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3-D display design concept for cockpit and mission crewstations *

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ABSTRACT

Simple visual cues increase human awareness and perception and decrease reaction times. Humans are visual beings requiring visual cues to warn them of impending danger especially in combat aviation. The simplest cues are those that allow the individual to immerse themselves in the situations to which they must respond. Two-dimensional (2-D) display technology has real limits on what types of information and how much information it can present to the viewer without becoming disorienting or confusing. True situational awareness requires a transition from 2-D to three-dimensional (3-D) display technology.

Keywords: 3-D displays, cockpit displays, SLM, AOM, AMLCD, DMD, computer generated hologram

1. INTRODUCTION

The human system is about 80% visual in normal circumstances.[1] During high levels of stress, such as combat, humans rely more heavily on sight, sometimes to the exclusion of all other senses. An example is a pilot shot down in Vietnam. During his bombing run he became so focused on what he was doing that he did not hear his navigator yelling that there was a radar lock on them. As a consequence his plane was shot down. He was recovered but it was not until he heard the flight tape that he believed reports stating that his navigator had actually warned him of the danger. Some sort of visual interrupt may be necessary to draw the attention of aviators to imminent danger. The next question that needed to be answered is, what type of visual interrupt should be used. A 2-D model, such as a flashing button, and a 3-D sphere, coming out of the instrument panel (see Figure 1), which would high light the area affected by a threat were both options. In a study conducted by Air Force researchers, it was found that during a visual search task, pilots performed 20% better using the 3-D version rather then the 2-D version of the threat sphere.[1] Researchers at Wright-Patterson AFB used this information to decide that the visual interrupt should be 3-D. An alternative approach involves a haptic vest display rather than a visual.

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Figure 1. Concept illustration of 3-D sphere shown coming out of instrument panel.

2. TYPES OF 3-D

Three major types of 3-D displays are currently being developed: stereoscopic, auto-stereoscopic, and true 3-D displays. Stereoscopic and auto-stereoscopic take advantage of the versatility of the human brain and its ability to integrate visual scenes. Both of these technologies operate by taking two different perspectives of the same object and combining them in a way so that the viewer receives a perception of depth. Each perspective is slightly to the right and left of centerline to correspond to the view from the right and left eye respectively. The current version of a stereoscopic display consists of a monitor and a pair of polarizing glasses. The monitor alternately displays the left and right image at 120 Hz. The viewer then has to don polarizing glasses synchronized with an infrared signal or a wire to block out the left eye while the view corresponding to the right eye is on the screen and vise-versa. Since the monitor and polarizers are flickering at 120 Hz and 60 Hz respectively, the viewer does not notice the flicker and consciously perceives only one 3-D image. Such a stereoscopic display produces a realistic 3-D image but without look around capability; no matter how far one moves right or left one will not be able to see a different perspective. One will only see the perspective given at the full frontal position.

Autostereoscopic displays present a three-dimensional image to a viewer without the need for glasses or other encumbering viewing aids, however, the position of the viewer is critical. This type of display only needs a flat screen monitor and a lenticular sheet of vertically arrayed cylindrical lenses. The 3-D effect is produced by projecting the right and left perspective in alternating vertical columns. The lenticular sheet is then produced and laid over the top of the monitor so that the individual, in this case, half-cylindrical lenses of the lenticular sheet are matched to the exact size and spacing of the vertical strips of the left and right perspectives. Thus, if the viewer is positioned at the correct place, a 3-D picture can be viewed. As with the stereoscopic display however, the auto-stereoscopic display has no look around capability and is further limited by the fact that the viewing position is severely restricted.

