

## Waveguide-Based Optical Smart Helmet for Augmented Vision and Health Monitoring in Industrial and Clinical Safety Applications

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The issue of road safety is of paramount importance and a concern when it comes to two-wheelers. Two wheelers are more prone to road accidents, especially due to blind spots. Waveguide optical display technology is an emerging technology that can potentially transform driver visual display systems by enabling the rider's helmet visor itself to become a see-through head-up display, similar to something from a science fiction movie. The possibilities of such a display system is boundless. It will enable the rider to see and process multiple information seamlessly without affecting his concentration. This paper will describe driver visual display systems, waveguide optical display technology, development of the concept prototype, results of preliminary evaluations and recommendations for follow-on research and development.

**KEYWORDS:** Smart helmet, head-up-display, waveguide optical technology, pico projector.

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### 1. INTRODUCTION

Often motorcycle accidents happen due to poor visibility and lack of information to the driver. During the ride drivers have a critical need to view communication, navigation, and other sensor data in real time. Motorcycles usually have displays and gauges which are located on the dashboard, which requires the rider to take a moment off the road to process the information. Moreover the side view mirrors are always prone to blind spots no matter how they are placed. This have been serious limitation of motorcycles.

Head-up displays (HUDs) have been a topic of interest for the last few decades, and their use in areas such as avionics and medicine is widespread, or at least desired. Furthermore, the ubiquity of portable devices and the trend towards wearable computing reawakens the interest for lightweight HUD systems. In the last few years, HUD designs have been reported and industrialized mostly in the form of glasses, which superimpose information over the user's field of vision (FOV) via optical components such as beam-splitters, wedge prisms, or other kinds of free-form elements. The design of such optical systems is challenging since it must meet several criterion: HUDs must feature a high brightness, preserve the user FOV, be adjustable, and provide a virtual image of a decent size with minimal fatigue for the user. The virtual image must be visible within a sufficiently large eyebox especially when there is a relative movement between the HUD and the user head. HUD systems designed for augmented reality must display a wide-angle image approaching the eye FOV so that virtual objects or information can be mapped to objects of the real-world view. On the other hand, other kinds of HUD systems are designed for hand-free interaction with electronic devices [4]. In this case, a narrower FOV is sufficient, and such systems are potentially less invasive. Head-up display systems (HUDS) belong to the latter case, and strictly require that the user FOV remains cleared of all bulky optical element.

To the best of our knowledge, no HUDS meeting all the requirements described above was reported so far. Livemap (livemap.info) is preparing a monocular HUDS for motorcyclists. Their optical system is located on top of the helmet, expanding its height and decreasing in particular the vertical FOV. Skully (skully.com) has also designed and sells a monocular HUDS for motorcyclists, forming a virtual image on an edge of the user vision. Nuviz (ridenuviz.com) prepares a similar HUDS, and Crosshelmet (crosshelmet.com) develops a HUDS with optical system located at top. In fact, such systems are often limited by their luminosity, since they relay a screen image formed by light emitting diodes (LEDs). Also, those designs reduce the user FOV. Most reports of HUDSs, despite not always targeting motorcycle users, require bulky optical components which can hardly be integrated inside a commercial motorcycle helmet without conflicting with its security padding elements. In this work the inclusion of a DLP nHD optical engine micro-projector from Texas Instruments permits the visualization of an ultra-bright image, visible in daylight conditions. The tight adjustment of the helmet on the head, as well as the alignment knobs guarantee that the user eye remains in the virtual image eyebox. The presented design is compact, and will fit inside a commercial helmet without substantial modifications. Moreover, the HUDS consists of a module attached to the side of the helmet, therefore letting the user FOV unaffected and preserving the safety components of the helmet. A simple yet efficient optical design based on waveguide optical components is presented. In this paper, we report a new non-obtrusive and high brightness HUD targeting motorcycle users

## 2. WAVEGUIDE OPTIC TECHNOLOGY

Waveguide optical displays couple images from a micro display into a waveguide, translates the images through a series of internal reflections finally exiting toward the eye. This provides a magnified, see-through virtual display image at a specific distance in front of the viewer. These systems use a number of different optical approaches including diffractive, holographic, polarized, and reflective optics.

**Diffractive waveguides** use deep slanted diffraction gratings to couple optically collimated (magnified) light from the micro display into the waveguide; then exit to the eye through another set of diffraction gratings. These gratings are fairly expensive to manufacture, and have an intrinsically small field-of-view.

