Application of Augmented Virtuality to Close Air Support JTAC Training

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ABSTRACT

Close Air Support (CAS) and the Joint Terminal Attack Controllers (JTACs) who direct the fires and effects CAS delivers to support ground combat activities, have provided an important capability in both Operation Iraqi Freedom and Operation Enduring Freedom. Maintaining JTAC currency is thus a foundational aspect of Force Preparation; building the next generation of JTACs will help Secure the Future. High cost/large footprint fixed immersive CAS simulators like the Joint Fires & Effects Trainer System CAS Module at Fort Sill provide a verified, validated, and accredited alternative to live controls, but constrained resources, coupled with a significant requirement for qualified personnel, demand an alternative solution. Current head-mounted display (HMD) solutions offer limited simulation options for the tools JTACs normally use in their work: essential aspects of training and qualification. The Army Research Laboratory, Simulation and Training Technology Center (ARL STTC) developed a prototype implementation of Augmented Virtuality (AV) technology which promises to provide an immersive, cognitively challenging JTAC simulation solution offering a full suite of low-cost, JTAC tools as simulated military equipment surrogates. AV is a mixed reality technology which introduces real-world objects into a virtual scenegraph; as contrasted with Augmented Reality (in which synthetic objects are combined with a real world view), the user's principle experience and perception is of the virtual world. This paper will describe the conceptualization and development of this novel, Augmented Virtuality educational tool, including the software development; material fabrication; and hardware development and integration required to address and overcome the design challenges in this approach.

ABOUT THE AUTHORS

James H. Korris, a pioneer of the current trend in game-based simulation for military training, is CEO and President of Creative Technologies Incorporated (CTI). From its establishment in 1999 until October 2006, Korris served as Creative Director of the Institute for Creative Technologies, a University Affiliated Research Center devoted to immersive virtual simulation with principle funding from the U.S. Army at the University of Southern California. CTI team members have produced award-winning simulation applications including a mobile, motion-platform demonstrator for the Army's Future Combat Systems program and trainers for CAS, and Call For Fire (CFF) along with desktop cognitive applications for bilateral negotiations, squad, platoon and company leadership and threat indicator identification. Currently, Korris is leading a CTI effort to develop a next-generation CAS/Call For Fire training capability along with novel mobile platform applications. Korris served as a member of the Naval Research Advisory Committee, the senior scientific advisory group to the Secretary of the Navy, the Chief of Naval Operations, Commandant of the Marine Corps, and the Chief of Naval Research from 2007 until 2011. Korris is a graduate of Yale University (B.A., Economics) and Harvard University (M.B.A.).

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INTRODUCTION

Close Air Support (CAS), air action by fixed or rotary winged aircraft, against hostile targets in close proximity to friendly forces, requires detailed integration of air missions with fires and the movement of forces. CAS is a significant defense capability for the U.S. Indirect fires and effects delivery by U.S. ground forces artillery is a further significant force multiplier. Even in conflict with non-state actors, indirect fire from mortars play an important part as they have in Operation Iraqi Freedom and Operation Enduring Freedom.

As with other defense systems, U.S. Warfighters are squarely at the "center of the formation" for these capabilities. For the Joint Terminal Attack Controllers (JTACs), Joint Forward Observers (JFOs) and Forward Observers (FOs) who direct the application of CAS, CCA and artillery battlefield effects, initial and maintenance (currency) training are of the essence in establishing and maintaining these perishable skills. While the precise application of air-delivered and artillery fires often have a decisive effect on combat engagements, operator error can result in mission failure, unacceptable collateral damage and fratricide. The downside risks are compelling; training is the best remedy.

Good training, however, comes at a price. Live domain exercises are costly and challenging to coordinate, particularly in times of high deployment. While computer-based virtual simulation solutions for artillery CFF have been available for nearly 30 years[1], virtual CAS training tools began appearing only in the last decade[3].

Currently, 30% of the 12 controls required to maintain annual JTAC currency may be performed in the virtual domain.[4] Taking into account the cost of aircraft flight time and maintenance, targets, ordnance and training range usage, savings approaching 30% for the annual training requirement for, potentially, the entire JTAC community, are significant. Moreover, the ability to train under a broad range of environmental conditions,

utilizing a wide assortment of equipment and platforms, extends operator capability, competence and confidence.