There are three classes of autostereoscopic displays: re-imaging, volumetric, and parallax. Re-imaging displays project an existing three-dimensional object to a new location or depth. Volumetric displays illuminate points in a spatial volume. Parallax displays emit directionally-varying image information into the viewing zone. Parallax displays are the most common autostereoscopic displays and are most compatible with computer graphics.[4]

The true 3-D display may use the principle of holography to produce a 3-D image. A hologram is a 2-D recording of a 2-D interference pattern of two or more coherent light sources. Such an interference pattern is a 2-D intensity function and may, in principal, be written on a 2-D recording medium whose response is a function of intensity (e.g. photographic film, charge pattern in a photorefractive medium) or of phase (liquid crystal medium). Usually there is the reference source and the object source, the beam reflected off the object of the hologram. To produce an electronic 3-D display based on holography one needs a spatial light modulator (SLM) and a reference beam. The SLM is used to reproduce the 2-D interference intensity pattern of the hologram and then the reference beam is either shined through it or reflected off it depending on how the SLM modulates light. The interference pattern can either be generated by using a digital camera, CCD, or by producing the pattern on the computer, computer generated hologram (CGH). The true 3-D display offers the most potential. It can produce look around objects and eventually with the increase of technology in certain areas, real time 3-D TV.

3. COMPETING TECHNOLOGIES FOR SLM

At present there are three technologies that have been used as SLM: acousto-optic modulators (AOM) cells, liquid crystal displays (LCD) with polarizer, and digital micromirror device (DMD).

3.1 Acousto-optic modulator (AOM) cells

Acousto-optic modulator cells may be made of tellurium dioxide.[2] In 3-D mode the digital signal is transferred into high frequency signal that is propagated in the AOM as a compression sound wave that modulates the refractive index. The current holovideo system as designed by MIT uses what is called the "scophony" approach. "The scophony geometry exploits the fact that only a small part of a hologram needs to be illuminated at any one moment as long as two conditions are met: (1) all sub-holograms comprising the overall hologram must be illuminated during the image latency time (integration time) of the human eye; (2) the instantaneously illuminated sub-hologram must be large enough so that the limit set by diffraction allows a resolution that is acceptable for the image. A typical AOM … operated in the slow shear mode dynamically modulates a beam of light with approximately 2000 collinear samples at a given moment. This pattern scrolls across the aperture of the modulator at the speed of sound (617 m/s). In the scophony approach, a horizontally scanning mirror is used to compensate for the rapid propagation of the modulating acoustic signal within the AOM, and to provide a means of spatial multiplexing. In this way, the image of the AOM is virtually scanned to produce a full 32-KB holo-line. A vertically scanning galvanometric mirror provides the vertical positioning of each holo-line." [2] The MIT display is shown in Figure 2 below.

