Multi-view 3D display with high brightness based on a parallax barrier

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A multi-view three-dimensional (3D) display provides a more realistic experience than a two-view 3D display. Therefore, a multi-view 3D display with high brightness based on a parallax barrier is proposed. The parallax barrier in the 3D display has a gradient transmittance with enhanced frequency characteristic, which indicates that the aperture ratio of the parallax barrier can be increased, thereby improving brightness. Gradient transmittance is also helpful in reducing crosstalk. A prototype of the 3D display is developed. Experimental result shows that the 3D display has higher brightness than a conventional display. In addition, crosstalk is limited at a low level.

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In recent years, autostereoscopic displays with parallax barriers have developed extensively. Geometric optical design and computational processing make parallax barriers useful in typical three-dimensional (3D) displays[1−5]. For a conventional parallax barrier 3D display, the parallax barrier is used to form 3D images[6−9]. The parameters of the parallax barrier are often designed in the spatial domain. With regard to this aspect, the parallax barrier must have a calculated width of transparent stripes to avoid crosstalk. If the width of the transparent stripes is increased and it exceeds the permitted range, then crosstalk appears. The width of the transparent stripes is related to the number of views[10]. In a multi-view 3D display[11,12], the parallax barrier often has transparent stripes with a small width, which limits aperture ratio and brightness when the number of view is large[13−16]. For example, in a parallax barrier 3D display with eight views, the aperture ratio of the parallax barrier is 12.5%. Therefore, the parallax barrier permits 12.5% of the light to pass through the transparent stripes, and brightness is limited to 12.5% of the two-dimensional (2D) display panel.

To provide high brightness in a multi-view 3D display based on parallax barriers, we propose a multi-view 3D display based on a parallax barrier with a gradient transmittance that has an enhanced frequency characteristic. The aperture ratio of the parallax barriers is increased, thus improving brightness and reducing crosstalk of the 3D display.

The proposed eight-view 3D display consists of a 2D display panel and a parallax barrier, as shown in Fig. 1. The display panel is used to provide eight parallax images. The parallax barrier is used to display the eight parallax images in different spatial directions.

The parallax barrier designed in the frequency domain has high transmittance, as shown in Fig. 2. Transmittance is 100% at the center of the transparent stripes. Meanwhile, transmittance follows a cosine function at other areas of the transparent stripes. Therefore, an integral of the function in a period shows that total transmittance is increased to 27.5%, which is higher than the conventional transmittance of 12.5%.

The synthetic image is considered as a signal, and the parallax barrier is regarded as an optical system. The signal is modulated by the system, and 3D images are displayed. The spatial relationship between the images and the parallax barrier is not a simple discrete function. A tiny shift or a slight change in the width of the transparent areas can already influence the display effect.

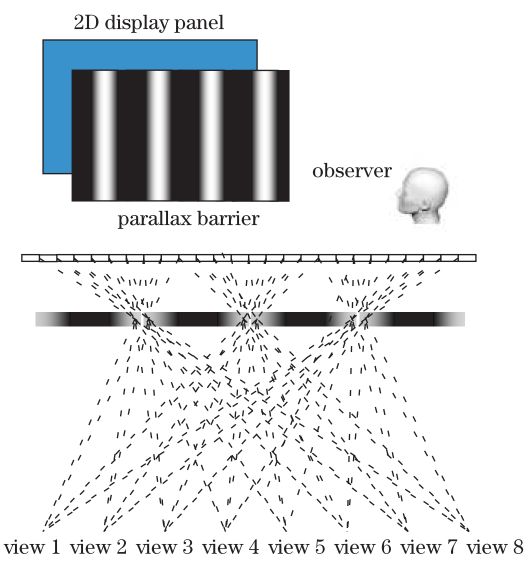


Fig. 1. 3D display based on a parallax barrier with gradient transmittance. (a) Structure of the proposed 3D display; (b) structure of the proposed 3D display.

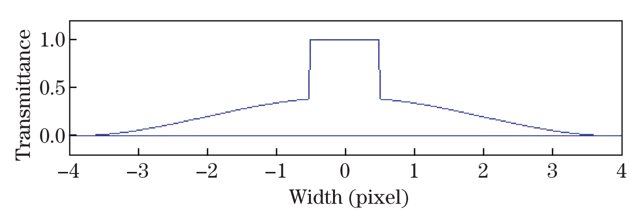


Fig. 2. Transmittance distribution in the transparent areas of the proposed parallax barrier.