CAS/CCA Virtual Simulation

Developing acceptable, versatile, virtual JTAC/JFO training solutions is not without its challenges. There are, for example, three kinds of CAS with differing virtual simulation requirements:

1. Type 1 control is employed when the JTAC visually acquires the attacking aircraft and the target.
2. In Type 2 controls the JTAC is unable either (a) to visually acquire the attacking aircraft at weapons release, (b) cannot visually acquire the target, or (c) the attacking aircraft cannot acquire the target prior to weapons release.
3. In Type 3 CAS, JTACs provide clearance for multiple attacks within a single engagement while either unable to visually acquire the attacking aircraft at weapons release, unable to visually acquire the target, or the attacking aircraft is unable to acquire the target prior to weapons release.

CAS involves a dialog between the observer and the pilot. The observer lays out the geometry of the mission from the initial point, through the attack to egress. The mission data is contained in a nine-line brief, with each line corresponding to different mission data requirements. The plan must take into consideration the disposition of enemy air defense threats, the characteristics of the munitions employed and the location of friendly forces and non-combatants. The observer may use laser tools, artillery or even small arms rounds to mark the target. The mission may require a pilot "talk-on" procedure to pick out the target from visual cues.

As Type 1 CAS requires the observer to visually acquire the ground target along with the aircraft during ingress, the JTAC needs overhead and over-the-shoulder views along with a sightline to the target area

in simulation. With the aircraft or the target out of sight in Type 2 CAS, the observation task is slightly less complex. Type 1 controls will satisfy Type 2 requirements.

Type 3 CAS, which relies on observer situational awareness of enemy movements, has the most modest virtual simulation requirement. In this case, the observer must have accurate information and apply good judgment with respect to the situation in the target area, clearing, for example, an attack aircraft to engage an enemy tank column on the move, out of sight of the observer.

From this, we may conclude that a system capable of simulating Type 1 CAS controls will be adequate for simulating Type 2 CAS and Type 3 CAS as well.

Particularly for Type 1 CAS, the observer needs the ability to visualize the world from the point of view of a rapidly-moving platform in the air at a distance of up to several miles. This ability requires talent and practice; virtual simulation offers the best opportunity for both frequency and variability of rehearsal conditions.

Limitations of Current Systems

While the Joint Forces Command Joint Close Air Support Executive Steering Committee has fully and partially certified a range of systems for training CAS, there are limitations with the options currently available[2]. In particular:

1. CAS domes typically support Type 1 CAS, including the JTAC/JFO tools needed for target identification and designation. These domes, however, generally have a large footprint and come at a high price. As a consequence, the number of dome systems available for training is insufficient to meet the training needs of the entire community. Moreover, as the simulated military equipment, including laser target designators, illuminators, rangefinders, handheld data-entry devices, and small arms, can be quite costly, a full set of tools is generally not available with these systems.
2. Virtual-Reality Head-Mounted Display (VR HMD) systems typically support Type 1 CAS with some caveats. The Inertial Measurement Units (IMUs) integrated in these systems support overhead and peripheral views but, as the user's experience is entirely of the virtual world, there is no opportunity to experience the form, fit and function of JTAC and JFO

tools. When the user selects from a collection of virtual tools, the user's viewport changes to a view corresponding to the tool. Generally, tool functionality is limited. For this reason, current HMD trainers have not been accepted to satisfy controls for a range of military equipment including laser designators.
3. Desktop systems allow the user to alter their point of view and navigate the virtual three-dimensional (3D) space around them by means of human computer interfaces (i.e. keyboard, mouse or joystick). These systems typically have the same limitations as VR HMD systems but offer a less immersive/intuitive experience due to the nature of the display, viz. desktop monitors vs. domes or HMDs. While the field of regard of both approaches may be identical, navigation in an HMD configuration is intuitive: if the user wishes to view the world over his right shoulder, he looks over his right shoulder. In a desktop/monitor configuration, the user has to navigate to this viewpoint using a computer interface.

Augmented Virtuality Approach

The mixed reality spectrum has been described[5] as a reality-virtuality continuum that extends from the real world at one extreme to a completely virtual environment at the other. Between lie at least two categories of mixed reality: Augmented Reality and Augmented Virtuality (AV).

These two categories are similar, being, essentially, mirror images of each other. With augmented reality, the user's principal experience is of the real world with some synthetic objects inserted into the user's field of view. Using an optical or video see-through HMD, the user's position and orientation is tracked with synthetic objects, and the required occlusional algorithms, placing the object correctly in the real world view.