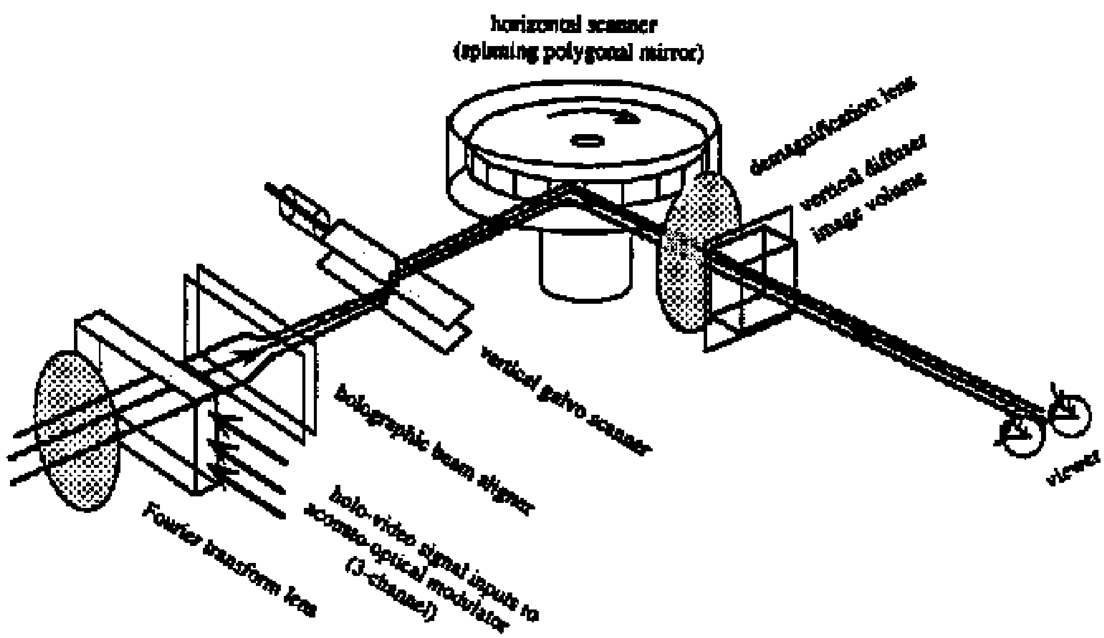

Figure 2. Three Channel AOM.[2]

There are two main draw backs to this system. First, due to the fact that the CGH is digital it must be converted into a analog signal before it can be used by the AOM. Second, there is a need for a complicated scanner mechanism to slow and capture the individual holo-lines and then project them to the corresponding spot in the horizontal and vertical plane.

3.2 Liquid-crystal display cells (LCD)

Liquid crystals consist of "elongated molecules held together at their ends by dipolar forces."[3] The alignment of one crystal is affected by the alignments of the other crystals around it, "cooperative alignment". Liquid crystals also display another characteristic that is important to LCD's. They will, under the influence of an electric field, twist or rotate with respect to the strength of the electric field. Thus LCD's use this principle to change the polarity of the light as it passes through. With the aid of a pair of polarizing lenses each pixel can be made to pass or shut out light.

To produce a 3-D display the CGH interference pattern is input pixel by pixel into the LCD. A collimated coherent beam is then shined through it and a 3-D image is produced. A proposed schematic is shown in Figure 3 below.

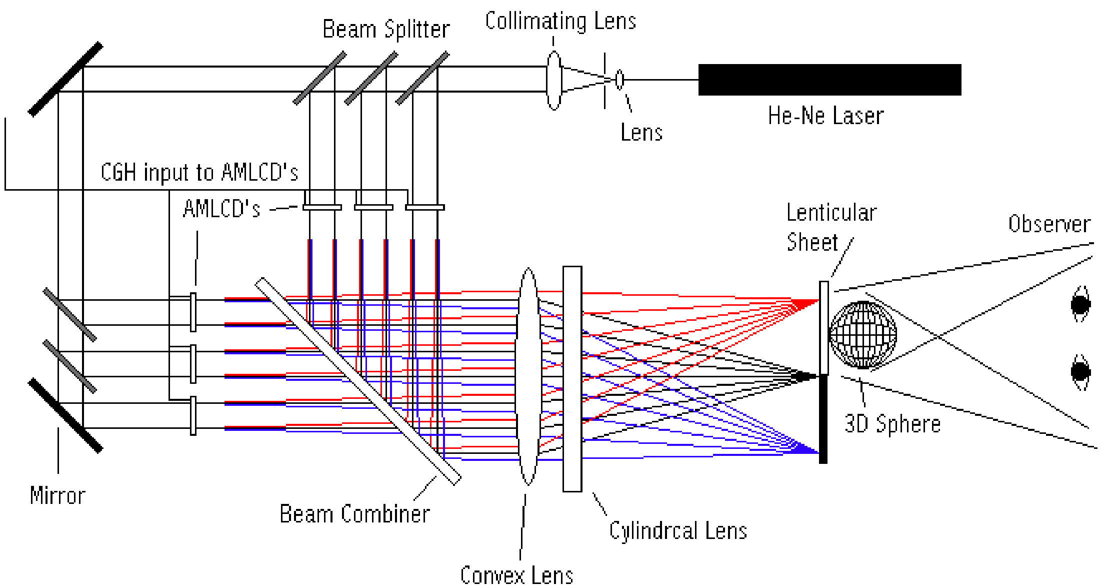

Figure 3. Tiled LCD approach.

In this design many LCD's are tiled together optically to produce better resolution in the horizontal plane. Most LCD's have a 4 by 3 aspect ratio and therefore will produce a flat almost 2-D image. In order to produce a 3-D image with good depth cues one needs resolution in the horizontal plane of several thousand pixels (Kpixels). Such LCD's with Kpixels per line are just now becoming available. Tiling is no longer the only method available to produce good quality 3-D images: special miniature devices based on miniature displays can now be designed (e.g. 10 lines by 1024 pixels per line).

