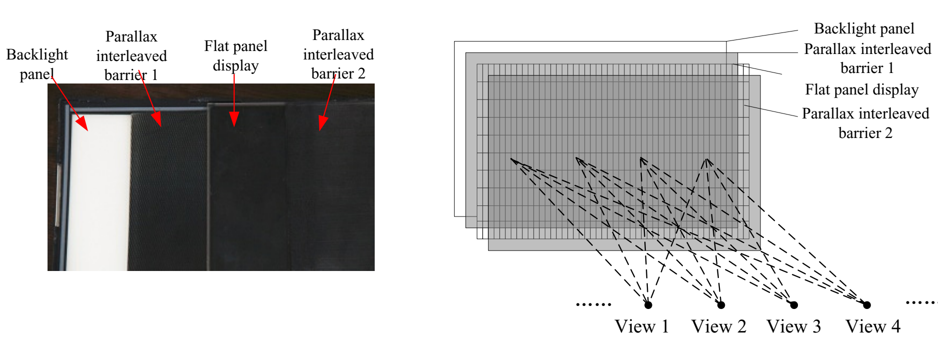


Fig. 1. Configuration of the 3D display based on two parallax interleaved barriers.

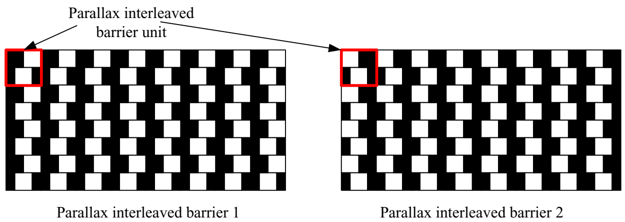


Fig. 2. Parallax interleaved barriers in the proposed display.

to modulate the pixels and block the unnecessary light. The two units work together to direct the pixels' information in one square unit to four horizontal views.

The pixel arrangement in the liquid crystal display panel is shown in Fig. 3(a), and every four pixels make up a pixel unit. The numbers 1, 2, 3, and 4 represent the pixels of different parallax images, respectively. The pixel unit and two parallax interleaved barrier units constitute a display unit, as shown in Fig. 3(b). Every display unit is a multi-view pixel, which reduces the display resolution twice in the horizontal and vertical directions simultaneously, and they make each view with a uniform resolution.

Figure 4 shows the principle of the uniform resolution 3D display system. The odd and even horizontal rows are analyzed. W_1 and W_{b1} are the slit width and black strip width of parallax interleaved barrier 1. W_2 and W_{b2} are the slit width and black strip width of parallax interleaved barrier 2. The two parallax interleaved barriers are placed at D and d from the flat-panel display. The optimal viewing distance is L and the width of pixel's pitch of the panel display is W_p. Q is the interval between the adjacent views formed by the same row. For the odd rows, it displays parallax images 1 and 3. According to the geometric analysis, we get

$$\frac{W_p}{Q} = \frac{D}{L + D + d}, \tag{1}$$

$$\frac{W_1}{Q} = \frac{D}{L + d}. \tag{2}$$

Based on Eqs. (1) and (2), the relationship among Q, W_p, and W_1 can be given as

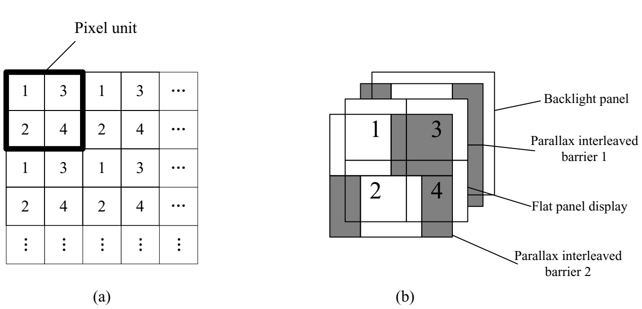


Fig. 3. 3D display based on dual parallax interleaved barriers: (a) pixels arrangement in the 2D display panel and (b) four-view display unit.

