One-dimensional integral imaging display using a variable parallax barrier

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Abstract. We analyze the effect of aperture width of the parallax barrier on the viewing angle of one-dimensional integral imaging (1-DII) display and propose a 1-DII display that consists of a display panel and a variable parallax barrier. When the variable parallax barrier changes its aperture width, the viewing angle and the optical efficiency of the proposed 1-DII display are compared. The viewing angle is increased by decreasing the aperture width of the variable parallax barrier, while the optical efficiency is increased by increasing the aperture width of the variable parallax barrier.
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1 Introduction

Integral imaging (II) display that presents true three-dimensional (3-D) images with full parallax and continuous viewpoints is regarded as a promising 3-D display.[1] But it is difficult to realize high resolution, wide viewing angle, and large depth display.[2–4] To overcome these disadvantages, a number of methods have been proposed.[5–7] A conventional one-dimensional integral imaging (1-DII) display reduces ray information by removing vertical parallax and provides 3-D images with high resolution in the vertical direction.[8–10] Although 1-DII autostereoscopic display resembles a multiview display, an important difference between the 1-DII display and the multiview autostereoscopic display is defined in terms of the position and the interval of beam condensing points. There is no need to predetermine the observer's viewpoints in the 1-DII display. However, the observer's viewpoints are light ray converging points and are an important design parameter in the multiview autostereoscopic display. The 1-DII displays have been implemented by using a parallax barrier or a lenticular lens array. The 1-DII display using a parallax barrier uses less space and a lower cost than that using a lenticular lens array.[11] Moreover, using the parallax barrier is simpler and has a lower cost than using the lenticular lens array. So the 1-DII display using a parallax barrier is a practical solution for a low cost and easy-viewable 3-D display. However, the relationship between the aperture width of the parallax barrier and the viewing angle of the 1-DII display has not been studied. Therefore, we analyze the effect of aperture width of the parallax barrier on the viewing angle of the 1-DII display. Moreover, we propose a 1-DII display using a variable parallax barrier. The viewing angle and the optical efficiency can be adjusted by adjusting the aperture width of the variable parallax barrier.

2 Structure and Principle

The primary viewing zone of the 1-DII display using a parallax barrier is shown in Fig. 1. Lights emitted from an elemental image displayed on the display panel are modulated by the corresponding slit and the theoretical viewing zone, in which the observer can theoretically see 3-D images is determined by the solid lines. However, flipping images are seen in part of the theoretical viewing zone which is determined by the long-dashed lines. Therefore, orthoscopic images are only seen in the primary viewing zone which is determined by the short-dashed lines.

Suppose that each parallax barrier ideally integrates the light into one line, point A is one point of the ideal line, L is the distance between the parallax barrier and the observer, g is the gap between the parallax barrier and the display panel, and l is the distance between the point A and the display panel. The pitch and the aperture width of the parallax barrier are P_B and P_W, respectively. Based on the geometric relationships in Fig. 1, the viewing angle θ can be obtained as

$$\theta = 2 \arctan\left(\frac{P_B}{2l}\right). \tag{1}$$

The relationship between l and P_W exists as

$$l = \frac{P_B g}{P_B - P_W}. \tag{2}$$

From Eqs. (1) and (2), the relationship between the aperture width and the viewing angle is obtained as

$$\theta = 2 \arctan\left(\frac{P_B - P_W}{2g}\right). \tag{3}$$

From Eq. (3), we can see that when P_B and g are fixed, the viewing angle θ can be increased by decreasing the aperture width and vice verse. The relationship between the aperture width and the viewing angle are not only obtained in 1-DII display using a parallax barrier but also in two-dimensional integral imaging display using a pinhole array.

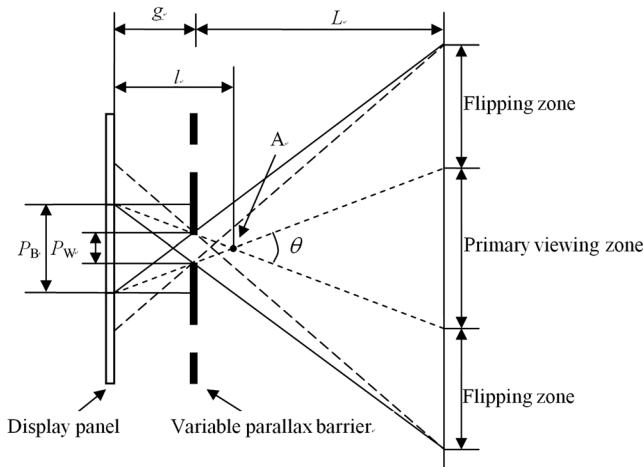The optical efficiency of the 1-DII display using a parallax barrier φ is[12]

Fig. 1 Primary viewing zone of the one-dimensional integral imaging (1-DII) display using a parallax barrier.

$$\varphi = \frac{P_W}{P_B}. \qquad (4)$$

It is obvious that the optical efficiency of the 1-DII display is increased by increasing the aperture width of the parallax barrier and vice verse. As mentioned above, the viewing angle and the optical efficiency of the 1-DII display using a parallax barrier cannot be simultaneously improved by adjusting the aperture width of the parallax barrier. Therefore, we proposed a 1-DII display using a variable parallax barrier. Figure 2 illustrates the structure of the proposed 1-DII display. It consists of a display panel and a variable parallax barrier. Aperture centers of the variable parallax barrier are located at the centers of the corresponding elemental images on the display panel. Lights from the elemental image array (EIA) displayed on the display panel are modulated by the variable parallax barrier, which reconstructs the angular distribution of the rays and hence displays the 3-D images.

