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Computer Graphics – Literature Review 3

For this Literature review, I chose to look at two papers that each propose designs for head-mounted augmented reality near-eye displays, similar in function and principle to the Google Glass. My primary essay is "Retinal 3D: Augmented Reality Near-Eye Display Via Pupil-Tracked Light Field Projection on Retina", written by Changwon Jang, Kiseung Bang, Seokil Moon, Jonghyum Kim, Seungjae Lee, and Byoungho Lee for the November 2017 edition of "ACM Transactions on Graphics". My secondary essay is "3D holographic head mounted display using holographic optical elements with astigmatism aberration compensation", written by Han-Ju Yeom, Hee-Jae Kim, Seong-Bok Kim, HuiJun Zhang, BoNi Li, Yeong-Min Ji, Sang-Hoo Kim, and Jae-Hyeung Park for the December 2015 edition of "Optics Express".

To be more specific, the primary goal of both papers' AR goggle designs is to solve the vergence-accommodation mismatch, a problem that must be solved for AR devices to be viable in the mainstream. In most head-mounted displays, the images presented to the user are projected onto the display's conjugate plane, and since that plane is only centimeters from the user's eyes, the user's eyes will focus on the plane so they can see the image. However, in the real world, a person's eyes are accustomed to automatically altering their focus intensity based on the angle of the eyes' optical axes. For example, if one were to hold an object up close between their eyes, provided the user has no visual impairment, their eyes will adjust their focus intensity to bring the object into focus. The problem with this is that, with most head-mounted displays, the intensity of focus and distance between the eye and the image is not in sync with the distance of optical axes convergence a person's eyes are naturally used to, causing eye strain for the user under prolonged use. Tangentially, this problem is also the reason why 3D films tend to cause eye strain in viewers.

Starting with my secondary essay, "3D holographic head mounted display using holographic optical elements with astigmatism aberration compensation" attempts to solve this issue with a headset that, rather than generating 2D images for each eye that the user can perceive as 3-dimensional, instead creates a single 3D holographic image and uses two holographic optical elements to project that image to both eyes at arbitrary positions beyond the scope of the headset's conjugate plane, sidestepping the issue.

Here's how it works: The model proposed is made up of a spatial light modulator (SLM), a waveguide in the shape of a flat see-through bar, and two reflective holographic optical elements (HOEs). To start, image data is given to the SLM with forms the image by diffracting a laser light into the waveguide, with one of the HOEs acting as a receiver. From there, the receiver HOE reflects the diffracted light into the waveguide, which it then travels through via multiple internal reflections to reach the other HOE. This HOE then reflects the diffracted light rays directly into the user's eye, where they can now see both a virtual image of the SLM and the image the SLM produced projected a distance away from themselves equivalent to the distance of the light rays' optical path length.

While the paper did not end up producing a wearable model of their proposed device, they were able to create a prototype device that could produce virtual images using the method above in order to test their hypothesis. What they found was that their method was capable of producing holographic images that were clear enough to be recognizable and whose distance from the user and their position adjacent to the user could be altered without sacrificing clarity. However, due to the images' nature as diffracted laser light, the resolution of the objects created by this method were extremely limited and said objects were limited in size due to not being able to exceed the area of the spatial light modulator. Moreover, while the paper presented a model for how a potential head-mounted display would function, it did not end up creating a wearable prototype of said display. Regardless, the paper was able to devise a method that could sidestep the accommodation-vergence mismatch, so it was successful in what it set out to accomplish.

Moving onto my primary essay, "Retinal 3D: Augmented Reality Near-Eye Display Via Pupil-Tracked Light Field Projection on Retina" attempts to get around the vergence-accommodation mismatch by designing a headset that provides monocular focus cues to the eyes alongside the 2D images each optical display produces. In theory, providing these cues to each eye would allow them to naturally adjust their angle of convergence to within the headset's conjugate plane, correcting the user's sight. This method is in direct contrast to that of my secondary essay's, which attempted to do the reverse by projecting its images beyond its display's conjugate plane so that it could align with the user's natural optical axes convergence.

