Augmenting Reality in Automobiles

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ABSTRACT

Automobiles and the automotive market are undergoing a revolution, the marque bands are looking to cement their brand identity through interior design and an increasingly differentiated user experience. As with head up displays, Augmented Reality offers a compelling safety case, however it also offers automotive manufacturers the opportunity to extend their brand beyond the confines of the vehicle. Thus far, its adoption has been impaired by the physical volume of the optical system required to create a compellingly wide field of view and virtual image distance.

1 INTRODUCTION

The use of HUD in automobiles has been studied extensively [1], [2] and has been shown to have a number of significant safety benefits, the most important of which is enabling the driver of the vehicle to maintain their gaze on the road thereby improving situational awareness.

1.1 Human Factors

When compared to automotive interior displays, head-up displays place information just below the driver's main line of sight reducing the angular range of motion the eye needs to go through (glance down angle) in order to obtain information, allowing the extra-vehicle scene to be maintained in the parafoveal visual field.

The biggest benefit of head-up displays is in the reduced demand to adjust the focal length of the human eye. Typically, a driver is focused at infinity while driving, to refocus on an interior display positioned at a distance of 1m takes ~700mS, whereas for information presented at a typical head-up display distance of 2.3m only takes ~200mS. While refocusing, the brain takes in no new information and as we age this refocusing time increases, this duration can equate to a significant distance when travelling at speed.

To make the best use of head-up displays & the ability to augment reality we first need to understand how the human visual system is able to determine information about objects in a three-dimensional environment.

1.2 Perception Of 3D space

The human visual system needs both physical and psychological depth cues to fully recognise the third dimension. The three major physical depth cues that the human brain uses to gain 3D sensation are:-

- Accommodation is the measure of exertion as signalled by the Ciliary muscles which contort the lens in the eye. This lens deformation results in a focal length change in the eye thereby bringing an object at a specific distance into sharp focus.
- Convergence is the measure of exertion as signalled by the Oculomotor muscles used to rotate the eyes to fixate on a near object. The angular difference between the viewing directions of two eyes directly provides a measure of distance.
- Binocular disparity refers to differences disparity in retinal images acquired by the left eye and the right eye.

In addition to the physiological depth cues, the human brain can also gain a sense of depth by extracting the following psychological depth cues from 2D images, these include:-

- Linear perspective is the illusion that size changes with distance such as a road converging at a distant point.
- Occlusion is the truncation of objects behind other opaque body. The human brain learns to interpret partially occluded objects as being behind near items.
- Shading and shadows cast by objects provide indications of spatial and textural relationships. Variations in the scattered light intensity infers an objects shape, surface texture and orientation.
- Prior knowledge of objects and how they behave when in motion, such as vehicles, can be used to infer their distance.

In practice all of these depth cues are used when driving, however, the three key physiological cues for depth perception become very small at distances greater than 6m. Provided that psychological depth cues are in place, virtual images beyond 6m will be perceived as being fused with the real world thereby enabling seamless augmentation of reality.

2 REQUIREMENTS OF AR HUD

The display requirements for head-up displays are well understood. Given that the display is showing essential driving information such as speed or basic symbology against a potentially cluttered background, it is paramount that the luminance levels are significantly above ambient conditions to ensure that it is easy to acquire information.

Before we can understand the requirement for a display that may be used to augment reality we must first consider the potential applications :-

- Lane departure visualisation
- Automatic cruise control gap setting
- Navigation
- Pedestrian / urban highlighting
- Traffic signs both highlighting & virtual
- Forward collision alert
- Autonomous vehicle visualisations
- Night vision

These features present a significantly different challenge, utilising a much larger area of the drivers' field of view (covering a minimum three lanes of a motorway >10 deg) and much greater pixel utilisation. In order for this not to be a distraction the information needs to be presented at or very close to the light levels of the scene, augmenting with salient information.

Given the different requirements of the two types of information (AR vs Essential) it is better to present the information on two distinctly different depths:-

- Essential driving information (near)
- Augmentation information (fused upon reality)

This gives the added benefit that the far information can be switched off when in queuing traffic, reducing depth cue confusion and cognitive loading.

3 ENABLING TECHNOLOGIES

The current dominant display technology utilised in automotive Head Up Displays is LED backlit TFT LCD's, a typical single image plane HUD with a horizontal FOV of 3 x 7 degrees will package in a volume of 6-8L

Given that AR HUD needs a field of view of at least 10 degrees horizontal, scaling the design leads to packaging volume significantly beyond 10L for a single image plane. Adding a 2nd image plane (traditionally positioned at approximately 2.5m in front of the driver), will be a further increase volume. As the volume increases it becomes increasingly difficult to package the HUD, with significant clashes occurring with the vehicle steering column, firewall, cross car beam and instrument cluster.

To mitigate the increased packaging volume higher magnification virtual image projection optics may be employed; as the magnification increases the imager (TFT) becomes smaller. However, the higher magnification applies both to the image and to the concentration of solar radiation. The large primary imaging mirror presents a significant area over which to gather solar radiation that is ultimately being concentrated on to a physically smaller area as shown in Fig. 1. Counter measures are needed to prevent the Head-Up Display from combusting in the vehicle.

