Reducing Moiré in Flat-Panel 3D Displays with a Random Parallax Barrier

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Abstract

Flat-panel 3D displays using conventional slit parallax barriers often encounter significant issues, including moiré patterns and crosstalk. To address these challenges, this paper introduces a novel random parallax barrier design. By disrupting the periodic alignment between the parallax barrier and display panel, the proposed approach effectively mitigates moiré artifacts and minimizes crosstalk. Experimental results demonstrate that the random parallax barrier not only equalizes resolution and suppresses moiré effects but also improves image detail retention, delivering sharper and more realistic visual performance.

Keywords

Light field display; random parallax barrier; moiré.

1. Introduction

Autostereoscopic 3D display technology allows viewers to experience 3D images without requiring specialized equipment. In recent years, this technology has demonstrated significant potential for widespread application and commercialization across diverse fields, including film and television entertainment, gaming, multimedia, healthcare, and education [1,2].

Parallax barrier 3D displays have gained popularity due to their relatively simple structure and cost-effectiveness. These displays typically utilize conventional parallax barriers with translucent strips aligned parallel to the 3D column pixels of the LCD. However, because the LCD and the parallax barrier are periodic structures, their alignment can produce unwanted periodic black-and-white gradient stripes, commonly referred to as moiré patterns, which significantly degrade the quality of stereoscopic displays. Efforts to mitigate or eliminate the moiré effect have focused on optimizing structural parameters. For example, tilted parallax barriers have been shown to reduce moiré patterns, but they often increase crosstalk between viewpoints [3,4]. Optical solutions, such as the use of optical diffusers to disrupt the periodicity of the structure have also been explored, but these solutions frequently compromise image quality [5,6,7]. In the case of free-form stereoscopic displays on LED screens, the moiré effect can be minimized by adjusting the width of the black matrix or the pixel spacing. However, for LCDs, the small size of the black matrix, limited adjustment space, and high production costs pose significant challenges. In near-eye displays, light field near-eye displays have leveraged random pinhole structures and spatially randomized light modulators to disrupt the periodicity of elemental images, providing a potential pathway to reduce moiré artifacts [8].

To address the issue of moiré patterns, this paper introduces a novel random parallax barrier autostereoscopic 3D display, which comprises a collimated backlight, an LCD, and a random parallax barrier. The proposed system disrupts the alignment between the barrier period and the pixel period of the LCD by randomly shifting the transmissive strips of the vertical parallax barrier in pixel-sized increments. This method effectively suppresses moiré artifacts without significantly increasing crosstalk. Moreover, it addresses the resolution imbalance between the horizontal and vertical directions while mitigating the degradation in display quality typically caused by an increased number of viewpoints.

2. Construction and Principle

Parallax barrier 3D display is a barrier baffle placed in a specific position in front of or behind the display, using the light-splitting effect of the baffle, so that the parity pixel columns on the display enter the viewer's left and right eyes, respectively, and through the fusion of the human brain, thus producing stereoscopic visual effects. The main parameters include the number of viewpoints (K), slit barrier period (T), viewing distance (L), and distance between the LCD screen and the barrier (D). As shown in Fig. 1, the relationship between the parameters can be obtained according to the principles of mathematical geometry, the formula can be expressed as:

$$\begin{cases} D = \dfrac{P \cdot L}{E + P} \\ T = \dfrac{K \cdot P \cdot E}{E + P} \\ W = \dfrac{P \cdot E}{E + P} \end{cases} \tag{1}$$

Where W is the width of the slit, P is the sub-pixel width, and E is the viewpoint spacing.

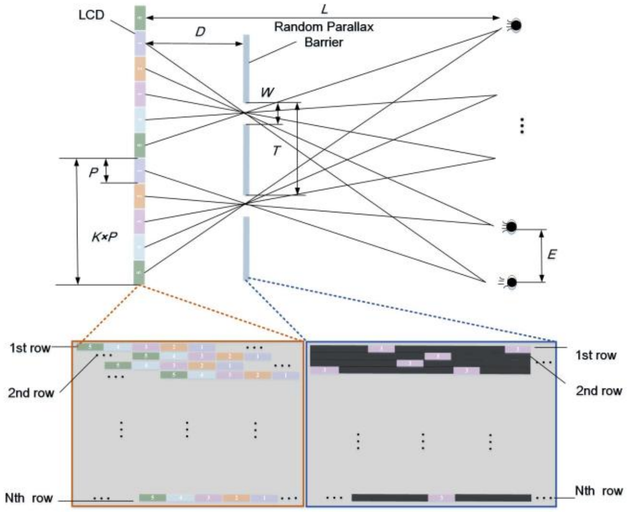

Figure 1. Principles of random parallax barriers based 3D display.

