A Comparison of Substrate-guided and Free Space Augmented Reality Optical Architectures for Automotive Head-up Displays (HUDs)

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Abstract:

Heads up display (HUD) and helmet mounted display (HMD) technology has been actively developed by Luminit since its creation in 2006. The development started as part of the U.S. SBIR government-sponsored programs and has since resulted in the successful commercialization of holograms in consumer electronics AR devices such as Focals by North smart glasses and 3D AR HUDs for automotive windshields. Based on our decades long research in Holographic Optical Element (HOE) technology, this configuration uses open space holograms implemented in retinal scan imaging architecture. Currently, there are two geometries used in HMD and HUD displays: substrate guided and free space. In this paper, we will describe some of their key differences.

Introduction

HUDs/HMDs have seen accelerated growth in recent years thanks to the popularity of AR and VR, and new sophisticated designs have evolved [1]. DigiLens, Vuzix and other companies successfully designed new HMDs with expanded eye boxes. However, these HMDs are costly, usually >$1000/unit because of high requirements to the holographic medium (high refractive index change) and complexity of the waveguide structure. There are also some image problems in this design, like excessive scattering and low efficiency, that probably will be solved with time.

Luminit has designed several HUDs with substrate-guided (sometimes referred to as waveguided) and non-substrate-guided holograms [2]. This paper will explore the advantages of HOE-based substrate guided holograms verses free space architectures used in other automotive HUDs. Note that we will refer to geometries as free space if light propagates in air instead of a glass or plastic substrate.

Substrate Guided Holograms

Luminit substrate guided hologram HUDs use standard holographic polymers and simple holographic optical elements (holographic lens and holographic grating). Advantages include >90% transmission and low <1% haze. These holograms can be also be easily copied and affordably mass produced. Despite its cost efficiency, the optical parameters of the Luminit HUDs are impressive. The resolution of the retrieved virtual image is better than 2 angular minutes, achieved luminance >1300nit, and eye box and eye relief are up to standard.

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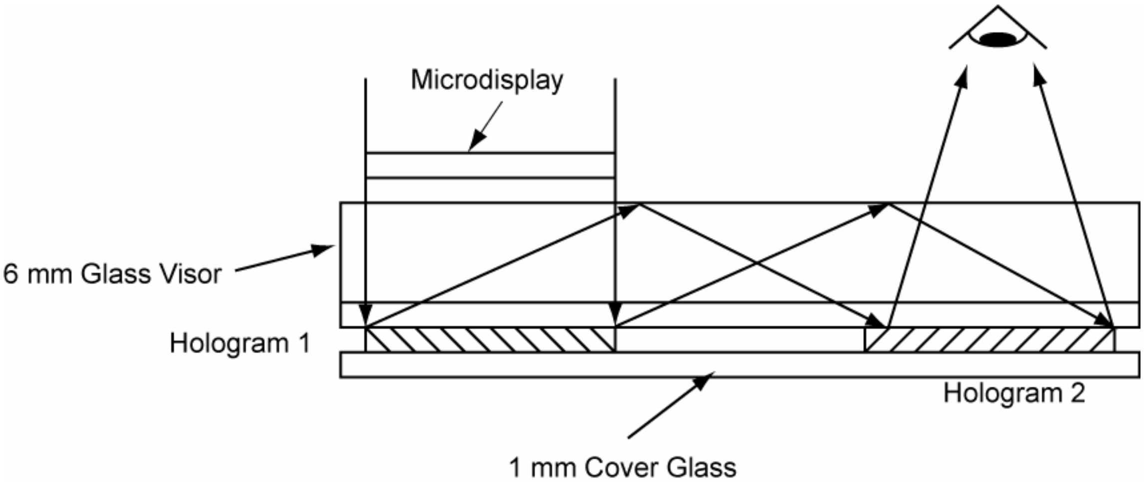

Figure 1. Conceptual drawing of the Luminit HMD.

In Figure 1, the micro-display and the viewer's eye are on the same side of the visor. The viewer, micro-display, and holograms can be on the different sides. The micro-display here should be either LED-based or OLED with rather wide spectrum [2].

Similar advantages of our substrate guided holograms apply to HUD systems that require larger, brighter images. Made with a thin (5-50 micron) photopolymer recording media, Luminit's single-layer RBG hologram uses advanced holographic optical element designs to replace traditional bulky optics with a thin, lightweight clear film component. Our laser-HUD design occupies <1.5 liters, making it ideal for automotive HUD systems where space and weight are limited. The holograms recorded in this single-layer film have properties of "volume" (Bragg) holograms that can provide optical power and perform both lens and mirror functions, in addition to being wavelength and angularly selective with very low scattering. Transparency is above 90%, diffraction efficiency can be up to 80% and these systems provide a larger virtual image size and larger Field of View (FOV).

