Light-Field Displays: a View-Dependent Approach

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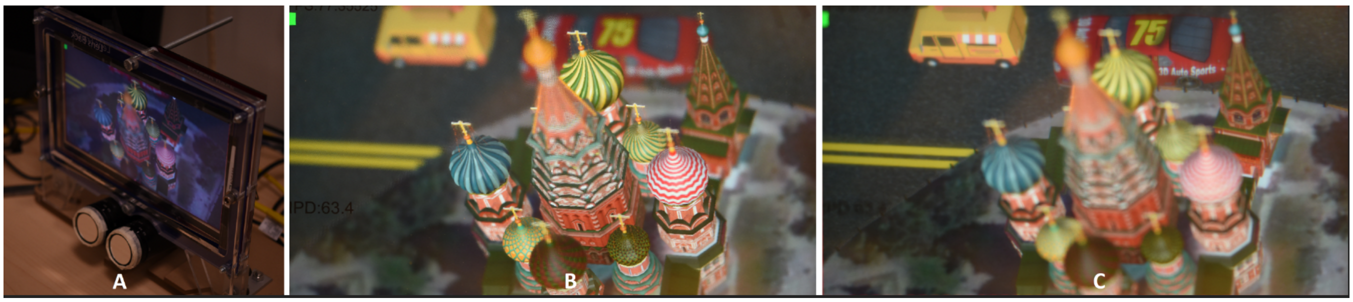

Figure 1: A. 72 PPI dynamic view-dependent light-field display. B. Focus at near distance. C. Focus at far distance. 3D models: Stockcar racecar (Unity asset store license) and St. Basil's Cathedral and Simple Town Lite (3D Warehouse license).

ABSTRACT

Most 3D displays suffer from the vergence-accommodation conflict, which is a significant contributor to eyestrain. Light-field displays avoid this conflict by directly supporting accommodation but they are viewed as requiring too much resolution to be practical, due to the tradeoff between spatial and angular resolution. We demo three light-field display prototypes that show a view-dependent approach which sacrifices viewer independence to achieve acceptable performance with reasonable display resolutions. When combined with a directional backlight and eye tracking system, this approach can provide a 3D volume from which a viewer can see 3D objects with accommodation, without wearing special glasses.

KEYWORDS

3D display, super multi view display, vergence accommodation conflict, integral imaging, compute shader

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1 INTRODUCTION

A major challenge in 3D displays is the vergence-accommodation conflict, which is a significant contributor to eyestrain. Many different display approaches have been developed to present depth cues correctly to overcome this conflict, including tensor displays, holographic displays, volumetric displays, multi-focal plane displays, and light-field displays [Maimone et al. 2017; Takaki and Nago 2010; Ueno and Takaki 2018; Wetzstein et al. 2012]. Light-field displays work by approximating the directional beams of light emitted from real objects. If at least two directional beams from a single 3D point enter the eye pupil, then light-field displays begin to support accommodation.

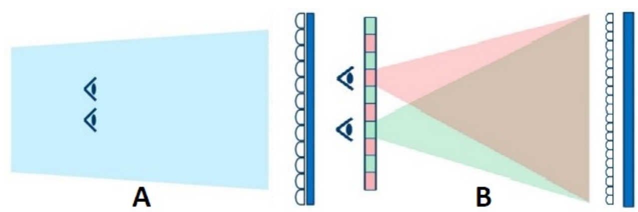

Figure 2: A. Brute-force integral display with large viewing zone. B. View-dependent approach that steers available resolution into small repeating eyeboxes.

The most straightforward way to implement a light-field display is a brute-force integral display. This approach typically provides a large eyebox and field of view (FOV), spreading the available pixels over a large viewing area (Figure 2A). Only a tiny fraction of the pixels is visible at any instant, so the underlying display resolution must be ludicrously high, around two orders of magnitude higher than available in today's displays. Therefore, we implemented a view-dependent approach for light-field displays, by designing and building custom microlens arrays (MLAs) with long focal lengths

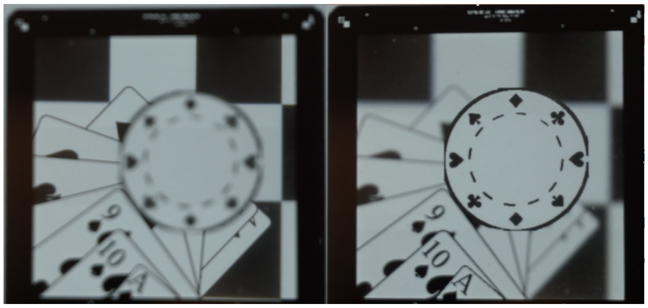

Figure 3: 100 PPI brute force integral display. Left: Viewer focuses to far distance. Right: Viewer focuses to near distance.

and placing those in front of high PPI LCD display panels to create high pixel densities inside small eye boxes while simultaneously providing a minimally acceptable spatial resolution (Figure 2B). This approach requires tracking a single viewer's eye positions and changing the rendered image in response to changing eye positions.

