Autostereoscopic 3D flat panel display using an LCD-pixel-associated parallax barrier*

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This letter reports an autostereoscopic three-dimensional (3D) flat panel display system employing a newly designed LCD-pixel-associated parallax barrier (LPB). The barrier's parameters can be conveniently determined by the LCD pixels and can help to greatly simplify the conventional design. The optical system of the proposed 3D display is built and simulated to verify the design. For further experimental demonstration, a 508-mm autostereoscopic 3D display prototype is developed and it presents good stereoscopic images. Experimental results agree well with the simulation, which reveals a strong potential for 3D display applications.

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With the rapid development of information technology, a tremendous amount of information is expected to be displayed more effectively. To produce super reality, an instantaneous display technique for 3D images is anticipated. Autostereoscopic displays, which provide 3D perception without special glasses or other headgear, are candidates for next-generation image media[1-3]. Due to the advantages of easy fabrication and low cost, parallax barriers used in autostereoscopic 3D flat panel display attract great attention[4-6]. However, the barrier's design still requires a series of cumbersome processes, which may suffer from a lot of experiences and trials. In practical applications, a design, which is uniquely determined by the pixel parameters of the LCD flat panel, will be more preferred. This letter tries to explore and verify such a design. We will focus on an LCD-pixel-associated parallax barrier (LPB) for the autostereoscopic 3D display system. The basic principle of the LPB design will be discussed in detail. For simulation verification, the optical system of the proposed 3D display is built and analyzed based on the Monte Carlo ray-tracing approach. Finally, a 508-mm autostereoscopic 3D prototype equipped with the designed LPB is developed and tested.

The proposed autostereoscopic 3D display system, as shown in Fig.1, consists of an LCD flat display panel, an LCD-pixel-associated parallax barrier, and an appropriate viewing zone. The LCD flat panel is employed to provide synthetic images of the left and right viewing zones. The synthetic images are then separated by the LPB located between the LCD panel and the viewer. The transparent and the opaque parts of the LPB are arranged side by side in line. Fig.1 shows a dual-viewpoint 3D display system. The LPB's period, including independent transparent and opaque parts, should be double of the color pixel width. Actually, the width of the transparent/opaque part is equal to that of a single color pixel. The rays emitted from neighboring pixel columns should be directed and redistributed into the left or right viewing zone. Thus, left eye can see the odd pixel columns while right eye sees even ones.

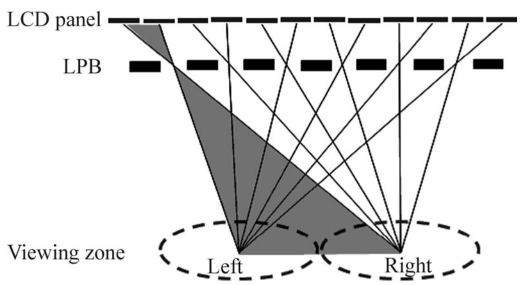

Fig.1 The proposed autostereoscopic 3D flat panel display system

Correct stereoscopic parallax images correspond to an appropriate viewing zone. The appropriate viewing distance can be calculated from similar triangles shown in Fig.1. Assume that the pixel spacing and the center distance of the left/right viewing zones are l_P and l_Z, respectively. Then, the following proportional relationship can be obtained:

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$$\frac{l_P}{l_Z}=\frac{d_{L\_L}}{d_{L\_V}} \quad , \tag{1}$$

where d_{L_L} represents the vertical distance between the LCD panel and the LPB, and d_{L_V} is the appropriate viewing distance, i.e., the vertical distance between the LPB and the viewer. Therefore, the appropriate viewing distance can be calculated by the following expression:

$$d_{L\_V}=\frac{l_Z \cdot d_{L\_L}}{l_P} \quad . \tag{2}$$

In Eq.(2), l_Z should match the interpupillary distance. l_P is provided by the manufacturer of the LCD flat panel. Obviously, the appropriate viewing distance has a definite relationship with the parameter of d_{L_L}.