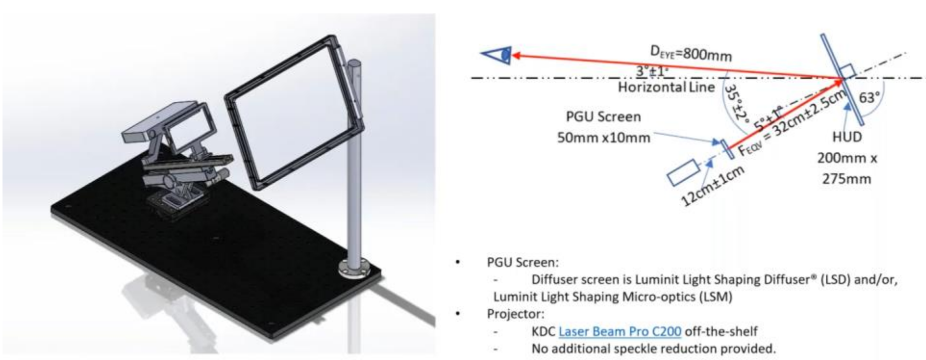

Figure 2. Solid model of a Luminit HUD demo - There are no lenses between the diffuser and the combiner hologram because all optical functions are in the volume of the hologram on a surface relief structure and embedded in an automotive windshield.

Wide spectrum microdisplay SGH architectures

Hologram 1 in Figure 1 is usually a holographic lens. In fact, it is the only optical element that has optical power and creates the virtual image. The holographic lens is usually recorded with one spherical wavefront, another collimated. The holographic material should be thick (~10-20um) holographic polymer. Thick holograms can be up to 100% efficient because they create only one diffractive order. They are also angular and wavelength selective (Bragg selectivity). Bragg selectivity results in the decrease of the diffraction efficiency if the playback beam or playback wavelength deviate from the recording. The micro-display is usually placed at the focal distance from the holographic lens to create a set of collimated beams, so the virtual image is coming from far away. Only beams deviated from the recording point within a small range of angles for one wavelength are retrieved efficiently. Thanks to the wide bandwidth of the micro-display, other wavelengths for the micro-display points shifted from the recording point are in Bragg. That is how the FOV is created. The problem is that the thick hologram wavelength acceptance is somewhat large. It can be from less than 1nm to several tens of nanometers, depending on the hologram thickness. It means that each microdisplay pixel will be dispersed, and the virtual image will be blurry. That is why Figure 1 shows another hologram (Hologram 2) that is in fact a simple holographic grating. Because all beams diffracted by the holographic lens are collimated, they are easily accepted by the holographic grating. However, now they are dispersed in the opposite direction, and the eye sees a perfectly focused image with some FOV. The only issue here is that there is some color shift across the FOV in the Bragg degeneration direction. At Luminit, we designed low dispersion HOEs that have small color shift (~20nm) across the FOV that not every eye can distinguish, and the FOV can be up to 25 degrees.

Narrow spectrum (laser) micro-display SGH

Despite a good quality image, holographic HUD with LED or OLED-based micro-displays can have low efficiency – 12-15% and low brightness. This is because the first hologram in the HUD works as a narrowband filter and cuts the spectrum of the micro-display. This problem is compounded if multiple elements are stacked (as done with surface relief structures and eyebox expansion). Luminit recently filed two patent applications for the laser-based HMD [3,4] that solve this problem. HMD based on these geometries can have the efficiency >90%, so they can create very bright and high-contrast virtual images that can be seen at any bright light condition (indoors and outdoors). The basis of this geometry is to design and record the holograms so that the image source is placed at an equivalent focal point (shown in Figure 3) at playback.

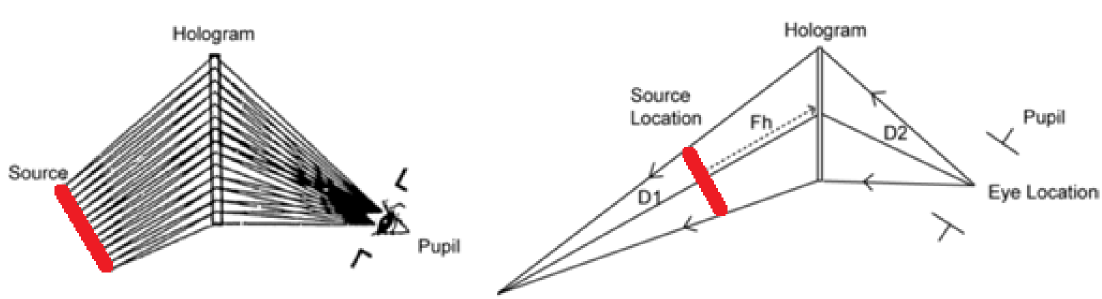

Figure 3. Luminit continuous lens geometry for narrow band (laser) illumination sources

Luminit is routinely building HUD demos based on this geometry. Proposed in [3, 4] geometries with SGH continuous lens fit better to HMDs because the design is more compact, has a lower profile, and is flexible in terms of placing holograms either on the external side of the visor or on the internal. Actual HMD playback geometry concept with SGH continuous lens shown in Figure 4.