3.3 Digital micromirror device (DMD)

The digital micromirror device (Texas Instruments, Inc.'s DMD™) might be considered as a spatial light modulator for holographic applications. Compensation for the particular attributes of DMD imaging has allowed the creation of full-color holographic stereograms of high image quality. A DMD consists of arrayed mirror elements that are electrostatically depressed or tilted to modulate the light shining on them.[1] The higher throughput and improved image makes the DMD an ideal spatial light modulator for holography. At first glance, the moving-mirror structure of the DMD would seem to preclude its use for holographic recording, however, early tests have demonstrated the usefulness of the device, leading to more analytical testing to compare the optical qualities of holograms made with DMDs to those made with LCDs. The DMD was proven to be superior to the LCD from a number of points of view.[6,7,8,9]

4. COCKPIT INTEGRATION

Right now the technology is not mature enough to allow a 3-D display prototype to be placed in the cockpit of todays research cockpits, let alone fighter aircraft cockpits. The options that we feel have the most potential and are ripe for laboratory exploration all use SLMs to produce a 3-D image of the threat environment. When the demand is great enough manufactures will produce LCD's that are many Kpixels in length and only a few Kpixels high; a volumetric 3-D effort at Laser Power Corporation also needs such a device. Such special SLM electronic display components will give rise to 3-D entertainment industry/TV and will carry over to the . Figures 4 and 5 below show possible ways that 3-D displays might be implemented in research cockpits to explore the potential and gauge the value of the true-3D approach

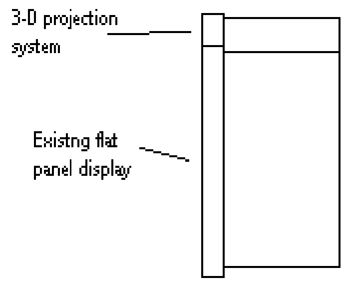

Figure 4. Possible ways that 3-D displays will be implemented in cockpits of the future—bezel mount as a small, auxillary/supplemenal display to an otherwise undisturbed 2-D display instrument panel.

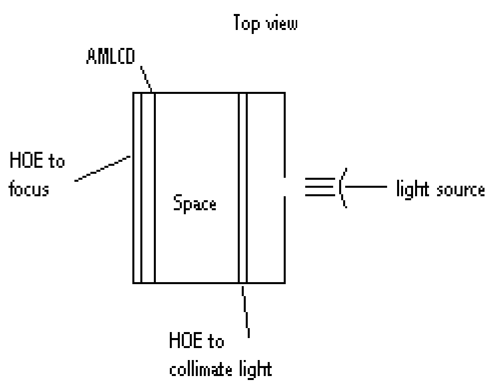

Figure 5. Possible ways that 3-D displays will be implemented in cockpits of the future—full screen 3-D as a replacement for a large 2-D instrument panel display.

5. CONCLUSIONS

There is a need for 3-D threat displays in cockpits. True 3D displays will help the pilot return safety by providing an interrupt to draw the pilots attention to imminent dangers. The best way to implement this is by using AOMs or AMLCDs which can eventually be fitted into the bezel area of existing flat panel displays. The accelerating advancement in computer technology has made the requisite ultra-high speed calculations feasible; thus, consideration should be given to computational holography as a means to pre-generate the 2-D holographic interference functions for 3-D symbol sets. Such pre-computed 3-D icons are then stored in a look up table for use in addressing a true-3D display to depict the necessary object at key times to the pilot to increase situation awareness (SA). The holograms can (1) at the edge of a normal 2-D display in its bezel area; (2) overlayed but "see-through", i.e. superimposed over the normal 2-D displays in the instrument panel, or (3) shown as projected on an area in front of the display as shown in Figure 1. The technology is mature enough to explore fabrication of option (1) now followed by human factors evaluation in a research cockpit.

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