8D Display: A Relightable Glasses-Free 3D Display

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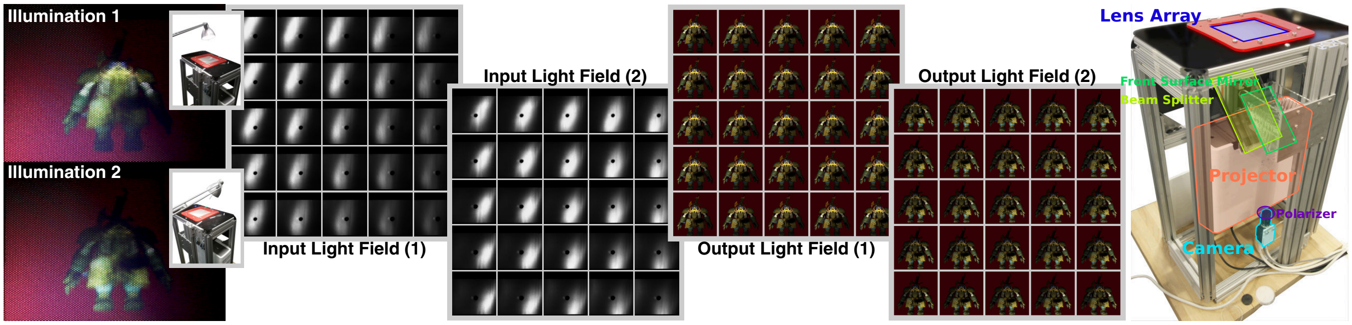

Figure 1: *(Left) Photograph of light field view under different incident illumination (Left, Inset). (Center) Captured and displayed light fields. (Right) Our projector-camera-based 8D Display prototype is ammenable to implementation using Sensor-In-Pixel LCD hardware.*

Abstract Imagine a display that behaves like a window. Glancing through it, viewers perceive a virtual 3D scene with correct parallax, without the need to wear glasses or track the user. Light that passes through the display correctly illuminates the virtual scene. While researchers have considered such displays, or prototyped subsets of these capabilities, we contribute a new, interactive, relightable, glasses-free 3D display. By simultaneously capturing a 4D light field, and displaying a 4D light field, we are able to realistically modulate the incident light on rendered content. We present our optical design, and GPU pipeline. Beyond mimicking the physical appearance of objects under natural lighting, an 8D display can create arbitrary directional illumination patterns and record their interaction with physical objects. Our hardware points the way towards novel 3D interfaces, in which users interact with digital content using light widgets, physical objects, and gesture.

Introduction Our 8D display prototype is a general purpose light transducer. With limitations, it is capable of mapping 4D lighting between the physical environment in front of the display and the digital environment behind it. Nayar et al. [2004] create a lighting sensitive display, though it cannot accurately map shadows and specularities. BRDF displays can simulate flat surfaces with a particular Bi-Directional Reflectance Distribution Function [Hullin et al. 2011]. 6D displays that demonstrate 4D relighting of 2D images have been shown in both active [Hirsch et al. 2009] and passive [Fuchs et al. 2008] modes. Our work contributes a real-time 8D display, composed of off-the-shelf optical elements and a new GPU rendering and capture pipeline, to make simultaneous real-time 4D lighting and 4D capture feasible for the first time.

8-Dimensional Rendering To achieve real-time rendering and decoding of light fields we have developed a new 8D GPU pipeline. We implement diffuse lighting in our prototype, which can be efficiently mapped to projective texture lookups. We implement a simplified version of the rendering equation, neglecting BRDFs.

$$L_o(\mathbf{x}, \omega) = \int_{\Omega} L_i(\mathbf{x}, \omega')(-\omega' \cdot \mathbf{n}) d\omega' \quad (1)$$

where L_i is the measured incident light field, L_o the displayed light field, and ω' the incoming lighting direction. Though in our model local regions are invariant in outgoing light direction, ω, each light field view is generated with a view matrix corresponding to a virtual skewed orthographic camera viewing the scene from ω. To capture a 4D light field we deinterlace images recorded from the back of the lens array in our GPU pipeline.

Optics and Implementation A hexagonal lens sheet (Fresnel Tech. #360), is placed atop a high-resolution sensor and display panel, composed of a 2048×2048 Point Gray Gazelle camera and 1080P Optoma projector, respectively. We achieve a $150mm$, $325dpi$ display by modifying our projector lens. The camera and projector are focused on a diffuser placed behind the lens sheet. A beam splitter system is used to overlap the projector and camera views (Figure 1). We prevent cross-talk between the camera and projector by multiplexing through crossed linear polarizers. The projector-camera system introduces unwanted calibration complexities, which are addressed in supplementary material. In all cases, an angle limiting material, such as privacy film, can be included in the optical system to prevent angular aliasing.

Results and Discussion The included video demonstrates our display simultaneously showing realistic horizontal and vertical parallax, without tracking or glasses, as well as relighting effects. A 3D model can be illuminated and shadowed by various light sources. Abundant interactive possibilities include: using an off-the-shelf light source as 6DoF input controller, direct manipulation of physical lights to cause relighting of 3D scenes, accurately mimicking surfaces with exotic BRDFs, and applying non-realistic physics to real lighting sources. Furthermore, our design is amenable to implementation on emerging Sensor-In-Pixel LCD technology, detailed in our supplement. Placing an appropriately designed lens sheet on such a panel will achieve an optically analogous system, paving the way for thin 8D displays.

References

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