The color pixel arrangement of the LCD panel is depicted in Fig.2(a). A complete pixel with a square surface is composed of the red/green/blue sub-pixels. The sizes of a complete pixel and a sub-pixel are 277 μm×277 μm and 92.33 μm×277 μm, respectively. Fig.2(b) shows the matching relationship between the LPB and the LCD sub-pixels for a dual-viewpoint system. The LCD sub-pixels are partly covered according to the LPB's period. The uncovered red/green/blue sub-pixels will rebuild several complete color pixel units to display a separate parallax image.

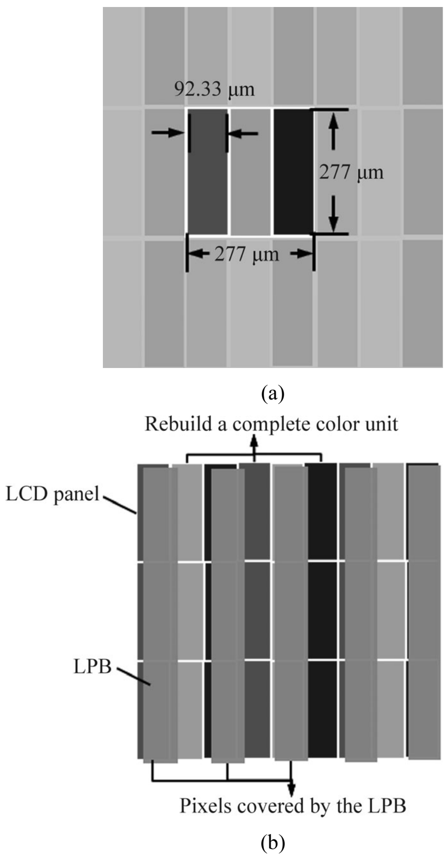

Fig.2 (a) Sub-pixel arrangement of the LCD panel; (b) Matching relationship between the LPB and the sub-pixels

To verify the LPB design, the optical system of the proposed 3D display is built and simulated by using the Monte Carlo ray-tracing approach in the optical analysis tool of TracePro®[7]. Ten million rays are traced from the red/green/blue sub-pixels, respectively. Fig.3 shows the simulated images and the corresponding normalized irradiance distribution at the optimal viewing distance. A series of zonal spots with an interval distribution are projected on the screen due to the LPB's light separation. More importantly, the centers of neighboring viewing zones are distributed with a fixed interval, which matches the interpupillary distance. It reveals that neighboring sub-pixels can produce independent viewing zones to ensure the autostereoscopic 3D display.

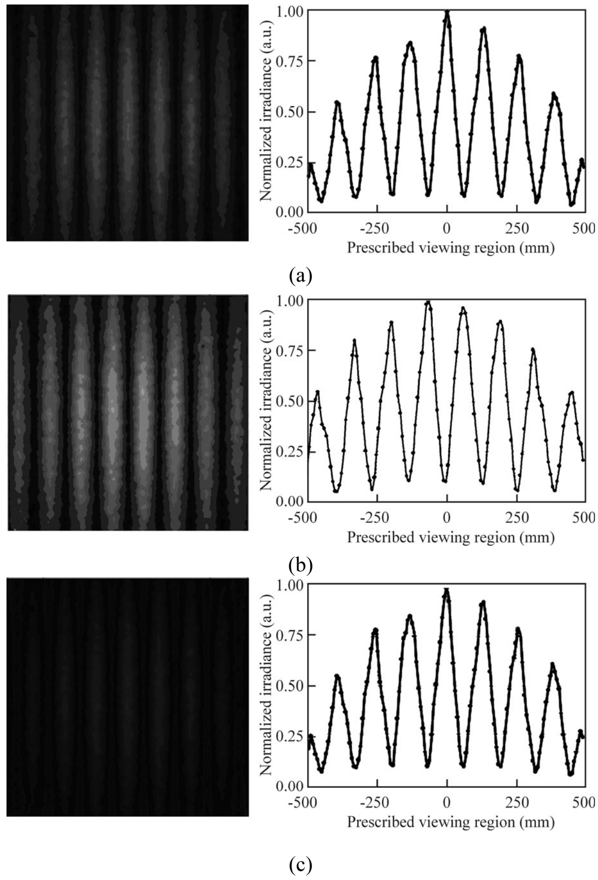

Fig.3 The simulated images and the corresponding normalized irradiance distributions at the optimal viewing distance: (a) From the red sub-pixel; (b) From the green sub-pixel; (c) From the blue sub-pixel