A random parallax barrier is characterized by shading and transmitting bars that are misaligned in the vertical direction at intervals of H (an integer multiple of the pixel height). In the horizontal direction, the misalignment of the light-transmitting and light-shielding bars is an integer multiple of the pixel width, while the period of each row remains constant. This random

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parallax barrier is realized by controlling the transmission of polarized light through an LCD screen. The electro-optical effect of the liquid crystal enables the implementation of a random parallax barrier stereoscopic display. As shown in Fig. 1(b), due to the random misalignment of each row in the parallax barrier, the pixel information displayed on each line of the LCD screen is rearranged. Unlike traditional parallax barrier, which only allow the viewing of pixel columns corresponding to specific viewpoints, the random parallax barrier allows the entire screen to display viewpoint-specific pixel information, thereby significantly enhancing the display quality.

In stereoscopic display, the periodic black matrix of the LCD screen and the periodic structure of the parallax barrier placed in front of the screen interfere with each other, leading to the generation of moiré patterns. To reduce the impact of moiré, a common approach is to tilt the parallax barrier relative to the LCD screen. However, this can result in the observer simultaneously viewing information from multiple parallax images, thus increasing crosstalk between different viewpoints and degrading the stereoscopic effect. The moiré pattern generation cycle can be expressed as:

$$N = \frac{ab}{\sqrt{a^2 + b^2 - 2ab\cos\theta}} \qquad (2)$$

Where: $\boldsymbol{a}$ is the barrier distance of barrier 1; $\boldsymbol{b}$ is the barrier distance of barrier 2; $\boldsymbol{\theta}$ is the deflection angle between the two barrier. In the barrier distance to determine the case, the deflection angle $\boldsymbol{\theta}$ is the main influence of Moiré.

To reduce moiré, the difference between the parallax barrier period and the pixel period of the LCD screen can be increased by randomly shifting the position of the transmissive stripes. This randomization decreases the correlation between the beam-splitting element and the display, thereby reducing the contrast of the moiré. To investigate the formation mechanism and characteristics of moiré in slit- autostereoscopic 3D displays, a model is developed, and optical path simulations are conducted. The corresponding parallax barrier structure is constructed using mechanical design software, while the light source array is simulated in optical design software to model the LCD screen. The barrier plane is positioned perpendicular to the light direction, with a specific deflection angle relative to the LCD screen. An optical lens is constructed and parameters such as the diameter of the entry pupil, the size of the field of view, the operating wavelength and the focal length are adjusted to approximate the human eye. The aim is to simulate the results of the human eye's observation of moiré, which is then captured by a detector.

In order to be able to simulate the moiré better, the size of the simulation area is 30 mm × 30 mm. The screen has a black matrix period of 0.091mm and a barrier period of 0.9 mm, simulations and experiments are conducted at a viewing distance of 500 mm to observe the period and frequency of moiré stripes under different tilt angles. Tilt angles of 5°, 10°, and 15°, as well as a random parallax barrier, are selected for simulation. The results, shown in Fig. 2, from left to right are the simulation results, the experimental results, and the spectrograms of the moiré, from top to bottom are the moiré patterns at different angles and the moiré patterns generated by the random parallax barrier. The simulation results show that the period of the moiré gradually decreases and becomes less obvious as the tilt angle increases, and the random parallax barrier causes the moiré to look blurrier without obvious interference fringes due to the destruction of the periodicity. The experimental phenomenon also verifies the accuracy of the simulation results, and both increasing the tilt angle and using the random parallax barrier can effectively suppress the moiré due to the resolution limit of the human eye. In the spectrogram after Fourier transform, the higher the frequency, the farther the symmetric frequency point is from the center, and the lower the frequency, the closer the symmetric frequency point is to the center, which also proves the effectiveness of the changed method.