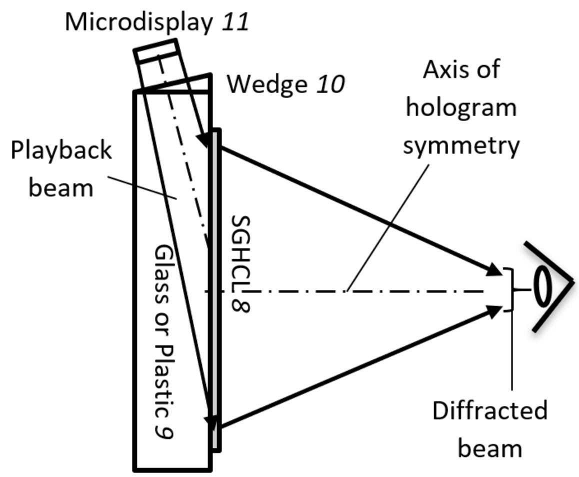

Figure 4. Conceptual drawing of the Luminit SGH using narrow band illumination (laser)

Free space architectures

When compared to SGH geometries, free space geometries require that the path where light propagates be free of obstructions. A diagram of an example of this geometry is shown in Figure 5.

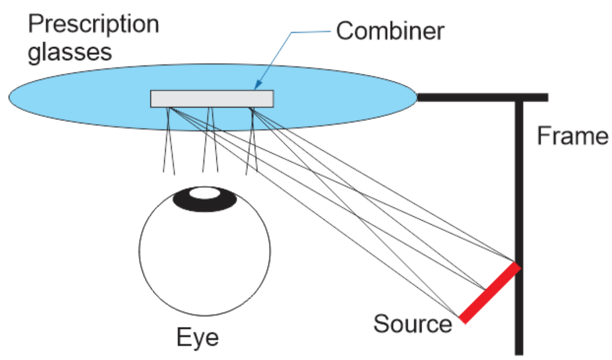

Figure 5. Free space, single hologram geometry.

If the combiner is a simple reflector, or a reflection with optical power, a broad spectral source (OLED or LED) can be used. In the case of a single hologram geometry, narrow band illumination is required. The hologram is recorded similar to Figures 3 and 4 but instead of using a substrate or waveguide for playback, the light propagates in air.

A special case of free space geometries is the first generation of the Focals by North AR smart glasses. Luminit developed and manufactured the holograms that enable these glasses. In this case, the image is formed by rastering a laser on the retina of the user. The hologram enables the projection by reflecting to the eye and focusing it through the iris of the user as shown in Figure 6. The projection is provided by a scanning laser projector.

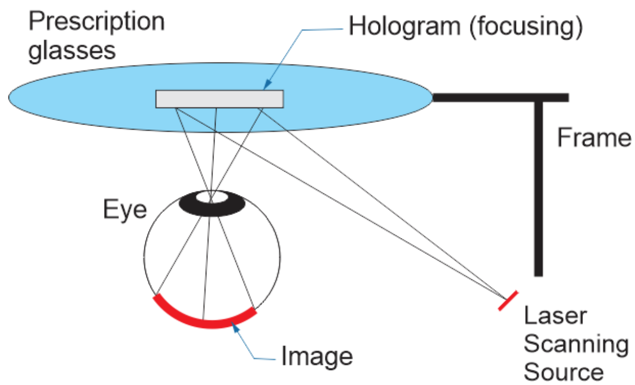

Figure 6. Retinal display using a hologram combiner

When considering the use case of HMD and ergonomics (i.e., shape and features of the face and head of the user), these geometries are susceptible to person-to-person facial differences and obstructions such as hair, body modifications, etc. Specifically to retinal scan applications, it can be seen in Figure 6 that the eye box of this geometry is smaller than what is possible with others. Although eye box expansion techniques exist, this limitation requires fitting for the proper user experience.

Conclusions

We showed a comparison of the substrate-guided hologram and free space geometries. The main drawback of free space geometries is the susceptibility to obstructions and user-to-user anatomic differences. We showed that SGH geometries are capable larger eye boxes than retinal displays. While SGH geometries may have limited efficiency (brightness), an equivalent focus hologram playback enables us to use narrow band (laser) illumination and increase the efficiency to >90%.

References

1. Leon Eisen, Michael Meyklyar, Michael Golub, Asher A. Friesem, Ioseph Gurwich, and Victor Weiss "Planar configuration for image projection", June 2006 _ Vol. 45, No. 17 _ APPLIED OPTICS
2. U.S. patent #10274660 "Holographic substrate-guided wave-based see-through display"
3. U.S. Patent Application 16/800,531, F. Dimov et al., "Head-mounted display having volume substrate-guided holographic continuous lens optics with laser illuminated microdisplay," 2020.
4. U.S. Patent Application 16/835,630, F. Dimov, "Laser-based waveguided illumination for a front-lit LCOS display," 2020.