There is only an elemental image integrated in Fig. 1. In practice, the more elemental images that are integrated, the smaller the viewing angle becomes.[13] The viewing angle of the proposed 1-DII display θ' can be obtained as

$$\theta' = 2 \arctan \left[\frac{P_B - P_W}{2g} - \frac{(N-1)P_B}{2L} \right], \qquad (5)$$

where N is the number of the elemental images in the horizontal direction. Whatever the number of the elemental
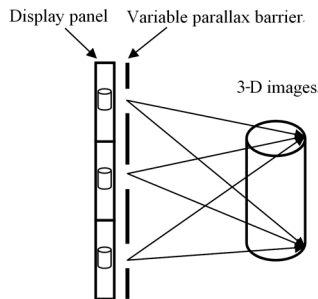
images integrated, the viewing angle of the proposed 1-DII display can also be increased by decreasing the aperture width of the variable parallax barrier and vice verse.

3 Experiments and Results

We performed an experiment to verify the proposed 1-DII display. In our experiment, a back light unit and a printed film were combined as a display panel with a high resolution. The display panel was used to generate three identical EIAs, simultaneously. Another printed film was used to generate three parallax barriers with different aperture widths. A high-resolution printer, SCREEN Tanto 6120, was used to print two films, and two printed films are stuck well on a glass substrate. The parameters of the prototype are shown in Table 1.

The EIA of 3-D scenes "SC" is generated by using a computer.[14] The EIA consists of 51 elemental images and each elemental image has 60×2100 pixels. The letters "S" and "C" are located 60 mm in front of and behind the display panel, respectively.

The top, center, and bottom scene "SC"s are behind the three parallax barriers with the aperture widths are 0.25, 0.5, and 0.75 mm, respectively. Corresponding to the aperture widths of three parallax barriers, the viewing angles are 18, 14.6, and 12 deg, respectively. When the viewing angle is 8 deg to the left, there are flipping images in the center and bottom scenes, as shown in Fig. 3(a). Decreasing the viewing angle to 7 deg to the left, there are also flipping images in the bottom scene, as shown in Fig. 3(b). Decreasing the viewing angle to the middle, the full white luminances of 3-D images reconstructed through three parallax barriers are 10.2, 20.1, and 30.6 cd/m², as shown in Fig. 3(c). The optical efficiencies of three 3-D images are 5.1%, 10.05%, and 15.3%, respectively. When the viewing angle increases to 7 deg to the right, there are flipping images in the bottom scene, as shown in Fig. 3(d). Increasing the viewing angle to

Table 1 Parameters of the prototype.

Specifications	Values
P_B (mm)	5
g (mm)	5
L (mm)	390
N	51

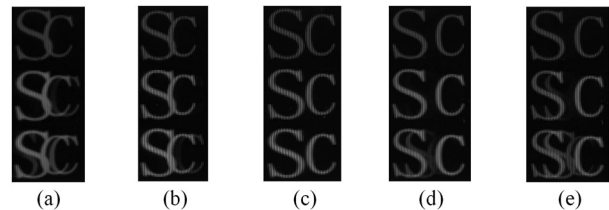**Fig. 2** Structure of the proposed 1-DII display.

Fig. 3 Images viewed from (a) left 8 deg, (b) left 7 deg, (c) middle, (d) right 7 deg, and (e) right 8 deg.

8 deg to the right, there are also flipping images in the center and bottom scenes, as shown in Fig. 3(e).

The experimental results proved that the viewing angle of the proposed 1-DII display is increased by decreasing the aperture width of the parallax barrier. The experimental results also show that the optical efficiency of the proposed 1-DII display is increased by increasing the aperture width of the parallax barrier. For multiple observers, the viewing angle is more important than the optical efficiency. For a single observer, the optical efficiency is more important than the viewing angle. Viewing angle priority 1-DII display is obtained by decreasing the aperture width of the variable parallax barrier, while brightness priority 1-DII display is obtained by increasing the aperture width of the variable parallax barrier. Therefore, the aperture width of the variable parallax barrier can be adjusted to satisfy the observers' requirements in the real time.

4 Conclusions

A 1-DII display using a variable parallax barrier is proposed. Its operation principle and calculation equations are described in detail. The viewing angle and the optical efficiency of the proposed 1-DII display are adjusted by adjusting the aperture width of the variable parallax barrier. It could be helpful for mobile applications.

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