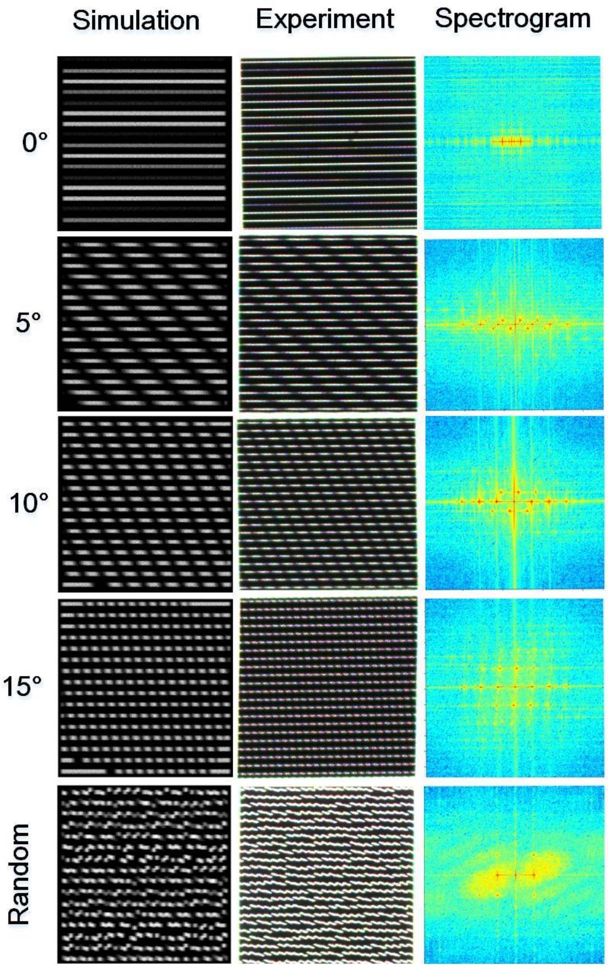

Figure 2. Characterization of moiré under different conditions.

Additionally, the random parallax barrier enables the 3D display system to utilize both horizontal and vertical pixels to form stereoscopic viewpoints, thereby equalizing the resolution in both directions. This resolution equalization significantly enhances the display quality, while also alleviating the degradation of image quality that typically occurs with an increased number of viewpoints. Traditionally, stereoscopic images are synthesized by extracting parallax images from column pixels and recombining them at specific positions to form a new synthesized image for display. To address the issue of resolution imbalance, a parallax encoding method is proposed. In this method, the parallax image array captured by the raster and virtual camera array is pixel-coordinated. Pixel coordinates are extracted from each viewpoint image according to the mapped optical path, and then rearranged to synthesize the stereoscopic image. This approach ensures that the pixels from the parallax images are uniformly distributed in the synthesized image, effectively equalizing the resolution.

3. Experiments and Results

Random parallax barriers are effective on both monochrome and color displays, and in this paper, a monochrome flat-panel 3D display system is built to verify the effectiveness of the scheme, as shown in Fig. 3. The experimental setup consists of a backlight module and two LCD screens without backlight, the backlight module consists of an LED array and a Fresnel lens. Each panel has a size of 8.9 inches, a resolution of 3840×2400, a pixel density of 508 PPI, and a pixel size of 0.05 mm. The main parameter specifications of the random parallax light field display system are summarized in Table 1. After the construction of the three-dimensional display system, the viewing angle is about 25°, according to the formula (1) to obtain the optimal viewing distance of 1500 mm, the resolution of the three-dimensional image is 349 × 218.

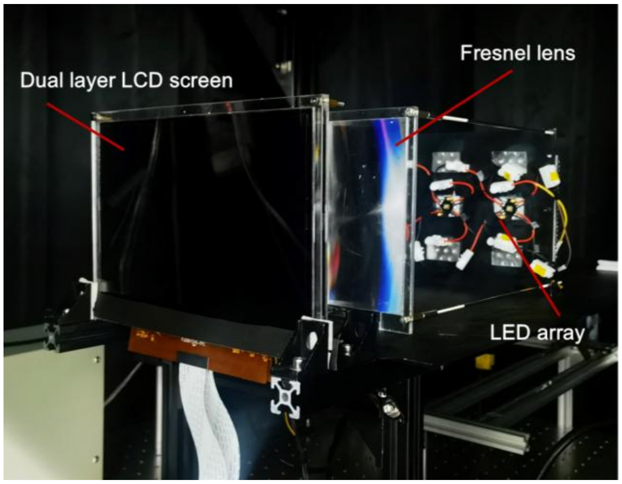

Figure 3. Autostereoscopic 3D display system based on random parallax barrier.

