Ground autostereoscopic display with new type non-uniform barrier

Shujun Xing¹, Shuo Liu^{*2}, Xinzhu Sang¹, Huilong Cui, Xunbo Yu¹, Duo Chen¹

¹ State Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications
(BUPT), 100876 Beijing, China

² Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences,
Beijing 100094, China

Corresponding author's email: [*liushuo@radi.ac.cn](mailto:liushuo@radi.ac.cn)

Abstract

This paper analyze the drawbacks of traditional parallax barrier with the uniform slits for large-scale ground autostereoscopic display firstly. And then an approach of designing non-uniform barrier for ground display is proposed by use of the reverse ray-tracing technique and Iterative approximate algorithm. Form the numerical simulation, it is proved that low cross-talk feature of the non-uniform barrier is an advantage relative to traditional parallax barrier .

Keywords: Ground autostereoscopic display; non-uniform barrier; reverse ray-tracing technique

1. Introduction

Autostereoscopic displays provide depth perception without observers having to wear special glasses. A wide variety of these displays have been devised over the past several decades, such as Integral imaging display, Parallax-based display. But they all provide three-dimensional (3D) display in the front of screens which are in parallel with the walls, and the sense of immersion is decreased. Many research institutes try to design autostereoscopic displays for tabletop [1-4]. However, the displays devices can't be compatible with the traditional autostereoscopic display images [5]. So this paper presents a nine-view large size ground autostereoscopic display and its associated barrier generating methods based on reverse ray tracing technique [6][7].

In this paper we will introduce the hardware configuration of the autostereoscopic ground display and analyze the drawbacks of traditional parallax barrier with the uniform slits by first. We find that the traditional parallax barrier is not suitable for ground display and then propose the non-uniform barrier slits generating method. At end, the simulation result is to illustrate the effectiveness of the non-uniform barrier.

2. System hardware structure of ground auto-stereo displays

(a)

(b)

(c)

Fig .1 Ground auto-stereo display system : (a)the system hardware structure:Four PC clients output 3D stereo image to each ground display LCD screen by receiving server's commands.(b)The coordinate system for the display system(c)the center of four autostereoscopic displays and the gap LR, TB between them.

As depicted in **Fig.1**, our ground display system is composed of one sever ,four PC clients and four special autostereoscopic displays. Sever and PC clients are connected by the local network. According to the computer graphic, the model-view matrix of the server's virtual camera is sent to the virtual camera of PC clients and each PC client can calculate its own model-view matrix by observer's eye position[8]. The four autostereoscopic displays by using non-uniform slits barrier is different from the traditional parallax barrier.

3. The drawbacks of traditional parallax barrier with the uniform slits

In the design process of traditional parallax barrier with the uniform slits,it is exclude to consider the impact of the refractive index n_i and the angle of incidence θ . As the arrangement of sub-pixels for nine-viewpoint autostereoscopic display in LCD panel is depicted in Fig.2, the eye of observer would see the error sub-pixel with the increase of x or y . When the distance between S_n and S_r is more than one pixel length, the cross-talk will appear .

Fig.2 Error pixels caused by traditional parallax barrier without considering n_i and θ :when x is equal to 0,each slit's position have different refraction angle θ and may caused observer to get the error view zone sub-pixels (b)the LCD-panel sub-pixels and traditional slits arrangement (c) with the increase of slit positions'y value,the distance between start point S_n and error start point S_r will be increased.

If the traditional parallax barrier auto-stereoscopic display is applied to show ground 3D scene, Fig.2 is the simulation result by the use of the reference [5] approach when the eye position is (0,0,2.5m). The table 1 is to show the simulation parameters which have the same physical meaning as in the reference [6]. C_{lt} , C_{rt} , C_{lb} , C_{rb} represent the center position of the four LCD screens. As is depicted in Fig. 3, the cross-talk is very serious because it is hard to find a complete viewpoint image for the observer. Therefore, traditional parallax barrier with the uniform slits have the obvious drawbacks for grounds auto-stereoscopic display.

Table 1. List of Parameters and Values Used in the traditional auto-stereo display device Simulation

Parameters	values
View map	
Number of total views N_t	9
Number of subpixels in subpixel group N_h	4.5
Number of lines in subpixelgroup N_v	2
View map angle φ_s	9.462°
Horizontal off-set x_{os}	-2.8
Parallax barriers	
Refractive index n_i/n_t	1.5/1.0
Lenticular slanted angles φ_s	9.462°
Horizontal barrier pitch P_h	471.138 μm