In AV, the user's principal experience is of a synthetic world with voids in the scenegraph allowing the view of static or tracked real world objects to pass through the HMD to the user. This approach is illustrated in Figures 1 through 4. AV, combined with a novel approach to simulated military equipment development, constitutes a fourth variant of CAS, CCA and CFF simulation training.

Figure 1: Real world view of user's desktop with components and surrogates

Figure 2: User's view of virtual world. Note the virtual geometry corresponding to real world surrogates in Figure 1 (binoculars and compasses)
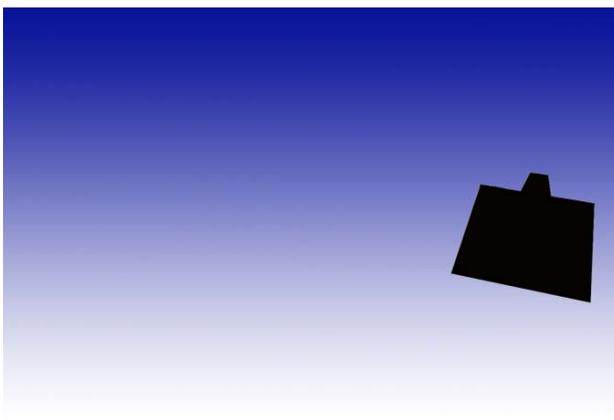

Figure 3: Mask matches geometry of real world component (the map board in Figure 1)

Figure 4: Virtual world with scenegraph void matches geometry of real world component. Component is visible through the void in the HMD's scenegraph (simulated view).

JOINT FIRES and EFFECTS IMPROVEMENTS, CALL FOR FIRE TRAINER-AUGMENTED VIRTUALITY

In 2011, the U.S. Army Research Laboratory's Simulation and Training Technology Center developed an AV solution for CAS, CCA and CFF simulation training: Call For Fire Trainer-Augmented Virtuality (CFFT-AV). The AV approach, it is believed, has the potential to support a dome-like training experience without the facilities requirements or cost of a dome.

A similar approach was employed in the U.S. Army's Aviation Combined Arms Tactical Trainer (AV-CATT) enabling pilots and nonrated crew members to experience simulated rotary flight in an aircraft mockup without an enveloping display to provide out-the-window views.[6]

With Augmented Virtuality, CFFT-AV provides for the integration of some real world user tools, like maps and laptops, which are problematic to simulate. Taking AV-CATT methods a step further to support a more comprehensive complement of JTAC and JFO tools for training, a new kind of training surrogate was conceived and developed.

In dome or large-format display environments, simulated military equipment surrogates are generally derived from real world equipment modified to include micro-display hardware. For example, when the user looks through a surrogate Ground Laser Target Designator II (GLTD II), he sees a subtended rendered view of the virtual world on a micro-display embedded in the system optics. In this way, the user's simulation view matches what a real-world GLTD II user would see.

In CFFT-AV, the team's engineers developed light detection and ranging (LIDAR) point clouds of real-world equipment, subsequently employing a 3D printer to produce low-cost surrogates of the equipment. The knobs and switches required for operation were added along with a microprocessor-based system that sensed button states, transmitting them over Universal Serial Bus (USB) connectivity to the simulation application. The tracked surrogates appear as virtual objects in the user's virtual view (Figure 5).

Figure 5: Virtual objects track real world surrogates

As the surrogate button states are known, the simulation application updates the appearance of the tracked model in the scenegraph to reflect the position and values of the surrogate hardware.

As all surrogates, along with the user's head, are tracked, it is possible to determine when the surrogate comes into close proximity with the user's eyes. At this point, the user's rendered view shifts to a viewport corresponding to the surrogate (Figure 6).

Figure 6: View shifts to surrogate object viewport when object is held in proximity to the user's eyes.

In this respect, the user's experience is similar to the VR HMD systems previously described. However, as the user is holding a physical object with the same detent, rocker, pushbutton and push-wheel switches as the corresponding real-world object, the requirement to provide a training experience that matches the form, fit and function of real-world tools is satisfied. Utilizing this approach, JTAC/JFO tools like the M4 Carbine (used, in some circumstances, to mark targets), were simulated, ostensibly, for the first time in a CAS/CCA/CFF simulator.