Table 1 Specifications of autostereoscopic display

Specifications	Numerical value
Number of view	11
2D Resolution	3840×2400
Pixel pitch	0.05mm
Distance between the flat display screen and parallax barrier	1.2mm
Slit width	0.05mm
Period of the slit	1.25mm

For applications in entertainment, healthcare and education, monochromatic dice and human skulls were chosen as display images for the experiment. As shown in Fig. 4. Each row shows a different object, and each column is the image displayed by a different parallax barrier at different viewing angles. When displayed as a whole, conventional parallax barriers have noticeable black and white stripes that affect viewing comfort, while randomized parallax barriers have a uniform image. When zoomed in, the random slit barrier significantly improves the image quality, and compared with the imaging effect of the traditional parallax barrier, the random parallax barrier can better retain the details and show a higher resolution. At the same time, the random parallax barriers showed no significant crosstalk compared to the vertical inspection barriers. For example, when displaying dice points, details are not accurately displayed due to the inherent flaws of traditional barriers, while randomized barriers solve this problem perfectly. This demonstrates that the proposed method effectively mitigates the display ratio imbalance typically caused by conventional barrier. Not only does it prevent this imbalance, but it also disrupts the interference caused by the periodic arrangement of traditional parallax barriers, leading to more detailed and realistic image performance.

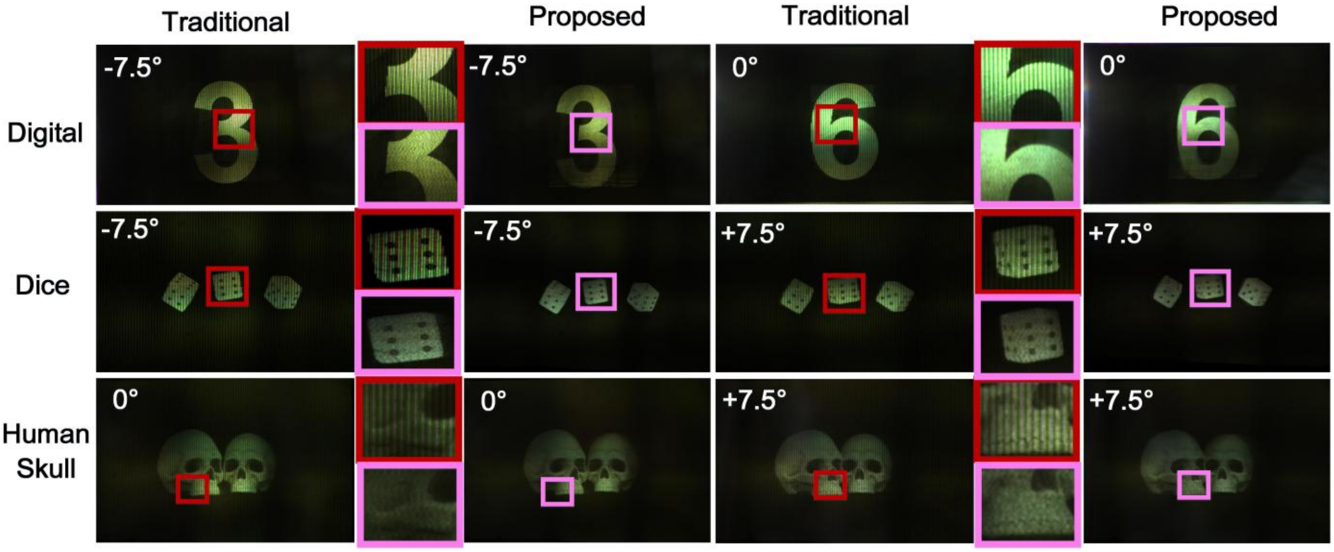

Figure 4. Display the effect of the conventional parallax barrier and the proposed parallax barrier at different viewpoints.

4. Conclusion

This paper presents a random parallax barrier that successfully mitigates moiré interference while preserving the essential parallax effect through the introduction of a moderate random offset, without substantially increasing crosstalk. Experimental results confirm that the proposed approach not only balances display resolution but also improves image detail retention, delivering a clearer and more natural 3D visual experience across multiple viewpoints. Future work will focus on extending this method to make it applicable to color 3D displays.

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