Re-engineering the Wheatstone stereoscope

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A low-cost retro stereoscope for virtual reality and other immersive applications uses flat-panel LCDs and achieves high field of view with high resolution.

Therapeutic applications using virtual reality (VR) can deliver excellent outcomes in treating phobias\(^1,2\) and show great promise in cases of post-traumatic stress disorder.\(^3\) VR analgesia has reduced subjective pain ratings of burn victims undergoing excruciating wound-care procedures by 30–90\%.\(^4\) And functional magnetic resonance imaging scans have shown that pain-related brain activity levels in healthy individuals drop by 50–90\%.\(^5\) In both these modalities, immersion is identified as a key factor.\(^6,7\) However, head-mounted displays (HMDs) that even marginally match the capabilities of the human visual system remain extremely expensive. Stereoscopes may provide an excellent compromise at a fraction of the cost of wide field-of-view (FOV) HMDs.

Progress in developing the requisite technologies—primarily high-resolution microdisplays—has been slow, and they have proved difficult to interface. Various near-eye optical systems work well for low FOV but rise rapidly in cost, complexity, and size with higher applications. This contrasts markedly with direct-view LCD displays, now commonly available in resolutions beyond high-definition television while costing less than $600.

The major limitation with LCD is the 60Hz refresh rate such that two displays are required for stereoscopic use. The issue then becomes how to deploy them so that each display is viewed by only one eye. This can be accomplished with a polarization beamsplitter,\(^5\) but also by optimizing a 150-year-old invention known as the Wheatstone stereoscope. Work has been done with these scopes using cathode ray tubes,\(^9–11\) but large LCD panels offer a unique opportunity to optimize performance.\(^12\)

The Wheatstone stereoscope employs two mirrors whose reflections form an overlapped image at an angle, as shown in Figure 1. Optionally, the images can be viewed through a magnifier (such as reading glasses) for greater comfort. Glasses, which also mitigate the conflict between convergence and lens accommodation, are an adequate substitute for expensive, distorting wide FOV eyepieces. The amount of overlap between the eyes can be reduced to increase the total binocular FOV (see Figure 2).

Overlap of the images can be controlled by adjusting the angle between the mirrors from the archetypical 90\(^\circ\) and compensating for the resulting swing of the virtual image by rotating the LCDs. If the angle of the mirrors is too great, viewers who are too close will see a distracting reflection of their own face blocking the image. If the angle is too great and the viewer too far away, he or she will see a form of crosstalk wherein each eye sees the reflection of the other eye’s display. A baffle between the eyes can serve as a septum to prevent both problems but reduces the overlap region where the viewer normally sees a stereo image framed by nose and brow. This yields an upper limit on the usable mirror angle and thus the maximum binocular FOV.

For our display, FOV is determined by the angle subtended by the LCD to the eye, folded about the mirror. Placement of the monocular FOV for each eye, which determines the overlap versus binocular FOV trade-off, is determined by the position of the reflected LCD image. By widening the angle between the mirrors to 100\(^\circ\), we can increase the binocular horizontal FOV (HFOV) to 89\(^\circ\) as the overlap drops to about 49\(^\circ\). Narrowing the

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mirror angle to 80° while also moving the LCDs further from the mirrors, we can increase the overlap to 100%, but at the expense of reducing the merged HFOV to about 62°. This configuration also reduces the need for a septum and provides flexibility in head positioning.

We are impressed with the results of our 'low-tech' approach to immersive display, and optimistic that a single-mirror system, shown in Figure 3, will provide an even simpler solution. By eliminating one mirror and moving the corresponding LCD directly in front of the viewer, we have a functionally identical system with one less component to be adjusted. However, the directly viewed image must be corrected to match the reflected image. Our next goal will be to construct such a system using a front surface-enhanced metallic mirror and to compensate for differences in brightness and color. We are also investigating more sophisticated stereoscopes. But in terms of price and performance, the simple Wheatstone configuration may prove to be the design of choice for VR therapy and other applications.

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References

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