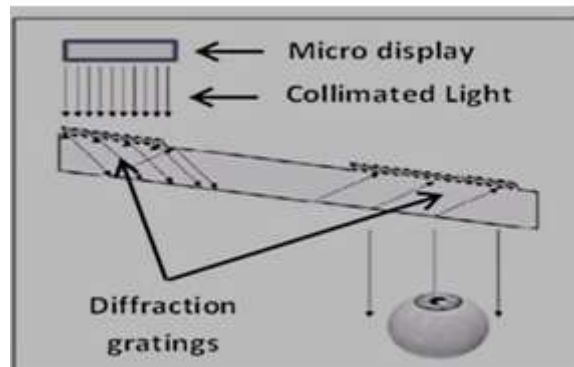


Fig 1. Diffractive waveguide

**Holographic waveguides** reflect specific wavelengths of optically collimated light from a micro display at a certain angle relative to an embedded hologram. Holographic waveguides have a limited field-of-view due to light losses through the embedded holograms. Since each holographic element can reflect only one wavelength of light, three individual holograms per holographic element are required -Red, Green, and Blue respectively – to provide full colour transmission capability

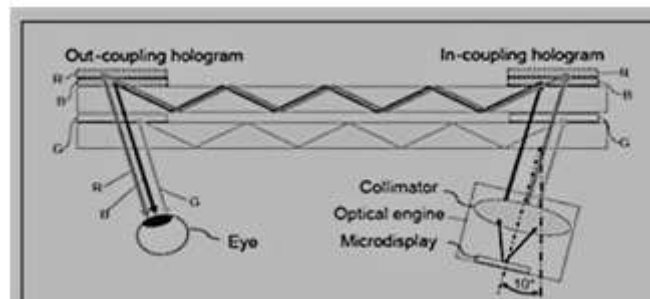


Fig 2. Holographic Waveguide

**Polarized waveguides** use multi-layer coatings with embedded polarized reflectors to couple the micro display image into the waveguide and extract the light towards the eye. The polarized coatings must be deposited on a glass substrate since plastic is not yet compatible with this process. Polarized waveguides typically require very high brightness level micro displays due to significant light losses.

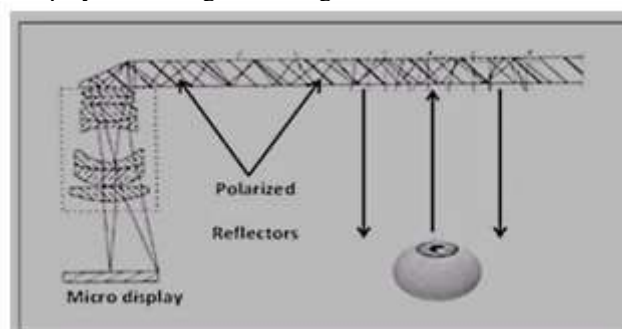
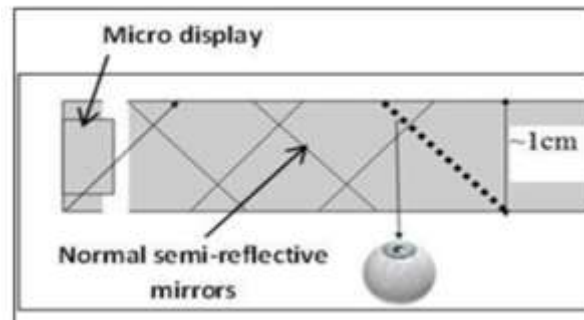


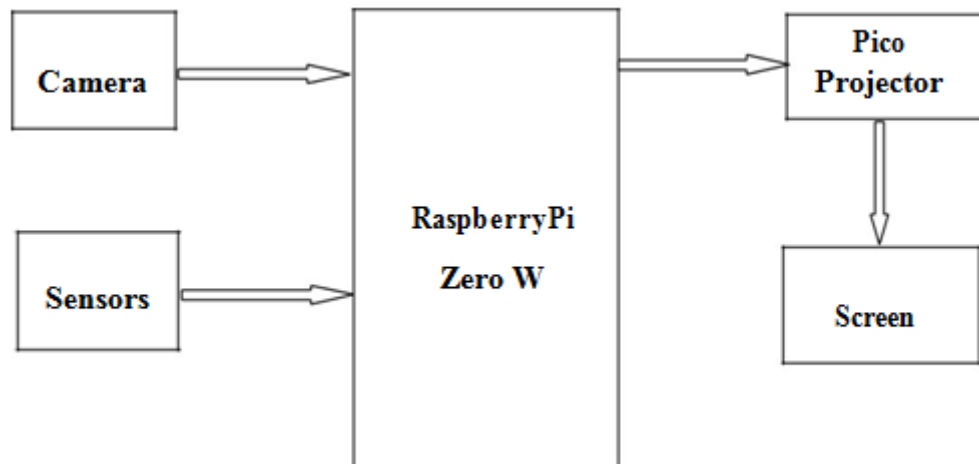
Fig 3. Polarized Wavelength

**Reflective Waveguides** use an off-axis projection micro display and semi-reflective curved mirrors to optically couple collimated light from the micro display into the waveguide. Reflective systems tend to be more power efficient since there is no light loss due to polarization, grating, or holographic effects. Reflective wave guides can be manufactured from glass.



*Fig 4. Reflective waveguide*

### 3. ARCHITECTURE OF PROPOSED SYSYTEM



*Fig 5. Block Diagram*

The block diagram of whole system is shown in Fig.5. Raspberry Pi Zero W is a small size micro controller with dimension 65mm x 30mm. It have 40 input/output (I/O) pins. The first RaspberryPi Zero was released in November 2015 for US\$5. It became the newest mainline Raspberry Pi by 2017. The Raspberry Pi Zero W, a version of the Zero with Wi-Fi and Bluetooth capabilities was launched on 28 February 2017 for US\$10.