In terms of audio, Open Audio Library (OpenAL) was utilized to simulate the user's directional sound field with four satellite speakers positioned at the corners of the CFFT-AV lane and an omnidirectional subwoofer. As the virtual "world" is static in the CFFT-AV configuration, when the user turns, the world's sound remains oriented correctly.

Limitations of the Approach

Key to current AV technology is the user's HMD: an optical or video see-through apparatus with an integrated micro-display or miniature projection system. The video see-through option was discarded early in the research process as this category of HMD typically utilizes super video graphics array (SVGA, 800 X 600 resolution) cameras for video capture (Figure 7). As a result, the visual acuity required for users to resolve, for example, the fine print on a map or eight point type on a monitor was not present. While substituting compact higher resolution cameras is an option, the limiting factor on these systems is the optical component as opposed to the sensor. In this respect, high-resolution images produced on mobile phones lack sharp detail notwithstanding the pixel count
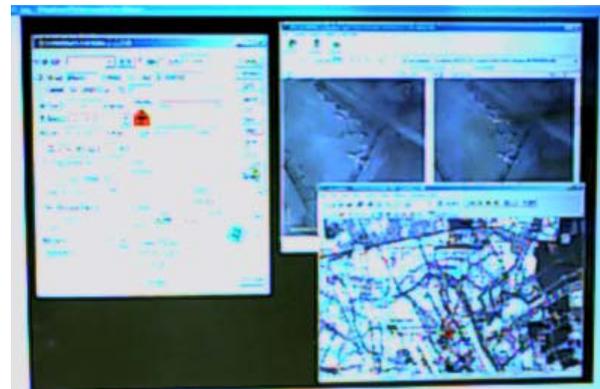

Figure 7: Laptop screen viewed with a commodity SVGA camera. Representative of video see-through HMDs.

Optical see-through systems, in theory, do not suffer from these video capture limitations, but there is, however, a restriction regarding the ambient light in the simulation environment.

At the heart of current optical see-through systems is what amounts to a one-way mirror such as are employed in police lineups to protect the identity of witnesses. A thin coating on the mirror reflects light, provided the light level on the reflecting side exceeds the light level on the see-through side. Absent this differential, each side has an attenuated view. The one-way mirror in a typical optical see-through HMD attenuates the real-world view by roughly 50%.

The one-way reflectance allows the user to view a micro-display. In scenegraph voids (regions rendered as 100% black), the real world may be seen. If, however, the real-world luminance is higher than the display, the real-world will be seen through the HMD with a ghosted overlay of the scenegraph.

Figure 8 plots luminance, measured in candela per square meter (cd/m^2 or nits) against cathode current measured in milliamps (mA) for the eMagine organic light-emitting diode microdisplay, model OLED-XL, a commonly-used component in optical see-through HMDs. The higher the current, the brighter the scene.
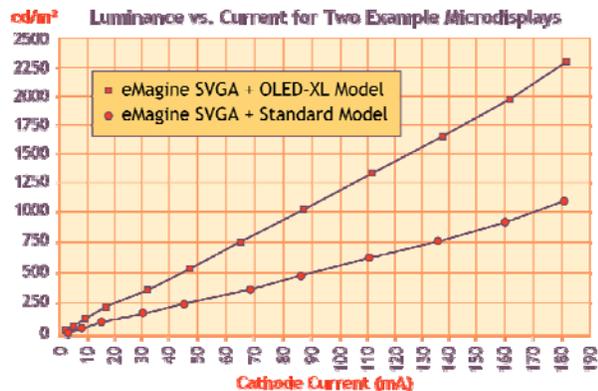

Figure 8: Luminance vs. current, eMagin OLED-XL microdisplays[7]

With a current of zero (corresponding to 100% black in the scenegraph), luminance is zero and optical see-through transmission is complete. As current increases, luminance grows in roughly linear fashion to a peak of 2,250 cd/m^2.

