

A 3D Full Windshield Head Up Display

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ABSTRACT

A new concept of Head Up Display is presented, using the windshield as a transparent screen. This breakthrough technology does not need the use of complex combiner, bulky optics and overhead projection unit. The novel system uses several holographic optical elements to perform a 3D stereoscopic display, with the ability to present floating graphical objects in a large field of view. Augmented Reality display will be possible, increasing considerably the User Experience and situational awareness, without the need of wearing a bulky and complex Head Mounted Display.

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INTRODUCTION

Head-Up Displays (HUD) has been used on board aircrafts for several decades. Initially designed for military applications as a means of targeting, they are used now to improve situational awareness, thanks to the ability to superimpose information in conformity with the external landscape. So HUD was the first application of what we now call Augmented Reality (AR).

In order to reduce eye re-focusing time, and to reduce parallax issues, images are collimated, so symbols are perceived far away.

But the head projection unit able to generate a bright collimated image is very bulky, and the associated complex optic engine is very expensive.

Collimated images are also only visible on a very small eye-box, resulting in a poor user experience.

In this paper, we present a novel system, using simulated collimation, Holographic Optical Elements and spectral interferential filters. With these breakthrough technologies, applicated to HUD, we remove the need of complex refractive optics, and offer a theoretical infinite eye-box, for an outstanding user experience.

BACKGROUND

Head-Up Displays have, for the last decades, retained the same main architecture: source, projector and combiner. The projector creates an intermediate image from the object source, which is collimated to infinity and superimposed on the external world by a combiner.

At first HUDs used CRT and a partially reflective plane combiner, then a holographic curved combiner. Further generations introduced LCD display with CCFL lamp backlight, and then LED backlight, associated with dielectric coated combiner. The latest generation

introduces diffractive optics and a thin combiner based on pupil expansion. Throughout these generations, the functional role of each element remains the same.

Avionics HUD are collimated to a long distance, enough to be perceived as infinity. In this case, symbology such as speed vector, horizontal situation, synthetic vision, enhanced vision, is superimposed with the real world, without parallax issue when the pilot moves his head inside the eyebox, offering an augmented reality function. In addition, the combiner located near the pilot's eyes provides a large field of view, generally more than 30° in horizontal and 20° in vertical. These characteristics improve the user experience and increase the pilot's situational awareness in critical phases of flight such as approach, landing and taxiing.

In counterpart, large projector space envelope, limited head clearance and limited eye motion box are the drawbacks of current avionics HUDs.

To address those it has been envisioned to use the windshield surface. Windshield projection has been explored for years within the automotive market

Automotive Head-Up Displays are mainly used to display information while keeping eyes on the road. This includes speed, navigation directions, warning and information relative to the car's condition.

This information is not displayed in conformity with the landscape, generating parallax errors between symbology displayed a few meters away and the real world in the background.

Automotive HUD field of view (FOV) is limited by the size of the HUD box, this limitation came from the necessary large mirror required to reflect the image on the full windshield, as shown on figure 4



Figure 1. Avionics HUD: Overhead projection unit and combiner in front of the eyes (Source: THALES Avionics Onboard blog).

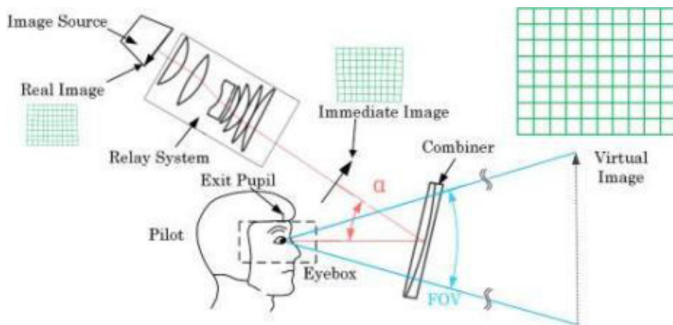


Figure 2. Avionics HUD: The intermediate image from a relay optics is reflected by the combiner [1].

