EMBEDDED TRAINING DISPLAY TECHNOLOGY FOR THE ARMY'S FUTURE COMBAT VEHICLES

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ABSTRACT

This paper describes an innovative solution for a low cost, compact, lightweight (i.e. <500g), see-through, deployable head-mounted projection display (HMPD) system for embedded training simulation of out-the-window (OTW) scenes for Future Combat System ground vehicles. A unique capability is that virtual images are visible only when the user is looking at strategically located screens that simulate windows in the real environment. The display is inherently see-through with the physical surroundings visible through the display optics. This provides users with unencumbered access to the vehicle's controls while viewing the simulated OTW scene. In this paper we shall detail the underlying principle of the display, its optical design and assessment, and show an early integration of the optics in a HMPD prototype for demonstration.

1. OBJECTIVE & BACKGROUND

The U.S. Army is embarking in a major revolutionary transformation that transcends the whole Department and will change the way it conducts its future mission and business. The Army's Objective Force captures this transformation (U.S. Army, 2002). When thinking about the Objective Force, one must not think of it only in terms of its material components (Roos, 2002). Objective Force is a synonymous term for the Army of the future. The Objective Force is holistic given that it actually stretches not only from space to mud but also from factory to foxhole. Furthermore, it is characterized by an integrated Joint, Interagency, and Multinational Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance architecture. Finally, it is strategically and operationally responsive. It can deploy a brigade-size Unit of Action in 96 hours, a division-sized Unit of Employment in 120 hours and 5 in 30 days, using a mix of air, sea, and land movement and pre-positioned equipment. The major piece of the Objective Force is the Future Combat System (FCS), which will consist of both manned and unmanned ground platforms, unmanned aerial vehicles, distributed sensors, and a variety of fire systems. The plan is to replace existing legacy units with FCS equipped units, where rapid deployment is essential.

The Objective Force transformation emphasizes embedded training capabilities into actual tactical systems. Embedded training provides a full task framework for the unit to conduct planning, training and rehearsals, anytime and anywhere (Hart, Green, Dolezal, 2002). The currently fielded Army training devices are limited to appended systems, not truly embedded into the platform. Of particular concern is the ability to address the out-the-window simulation of the virtual environment on the real platform. In a partnership with the ODA Laboratory (http//odalab.creol.ucf.edu) at the University of Central Florida, NVIS Inc. is developing an FCS embedded display system, utilizing microdisplays combined with custom designed projection optics in a head-mounted configuration.

In this paper, we shall report on the design of innovative lightweight optics that projects a 15mm (i.e. 0.6 inches) diagonal Organic Light Emitting Diode (OLED) 800x600 color pixels microdisplay into a 41 degrees diagonal field of view (FOV), all within 8g

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optics per eye. We shall also discuss the associated optomechanics conceived to package the assembly in an ultra compact design. The technical specifications of the system are shown in Table 1.

Table 1. Display Specifications

ELECTRONICS	
Display Technology	OLED
Active area	12 mm x 9 mm (diagonal 15 mm)
Video format	852 (x3) x 600 pixels 60 Hz
Video Input	VESA compatible analog, R, G, B
Color	Full
Serial link	2-wire
OPTICAL	
EPD (Exit Pupil Diameter)	12 mm
Eye Relief	> 30 mm (easily accommodates eye glasses)
FOV (Field of View)	33° (Horizontal) 25° (Vertical) 41° (Diagonal)
Stereoscopic Capability	Yes
Projected Image Plane Distance	1.5 m
MECHANICAL	
Interpupillary adjustment	Independent left and right, 53 mm to 73 mm
Up-Down adjustment	> ±10mm

2. RESULTS

2.1 OLED Microdisplays and Associated Electronics

The OLED kit used in developing the prototype is available from eMagin Corporation. A binocular version, part number EMA-100136-052, SVGA PC Interface Kit, is shown in Fig. 1. The kit contains two microdisplays on a single cable assembly, the main cable from the PC interface box to the microdisplays. A USB cable is included that can supply power to the displays from the USB port a computer.