Therefore, the signals of the image and the parallax barrier are considered as a continuous spatial function. The relationship between the signal and the system is given by[17]

$$g(x) = k(x) * h(x), \quad (1)$$

$$G(\mathrm{j}2\pi f) = K(\mathrm{j}2\pi f)H(\mathrm{j}2\pi f), \quad (2)$$

where $k(x)$ is the value of the pixels in the element images of the synthetic image; $h(x)$ is the transmittance distribution in the transparent areas of the parallax barrier; $g(x)$ is the value of the pixels displayed in the 3D images; x is the shifting on the horizontal direction; $K(\mathrm{j}2\pi f)$, $H(\mathrm{j}2\pi f)$, and $G(\mathrm{j}2\pi f)$ are their Fourier transformations; f is the spatial frequency. These Fourier transformations can be obtained by using

$$Z(\mathrm{j}2\pi f) = \int_{-\infty}^{+\infty} z(x)\mathrm{e}^{-\mathrm{j}2\pi f x}\mathrm{d}x, \quad (3)$$

where Z means the frequency spectrum, and z means the spatial function. Most information is included in the main lobe of the frequency spectrum. As commonly known in image processing, the low-frequency part stands for the wide-range information, the synthetic image indicates the similarity among different parallax images, and the high-frequency part represents the details in the synthetic image. The pixels of different parallax images are located column by column. As such, the high-frequency part indicates the difference among various parallax images. Therefore, if $H(\mathrm{j}2\pi f)$ has a wider frequency range of the main lobe than $F(\mathrm{j}2\pi f)$ does, then the optical system will have an adequate high-frequency response. This adequate response can present the difference among parallax images correctly, which means that it can display most information in synthetic images and can limit crosstalk at a low level. Enhancing the high-frequency domain of a synthetic image is also helpful to reduce crosstalk.

Gradient transmittance can increase the high-frequency response of the parallax barrier. As shown in Fig. 2, the parallax barrier has two areas. The transparent center areas exhibit the highest transmittance and an appropriate width to match the pixel width on the 2D display panel. These areas can provide a concentrated signal to achieve the highest-frequency response and not cause any crosstalk. The other area of the transparent stripes is also designed for high-frequency responses. An ideal frequency spectrum for this area is a gate function. Therefore, after conducting a Fourier inversion for the gate function, this area was designed by following a cosine function. The Fourier transformations of the conventional and the proposed parallax barriers with the same total transmittance are shown in Figs. 3(a) and (b), respectively. These transformations are obtained by using Eq. (3). Figure 3 show that using a gradient transmittance increases high-frequency response in the proposed 3D display. The frequency range is increased from 2.4 to 6.1 rad/mm. The Fourier transformation of the synthetic image is presented in Fig. 3(c). Meanwhile, the frequency range of this image is approximately 6.2 rad/mm, which means that the proposed 3D display can exhibit most information of the synthetic image. The parallax barrier with gradient transmittance can be optimized further and can exhibit better frequency characteristic. Therefore, compared with the conventional eight-view 3D display, the gradient transmittance of the proposed 3D display increases aperture ratio and brightness.

A prototype of the proposed 3D display with eight views, called Prototype I, is developed. A 19-inch liquid crystal display monitor with a resolution of 1440× 900 is used as the 2D display panel. The parallax barrier is printed on a film to achieve the designated transmittance. Furthermore, the parallax barrier has a total transmittance of 27.5%, and its pitch is 3.7 mm. The distance of the parallax barrier from the 2D display panel is 15 mm. A series of parallax images is used to verify the display effect.

For comparison, two conventional parallax barrier 3D display prototypes, called Prototypes II and III, are also developed. Prototype II has the same transmittance of 27.5% as Prototype I but has no gradient transmittance. This prototype is used to verify crosstalk reduction. Prototype III has a normal transmittance of 12.5% and is used to compare brightness performance.