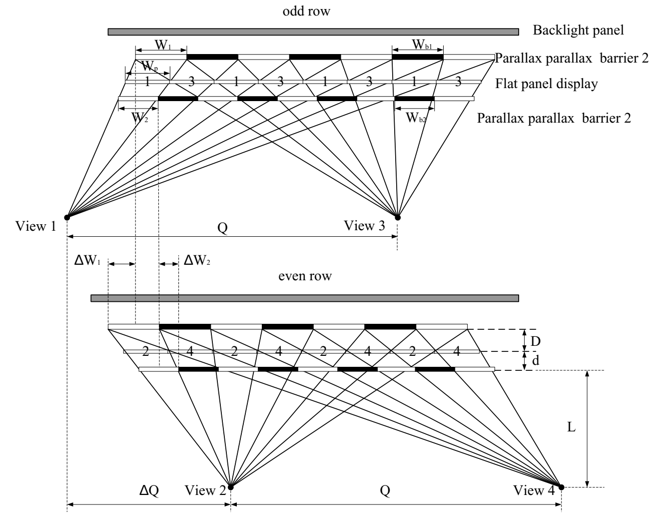


Fig. 4. Principle of the proposed 3D display with uniform resolution.

$$W_1 = \frac{Q \bullet W_p}{Q - W_p}. \tag{3}$$

The other parameters can be determined by

$$d = \frac{W_p}{Q} \bullet L, \tag{4}$$

$$W_2 = \frac{L}{L + d} \bullet W_p, \tag{5}$$

$$D = \frac{W_1}{W_2} \bullet d, \tag{6}$$

$$W_1 = W_{b1}, W_2 = W_{b2}. \tag{7}$$

In the proposed 3D display system, for the even rows, to form the views 2 and 4 at different positions from views 1 and 3, the slit of the two parallax interleaved barriers needs to shift to the opposite direction. Here, the slit of parallax barrier 1 deviates ΔW_1 to the left and the slit of parallax interleaved barrier 2 deviates ΔW_2 to the right. ΔQ is the interval between view 1 and view 2. The following geometric relations are satisfied:

$$W_1 = \frac{d}{L + d} \bullet Q, \Delta W_1 = \frac{d}{L + d} \bullet \Delta Q, \tag{8}$$

$$W_2 = \frac{d}{L + d} \bullet Q, \Delta W_2 = \frac{d}{L + d} \bullet \Delta Q. \tag{9}$$

Obviously, to distribute the viewing points uniformly, ΔQ should be equal to half of Q. According to Eqs. (6) and (7), the following relations can be deduced:

$$\Delta W_1 = {}^{1}\!/_{2} \bullet W_1, \tag{10}$$

$$\Delta W_2 = {}^{1}\!/_{2} \bullet W_2. \tag{11}$$

Table 1. Parameters of the Proposed 3D Display System

Parameters	Value (mm)
W_p	0.3114
ΔQ	65
Q	130
L	2000
W_1	0.3121
W_2	0.3107
W_{b1}	0.3121
W_{b2}	0.3107
D	4.813
d	4.791
ΔW_1	0.1561
ΔW_2	0.1554

In the experiment, the size of the 2D display panel is 27 inches, and its resolution is 1920×1080. The value of W_p is 0.3114 mm. The distance between the adjacent viewing points (ΔQ) is equal to the interpupillary distance (65 mm). The viewing distance to the screen (L) is set as 2 m. According to the above relations, the other parameters W_1, W_2, W_{b1}, W_{b2}, D, d, ΔW_1, and ΔW_2 of the proposed 3D display can be calculated. All the parameters are listed in Table 1.

A 3D display method with two parallax barriers presented in Ref. [14] showed the brightness distribution of a single parallax image at the optimal view distance. There was a sidelobe near the main peak of view 1's brightness distribution curve. The sidelobe was located between the positions of view 2 and view 3. It can bring crosstalk to the 3D display system. Here, the proposed method's brightness distribution curve of view 1 is shown in Fig. 5. There is little needless light intensity distribution beside the main peak of view 1.