The Raspberry Pi Camera v2 is a high quality 8 megapixel camera with Sony IMX219 image sensor. It is a custom designed add-on board for Raspberry Pi, with a fixed focus lens. It has a capacity of 3280 x 2464 pixel static image. It also supports 1080p30, 720p60 and 640x480p60/90 video. It is attached to Pi by way of one of the small sockets on the board upper surface and camera is interfaced using the dedicated CSI interface designed especially for cameras. The board is very tiny, at around 25mm x 23mm x 9mm. It weighs just over 3g, making it perfect for mobile or other applications where weight and size are important. A short ribbon cable is used to connect to RaspberryPi.

A pico projector is a device that can be held on the hand and has all the characteristics of a projector. They are mobile, low energy consumption and have same resolution as compared to large projectors. A pico projector is a small hardware device designed to project content from a smartphone, camera, tablet, notebook or memory device onto a wall or other flat surface. The pico projector we use is DLPDLR2000EVM from Texas Instruments, which is an easy-to-use, p2p evaluation platform for a wide array of mobile and portable display applications for all markets including consumers, wearables, industrial, medical, and Internet of Things (IoT). This device features the DLP2000 chipset comprised of the DLP2000 .2 nHD DMD, DLPC2607 display controller and DLPA1000 PMIC/LED driver. This EVM comes equipped with a production ready optical engine and processor 8/16/24-bit RGB parallel video interface in a small-form factor is supported by the processor interface.

#### 4. CONCLUSION

The image quality is assessed by comparing the image as seen from inside the helmet with the source image projected onto a wall. The virtual image seen outside on a sunny day, at high luminosity, when a 30 dB neutral density (ND) filter is set after the projector and the virtual image seen indoors, with higher attenuation of 34.7 dB. To estimate the virtual image deformation, a picture of the source image is projected onto a wall is compared with the picture. Keypoints in the image are selected. Corresponding keypoints are found on image on the wall and are superimposed. Minor image deformations can be seen, and originate mainly from the fact that the light beam reaching lenses does not necessarily coincides with their optical axes, depending on the adjustment of mirrors. A spot diagram of the simulated system picturing the spot size on the retina for each wavelength of the system is analysed. The variation in spot size origins from the 193 nm wavelength difference between the blue and red laser of the projector. Therefore, despite the use of achromatic lenses, different wavelengths focus at slightly different z-values. The projector has a resolution of  $N_x \times N_y = 640 \times 360$  pixels, which represents 91 pixels/° horizontally and 96 pixels/° vertically. Both numbers are under the eye resolution limit. The waist size on the retina is therefore larger and the system resolution is higher than the one perceived by the eye. This is further confirmed by the spot size. The power of the system is of 84 nW per eye, after an attenuation of 34.7 dB with the use of ND filters. Coupled with a software control, the system can adapt to any lighting condition.

In conclusion, we have reported a new design of HUD suitable for motorcycle users. The system features a good compactness, smoothly fits inside a standard helmet with minimal work, and provides high luminosity for daylight conditions. The system is adjustable via two rotations and one translation per eye, and an additional degree of freedoms provided to adjust the beam convergence. The projected image is visible at the right side of the user FOV, thereby suited for driving conditions.

#### REFERENCES

- [1] Ito, K., Nishimura, H., & Ogi, T. (2018). Motorcycle HUD design of presenting information for navigation system. 2018 IEEE International Conference on Consumer Electronics (ICCE). doi:10.1109/icce.2018.8326113
- [2] Tsuchida, T., Yachida, T., & Masuya, Y. (2018). Advantage of Head-Up Display for Automobiles. 2018 25th International Workshop on Active-Matrix Flatpanel Displays and Devices (AM-FPD). doi:10.23919/am-fpd.2018.8437396.
- [3] Chouksey, S., & Sirsikar, S. (2016). A prototype of low cost heads up display for automobiles navigation system. 2016 International Conference on Computing, Analytics and Security Trends (CAST). doi:10.1109/cast.2016.7914967
- [4] North, T., Wagner, M., Bourquin, S., & Kilcher, L. (2016). Compact and High-Brightness Helmet-Mounted Head-Up Display System by Retinal Laser Projection. *Journal of Display Technology*, 12(9), 982–985. doi:10.1109/jdt.2016.2522998
- [5] Gallagher, D. G., & Manley, R. J. (2014). Diver's full face mask head-up display system using waveguide optical display technology OSJ — 140214–001. 2014 Oceans - St. John's. doi:10.1109/oceans.2014.7002976
- [6] Ju-Na, Gwo-Bin Lee, & Wen-Fung Pan. (2005). Projection display technique utilizing three-color-mixing waveguides and microscanning devices. *IEEE Photonics Technology Letters*, 17(1), 217–219. doi:10.1109/lpt.2004.836909.