2 PROOF OF CONCEPT SYSTEMS

Three light-field display prototypes validate our approach:

2.1 100 PPI brute-force integral display

Figure 3 shows our brute-force integral display, consisting of a lithographic plate with a 25,000 PPI static binary image and a custom 100 PPI MLA. There are roughly 250×250 pixels under each lens. The eye box size is about $150mm \times 150mm$. More than 4×4 directional views enter an average sized pupil of $4mm$ diameter. This compelling light-field display has about 6 inches depth of field and proves that viewers can accommodate to different depths.

2.2 72 PPI dynamic view-dependent light-field display

We combined custom, long focal length 72 PPI MLAs with a 10.1inch 4K LCD panel to create high view density inside repeating, small eye boxes. As the viewer moves, we steer the eyebox regions dynamically toward the viewer's pupils by tracking the eye positions and updating the rendering in real time. Figure 1 shows the system and images displayed on this system. While the image quality is lower than in Figure 3, this is a dynamic display achieved with a display panel available today.

2.3 72 PPI static view-dependent light-field display using 1500 PPI prints

The 4K resolution of the LCD panel limits the quality and depth of field of the 3D scene in the previous system. To demonstrate what will be feasible with higher resolution displays, we printed static 1500 PPI Light Value Technology (LVT) prints and used those in place of a dynamic display. Figure 4 shows this prototype, which has three separate static displays to cover a wide range of interpupillary distances (IPDs). Since the displays are static, each display can only be viewed from a fixed viewpoint. The image quality is greatly improved and the depth of field is over 12 inches.

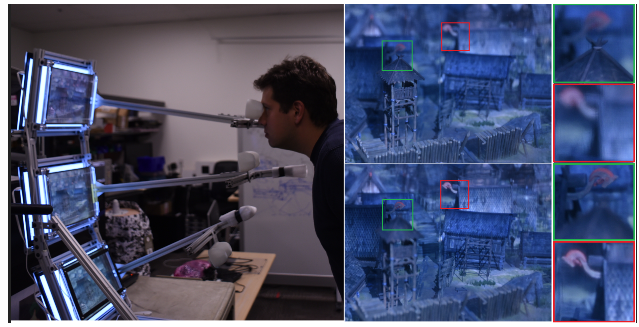

Figure 4: Left: Static view-dependent light-field display prototypes using 1500 PPI LVT static prints. Right: Images captured from this prototype, showing focusing to two different depths. 3D models: Viking village (Unity asset store license)

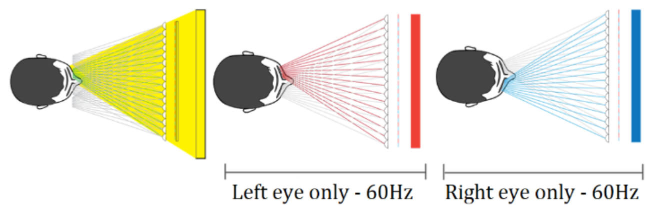

Figure 5: Time Multiplexing with Directional Backlighting

3 LIMITATIONS AND CONCLUSION

To provide different imagery to the left and right eyes, we split the eyebox into two horizontal regions, one for the left and the other for the right eye views. The size of these eyeboxes vary with the distance away from the display. The viewer sees the correct imagery only when his/her IPD is an odd multiple of the half eyebox width, which occurs at certain discrete viewing distances. Extending this into a full 3D viewing volume can be accomplished by combining the view-dependent light-field display with a directional backlight that enables time-multiplexed sequential illumination of left and right eye views (Figure 5) [Li et al. 2020].

Because of the tradeoff in spatial and angular resolution in brute-force integral displays, light-field displays are generally considered impractical. Our view-dependent approach suggests a way to make light-field displays practical in the near future, by sacrificing viewer independence.

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