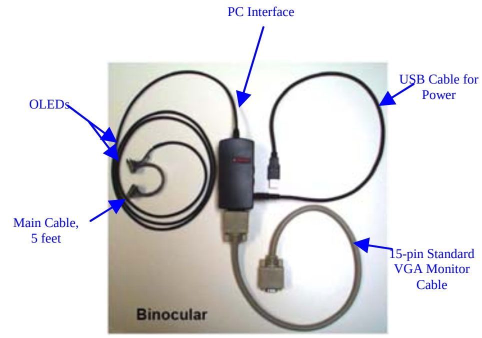


Fig. 1. SVGA PC interface kit from eMagin

2.2 Overall Optical Layout

Head-mounted projection optics as opposed to eyepiece design has emerged as a new paradigm to design HMDs (Fisher, 1996; Arrington, Geri, 2000; Hua, Girardot, Gao & Rolland, 2000; Rolland, Biocca, Hua, Ha, 2004). In order to provide images to the eyes of the user, yet maximize light efficiency throughput, retro-reflective optical screens are utilized instead of conventional diffusing projection screens. The use of such optical material is critical to enabling the design of head-mounted miniature projection systems with sufficient light throughput. As shown in Fig. 2 where the system for one eye is presented, a microdisplay located beyond the focal point of the projection lens is used to display a computer-generated image. Through the projection optics, an image is formed. A beamsplitter, placed after the projection lens at 45 degrees with respect to the optical axis, bends the rays at 90 degrees away from the eyes and towards the optical screens strategically placed in the environment. Such geometry creates the potential to open virtual windows onto the user-surrounding environment, once imagery falls upon the screens. In enclosed, spatially tight environments such as aerial or ground vehicles (e.g. cockpits and tanks), the retro-reflective screens are purposely located at about 1.5 meter from the user. Such placement approximates the distance of the user from the vehicle walls. Importantly, the screens are deformable and do not require being placed flat in the environment. Bending of the material does not induce optical distortion because the screens are made of microoptics structures such as optical beads or corner cubes of about 100 µm in size each.

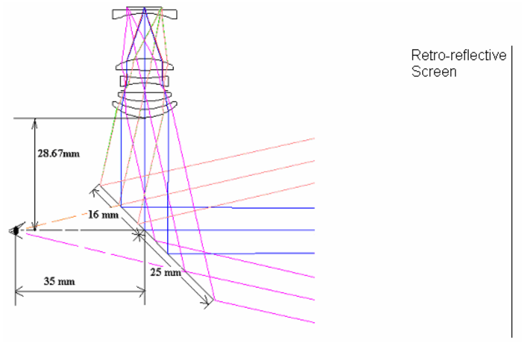


Fig. 2. Optics Layout

Therefore, the screens can be located quickly with no required placement calibration to conform to the environmental shape. Because of the optical characteristics of retro-reflective materials, the rays, to a first order approximation, are reflected back onto themselves in the opposite direction upon hitting the material surface, which allows the light to reach the users eyes. In practice, light is diffracted off the microstructures and optimized relative placement of the projected images with respect to the screens will minimize diffraction blur of the images. A user can thus perceive the stereoscopic images from the exit pupils of the overall optics assembly (i.e. projection optics together with the beamsplitter), which are optically co-located with the users eyes. The aperture stop of the projection optics alone however is located within the projection optics, which accounts for being able to design large FOV optics without a need to scale the projection optics up linearly in size and cubically in weight. Thus, such optical design choice allows scalability of the head-mounted projector in FOV without scalability of the optics, thus leading to overall extremely compact designs across a large range of FOVs.

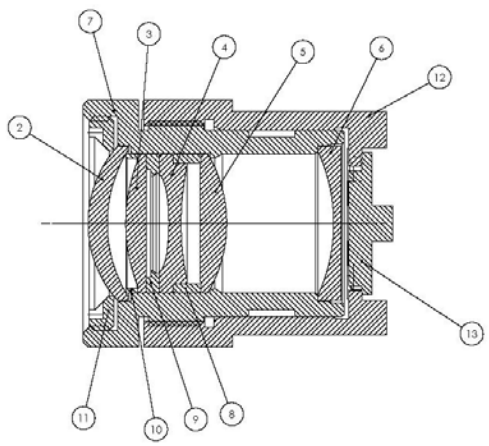
2.3 Optical Design

A key component to designing lightweight, compact, and high-quality optics for HMDs lies in the specifics of the microdisplay, especially its physical size and whether it is self-emitting or requires additional illumination optics. If illumination optics is required, schemes for compact illumination are an additional challenge to the design. The larger the microdisplay, the easier is the optical design for a given FOV. However, compactness can be compromised for the larger size microdisplays exceeding 1” diagonal. Furthermore, the display resolution and color capability will further push high requirements on the optics. The high-resolution 800x600 pixels OLED (i.e. eMagin Corporation) chosen for a prototyping phase of this project is color, thus requiring optical aberration correction across the visible spectrum.

