High-Resolution Multi-Person Viewing Naked-Eye 3D Display System Based on Eye Tracking and Spatiotemporal Multiplexing Technology

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Abstract
With the development of naked-eye 3D display technology, users can freely experience the three-dimensional effect without glasses, in which the light field display has gradually entered the public's field of vision because of its high-precision reconstruction of virtual 3D scenes. However, the trade-off between the number of viewpoints and the 2D display effect is still the bottleneck of this technology. In this paper, a high-resolution multi-person stereoscopic display system is realized by dynamic collimation backlight, human eye tracking algorithm and new driving scheme. The main technology is the use of collimated backlight, beam splitting and optical waveguide to realize the time division multiplexing of backlight; With the multi-person tracking algorithm and the mapping algorithm, the smooth 3D motion parallax is realized. The combination of multi-person eye tracking technology and spatio-temporal multiplexing technology makes the spatial resolution greatly improved.

Author Keywords
Light field display; Multiple person eye tracking; Excellent 2D display effect.;

1. Introduction
In recent years, with the rapid development of the display technology industry, the resolution of 2D displays has been significantly increasing, gradually advancing from 2K to 4K, 8K, and even 16K. However, as resolution continues to improve, the human eye's ability to perceive changes in resolution gradually reaches its limit, to the point where people begin to find it difficult to notice significant differences in this increase. Therefore, 3D display technology is also gradually entering people's lives, bringing viewers a more immersive and three-dimensional viewing experience. Naked-eye 3D display technology has become an important development direction in the field of future displays because it allows for clear display effects without the need for any auxiliary equipments [1,2].

The cylindrical lens grating autostereoscopic 3D technology is based on the principle of stereoscopic vision. It achieves the viewing of stereoscopic images by using specific optical occlusion and light path propagation control to transmit images with parallax to the left and right eyes of a person, respectively. This technology utilizes the refraction of light by the cylindrical lens grating to project the parallax images on the display screen onto their corresponding viewing areas in the horizontal direction, allowing the viewer's left and right eyes to see different parallax images, thus forming stereoscopic vision. In the field of naked-eye 3D display technology, light field display technology, with its ease of integration and low cost, has tremendous commercial development prospects [3,4].

Despite the promising future of light field display technology, a critical challenge remains in balancing the number of viewpoints and 3D display resolution. Specifically, single-person light field displays with eye-tracking capabilities can achieve high-quality 3D and 2D visual effects, but they are limited to one viewer at a time[5]. In contrast, multi-person light field displays can support simultaneous viewing by multiple users, often at the expense of 3D resolution and 2D display quality. This trade-off between the number of viewpoints and display quality continues to be the main bottleneck hindering the widespread adoption of light field display technology.

In this paper, To address the conflict between the number of viewpoints and display quality in light field displays, this paper proposes an innovative solution based on a high-refresh-rate LCD screen, dynamic collimation backlight technology, eye-tracking algorithms, and a new driving scheme, successfully implementing a high-resolution light field display that can be viewed by multiple people, aiming to provide higher quality display effects while meeting the needs of simultaneous viewing by multiple individuals.

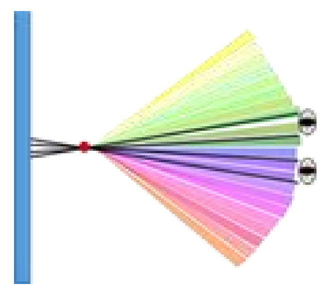

Figure 1. Light Field Display Schematic Diagram

2. Method
System Structure: High-resolution multi-person stereoscopic display system mainly consists of four parts: FPGA unit, backlight unit, eye tracking unit, and PC unit. The FPGA unit obtains the signal, the backlight driver unit used to drive the direction of the backlight, eye tracking unit obtains eye coordinates, and PC unit make an interleaved plot. The block diagram of the high-resolution multi-person stereoscopic display system is shown in Figure 2.

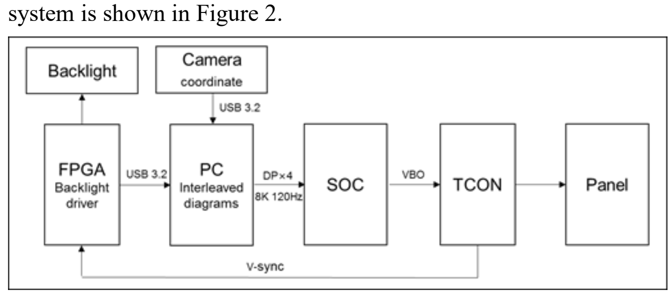

Figure 2. The block diagram of the high-resolution multi-person stereoscopic display system.

FPGA unit: The FPGA, acting as the backlight driving unit, is responsible for receiving the V-sync signal from the TCON and generating the corresponding timing from the driving IC based on

ISSN 0097-996X/25/5603-1821-$1.00 © 2025

this signal. It then transmits these timing signals to both the backlight and the PC end to ensure synchronization between the backlight and the PC end.

Backlight unit: Based on the timing within the FPGA, the backlight direction is switched accordingly.

Camera unit: The camera, as a tool for capturing facial images, can divide the space into different areas after exposure, and identify the largest face in front of the camera from the captured images within these areas. After recognition is completed, AI algorithms are used to accurately calculate the coordinates of the person's eye.