Here's how my primary essay's method works: At the offset, the data for a given object is passed to a series of laser diodes that then output said image data as a cluster of laser beams. These beams are then reflected off of a mirror known as an MEMS mirror into a series of other lenses and mirrors which shape the lasers into a parallel stream of light. Once properly shaped, the light is then bounced from an electronically-controlled, fast-steering mirror onto a holographic image combiner (or HIC for short). The HIC is an entirely transparent lens which only reacts to light of a specific wavelength at angles the steering mirror is built to reflect light into. Once the reflected light reaches here, it is refracted through three lens layers that each capture a different color of light, which it then refracts directly into the user's pupil.

Two important features of this method that sets it apart from my secondary essay is its implementation of a dynamic eye-box, with the goal being to solve the limited field of view of most augmented reality headsets, and the use of localized light field scanning in order to generate focus cues for the eye. For the dynamic eye-box, a small camera is set up on both sides of the display that track the movement of the user's pupils in real time. Based on where the pupil is positioned, the headset adjusts the angle of the previously mentioned fast-steering mirror so that the projected image always enters the eye at the correct angle to be visible, giving the eye room to move around without blurring the produced image. As for the localized light field scanning, this method modifies a traditional method of producing visual cues, which involves sampling light rays that are emanated from an image source, a method that while effective requires a large amount of computation load to work properly. This paper attempts to solve the issue by, rather than sending light rays in one continuous stream to cover a user's entire eye box area, instead reflect multiple light rays at different angles only into a user's pupil. This, alongside the fast-steering mirror and pupil tracking, allows the eye to move freely within the confines of the headset whilst keeping the image clear at multiple viewing angles.

After testing, the paper found that their Retinal 3D prototype was able to produce virtual images at a resolution comparable to other modern prototypes in the same field with a larger field of vision, high transparency, and a brightness/contrast sufficiently high for most augmented reality applications available. The paper does note significant room for improvement however, specifically a framerate currently limited below 15 frames per second, a pupil-tracking system that only works reliably in consistent lighting conditions, and a bulky frame that's much more cumbersome than comparable AR prototypes. That being said, this paper's model does represent an impressive step forward toward a commercially viable augmented reality headset.

Bibliography:

1) Retinal 3D: Augmented Reality Near-Eye Display Via Pupil-Tracked Light Field Projection on Retina

@article{Jang:2017:RAR:3130800.3130889,
 author = {Jang, Changwon and Bang, Kiseung and Moon, Seokil and Kim, Jonghyun and Lee, Seungjae and Lee, Byoungho},
 title = {Retinal 3D: Augmented Reality Near-eye Display via Pupil-tracked Light Field Projection on Retina},
 journal = {ACM Trans. Graph.},
 issue_date = {November 2017},
 volume = {36},
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 pages = {190:1--190:13},
 articleno = {190},
 numpages = {13},
 url = {http://doi.acm.org/10.1145/3130800.3130889},
 doi = {10.1145/3130800.3130889},
 acmid = {3130889},
 publisher = {ACM},
 address = {New York, NY, USA},
 keywords = {computational displays, eye tracking, holographic optical element, near-eye display, vergence-accommodation conflict},
}

2) 3D holographic head mounted display using holographic optical elements with astigmatism aberration compensation

@article{Yeom:15,
author = {Han-Ju Yeom and Hee-Jae Kim and Seong-Bok Kim and HuiJun Zhang and BoNi Li and Yeong-Min Ji and Sang-Hoo Kim and Jae-Hyeung Park},
journal = {Opt. Express},
keywords = {Aberration compensation; Computer holography; Heads-up displays; Holographic display; Holographic optical elements},
number = {25},
pages = {32025--32034},
publisher = {OSA},
title = {3D holographic head mounted display using holographic optical elements with astigmatism aberration compensation},
volume = {23},

abstract = {We propose a bar-type three-dimensional holographic head mounted display using two holographic optical elements. Conventional stereoscopic head mounted displays may suffer from eye fatigue because the images presented to each eye are two-dimensional ones, which causes mismatch between the accommodation and vergence responses of the eye. The proposed holographic head mounted display delivers three-dimensional holographic images to each eye, removing the eye fatigue problem. In this paper, we discuss the configuration of the bar-type waveguide head mounted displays and analyze the aberration caused by the non-symmetric diffraction angle of the holographic optical elements which are used as input and output couplers. Pre-distortion of the hologram is also proposed in the paper to compensate the aberration. The experimental results show that proposed head mounted display can present three-dimensional see-through holographic images to each eye with correct focus cues.},
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