For further experimental demonstration, a 508-mm autostereoscopic 3D display prototype is developed and analyzed. The prototype's parameters are listed in Tab.1. An LCD flat panel with the diagonal size of 508 mm and the resolution of 1600 pixel×900 pixel is employed to provide synthetic parallax images. The LPB is fabricated by etching photolithographical method based on the material of PMMA. The interval of the viewing zones should be in accordance with the interpupillary distance, which is set to be 65 mm. The optimal viewing distance is calculated to be 704 mm from Eq.(2), which is suitable for a desktop display use.

Tab.1 Design parameters of the proposed 3D display system

Component	Parameter	Value
LCD flat panel	Diagonal size	508 mm
	Resolution	1600 pixel×900 pixel
LPB	Period	184.66 μm
	Thickness	1 mm
Viewing zone	Viewing distance	704 mm
	Interpupillary distance	65 mm

The fabrication technology of parallax barrier has been commercially available, but the machining accuracy would finally produce an effect on the visual effect of stereoscopic display. Therefore, the designed LPB is measured under 100× magnification from an Olympus microscope. Fig.4 shows the fabricated LPB and the precision measurement results. Transparent/opaque width of the LPB is fluctuated within ±1 μm around the design value of 92.33 μm. The average widths of transparent and opaque parts are 92.45 μm and 93.20 μm, respectively. Accurate machining results ensure that the system could possibly offer a correct visual effect of stereoscopic display.

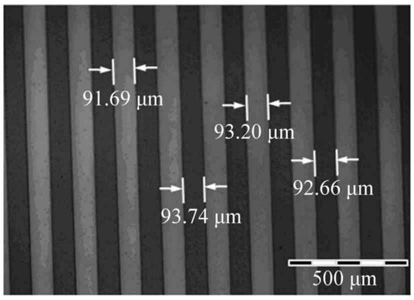

Fig.4 The fabricated LPB under 100× magnification from an Olympus microscope

After assembly and test, the prototype presents stereoscopic 3D images and videos. The optimal viewing distance is about 700 mm, which agrees well with the theoretical calculation and simulation result. The actual picture obtained with the stereoscopic 3D display system is shown in Fig.5. Obviously, a correct stereoscopic 3D image can be observed at this optimal viewing distance. It is not perfect that some colored stripes are observed simultaneously. There are two primary reasons for this. One is that the LPB is not flattened and fixed well in front of the LCD panel. The other is that the vertical arrangement between the sub-pixels and the LPB brings about the phenomenon of crosstalk. This can be alleviated by correcting the sub-pixel position or other methods[8]. The brightness of the prototype is over 130 cd/m^2, which can satisfy the requirement for desktop applications.

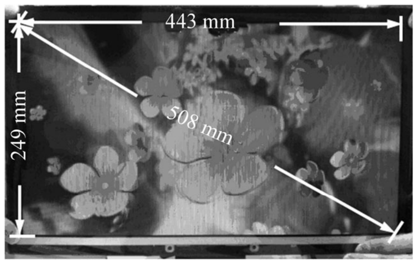

Fig.5 The actual picture obtained with the proposed 3D display system

In conclusion, this letter presents a dual-view autostereoscopic 3D display system equipped with an LCD-pixel-related parallax barrier. Good agreement is obtained between simulation analysis and experimental result. It is convenient to apply this simple method to practical 3D display systems with only the LCD sub-pixel's parameters taken into account, and thus good image is acquired and the design process can be simplified. We believe that the principle exploration given here is useful for further study of LPB-based multi-view 3D flat panel display systems.

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