PC unit: On the PC side, the interlaced plotting module is responsible for processing coordinates A and B separately, and combining the coordinates with the plotting according to timing information to achieve precise real-time dynamic display.

Technology Realization: In the frame corresponding to any positive integer N, the backlight system will face the BL direction, constructing the left viewing area. Immediately following, in the N+1 frame, the backlight system then turns to the BR direction, forming the right viewing area. This dynamic adjustment of the backlight direction is based on precise theoretical calculations and optical simulations to ensure perfect alignment with the optimal light-splitting angles of the lens array. Consequently, the left and right viewing areas achieve seamless connection in space, eliminating the issues of overlap and dark area transitions. The persistence of vision in the human eye allows the left and right viewing areas to be seamlessly spliced in space, achieving a better 2D display effect. When the dynamic backlight alternates with the display content at the appropriate frequency, A and B can each see the corresponding naked-eye 3D effect. With the combination of a tracking camera, it is possible to achieve a high-resolution light field display that multiple person can watch as shown in Figure 3.

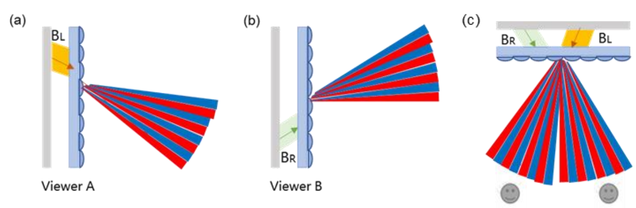

Figure 3. The principle of high-resolution multi-person viewing naked-eye 3D display

3. Results and Discussion

simulation results: On the basis of the above analysis, we simulated the optimal splitting angle of the backlight system respectively according to the designed parameters. Figure 5 presents the simulated results of light distribution at different angles for the backlight system, specifically simulating the light distribution from 35° to 60°. In figures (a) to (e), they correspond to the light distribution diagrams at 35°, 40° , 45°, 50°, 55°, and 60°, respectively. It can be observed from the diagrams that as the angle increases, the boundary between the red and blue viewing zones becomes more distinct, while the brightness value in the central area gradually decreases, and dark areas appear in certain regions. Figure 6 compiles the data on light distribution, from which we can conclude that at an angle of 50°, the light distribution is the most uniform. Taking into account the clarity of the boundary between the red and blue viewing zones, the dark areas caused by the splitting of viewing zones, and the uniformity of light distribution, we can determine that the optimal light-splitting angle for the backlight system is 50°, at which the overall brightness distribution is the most uniform and the 2D display effect is the best.

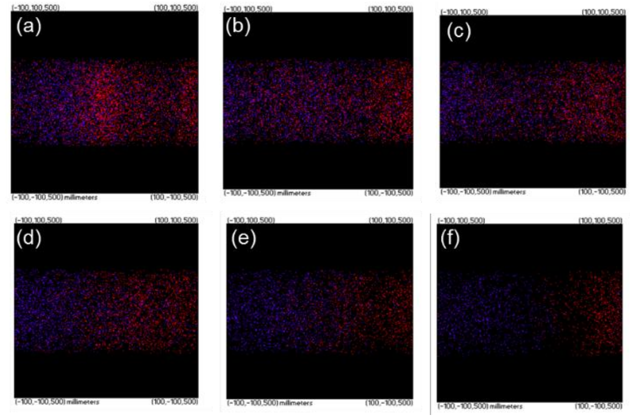

Figure 4. Simulation results of light distribution at different splitting angles of the backlight system.

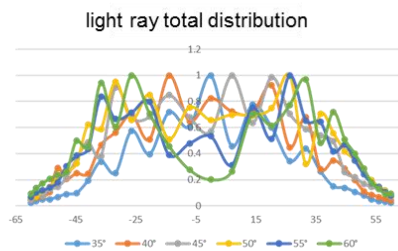

Figure 5. Light ray data statistics.

To further analyze the distribution of red and blue in each viewing area and the crosstalk after dynamic collimated backlight passes through the cylindrical lens, we conducted simulation experiments on the distribution of red and blue in viewing areas A and B under the condition of setting the backlight splitting angle to 50°. The results are shown in Figure 6. As can be discerned from the diagram, when the backlight splitting angle is set at 50° , the system is capable of forming two complete viewing zones in space, each of which exhibits satisfactory red-blue separation effects.

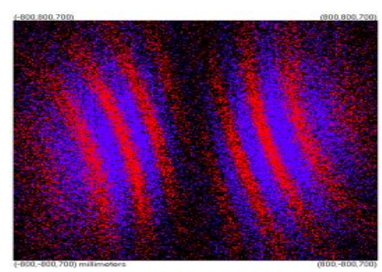

Figure 6. system simulation results.

4. Conclusion

The above results demonstrate that the dynamic backlight system, combined with eye tracking and a new drive system, can achieve a high-resolution light field display that multiple people can watch simultaneously. Compared to traditional light field displays, this solution can provide high-resolution naked-eye 3D effects for multiple viewers at the same time while also being compatible with 2D display effects, greatly expanding the application scenarios for naked-eye 3D displays. This development plays a crucial role in bringing light field display technology to the market.

5. Acknowledgements
Thanks for all the members at the R&D department for their support and cooperation

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