ThinVR: VR displays with wide FOV in a compact form factor

Joshua Ratcliff
Intel Labs

Alexey Supikov
Intel Labs

Santiago Alfaro
Intel Labs

Ronald Azuma
Intel Labs

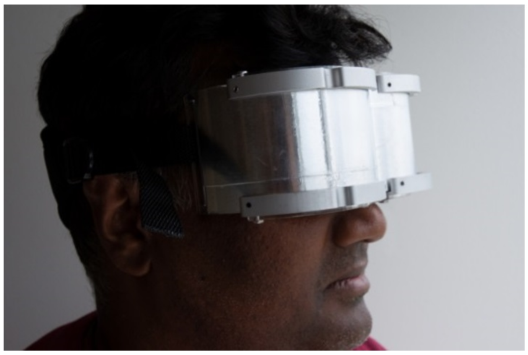

Figure 1: Left: ThinVR prototype with static print displays. Right: Photo taken in actual ThinVR prototype, covering the full FOV for one eye (about 130^{o} horizontal). Lens: Samyang 12mm f/2.8 fisheye. 3D models: Agent 327 (Blender Cloud) [CC-BY-4.0].

ABSTRACT

We demonstrate ThinVR as a new approach to simultaneously address the bulk and limited FOV of today's head-worn VR displays. ThinVR enables a VR display to provide 180 degrees horizontal FOV in a thin, compact form factor. Our approach is to replace traditional large optics with a curved microlens array of custom-designed heterogeneous lenslets and place these in front of a curved display. Custom-designed heterogeneous optics were crucial to make this approach work, since over a wide FOV, many lenslets are viewed off the central axis. We show the viability of the ThinVR approach through two demonstrations, using both dynamic and static displays.

KEYWORDS

Virtual reality, HMD, display, optics, lens arrays

ACM Reference Format:

Joshua Ratcliff, Alexey Supikov, Santiago Alfaro, and Ronald Azuma. 2020. ThinVR: VR displays with wide FOV in a compact form factor. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Emerging Technologies (SIGGRAPH '20 Emerging Technologies), August 17, 2020*. ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3388534.3407302

SIGGRAPH '20 Emerging Technologies, August 17, 2020, Virtual Events, USA

ACM ISBN 978-1-4503-7967-0/20/08.
https://doi.org/10.1145/3388534.3407302

1 MOTIVATION

Two problems restricting the acceptance of VR displays are their bulk and field-of-view (FOV). First, the volume occupied by modern consumer VR head-worn displays is nearly the same as the volume of such displays in the 1980's. Why? The fundamental reason is the distance between the optics and the display. Since the optics are large and F numbers below 1 are impractical, the focal length is constrained to be at least ~40-50mm. Second, most VR displays today provide about 90-110 degrees FOV, partly because supporting wide fields of view with traditional optics requires even larger optical elements, further increasing bulk. Providing wide FOV in a thin form factor would increase acceptance of VR near-eye displays.

2 RELATED WORK AND APPROACH

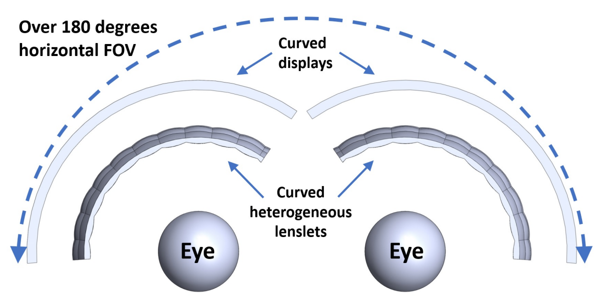

Figure 2: Scale diagram showing how two cylindrical displays provide 180 degrees horizontal FOV

Previous approaches to achieve thin near-eye displays include pancake optics [LaRussa and Gill 1978] and the Pinlight display

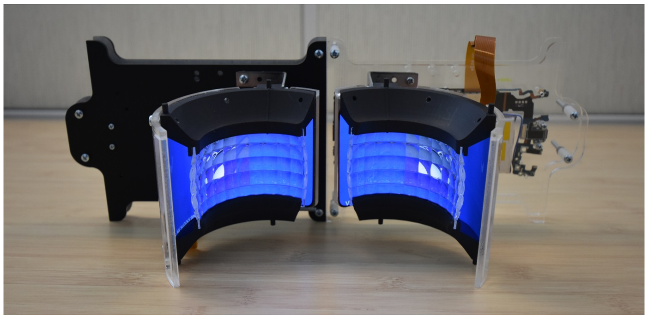

Figure 3: Dynamic ThinVR prototype with Galaxy S9 phone displays and electronics. Displays were set to blue background to make the lenslets easy to see.

[Maimone et al. 2014], along with several others. We chose to modify the approach of [Lanman and Luebke 2013], which placed arrays of homogeneous lenslets in front of microdisplays to build a near-eye light-field display. This display is exceptionally thin because the lenslets have small diameters. We exploit this property by modifying their approach to build a compact, wide FOV stereo VR head-worn display, rather than a near-eye light-field display.

