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Variable parallax barrier spacing in autostereoscopic displays

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ABSTRACT

In general, multi-view autostereoscopic displays can only provide autostereoscopic images with little crosstalk at the optimum viewing distance (OVD) in the depth direction, limiting the mobility of viewers. Therefore, this paper proposes a method of increasing viewer mobility in the depth direction by varying the distance separating the parallax barrier and the display. Computer simulations and experiments were conducted to verify changes in the OVD resulting from the application of the proposed method. The results showed that the proposed method is effective at changing the OVD with respect to changes in the viewing distance. Therefore this method minimizes changes in the 3D image quality due to the viewer's depth location.

1. Introduction

In the multi-view parallax barrier and lenticular lens structures, the valid viewing area from which 3D images can be viewed is limited to a diamond-like shape because of the optical characteristics involved in the formation of the viewing region, and the valid viewing area consists of many viewing regions. For this reason, the left and right views can be reversed depending on viewer's movements. In addition, most 3D displays are disturbed by crosstalk, referring to the interference between the adjacent viewpoints in the display. As crosstalk becomes more pronounced, 3D effects including depth resolution worsen, increasing the viewer's discomfort and degrading the image quality. Therefore, reducing crosstalk is important for achieving high quality displays [1,2]. Toward this objective, the optimum viewing distance (OVD) has been defined as the distance where there is little crosstalk from the 3D display surface to the viewing location [3].

To overcome shortcomings due to crosstalk, methods based on face tracking have been widely used. These methods change the 3D images or parallax barrier elements in response to the location of the viewer's face [2,4]. However, these methods are limited in that the 3D image resolution changes depending on the viewing distance [5,6]. Another drawback of these methods is that they require a liquid crystal display (LCD) with a high refresh rate for real-time implementation.

This paper proposes a variable parallax barrier spacing method that changes the OVD by changing the separation distance between the display and parallax barrier. This method will be shown experimentally and by simulation to minimize changes in the 3D image quality due to the viewer's depth location.

2. Design principle of the proposed variable parallax barrier spacing system

The equation used to design the parallax barrier, the parameters of which are summarized in Fig. 1, has been described in detail in the prior literature [7–11].

Fig. 1 shows a cross-sectional view of the parallax barrier-type autostereoscopic display based on the four-view parallax barrier used in this paper. In the figure, W_{UP} is the width of a unit pixel, N is the number of viewpoints, P is a period of the parallax barrier, A is the aperture width of the parallax barrier, D_V is the distance between the display and an initial viewpoint, W_{UV} is the difference between the initial viewpoint and an adjacent viewpoint, and D is the distance between the display and the parallax barrier:

$$D = \frac{W_{UP}}{(W_{UP} + W_{UV})} \times D_V \tag{1}$$

$$P = (N \times W_{UP}) \times \left(\frac{D_V - D}{D_V}\right) \tag{2}$$

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0030-4018/

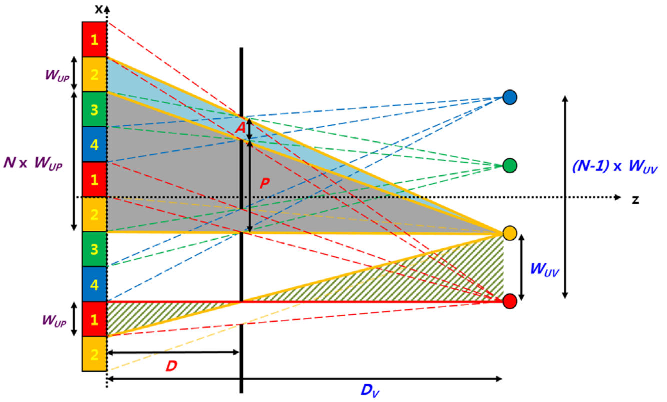

Fig. 1. Cross-sectional diagram of the parallax barrier-type autostereoscopic display.

$$A = W_{UP} \times \left(\frac{D_V - D}{D_V}\right) \tag{3}$$

The distance between the display and parallax barrier (D) is defined by Eq. (1), and the period of the parallax barrier (P) and the aperture width (A) of the parallax barrier are defined by Eqs. (2) and (3) respectively. The width (W_B) of the blocking ray component of the parallax barrier is $W_B = P - A$. The aperture width (A) can be determined by various methods; in this paper, the aperture was determined by the intersection between the parallax barrier and the two lines that connect the two ends of a unit pixel and the viewpoint. From Eqs. (2) and (3), the value of A is equivalent to P/N. This aperture can vary according to the purpose for which the parallax barrier is designed.

2.1. Limitations of viewing distance in autostereoscopic display

In general, multi-view autostereoscopic 3D displays provide precise 3D images when viewers are located in the OVD determined by the display design. Locations other than the valid viewing area cannot deliver precise 3D images, instead delivering images similar to those that suffer from image sticking, in which a mixture of images from multiple views is shown simultaneously; this phenomenon can be quantified by the extent of the crosstalk [1]. Each of the valid viewing areas is delineated as a diamond shape. The widest diamond-like valid viewing area in the vertical and horizontal planes, shown in Figs. 1 and 2, respectively, is where crosstalk is minimized; this area corresponds to the OVD. A characteristic of the OVD can be determined by that the full width at half maximum (FWHM) of the light intensity at its shortest [3,12]. The light intensity distribution can also be used to identify the extent of crosstalk at different viewer locations [9,13].