The specific optical design of the projection optics is also shown in Fig. 2. The self-emitting property of the OLED allows for quite a low weight and compact system. The optical design is composed of a main module consisting of four lenses and a field lens close to the microdisplay. The eye relief of the design is 35 mm as shown in Fig. 2, and may be modified for the prototype based on the actual eye-relief required. The eye clearance, accounting for the tilt of the mirror and the possible location of the eyeglasses with respect to the optics, is greater than 26 mm, accommodating most eyeglasses. Advanced optical design and manufacturing capabilities have achieved compact and lightweight optics of 8 grams per eye. Both glass and plastic optics were integrated, as well as the perfect combination of spherical, aspherical and diffractive surfaces to ensure both compactness and high image quality. This design is protected under UCF U.S. patents.

2.4 Optomechanical Design

Fig. 3 shows a detailed sectional view of the monocular optomechanical sub-assembly, complete with all the necessary elements to hold and protect the OLED and the projection optics. This module was made as compact as possible, in close collaboration with the optical designers, and the optics was assembled in the optical shop for optimal alignment of the various components, including the OLED on the optics.



ITEM NO.	QTY.	PART NO.	DESCRIPTION
1	1	rays-hmdrnd2	
2	1	30718-01	LENS 1
3	1	30718-02	LENS 2, DIFFRACTIVE
4	1	30718-03	LENS 3, ASPHERE
5	1	30718-04	LENS 4
6	1	30718-05	LENS 5
7	1	30718-06	LENS MOUNT
8	1	30718-07	SPACER, LENS 3 & 4
9	1	30718-08	SPACER, LENS 2 & 3
10	1	30718-09	SPACER, LENS 1 & 2
11	1	30718-10	RETAINER
12	1	30718-12	MOUNT, MICRO DISPLAY
13	1	30718-13	OLED MICRO DISPLAY

Fig. 3. Monocular lens-mount assembly

A preliminary study of the overall mechanical design approach was completed to decide the head mounting technique. One approach was to mount the display module (i.e. microdisplay & associated optics and optical mechanical housings) onto ITT Industries' off-the-shelf AN/AVS-9 type night vision goggles helmet-mounting plate, which can be easily clipped onto a standard flight helmet. This approach required developing a custom up-down mechanism for proper viewing. The other approach, which we adopted at this phase of prototyping, was to mount the display module onto a head fitting system currently being used by NVIS for its off-the-shelf HMD, nVisor SX.

An exploded view of the overall display mechanical modules is presented in Fig.4, revealing the major components of the monocular sub-assemblies: OLED, optics and mounts. For simplicity, other elements such as retaining rings and spacers are not shown. The beam splitter mirror allows folding of the optical path to direct the light from the OLED onto a retro-reflective screen. This screen then redirects the light back through the mirror to the user's eye.