Against these values, real-world light sources must be considered. Figure 9 charts familiar light sources and their luminance.
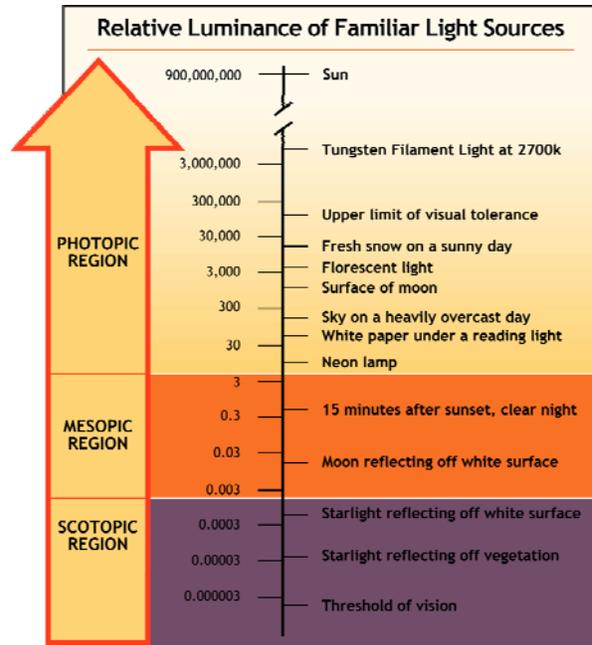

Figure 9: Relative luminance of familiar light sources[6]

An optical see-through OLED-based HMD with these characteristics must operate at the lower end of the photopic range to produce the proper required visual effect. Particular care must be taken with the darker regions of the scenegraph where values in the 150 nit range limit the allowable ambient light.

Add to this the luminance of real-world objects in the simulator environment. Laptops, for example, have luminance typically in the 150-300 nit range. This will easily overpower darker parts of the CFFT-AV scenegraph, particularly in night scenes. Reducing luminance of the laptop, however, must be considered in terms of the roughly 50% transmissibility of the one-way mirror which effectively attenuates incoming luminance by half.

On balance, laptop screens used in the CFFT-AV simulation environment need to be seen. Used to provide targeting data or simulated unmanned aerial system video feeds, the user must see what is on the screen in fine detail. For this reason, voids in the scenegraph tracked with the laptop or other digital display devices eliminate virtual scene ghosting that might occur from a bright laptop screen. Light spill from laptop screens or map lights must be carefully controlled to avoid washing out the virtual scene in other regions, however.

To provide the optimal setting for the AV effect, the CFFT-AV team developed a transportable cube-shaped environment (Figure 10) designed to reduce ambient light and acoustical bleed-through to adjacent training

lanes. The cube, made of extruded aluminum members and Sintra® panels, permits the flow of air for ventilation while allowing for overhead fire suppression measures.

Figure 10: CFFT-AV training environment designed to control ambient lighting and minimize acoustical bleed-through

User's Perception of Hand Position

Proprioception, the ability to know one's body in space, gives users an accurate sense of their hands' positions without visual input. An unimpaired person can, for example, touch his nose with either hand if his eyes are closed. On this basis, the CFFT-AV team reasoned that it would not be necessary to track and display, either virtually or visually, the user's hand in order to find and manipulate system surrogates.

As 3D geometries corresponding to the surrogates are visible in the scenegraph, the user needs to correlate proprioceptive knowledge of his hand with the position of virtual surrogates. This, the team discovered, was easy, with a modest amount of "searching around" to locate the device. Figure 11 shows the results of a test in which users were asked to find surrogates and real-world objects on the simulator desktop: the user's workspace.[*]

Virtual objects required, on average, 13% more time to locate than real-world surrogates viewed without an HMD. However, as the mean search time for virtual surrogates was 2.6 seconds, it was determined that, on average, the additional 0.3 seconds spent searching for surrogate tools would not significantly impact the usability of the system.

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[*] Five test volunteers were shown four real world surrogates and told: "This is a test to measure reaction time in picking up real world objects compared to picking up virtual objects. I'm going to call out the names of four objects: binoculars, little compass, big compass, and map. When I announce the object, reach for that object, pick it up, and hold it in front of you. This isn't a race for best time, so just do what comes naturally." After performing the exercise with real world surrogates, the volunteers wore the HMD and repeated the exercise.