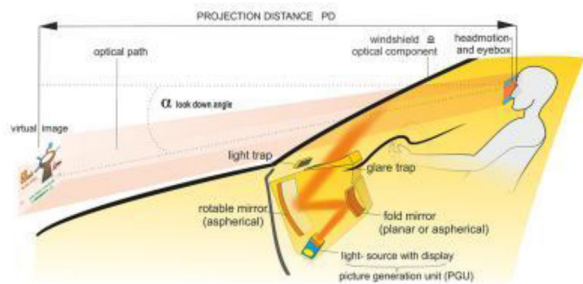


Figure 3. Automotive HUD: Picture generated in a box and reflected towards the windshield by mean of folded mirrors (Source: Continental)

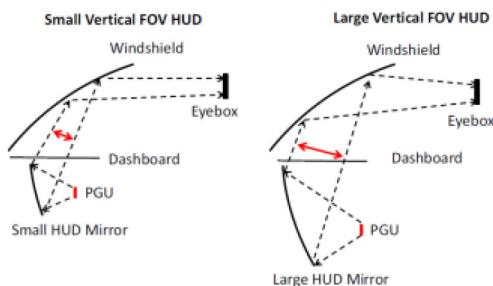


Figure 4. Field of view is limited by the HUD box size (Source: Texas Instrument [2])

Augmented Reality applications will require a very large field of view. But this critical parameter has a strong impact on the HUD box size, mainly due to horizontal (X) and vertical (Y) mirror dimensions, as shown in figure 5.

With this optical architecture, a HUD with a field of view of $14^\circ \times 6^\circ$ will require a mirror size of 325 mm x 175 mm.

For avionics applications, 35° in horizontal and 25° in vertical are common values. HUD box architecture would then require mirrors larger than 500 mm, not compatible with cockpit installation constraints, hence the different optical architecture currently used in avionics applications, resulting in a limited eyebox.

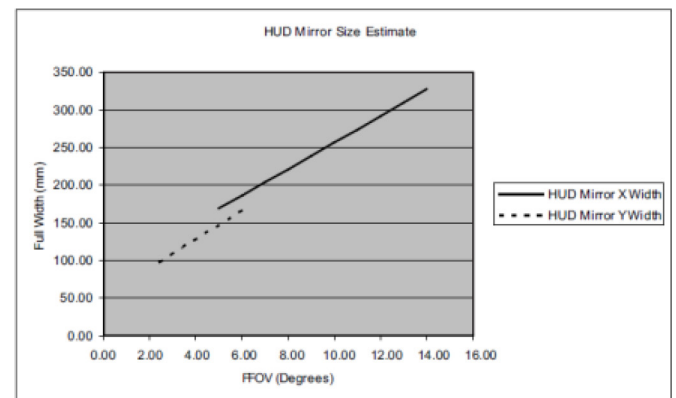


Figure 5. Field of view and HUD box mirror size (Source: Texas Instrument [3])

A full windshield head-up display using direct projection on a transparent screen is an alternative and a breakthrough with current HUD architectures. Papers [4] and [5] present such a HUD and such a HUD simulator.

DIRECT WINDSHIELD PROJECTION

Direct projection on windshield reduces installation constraints, thanks to the use of small projectors, and enables the removal of the combiner. Paper [6] presents a system, using a small UV laser projector, and a windshield including a layer with transparent phosphor.

With this concept, a bulky HUD system could be replaced by a basic video projector with a reduced footprint, and a transparent screen embedded on the windshield. But it raises several issues, particularly the mismatch between real world and images presented at short distance from the eyes, providing a bad user experience on augmented reality application (Fig. 6).

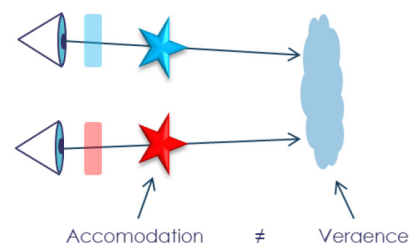


Figure 6. Displayed image in a different plane than the landscape behind, dissociation between accommodation and vergence

In summary, direct projection on a transparent screen could be an excellent solution for an eyes-out display as it solves most space envelope issues. But the lack of collimation and the vergence-accommodation conflict are critical showstoppers [7].

Simulated Collimation

An efficient augmented reality (AR) system should superimpose virtual objects on the real world.

For an AR HUD, horizon line, velocity vector, synthetic or enhanced vision shall be displayed in conformity with the real world, without accommodation effort and vergence issues.

