Crosstalk-Free Integral Imaging Based Head-Mounted Light-Field Displays using Directional Backlights

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Abstract

Conventional integral imaging-based head-mounted light field displays always face the intrinsic crosstalk issue due to the omni-direction emission in typical micro-display panels. In this paper, we adopt the micro-Köhler illumination to control the light emission direction of micro-display panel and thus fully address crosstalk issue.

Author Keywords

Integral imaging; Light field display; Head-mounted display; Crosstalk; Directional backlights

1. Introduction

In recent years, integral imaging (InI) based light field (LF) displays have been applied to head-mounted displays (HMD) to generate quasi-natural 3D scenes and thus mitigate the well-known vergence-accommodation conflict (VAC) issue in stereoscopic 3D displays [1,2]. In a conventional InI based head mounted light field display (LF-HMD), a micro lens array (MLA) is placed in front of the display panel. An array of elemental images (EIs) is presented on the display panel. By doing so, each microlens with the corresponding elemental image can generate a different perspective view of a 3D scene. These different perspective views integrally reconstruct the 3D scene with full parallax.

Nevertheless, typical micro-display panels exhibit quasi-omnidirectional emission, with light spreading over a wide angular range so that the light rays from a given elemental image not only pass through its own corresponding microlens but also other adjacent microlenses. Consequently, light rays passing through the corresponding microlens form a desired image, but crosstalk images are simultaneously formed through these MLA elements adjacent to the designated MLA-EI pair. In our previous study, crosstalk images can be reduced by placing a physical aperture array between the micro-display panel and MLA [3,4]. However, it can potentially cause vignetting and thus produce other image artifacts.

Therefore, to intrinsically remove crosstalk images, it is required to make lights from an elemental image that only passes through the corresponding microlens. To implement this concept, a directional backlight is introduced to control the angular range of the light emission from the micro-display panel. A method called micro-Köhler illumination has been applied to direct-view 3D integral imaging displays to get rid of the pseudo images beyond the viewing angle, which has similar cause of crosstalk images [5]. By applying micro-Köhler illumination to InI-based LF-HMDs, the crosstalk-free concept can be realized.

2. Method

To implement directional backlights in InI LF-HMDs, the micro-Köhler illumination is added to the typical configuration of InI based head-mounted light field displays as shown in Figure 2-1. The micro-Köhler illumination is adopted to control the light emission direction of the micro-display panel. It consists of a planer light source, a condenser lens, and another MLA as a field lens denoted as MLA_{Field}. The planar light source is positioned at the front focal plane of the condenser lens, causing the light emitted from the source to become collimated. The angular range of the collimated light after the condenser lens can expressed as

$$\Phi_{collimated} = 2 * tan^{-1}\left(\frac{H_S}{2*f_{cond}}\right) \qquad (1)$$

where H_S is the size of the planar light source.

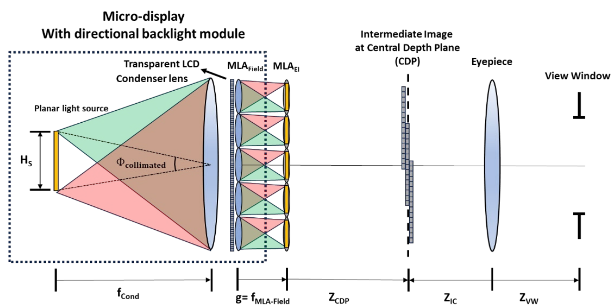

Figure 2-1. Schematic layout of InI-based LF-HMD with directional backlight module