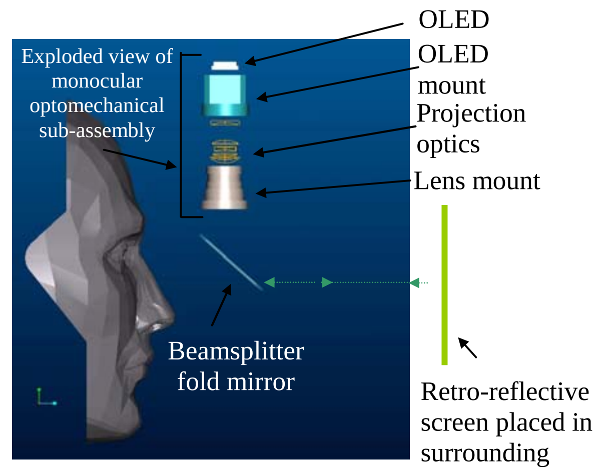
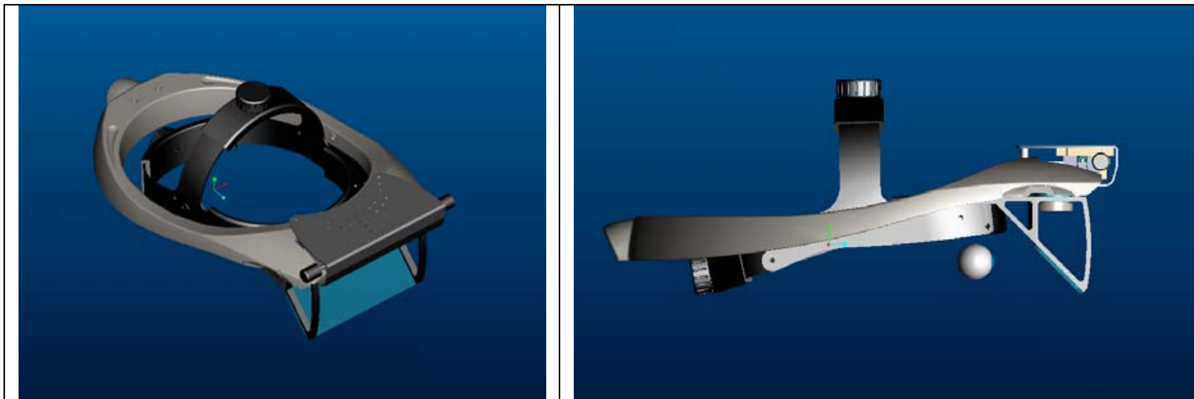


Fig. 4. Overall display exploded optomechanical design

The overall HMPD design is shown in Fig. 5. It consists of a lightweight shell with a comfortable head fitting system and a full range IPD (Interpupillary Distance) mechanism that is currently being used on NVIS nvisor SX HMD product. Integrated with this is the OLED optomechanical assembly including the microdisplays, projection optics, beamsplitter and the necessary structural components like the top cover and frame to hold the assembly in place.



(A) (B)

Fig. 5. (A). OLED HMPD 3D view (B). OLED HMPD side view

CONCLUSION

This work represents an innovative solution for a low-cost embedded display for use in training and simulation in deployed ground and air vehicles in response to an immediate and growing requirement for training systems that allow users to train for hazardous situations within a deployed vehicle. The requirements for embedded display systems call for extremely compact, lightweight devices that can be taken onboard vehicles and quickly assembled and disassembled for training sessions. A deployable embedded display concept for inside vehicles should have the following attributes: excellent overall image quality (brightness, resolution, field-of-view, etc.); low-cost; compact design; lightweight; low power consumption; and easy setup, installation and teardown, thus low calibration requirements. The display proposed precisely addresses these demanding requirements.

Unlike most head-mounted displays, the head-mounted projective display described in this paper is inherently see-through, with the augmented images only appearing where the retro-reflective screen is present. HMDs based on conventional eyepiece-design, even with see-through optics, suffer from poor registration between the out-the-window (OTW) scene and the vehicle interior, resulting in poor cutoff between the OTW scene and the physical surroundings. One of two main advantages of projection based HMDs is the natural cut out of the virtual environment by the real environment where the optical fabric stops. This provides the user with the correct cutoff between the real environment and the OTW scene. All other areas of the physical environment are visible through the display optics, allowing users to operate the vehicle controls that can be instrumented to the deployed image generator. Another advantage of the display is the natural occlusion of virtual objects by the users' hands if users were to extend their hands to grasp a virtual object displayed in front of them in the space created by the fabric. Such scenario could be used to train a soldier in an engineering repair task, which is beyond the scope of out-the-window visualization, but which could constitute an extension of the use of the technology. Such property of occlusion augments the sense of presence of virtual windows, thus potentially increasing the effectiveness in training scenarios. Such hypotheses will be tested for specific tasks in the FCS prototype test-bed. In the expansion of the research where we shall chose to mount the projection optics directly onto standard military headgear, the setup/teardown operations to create a rapidly deployable solution will be further optimized. Coupled with head tracking, the display concept provides an accurate perspective of the OTW scene with correct registration between the OTW scene and the vehicle's interior.

Finally, the current packaging of the optics as part of a stand alone headset demonstrates how miniature head-mounted projectors may be designed for potential use in a variety of 3D visualization tasks including 3D video games, wearable computers, and engineering and scientific visualization to name a few.

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