This has historically been achieved using a complex and bulky collimating optics inside the projector. But the collimated rays give a tunneling effect and the image is only visible inside a small eye-box.

With direct projection on a transparent screen, the image is formed at a finite distance on the screen. Real world superposition cannot be performed without the use of collimation.

With the transparent display, we propose to simulate collimation by using Stereoscopy (figure 7).

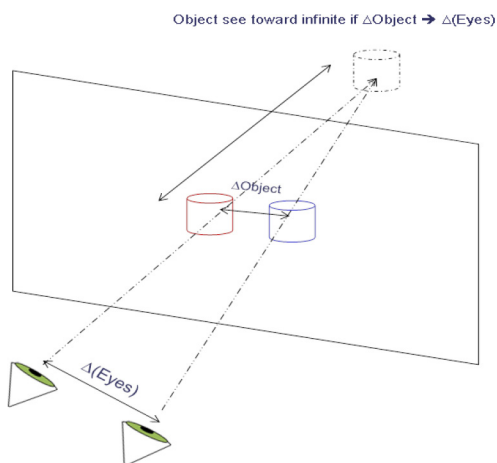


Figure 7. Simulated collimation using stereoscopy [7]

A stereoscopic projector is used to display left-eye image and right-eye image on the transparent screen, which is, in fact, a windshield with an optical layer.

When the distance of the two images on the screen match the inter-pupillary distance, the virtual object is seen at infinity. At the same time, as 3D glasses allow each eye to see only one image, the double vision issue is solved.

This system offers infinite viewing directions with no constraints such as the small eyebox and unique viewing point of traditional HUD.

3D Transparent Screen Used as HUD

The user wears a pair of 3D glasses, and camera-based head tracking is used to compensate the parallax error caused by head motion (figure 8).

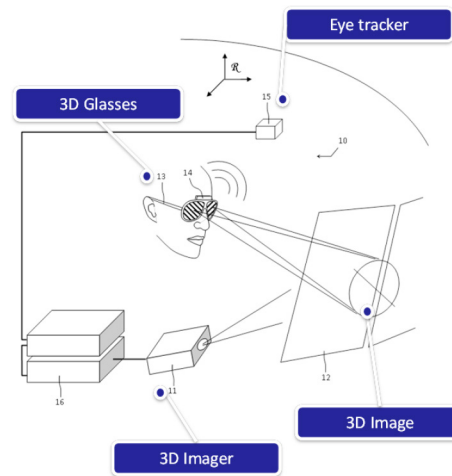


Figure 8. System view

3D Principle for Windshield Projection

A 3D system using polarized goggles cuts off at least 50% of the external luminance, due to light polarization.

An active shutter 3D system achieving more than 50% transmission of external luminance will require a complex synchronization mechanism between projection source & temporal eye shuttering and will so become tricky and bulky on head.

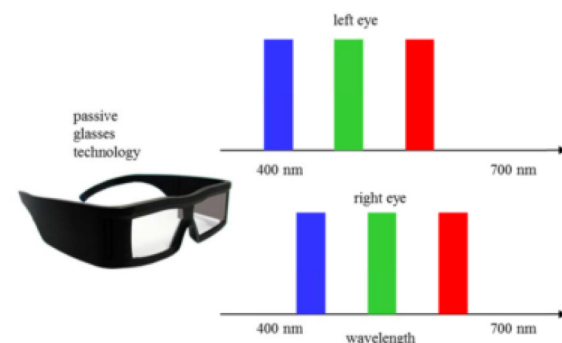


Figure 9. Spectral separation principle: Left and right images are coded in spectrally independent wavelengths [8]

The most suitable setup for a see-through system seems to be the wavelength multiplexing approach [8]. By using a bandpass filter for each color and each eye, it is possible to achieve a transmission rate of 60% (and more if narrow band sources are used) while using only a light passive component on head.

For an Avionics Head Up Display, displayed images are green, as requested by current Avionics standards [9].

The principle presented and adapted to our proposed application removes only a small bandwidth of the visible spectrum for the goggle notches, typically less than 30 nm of green at 520 nm and at 540 nm, resulting in an outstanding photopic transmission of more than 75%.

As these two notches are applied respectively to left and right eyes, the entire spectrum is visible by the two eyes, except for the notch wavelengths, only visible by one eye. Practically, in order to avoid