Study on the Design Parameters for Parallax-Barrier Light-Field Display

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ABSTRACT

Based on a designed periodic parallax barrier and a two-dimensional display, a Light-Field Display system is proposed. The panel provides synthetic image, and the subpixels are projected to different views. This paper shows how the factors affecting the image quality and their influence for different application scenarios.

1 Introduction

As 3D display can provide vivid scenes, a great progress has been made for autostereoscopic displays which provide a 3D impression without any special glasses.

Light-Field Display technology is an emerging 3D display technology, which records the light field information emitted from objects and reproduces the view information of the 3D scene by reconstruction [1],[2]. By controlling the light-emitting angle, it can provide better binocular parallax and motion parallax.

2 Experiment

2.1 Optical design for a parallax barrier light field display

Fig. 1 shows the design principle of a Light-Field Display. The panel provides different images of different views, while parallax barriers redirect light rays to different viewpoints. Parallax barriers block certain rays from the panel so that viewers can see different images from different directions.

The geometrical method only considers the relationships between the central point of subpixel and central point of parallax barrier. P_D and P_B are the pitches of the subpixels and barriers, f is the distance from panel to barriers, and α_B is aperture ratio of barrier.

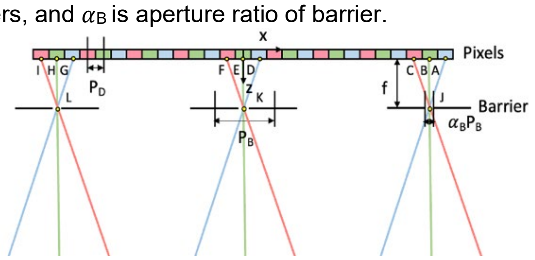


Fig. 1 Schematic diagram for the Light-Field Display designed at the x-z plane: top view.

Assume that the angles between $\overleftrightarrow{BJ}$ and $\overleftrightarrow{CJ}$, $\overleftrightarrow{EK}$ and $\overleftrightarrow{FK}$, $\overleftrightarrow{HL}$ and $\overleftrightarrow{IL}$ are θ, which is the angle of view 1, according to the geometric analysis, we get

$$\theta = \tan^{-1}\left(\frac{P_d}{f}\right) \quad (1)$$

Therefore, in this design, first we determine P_D and the angle θ which the subpixel is deviated to, and then f can be obtained from Eq. (1).

2.2 Interval between the adjacent views

The angular interval between the adjacent views of the light field for each group of subpixels is determined by the distance of the observer and inter-pupillary distance. As shown in Fig. 2, different views are sent to the right and left eyes for creating 3D image [3]. Therefore, the distance between the light fields of the two adjacent viewing angles is the distance between the eyes. When viewers are at a distance of 35 cm from the display, interval between the adjacent should be approximately 11°.

The pixel arrangement in the panel is shown in Fig. 3, and every nine subpixels make up a pixel unit. The numbers 1-9 represent the pixels of different parallax images.

We use Matlab® to do some simple image processing, interlacing of the light field views before input image [4].

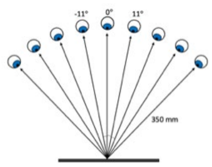


Fig. 2 A schematic diagram of each view point.

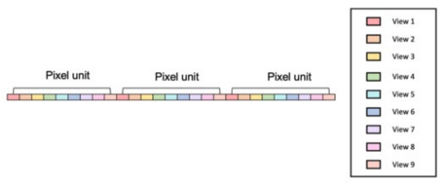


Fig. 3 The pixel arrangement on the panel.

3 Results

The simulation parameters are listed in Table 1.

Table 1 Simulation parameters.