The results for the three prototypes observed from the optimal viewing distance of 120 mm are shown in Fig. 4. Prototype II has serious crosstalk, whereas Prototype I has lower crosstalk than Prototype II. Therefore, the gradient transmittance in the proposed 3D display limits crosstalk at a low level. Only the darkest picture in Prototype I exhibits slight crosstalk for high brightness compared with the other images. Furthermore, Prototype I has higher brightness than Prototype III. Several pictures in Prototype III are too dark to distinguish the details of the images, particularly the "lighthouse" and "white followers" images. However, all the details can be seen in Prototype I. The brightness of Prototypes I and III is tested in a dark environment. An illuminometer shows that the average brightness of Prototype I is 18.34 cd/m^2, whereas that of Prototype III is 11.83 cd/m^2. This result shows that the proposed 3D display provides higher brightness than a conventional parallax barrier 3D display. Most importantly, the proposed 3D display

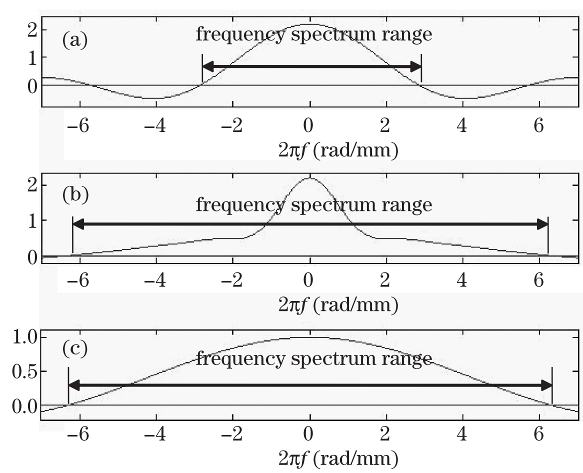
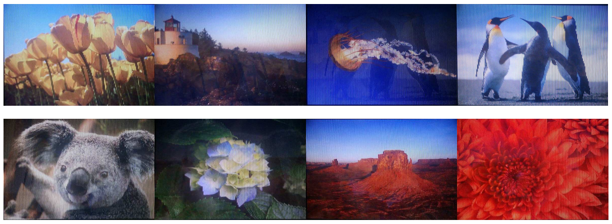
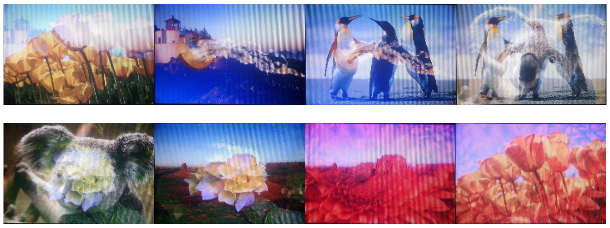


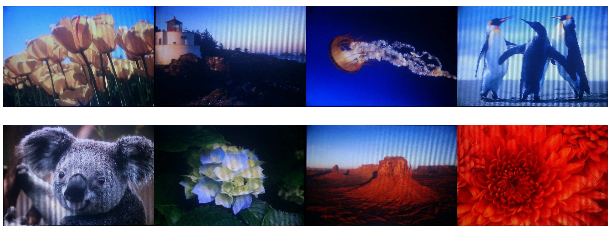
Fig. 3. Frequency characteristic of the parallax barriers. (a) Fourier transformation of the conventional parallax barrier $H_1(\mathrm{j}2\pi f)$; (b) Fourier transformation of the proposed parallax barrier $H_2(\mathrm{j}2\pi f)$; (c) Fourier transformation of the synthetic image $F(\mathrm{j}2\pi f)$



(a) Pictures from Prototype I



(b) Pictures from Prototype II



(c) Pictures from Prototype III

Fig. 4. Transmittance distribution in the transparent areas of the proposed parallax barrier.

exhibits a trade between crosstalk and brightness. However, if the frequency domain of the synthetic images is enhanced, then crosstalk will be decrease further. In the experiment, the synthetic image is generated by conventional method. The nature of the parallax barrier of the proposed 3D display is presented in Fig. 4.

In conclusion, a multi-view 3D display with high brightness is proposed based on a parallax barrier. The proposed display consists of a 2D display panel and a parallax barrier with gradient transmittance. The parallax barrier, which is designed in the frequency domain, has an enhanced frequency characteristic for gradient transmittance. This result indicates that the proposed 3D display can increase the aperture ratio of the parallax barrier, thus providing high brightness and reducing crosstalk. A prototype of the proposed 3D display is developed. The experiment results show that the proposed display provides high brightness and low crosstalk. We will conduct further studies on this display and will attempt to optimize the proposed parallax barrier to achieve better display quality.

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