Near-Eye Light Field Displays

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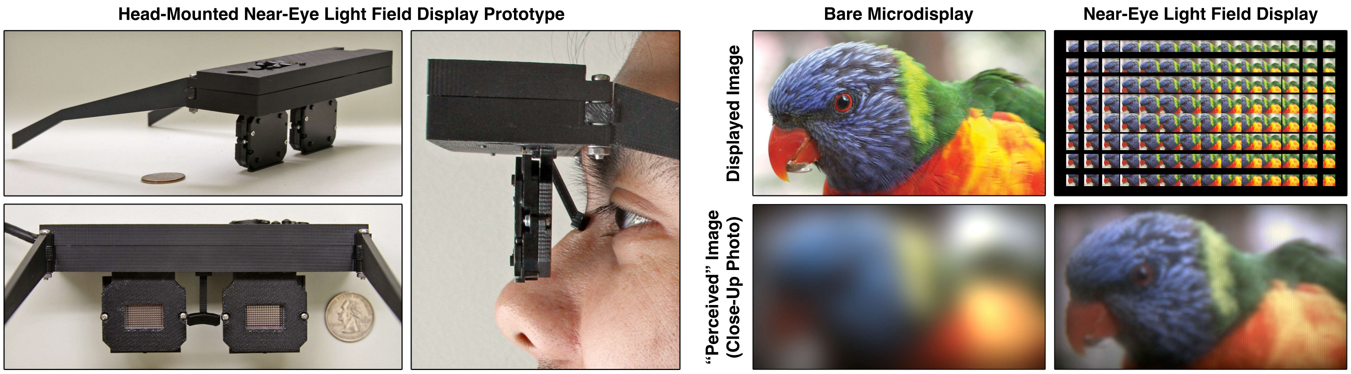

Figure 1: *Enabling thin, lightweight near-eye displays using light field displays. (Left) Our binocular near-eye display prototype comprises a pair of OLED panels covered with microlens arrays. This design enables a thin head-mounted display, since the black box containing driver electronics could be waist-mounted with longer OLED ribbon cables. (Right) Due to the limited range of human accommodation, a severely defocused image is perceived when a bare microdisplay is held close to the eye (here simulated as a close-up photograph of an OLED). Conventional near-eye displays require bulky magnifying optics to facilitate accommodation. We propose near-eye light field displays as thin, lightweight alternatives, achieving comfortable viewing by synthesizing a light field corresponding to a virtual scene located within the accommodation range (here implemented by viewing a microdisplay, depicting interlaced perspectives, through a microlens array).*

Abstract

We propose near-eye light field displays that enable thin, lightweight head-mounted displays (HMDs) capable of presenting accommodation, convergence, and binocular disparity depth cues. Sharp images are depicted by out-of-focus elements by synthesizing light fields corresponding to virtual objects within a viewer's natural accommodation range. Our primary contribution is to evaluate the capability of microlens arrays to achieve practical near-eye light field displays. Building on concepts shared with existing integral imaging displays and microlens-based light field cameras, we optimize performance in the context of near-eye viewing. As with light field cameras, our design supports continuous accommodation of the eye throughout a finite depth of field; as a result, binocular configurations provide a means to address the accommodation-convergence conflict occurring with existing stereoscopic displays. We construct a complete prototype display system, comprising: a custom-fabricated HMD using modified off-the-shelf parts and GPU-accelerated light field renderers (including ray tracing and a "backward compatible" method for existing stereoscopic content).

1 Overview

To be of practical utility, a near-eye display should provide high-resolution, wide-field-of-view imagery with compact, comfortable magnifying optics. However, current magnifier designs typically require multiple optical elements to minimize aberrations, leading to bulky eyewear with limited fields of view. We consider a simple alternative: placing a light field display directly in front of a user's eye (or a pair of such displays for binocular viewing). As shown in Figure 1, sharp imagery is depicted by synthesizing a light field for a virtual display (or a general 3D scene) within the viewer's unaided accommodation range. We demonstrate this design enables thin, lightweight head-mounted displays (HMDs) with wide fields of view and addresses accommodation-convergence conflict; however, these benefits come at a high cost: spatial resolution is reduced with microlens-based designs, although with commensurate gains in depth of field and in accurate rendering of retinal defocus. Through this work, we demonstrate how to mitigate resolution loss.

2 Hardware

OLED-based HMD Prototype: As shown in Figure 1, a binocular prototype was constructed using a pair of Sony ECX332A OLED microdisplays. Each 15.36×8.64 mm microdisplay has 1280×720 24-bit color pixels (i.e., 83.3 pixels per millimeter). Microlens arrays were affixed to the displays, weighing 0.7 grams and having a 1.0 mm lens pitch and 3.3 mm focal length. Each assembled eyepiece is 1.0 cm thick and achieves a spatial resolution of 146×78 pixels and a field of view of 29×16 degrees.

LVT-based Film Prototype: Practical applications will require two refinements in semiconductor manufacturing: higher-resolution and larger-format microdisplays, increasing image sharpness and the field of view, respectively. We emulate such high-resolution microdisplays using backlit 3.75×3.75 cm color films, developed using a light valve technology (LVT) film recorder at 120 pixels per millimeter. For these film-based prototypes, we estimate a spatial resolution of 534×534 pixels and a field of view of 67×67 degrees.

3 Software

Light Field Ray Tracing: The LVT and OLED prototypes contain microlens arrays with 35×35 and 14×8 lenses, respectively. Directly extending conventional rasterization would require rendering one projection of the 3D scene for each lens. As an alternative, we modified the NVIDIA OptiX GPU-accelerated ray tracing engine to support quad buffering in OpenGL—providing the HDMI 1.4a frame-packed 3D format required by the OLED driver electronics.

Supporting Stereoscopic Content: To implement a complete display system, a "backward compatibility" option is required for existing stereoscopic sources, including movies and video games. We propose the following solution: emulating the appearance of a conventional, planar autostereoscopic display. For our OpenGL-based implementation, each stereoscopic view is rendered to a texture attached to a frame buffer object (FBO). A GLSL fragment shader then generates the projections for each lens by sampling the stereoscopic view textures, as mapped onto the virtual display plane.