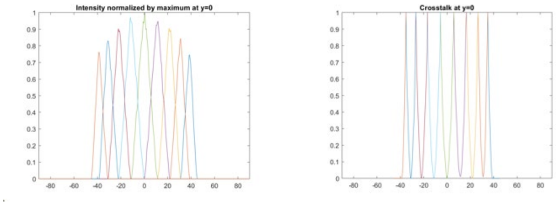
Parameters	Definition	Value
P_D	Pitch of subpixel	0.056 mm
P_B	Pitch of barrier	0.504 mm
α_B	Aperture ratio of barrier	10%
f	Distance from screen to the barrier	0.28 mm
P_E	Inter-pupillary distance	65 mm
OVD	Distance from the barrier to a viewer (Optimal viewing distance)	350 mm
S	Screen size	9.7 inch
n	Angular resolution (Number of views)	9
FOP	Field of parallax	78°
H	Horizontal parallax image's resolution	426

3.1 Ray tracing

To approach the real situation, ray tracing method is applied. Fig. 4(a) shows the nine-view parallax image's normalized luminous intensity distributions at the optimal viewing distance. Crosstalk is defined by Eq. (2) where I_j is the intensity of the correct image received by one view, $(\sum_{i=1}^{n} I_i) - I_j$ is the intensity of the incorrect image received from other views.

$$\text{Crosstalk}=\frac{(\sum_{i=1}^{n} I_i) - I_j}{Ij} \qquad (2)$$

From the intensity distributions in Fig. 4(a) and according to Eq. (2), crosstalk is obtained as shown in Fig. 4(b). The simulation results indicate that the proposed Light-Field Display has slight crosstalk at the viewing angle we designed.

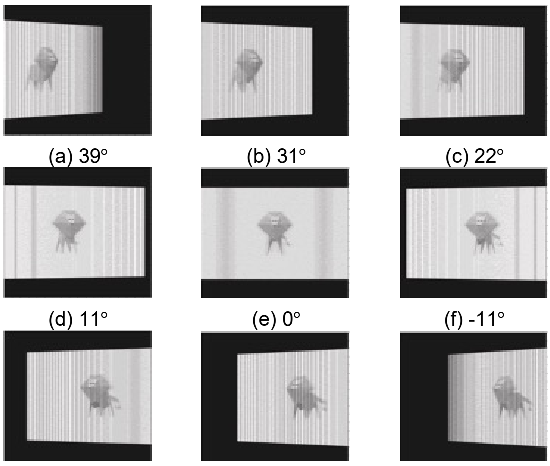


(a) (b)

Fig. 4 (a)Luminous intensity distribution (b) Crosstalk of different views at optimal viewing distance.

3.2 Image simulation

In image simulation, nine parallax pictures of a lion are used for the display content. Fig. 5 shows the nine different views in the horizontal direction. Matches the ray tracing result, at the optimal viewing distance, we can see that the image changes with the viewer's direction as a result of the effect of the parallax barriers placed on the panel. Furthermore, viewers can obtain good image quality and there is little crosstalk between the adjacent views.



(a) 39° (b) 31° (c) 22°
(d) 11° (e) 0° (f) -11°
(g) -22° (h) -31° (i) -39°

Fig. 5 Nine-view images at different viewing angles.

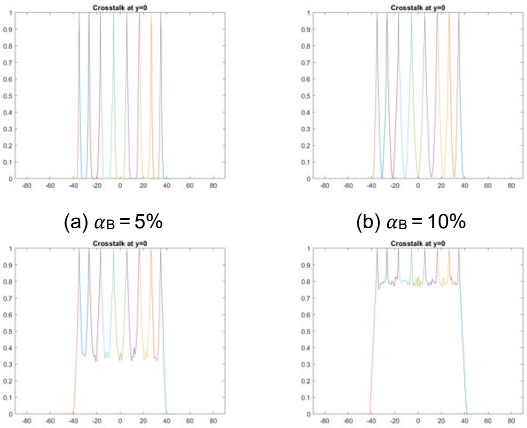
4 Discussion

Since a number of factors may affect the image quality, such as different FOP, angular resolution, image resolution, aperture ratio, etc. We modify some design parameters and evaluate the influence separately, which is assessed under three conditions.

(1) S = 9.7-inch, n = 9, FOP = 78°, modulate α_B
(2) S = 9.7-inch, α_B = 20%, modulate n
(3) n = 9, α_B = 10%, S = 9.7,14,50-inch

4.1 Different aperture ratios with a fixed angular resolution

First, the simulation assesses the effect of different aperture ratios on image quality, based on the prototype built in Table 1, we modify α_B from 5% to 20%. Fig. 6 shows that there is more serious crosstalk at large aperture ratio, however brightness decreases at small aperture ratio. We should consider the trade-off between them.