One solution is to work with narrow band light sources, such as lasers, enabling spectral filtering to be employed removing over 90% of the solar spectrum. This can be further supplemented with polarisation filtering to significantly decrease the amount of solar energy concentrated within the HUD package.

While narrow band light sources present a viable solution, the currently available automotive rated parts do not emit a sufficiently large amount of power to be viable for use with either LCD or DLP microdisplay devices.

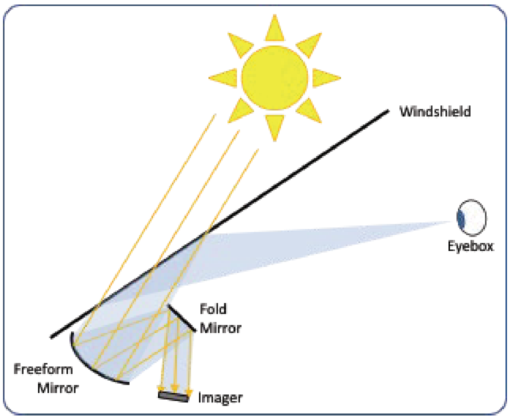

Fig. 1 Solar Loading

Phase only dynamic holography has been demonstrated as a viable display technology that is compatible with automotive qualified low power laser diodes.

4 PHASE ONLY HOLOGRAPHY

Phase only holography employs Computer Generated Holographic (CGH) techniques to reconstruct an image by spatially manipulating only the phase of light. To date two different methods of implementing a phase only holographic systems have been demonstrated:-

- Binary phase only holograms: Dr. Buckley et al. [3].
- Multi-level phase only holography: T Prof. Crossland et al. [4].

4.1 Computation of Phase Only Holograms

Calculating the spatial distribution of phase retardation states for high quality, high resolution holograms is computationally demanding. Direct Binary Search or Simulated Annealing techniques have traditionally been the best approach to derive high quality holograms. These approaches work by inspecting the contribution made by each point in the hologram to the image. Although this works well for simple spot for an image with 1024x512 pixels, calculating the interaction of all points requires 2.75×10^{11} complex mathematical operations per iteration.

Gerchberg Saxton [5] iterative phase retrieval algorithms have become increasingly popular due to their reduced computation time. By utilising two-dimensional fast Fourier transforms the number of complex mathematical operations is reduced to 1.99x107 per iteration for a 1024x512 pixel image.

Although the Gerchberg Saxton iterative algorithm significantly reduces the computational effort, it tends to stagnate quickly producing relatively noisy images with poor contrast.

Numerous constraint-based modifications to the iterative loop have been proposed in order to improve the performance. One such successful approach is the FIDOC [6] algorithm, while significantly better than Gerchberg Saxton, its contrast performance means it is unsuitable for transparent display applications such as HUD.

The research team at Envisics (formally Two Trees Photonics) has developed a new generation of iterative algorithms, the results shown in Fig. 2 and Fig. 3 demonstrate the advantage over the previous best performing phase retrieval algorithm FIDOC and Gerchberg Saxton.

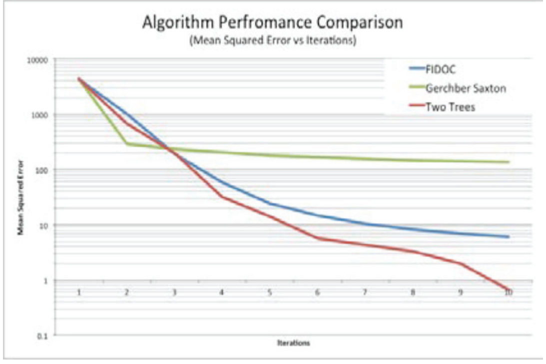

Fig. 2 Algorithm Comparison (Mean Squared Error)

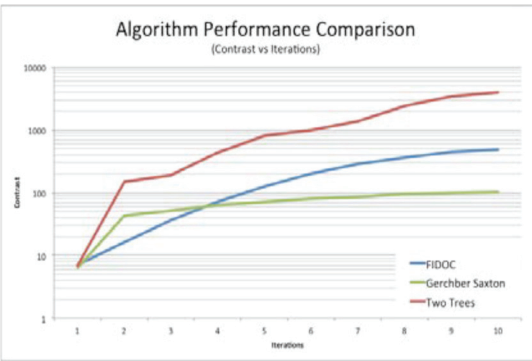

Fig. 3 Algorithm Comparison (Contrast)

5 PHASE ONLY SPATIAL LIGHT MODULATOR

The most well documented method of achieving phase only modulation is to utilise the 'Electrically Controlled Birefringence' (ECB) configuration of liquid crystals. The phase of light is altered by inducing a rotation preference to the liquid crystal n-director.