Our approach differs from previous work because we custom designed *heterogeneous* microlens arrays to make a large FOV feasible, and this was a difficult task. In a large FOV display, many lenslets are not viewed along their central axis, but rather at angles far from the central axis. Lenses are typically designed to be viewed along the central axis, and when viewed off-axis, they produce large distortions and aberrations. Thus, we had to design heterogeneous microlens arrays, where lenslets above and below the central horizontal row are optimized for off-axis viewing. By curving the optics and placing them in front of curved OLED displays, we achieved 180 degrees horizontal FOV in a form factor that more closely fits the viewer's face, reducing the bulk. (Figure 2).

3 DESIGN

Our design work consisted of two stages. First, we did a design space analysis to determine parameters for a practical implementation. Second, using custom simulation software, we created an optical design to meet the design target while providing good performance and manufacturability. For addtional details beyond the brief following summary, please see [Ratcliff et al. 2020].

- **Design Space**: To make good use of flexible OLED displays and to minimize design complexity, we curved both the display and the lens array along concentric cylindrical shapes, centered at the center of the eyeball. Two cylindrical display systems cover a full 180 degree horizontal FOV (Figure 2). This cylindrical shape reduced the optical design effort to one vertical column, where that column is replicated.
  Next, we needed to determine the key parameters of angular lenslet size and focal length, which in turn affects lens-to-display spacing and lenslet pitch. We conducted a design space analysis and chose a design that delivered an eyebox >12mm and resolution >9PPD (pixels per degree), assuming an 800 PPI display.
- **Optical Design**: Attempts to use traditional optical design tools were unsuccessful in providing the desired eyebox while controlling pupil swim distortions as the eye moved within the eyebox. A major reason for this was poor ray tracing performance, which greatly constrained our ability to search through the design space. Therefore, we implemented a real-time simulation of heterogeneous microlens arrays, which in turn enabled development of a custom optimizer specifically tuned to design heterogeneous microlens arrays for near-eye displays. Our optimization procedure converged on parameters that maximize sharpness while meeting distortion and eyebox constraints.

4 DEMONSTRATION PROTOTYPES

We proved the viability of the ThinVR approach by implementing two types of physical prototypes, complete with stereo content and hardware-adjustable interpupillary distance (IPD).

- **Dynamic prototype**: First, we built ThinVR prototypes with flexible OLED displays (Figure 3). We acquired flexible 570 PPI OLED displays, with 2960 by 1440 resolution, by extracting them from Samsung Galaxy S9 phones. This was a difficult task because the displays are not designed to be separated from their glass covers. However, these phone displays can only be driven by the Galaxy S9 electronics, so we had to mount those electronics and batteries onto the head-worn display, making our prototype much bulkier than it fundamentally has to be. Rendering occurs at 60 Hz on two Samsung Galaxy S9 phones, one for each display. We use the Google Daydream API to activate low-persistence display mode to reduce the effects of latency, and we use the orientation tracking from that API on one phone and send the computed orientation to the other phone so that both phones display a synchronized scene rendered in stereo.
- **Static prototype**: Second, to more accurately depict the potential of ThinVR to enable compact head-worn VR displays, we also built prototypes with static prints instead of phone displays. We used 2032 PPI light valve technology (LVT) transparencies illuminated by cylindrical backlights. These depict a static scene and do not respond to head motion, but these prototypes show fundamentally how thin this approach could be. By using 2032 PPI prints we also illustrate the image quality expected when such high resolution displays become available. The left image in Figure 1 shows a static display prototype.

REFERENCES

Douglas Lanman and David Luebke. 2013. Near-eye Light Field Displays. *ACM Trans. Graph.* 32, 6, Article 220 (Nov. 2013), 10 pages. https://doi.org/10.1145/2508363.2508366

Joseph A. LaRussa and Arthur T. Gill. 1978. The Holographic Pancake Window TM. In *SPIE Visual Simulation and Image Realism*, Vol. 0162. SPIE, 120–129. https://doi.org/10.1117/12.956898

Andrew Maimone, Douglas Lanman, Kishore Rathinavel, Kurtis Keller, David Luebke, and Henry Fuchs. 2014. Pinlight Displays: Wide Field of View Augmented Reality Eyeglasses Using Defocused Point Light Sources. *ACM Trans. Graph.* 33, 4, Article 89 (July 2014), 11 pages. https://doi.org/10.1145/2601097.2601141

Joshua Ratcliff, Alexey Supikov, Santiago Alfaro, and Ronald Azuma. 2020. ThinVR: Heterogeneous microlens arrays for compact, 180 degree FOV VR near-eye displays. *IEEE Transactions on Visualization and Computer Graphics* 26, 5 (May 2020), 1981–1990. https://doi.org/10.1109/TVCG.2020.2973064