Real Objects							Virtual Objects							Comparison	
	Test Subject							Test Subject						Difference (Virtual - Real)	Difference as % of Real
	1	2	3	4	5	Overall Average		1	2	3	4	5	Overall Average		
Big Compass	2.4	2.6	1.6	3.1	2.2		Big Compass	2.6	2.5	2.5	2.9	2.2			
Big Compass	2.0	2.8	1.7	2.1	2.4		Big Compass	3.5	2.5	2.3	3.1	2.2			
Big Compass	2.2	2.8	1.9	2.0	2.5		Big Compass	1.7	2.6	1.8	3.4	2.1			
Big Compass	1.8	3.0	1.8	2.0	2.4		Big Compass	2.0	2.2	2.0	2.8	2.7			
Big Compass	2.4	2.9	1.9	2.3	2.5		Big Compass	2.0	2.7	2.0	2.5	3.1			
Average	2.2	2.8	1.8	2.3	2.4	2.3		2.4	2.5	2.1	2.9	2.5	2.5	0.2	8%
Binoculars	2.0	3.1	2.1	3.8	1.7		Binoculars	2.2	3.0	2.3	1.9	2.5			
Binoculars	2.5	2.8	1.8	2.4	2.3		Binoculars	1.7	2.6	2.3	2.1	2.2			
Binoculars	1.9	2.9	1.7	2.2	2.7		Binoculars	2.0	3.1	2.5	3.3	2.8			
Binoculars	1.8	2.9	1.7	2.2	2.5		Binoculars	2.7	2.9	2.4	3.2	2.9			
Binoculars	1.5	3.1	1.8	2.0	3.2		Binoculars	2.6	2.6	2.3	3.0	3.0			
Average	1.9	3.0	1.8	2.5	2.5	2.3		2.2	2.8	2.4	2.7	2.7	2.6	0.2	9%
Little Compass	4.6	2.4	1.4	2.1	2.3		Little Compass	4.2	2.8	2.9	3.6	2.0			
Little Compass	1.3	2.3	1.7	2.3	2.1		Little Compass	3.8	2.6	2.0	3.0	2.9			
Little Compass	1.3	2.8	1.7	2.7	2.7		Little Compass	2.1	2.8	2.0	2.8	2.5			
Little Compass	1.8	3.2	1.3	2.3	2.3		Little Compass	2.0	3.1	2.0	2.9	3.2			
Little Compass	2.2	3.1	1.8	2.5	3.0		Little Compass	2.1	2.7	1.8	2.9	2.9			
Average	2.2	2.8	1.6	2.4	2.5	2.3		2.8	2.8	2.1	3.0	2.7	2.7	0.4	18%
Map	2.0	2.9	1.7	2.5	3.4		Map	2.8	2.6	2.3	3.2	2.6			
Map	2.0	3.0	2.1	2.4	3.5		Map	3.7	3.0	2.2	2.7	2.9			
Map	1.6	3.4	2.1	2.4	2.6		Map	4.1	2.8	2.1	1.8	2.7			
Map	1.7	2.8	2.1	2.4	2.3		Map	2.8	2.6	2.3	2.1	3.1			
Map	1.8	3.0	1.7	2.0	3.2		Map	2.2	3.3	2.4	2.5	2.7			
Average	1.8	3.0	1.9	2.3	3.0	2.4		3.1	2.9	2.3	2.5	2.8	2.7	0.3	11%
OVERALL AVERAGE	2.0	2.9	1.8	2.4	2.6	2.3	OVERALL AVERAGE	2.6	2.8	2.2	2.8	2.7	2.6	0.3	13%

Figure 11: Search time for virtual surrogates on the user desktop.

Head Mounted Displays

The CFFT-AV development team assessed two HMD design approaches for the system. Both had similar characteristics, viz. angular resolution measured in arc minutes per pixel, see-through transmissibility, angular field-of-view, weight, eye relief, inter-pupillary distance adjustment, and micro-display luminance. They differed, however, in the design of the optical block that allows views of the real world.

In the first approach, an asymmetric, anamorphic asphere prism is employed to direct the overhead-mounted micro-display to the user (Figure 12). A compensating optic is inserted between the prism and the real world.
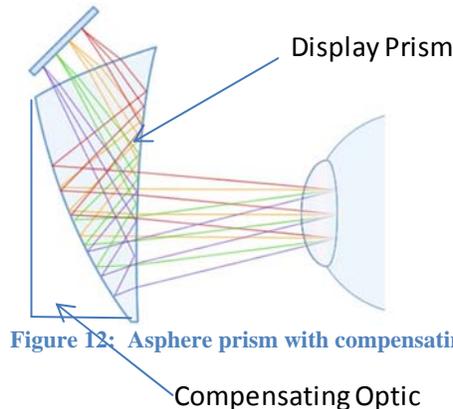

Display Prism

Figure 12: Asphere prism with compensating optic.