Fig. 2 shows the optical paths for different unit pixels, which are seen as 3D displays at different viewer locations. Fig. 2 (a) shows the optical paths for a viewer located at the OVD, in the center of the valid viewing area, where the most good quality of 3D images can be viewed, with almost no image sticking. Fig. 2 (b) shows the optical paths for a viewer closer to the display relative to the OVD, and Fig. 2(c) shows the optical paths for a viewer farther from the display in the opposite direction. As shown in Fig. 2(b) and (c), the viewpoints overlap for viewers not located in the OVD. Therefore, the viewer will see images from different viewpoints simultaneously, thereby increasing overall crosstalk.

The analysis in Fig. 2 considers only the optical path emitted from the center of each pixel, and therefore a quantitative analysis cannot be done on this basis. However, accurate analysis can be done by calculating crosstalk using a computer simulation based on the light intensity distribution [14]. For this purpose, crosstalk in the intensity distribution was calculated using CT, which was defined as the light intensity at different viewpoints relative to the center at the time of calculation divided by the light intensity at the center at the time of calculation; this definition is expressed by Eq. (4), in which $w_{A,i}$ and $w_{A,j}$ refer to the pure light intensity without noise at the i-th and j-th viewpoints at the time of calculation [1,3]:

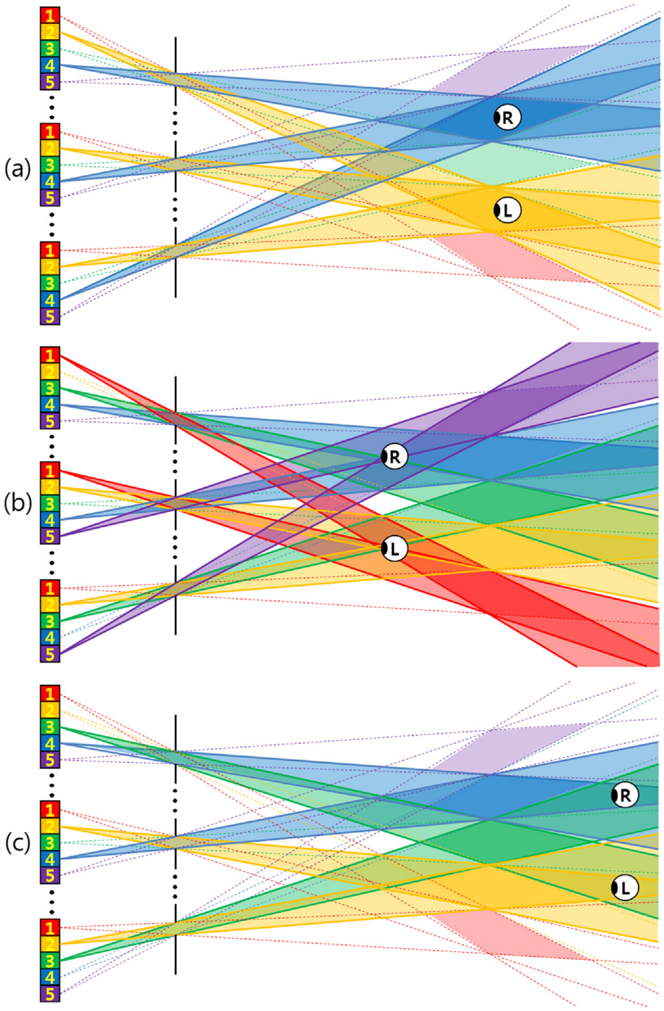

Fig. 2. Pixels seen in the 3D display according to viewer's position: (a) viewer is located at the OVD, (b) viewer is closer to the display, and (c) viewer is farther from the display.

$$\mathrm{CT}_i = \frac{\sum_{j=1}^{N} w_{A,j} - w_{A,i}}{w_{A,i}} = \frac{\sum_{j=1}^{N} w_{A,j}}{w_{A,i}} - 1 \tag{4}$$

Fig. 3 shows the computer simulation results for the light intensity distributions at each of the viewer locations shown in Fig. 2. The black lines indicate the positions of each of the viewer's eyes relative to the center of the display. These positions exhibit the least CT because images from different viewpoints are introduced least at the locations shown by the black lines. When a viewer is located at the OVD, 3D images can be precisely seen, but 34.66% of the light intensity is due to images from different viewpoints. Fig. 3(b) shows the light intensity distribution when a viewer is closer to the display relative to the OVD, as in Fig. 2(b). Compared to Fig. 3(a), the maximum CT values at all viewpoints were reduced, and the width of the light intensity distribution was increased. Therefore, the CT at the viewpoint corresponding to the eye position of the viewer was increased to 193.79%. Fig. 3