<i>Number of slits</i> N_s	2,560
<i>Horizontal bias</i> x_p	26.25 μm
<i>Number of crossing points in a single slit</i> N_s	108,000
subpixels	
<i>Horizontal pitch</i> P_{sx}	105 μm
<i>Vertical pitch</i> P_{sy}	315 μm
<i>Number of horizontal subpixels</i> N_x	$3,840 \times 3$
<i>Number of vertical lines</i> N_y	2,160
<i>Gap between the lens and subpixel</i> g	6.0 mm
Display screens	
<i>Horizontal grid spacing</i> Δx	6.3 mm
<i>Vertical grid spacing</i> Δy	6.3 mm
<i>Number of horizontal grid lines</i> M_x	192
<i>Number of horizontal grid lines</i> M_y	108
<i>Top-left Screen center</i> C_{tl}	(-0.6048, 1.0206, 0)
<i>bottom-left Screen center</i> C_{lb}	(-0.6048, 0.3402, 0)
<i>top-right Screen center</i> C_{tr}	(0.6048, 1.0206, 0)
<i>bottom-right Screen center</i> C_{br}	(0.6048, 0.3402, 0)

Fig. 3 Calculated intensity distribution on the traditional auto-stereo display screen observed at the optimal viewing distance of 2.5 m under various test images for which sub-pixels corresponding to a given view are white and the others are black. The observer's one eye is located at the position (0,0,2.5), where view 5 among the nine views can be observed over the entire display screen. It hard to see the full white image of view 5, so the traditional parallax barrier is not suited for the ground display.

4. The approach of designing non-uniform parallax barrier for ground display

Fig. 4 The start point S and the center S' of initial square $ABCD$

Assumed that the light ray emitted from a starting point S within the LCD panel is incident to a crossing point C_r on the interfacing surface and that the light ray is transmitted from the crossing point C and reaches the position of the observer's eye E , as shown in the Fig.. If the starting point S and eye E have a given value, the value of crossing point C_r is existence and uniqueness according to Fermat's theorem. The relationship between crossing point C_r , the observer's eye E and starting point S can be expressed as in the following equation[6]:

$$\begin{aligned} x_s &= -\tan(\sin^{-1}[(n_t / n_i) \sin(\tan^{-1}(\frac{\sqrt{(x_e - x_c)^2 + (y_e - y_c)^2}}{z_e - z_c}))]) \bullet \cos(\tan^{-1}(\frac{y_e - y_c}{x_e - x_c})) + x_c \\ y_s &= -\tan(\sin^{-1}[(n_t / n_i) \sin(\tan^{-1}(\frac{\sqrt{(x_e - x_c)^2 + (y_e - y_c)^2}}{z_e - z_c}))]) \bullet \sin(\tan^{-1}(\frac{y_e - y_c}{x_e - x_c})) + y_c \\ z_s &= -g \end{aligned} \quad (1)$$

So (x_c, y_c, z_c) is difficulty to calculated form the equation. For solving the problem, we devised an

iterative approximate algorithm to obtain the value of C_r .

4.1 Iterative approximate algorithm to obtain crossing point

As four crossing points A, B, C, D and the observer's eye E can generate four start points A', B', C', D' , if $ABCD$ is a square, $A'B'C'D'$ is an irregular quadrilateral. We define that $ABCD$ is the parent-square of $A'B'C'D'$ and $A'B'C'D'$ is the sub-quadrilateral of $ABCD$.

Step.1Create a square $ABCD$ whose side length is $w = 60\text{cm}$ and is center s' .

Step.2The irregular quadrilateral $A'B'C'D'$ can be calculated based on reverse ray tracing algorithm.

Step.3If Start point in the irregular quadrilateral $A'B'C'D'$, $ABCD$ can be Split-ed as four same size squares, so their side length is $w / 2^n$, $n=1$. Therefore, four same size squares have four sub-quadrilaterals in plane $A'B'C'D'$.

Step.4Find which sub-quadrilateral contains start point. If the quadrilateral contains the start point and the side length of its parent-square is more than $1.0e-10$, its parent-square will be splited by using the same

method in step2 and the value of n will increase one. When the side length parent-square is less than $1.0e-10$, the value of Cr is the center of the parent-square.

Fig. 5 Iterative approximate algorithm: (a) The splitting of parent-square (b) The definition of parent-square and sub-quadrilateral

4.2 The method to generating non-uniform barrier

The slanted 3D-LCD for multi-view system can overcome the drawback of Moiré-like effect and uneven use of the horizontal and vertical pixel resolution in the LCD panel. A series of start points with a slant angle to generate cross points which make up non-uniform parallax barrier can be expressed as

$$\begin{aligned} x_s &= -\tan \varphi_s \bullet y_s + P_h \bullet l \\ y_s &= \Delta y \bullet m \\ z_s &= -g \end{aligned} \quad (2)$$

Setting a given eye position and the series of start points, we can easily get the cross points by using the iterative approximate algorithm. Assumed that the eye position is (0,0,2.5m), the distance between adjacent slits is depicted in Fig. 6. From this, we can easily conclude that the distance increases gradually with the increase of the red line y value and x absolute value. So the slits of the new type auto-stereo barrier for ground display should be non-uniform.