The transparent micro-display panel attached to MLA_{Field} is placed after the condenser lens. The angular range of the collimated light determines the angular range of the light emission from the transparent micro-display panel. Then, MLA_{Field} as a field lens to bend the direction of the light emission to MLA_{EI} so that no light can pass through the adjacent microlenses as shown in Figure 2-2. After the collimated light passing through MLA_{Field}, it will be re-focused to generate an array of illuminated area. The array of each illuminated area can be defined as

$$H_{illuminatd} = H_S * \frac{g}{f_{cond}} \qquad (2)$$

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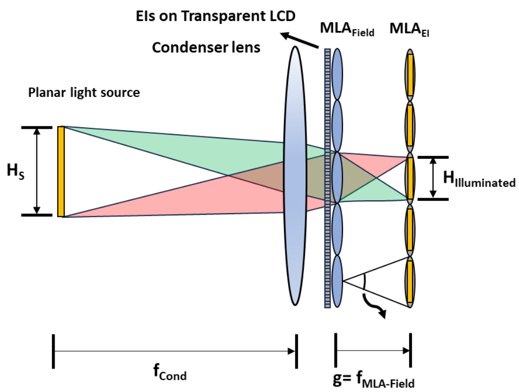

Figure 2-2. Schematic layout of directional backlight module

Utilizing the micro-Köhler illumination, the micro-display panel with directional backlights can replace the typical micro-display panel in InI based head-mounted light field displays under three requirements. In the micro-Köhler illumination, the focal length of MLA_{Field} needs to be equal to the gap between the micro-display panel and MLA_{EI}, g, which is a critical parameter that can affect system performance of InI based head-mounted light field displays, such as angular resolution, viewing window size, view density and so on [6,7]. Then, MLA_{Field} and MLA_{EI} need to have the same pitch and be aligned well. Besides, the required angular range of the collimated light is determined as

$$\Phi_{collimated-req} = 2 * tan^{-1}(\frac{D_{MLA}}{2*g}) \quad (3)$$

where D_{MLA} is the effective diameter of each microlenses. Therefore, according to Equation (1-3), it indicates that the size of the light source, H_s, needs to be adjusted to ensure the illuminated area, $H_{illuminatd}$, equal to the effective diameter, D_{MLA}.

3. Experiment and Results

3.1. Experimental Setup

The experimental setup of a crosstalk-free InI-based LF-HMD system is shown in Figure 3-1. To build the micro-display with directional backlights, an microOLED panel is used as the planar light source. A condenser lens with 36mm focal length, a transparent LCD panel, and an MLA with 4mm focal length as MLA_{Field} are placed. Following the micro-display with directional backlights, another MLA with 3.3mm focal length as MLA_{EI} is positioned, followed by an eyepiece and a camera.

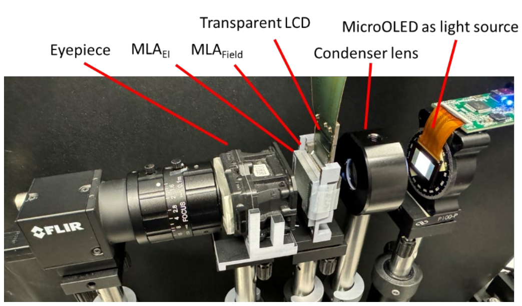

Figure 3-1. The experimental setup

3.2. Micro-Köhler Illumination

To validate the performance of micro-Köhler illumination, the image at the back focal plane of MLA_{Field} are captured as shown in Figure 3-2. During the validation, the MLA_{EI} and the transparent LCD are removed so that the eyepiece can be magnified the image at the back focal plane of MLA_{Field}. According to the Figure 3-2, the square illuminated area is replicated for each microlens on MLA_{EI}. Therefore, when MLA_{EI} is placed at this back focal plane, each microlens on MLA_{EI} can image their own elemental image to form a true-3D scene without any crosstalk image.

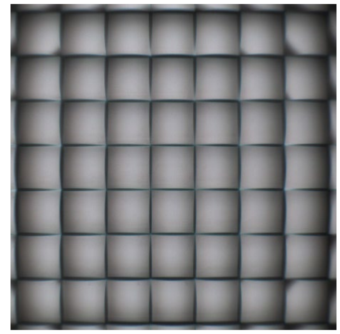

Figure 3-2. Illuminated area on the back focal plane of MLA_{Field}

3.3. Crosstalk-free InI-based LF-HMD

The crosstalk-free concept is demonstrated by capturing light field images in both conventional mode and crosstalk-free mode. The main optical specifications of the display system are shown in Table 1.