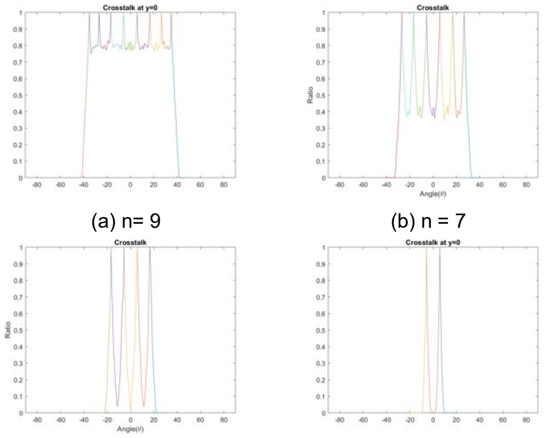


(a) α_B = 5% (b) α_B = 10%
(c) α_B = 15% (d) α_B = 20%

Fig. 6 Crosstalk distributions of different α_B at the optimal viewing distance.

4.2 Different angular resolution with a fixed aperture ratio

In the second part, to compare different angular resolution, we change n from 3 to 9. Again, the other simulation parameters are the same as Table 1. Since the interval between the adjacent views and total pixels of the panel are the same, there is a trade-off between spatial and angular resolution. The result of different angle resolution is shown in Fig. 7. It shows that as n decreases, crosstalk tends to be small. Crosstalk is close to 80% in 9 views, 40% in 7 views, but reduced to 0-10% for 3 and 5 views.



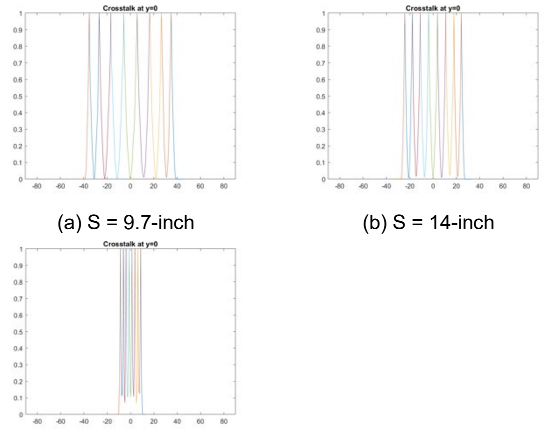
(a) n= 9 (b) n = 7

(c) n = 5 (d) n = 3

Fig. 7 Crosstalk distributions of different n at optimal viewing distance.

4.3 Different usage scenarios

In addition to the 9.7-inch tablet, the third part also conducts a simulation analysis for a 14-inch laptop and a 50-inch TV to verify that the design parameter proposed above can be applied to different display device. Crosstalk of the 9.7 and 14-inch panels are similar while the 50-inch panel may have a slight increase in crosstalk due to the interval of the adjacent views is smaller, as shown in Fig. 8.



(a) S = 9.7-inch (b) S = 14-inch

(c) S = 50-inch

Fig. 8 Crosstalk distributions of different usage scenarios at optimal viewing distance.

5 Conclusions

In this paper, a Light-Field Display based on parallax barrier is proposed. We put forward optical design principle by geometric method, and discuss different design parameters and application scenarios by ray tracing method.

The simulation results indicate that the larger aperture ratio, the greater crosstalk, but also the higher brightness, so we need to strike a balance between image quality and brightness. On a 9.7-inch panel, OVD=35 cm, FOP=78° and n=9, good image quality can be obtained when $\alpha_B = 10\%$. There is a slight difference between α_B=10% and α_B=5% and brightness of α_B=10% is about twice.

If the angular resolution is changed, as n becomes smaller, FOP will be smaller. That is, viewpoint can only be changed within a smaller angular range. However, the aperture ratio can be larger while similar image quality can be obtained, and spatial resolution will also become larger. Therefore, the choice needs to be made according to actual usage requirements.

And finally, by changing different application scenarios, it can verify that the design of this research is not restricted by panel size and viewing distance. Under the fixed aperture ratio and panel resolution, good image quality can be obtained in different application scenarios. Three conditions are all suitable for the proposed design and analysis methods. Although when the viewing distance becomes longer and the interval of the adjacent views becomes closer, it may be necessary to reduce the aperture ratio to achieve the same image quality. Our study in this paper may help in finding a better balance between the factors affected the image quality.

Acknowledgement

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