Fig. 6 The distance between adjacent slits in the new type non-uniform auto-stereo display with a set of given y values. Ten red lines with different y value is shown in (a). Each of them have an curve to express the distance between adjacent slits in(b).

5. The results of the simulation

We apply the approach to generate the new type auto-stereo barriers and read every cross point to simulate the full screen intensity distribution by use of reverse ray tracing technique. The barrier Parameters and Values is listed in the Table2 and the other Parameters and Values is same as the content in Table 1 except parallax barriers. Fig. 7 is the final results of the simulation. Form the result , the new type auto-stereo barriers have less cross-talk compare with the traditional Parallax barriers simulation result shown in the Fig.3.

Table 2. List of Parameters and Values Used in the non-uniform barrier auto-stereo display device Simulation

<i>The new type auto-stereo barriers</i>	
Refractive index n_i/n_t	1.5/1.0
Number of slits N_s	2,560
Number of crossing points in a single slit N_s	108,000
Cross points	Obtained by the method of section 4

Fig. 7 Calculated intensity distribution on the new-type auto-stereo display screen observed at the optimal viewing distance of 2.5 m under various test images for which sub-pixels corresponding to a given view are white and the others are black. The observer's one eye is located at the position (0,0,2.5), where view 5 among the nine views can be observed over the entire display screen.

The full width at halfmaximums (FWHMs) of the intensity distributions of traditional and new type barriers is 17% ,100% respectively for View5 image as is illustrated in fig.8. The FWHM in Fig.8 (b) is maximized since all the intensity values are around 100% of the maximum, leading to the full image of each view from the left to the right sides of display screen.

Fig.8 Cross sectional intensity distribution on the left-top display screen observed at optimal viewing distance 2.5 m. (a)cross sectional intensity distribution of the traditional auto-stereo display(b)cross sectional intensity distribution of the new type non-uniform auto-stereo display. The FWHM of the new type non-uniform auto-stereo display is better than the FWHM of the traditional auto-stereo display.

From Fig. 7 and Fig.8, it is found that the cross-talk of the new type non-uniform auto-stereo display is more lower than the traditional one.

6. Conclusion

In this study, the approach of designing non-uniform barrier is presented for ground auto-stereo display to overcome the drawbacks of traditional parallax barrier with the uniform slits. Cross points in the non-uniform barrier can be calculated by the Iterative approximate algorithm. Non-uniform barrier is different with the traditional parallax barrier with uniform distance between their slits. Form the full screen simulation for the ground auto-stereo display, low cross-talk feature is an advantage relative to traditional parallax barrier.

Acknowledgments:

This work is partly supported by the “863” Program (2015AA015902), the National Science Foundation of China (61177018) and the Program of Beijing Science and Technology Plan (D121100004812001).

References:

[1]Yoshida, S. (2011). fVisiOn: Glasses-free Tabletop 3-D Display - Its Design Concept and Prototype -. Reproduction, 3–5.

- [2]Yoshida, S., Kawakita, M., & Ando, H. (2011). Light-field generation by several screen types for glasses-free tabletop 3D display. *The True Vision-Capture, Transmission and Display of 3D Video (3DTV-CON)*, 2–5.
- [3]Xia, X., Liu, X., Li, H., Zheng, Z., Wang, H., & Peng, Y. (2013). A 360-degree floating 3D display based on light field regeneration. *Optics Express*, 21(9), 11237–11247. <http://doi.org/10.1364/OE.21.011237>
- [4]Ye, G., State, A., & Fuchs, H. (2010). A practical Multi-viewer tabletop autostereoscopic display. *Mixed and Augmented Reality (ISMAR)*, 2010 9th IEEE International Symposium on (pp.147-156). IEEE.
- [5]van Berkel, C. (1999). Image Preparation for 3D-LCD. *Proc. of SPIE, Stereoscopic Displays and Virtual Reality Systems VI*, 3639(May), 84–91.
- [6]Jung, S., Kang, H., Lee, B., & Kang, I. (2015). Numerical simulation of the displayed image on the entire screen of autostereoscopic displays, 23(6), 7842–7855. <http://doi.org/10.1364/OE.23.007842>
- [7]Jung, S.-M., & Kang, I.-B. (2014). Numerical simulation of the optical characteristics of autostereoscopic displays that have an aspherical lens array with a slanted angle. *Applied Optics*, 53(5), 868–77. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/24663265>
- [8]Xing, S., Yu, X., Zhao, T., Sang, X., Cai, Y., Chen, D., ... Dou, W. (2014). Configuration of virtual cameras for ground based 360° three-dimensional display. *Optik - International Journal for Light and Electron Optics*, 125(17), 4714–4717. <http://doi.org/http://dx.doi.org/10.1016/j.ijleo.2014.04.085>