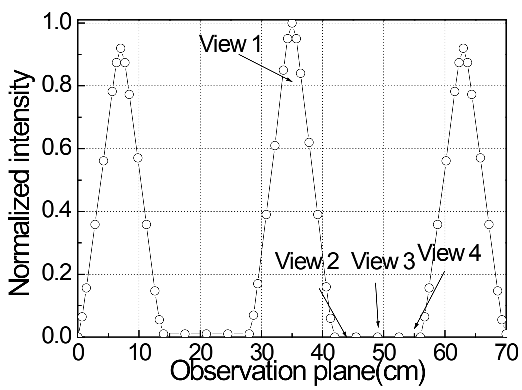


Fig. 5. Brightness distribution of view 1.

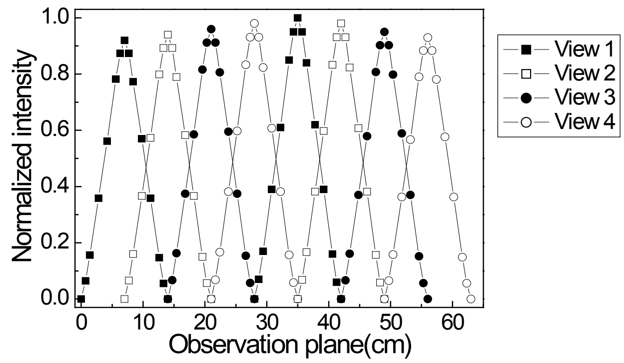


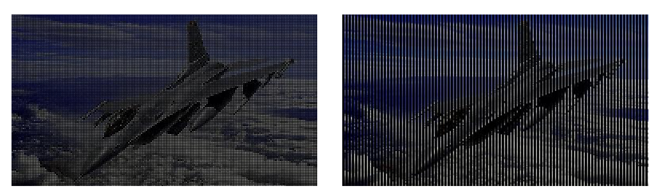
Fig. 6. Light intensity distribution of different views along the horizontal direction at the observation plane.

To evaluate the validity and rationality of 3D display, the light intensity distribution of every view is measured. The measured normalized luminance of each view is shown in Fig. 6. From the luminance distribution, we can see that the proposed 3D display can distribute the parallax images on the observation plane uniformly and there is little crosstalk between the adjacent views.

Based on the flat-panel display with the resolution of 1920×1080, the parallax images' resolution of the traditional four-view autostereoscopic display is 480×1080. The uniform resolution autostereoscopic display system provides every view with the resolution of 960×540. Figure 7 shows the comparison of the visual effects using two methods. The display content of the proposed method is more comfortable, but the brightness is lower than conventional type. In theory, both the proposed method and conventional type decrease the light intensity of display panel to one fourth for one view. However, for the proposed display system, two parallax barriers are used to modulate the pixels, which will block more light rays and lead to lower light intensity result, and the brightness with uniform resolution is decreased.

In the experiment, four parallax pictures of a plane were used for the display content. Figure 8 shows the four different views in the horizontal direction. The observer obtains high display quality images at the optimal viewing positions and there is little crosstalk between the adjacent views.

In conclusion, a 3D display with uniform resolution and low crosstalk based on two parallax interleaved



(a) (b)

Fig. 7. Comparison of the two methods of four-view 3D display: (a) effect of the proposed 3D display with uniform resolution and (b) effect of the conventional 3D display with non-uniform resolution.

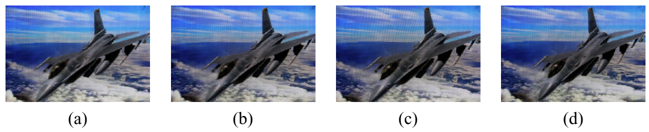


Fig. 8. Pictures shot from different directions of the proposed 3D display system.

barriers is demonstrated. The 2D flat panel displays the pixels of parallax images based on square pixel units. The two parallax interleaved barriers work simultaneously to uniformly distribute the pixels to different positions in the horizontal direction to form different views. There is little crosstalk between the adjacent views. The visual effect of the displayed 3D image is significantly improved.

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