Table 1. Specifications of the System.

Pattern Size on MicroOLED Panel, $\mathbf{H_s}$	9mm x 9mm
Condenser Lens Focal Length	36mm
MLA_{Field} Focal Length	4mm
MLA_{Field} Pitch	1mm
Pixel size of Transparent LCD	8.5μm
Resolution of Transparent LCD	1920(H)x1080(V) (Monochromatic)
Elemental image size	1mmx1mm
Central Depth Plane of 3D Scene	1D
MLA_{EI} Focal Length	3.3mm
MLA_{EI} Pitch	1mm
MLA_{EI} Magnification	2
Eyepiece Focal Length	18.5mm
Angular Resolution	3.16 arcmin (19ppd)

In the conventional mode, the condenser lens is removed, and the OLED micro-display is attached with the transparent LCD as its backlight so that the angular emission range spread across different directions. Thus, Figure 3-3 presents the captured 3D scene in conventional mode without directional backlights. The 3D scene consists of three sets of resolution targets placed at three different depths: 2.5 diopters, 1 diopter, and 0.1 diopters, from left to right, respectively. Even though the 3D scene is well-reconstructed, crosstalk images are noticeably present in the peripheral regions as highlighted in the zoomed-in box in Figure 3-3. In Figure 3-4, the image of the same reconstructed 3D scene is captured in crosstalk-free mode with directional backlights. Compared to Figure 3-3, there are no crosstalk images in Figure 3-4.

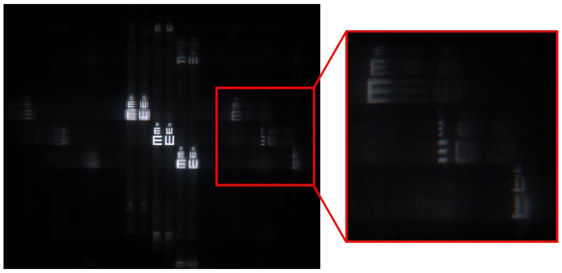

Figure 3-3. The 3D scene of InI-based LF-HMD in conventional mode

Figure 3-4. The 3D scene of InI-based LF-HMD in crosstalk-free mode

4. Conclusions

In this work, we utilize micro-Köhler illumination as directional backlights to demonstrate a crosstalk-free InI-based LF-HMD. By leveraging directional backlights, crosstalk issues can be significantly reduced. In the experimental results, the light field images in both conventional mode and crosstalk-free mode are captured. By comparison, the crosstalk-free concept is clearly demonstrated.

5. References

[1] Lanman H and Luebke D, Near-eye light field displays. ACM Trans Graph 2013;32(6),:1-10

[2] Hua H and Javidi B. A 3D integral imaging optical see-through head-mounted display. Opt Express 2014; 22(11):13484-13491

[3] Huang H and Hua H. An integral-imaging-based head-mounted light field display using a tunable lens and aperture array. Jnl Soc Info Display. 2017;25(3):200-207.

[4] Huang H and Hua H. High-performance integral-imaging-based light field augmented reality display using freeform optics. Opt Express 2018;26(13):17578-17590

[5] Tolosa Á , Martinez-Cuenca R, Navarro H, Saavedra G, Martínez-Corral M, Javidi B, and Pons A. Enhanced field-of-view integral imaging display using multi-Köhler illumination. Opt Express. 2014; 22(26):31853-31863

[6] Huang H and Hua H. Systematic characterization and optimization of 3D light field displays. Opt Express 2017;25(16):18508-18525

[7] Huang H and Hua H. Generalized methods and strategies for modeling and optimizing the optics of 3D head-mounted light field displays. Opt Express 2019; 27(18):25154-25171.