LCOS (Liquid Crystal on Silicon) devices encapsulate liquid crystals between an ITO coated glass substrate and a s mono-crystalline silicon semiconductor with a mirrored top surface, the mirrors acting as the pixel counter electrode. The utilisation of silicon processes has the advantage that the signal lines, gate lines and transistors are below the mirrored surface, resulting in very high fill factors. For example, the very latest LCOS backplanes have pixel sizes less than 3µm and fill factors in excess of 90%.

Combined, LCOS & ECB techniques form a good approximation of a phase only holographic film with the advantage that it may be refreshed at video rates.

5.1 LCOS Backplane Fundamentals

LCOS devices were originally developed for front projection & rear projection television applications and were later targeted at micro-projectors. Two design philosophies became dominant.

- DRAM (Analogue pixel drive)
- SRAM (Digital pixel drive)

DRAM (Dynamic Random Access Memory) backplanes employ a transistor beneath each pixel mirror to charge a capacitor (also beneath and connected to the mirror), the charge in the capacitor being sufficient to maintain the electric field across the liquid crystal until it is refreshed.

SRAM (Static Random Access Memory) backplane devices typically have a one or two bit memory embedded beneath the mirror. The voltage across the liquid crystal is a representation of the binary value in the SRAM. By utilising high speed signalling the SRAM is updated 50 to 100 times per video frame, allowing complex pulse modulation schemes to be employed. The simplified pixel drive structure allows SRAM backplanes to have smaller modulation elements than those found on DRAM designs, giving an advantageous increase in diffraction angle.

5.2 Application Of LCOS to Holography

The current commercially available LCOS backplanes were designed for the amplitude modulation of light for projection applications. The pixel drive scheme may give rise to instability in the electric field, impacting the n-director of the liquid crystal and creating slight variation in the grey shades that make up the image. These variations are averaged by the integration time of the human eye and have a negligible impact on perceived image quality.

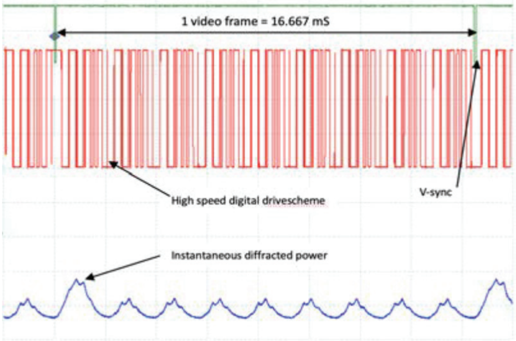

Fig. 4 Phase Noise (Instantaneous Variations In Diffracted Power)

However, the application of these backplanes for ECB mode phase only devices is problematic, the same instability in the electric field translates directly into phase noise (phase ripple) as shown in Fig. 4. Given the instantaneous constructive & destructive complex diffractive process of image formation in phase only holography, phase ripple results in unwanted noise in the image as shown in Fig. 5. As the device temperature increases, the lower viscosity of the LC further exasperates the issue as shown in Fig. 6.

Fig. 5 Impact Of Phase Ripple At 20°C

Fig. 6 Impact Of Phase Ripple At 50°C

The engineering team at Envisics have developed a custom silicon backplane specifically for the purposes of phase modulation. Core to its design is a small pixel size to enable larger diffraction angles and features designed to minimise phase noise across a wide range of operating temperatures, while still enabling the device to be refreshed at full motion video rates.

6 RESULTS

By combining custom phase modulators with our high-performance holographic algorithms, we have been able to demonstrate that real time holography is viable.

The first application is in automotive augmented reality head up displays, where our holographic technology can project high resolution information at multiple depths simultaneously, in full colour from a single compact projection engine. The photographs shown in Fig. 7 & Fig. 8 are of Envisics AR-HUD, with the near image at a distance of 2.3m and a far image at >10m.

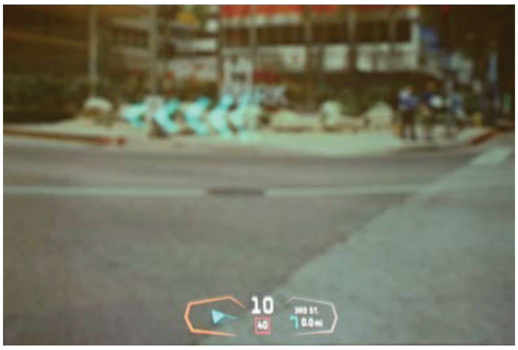

Fig. 7 Photograph Of Envisics AR-HUD Near Image

Fig. 8 Photograph Of Envisics AR-HUD Far Image

7 CONCLUSION

Realising the dream of high quality dynamic holographic displays is not something that can be addressed simply by the application of greater compute power or new algorithms. In practice, holography is the confluence of many scientific disciplines, only through understanding the interaction between them can the challenges of holography be addressed.

Envisics has made significant progress in developing the mathematics, devices, material science and system architectures needed to make this technology of sufficient quality and robustness to be acceptable in mass market applications.

Liquid Crystal Displays took 40 years to achieve the quality that is readily available today, by comparison holographic displays are only a few years into their development, it is entirely feasible that we will realise the kind of holographic displays that science fiction has promised.

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