Compensating Optic

In the second approach, a rectangular prism is employed with a concave mirror reflecting the overhead microdisplay into the semi-transparent beamsplitter (Figure 13).
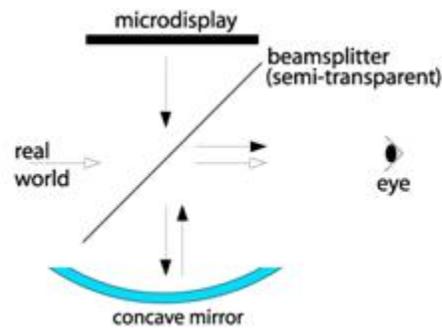

Figure 13: Rectangular prism with concave mirror.

While, theoretically, both design approaches can yield equivalent results, i.e. an undistorted view of the micro-display superimposed over a view of the real world as might be seen through an optical flat, in practice, the first method presents non-trivial design challenges. The optical see-through can be compromised by minor design flaws in prism design and lens quality. Since aberrations are typically not symmetrical about the optical/view axis, compensation over a reasonable pupil size is difficult, as systems of this type tend to have a relatively small sweet spot in the image.

As a practical matter, in the world of military simulation systems and the displays that support them, limited production runs are the norm. While an asphere prism for an optical see-through system may be perfected iteratively through successive designs, component manufacturers are reluctant to absorb the cost of this development process because of the limited production volumes customers require over which to amortize the cost of redesign, quoted in the $250,000 range for each iteration. As there is, to date, no "must-have" consumer product requiring high quality augmented reality displays, there is no alternative market from which to recoup non-recurring engineering investments.

In the case of CFFT-AV development, the asphere prism design initially did not enable users with 20/20 vision to read past the second line (80 inches) of the Snellen Near Vision Eye Chart (Figure 14) viewed at a distance of 18 inches. The HMD designer/integrator then replaced the as-built corrector lens with a more powerful 2.5 diopter optic. This enabled 20/20 vision users to resolve to the 24 inch line in the chart (third from the bottom). However, as noted previously, the display sweet spot was, perforce, quite small: a limitation that was exacerbated by the choice of display mount. For its initial configuration, this display was designed to fit an Aviatior's Night Vision Imaging System ANVIS night vision goggle mount that connects by detent to a standard issue U.S. Army Advanced Combat Helmet (ACH). Finding a suitable fit and placement for the display with the ACH in this configuration proved challenging. It was determined, given the variability of the user population, that a headband-type mount would require less setup and adjustment time when systems were put into use, thus diminishing preparation time in favor of time available for training.

The rectangular prism HMD variant was delivered with a headband mount configuration. That, coupled with a successful concave mirror installation, provided a real-world image that enabled 20/20 vision users to read the 20 inch line (second from the bottom) with consistent accuracy and minimal adjustment time. This was deemed the optimal configuration for the CFFT-AV system.
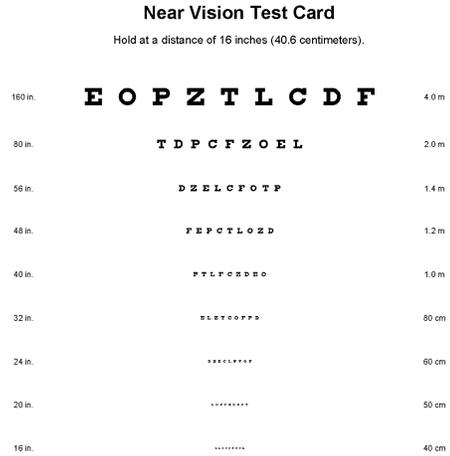

Figure 14: Snellen Near Vision Test Card (not full size)

Cable Management

Given the high degree of accuracy required for component tracking over the confined space of the system footprint, COTS Intersense IS 900 components were selected. The large number of surrogate and real world objects that had to be tracked, the limitation of wireless tracking with respect to total tracking capacity, decremented accuracy, increased cost and, downstream, the added burden in day-to-day use to maintain charges on wireless component batteries, together dictated a wired solution. This then gave rise to a cable management challenge as up to six items might be utilized in the user's workspace in a single session.

A number of options were considered including physical cable retractors such as are employed in consumer electronics retailing for theft deterrence. Ultimately, the team added a guide in the form of surrogate device outlines in the user's workspace (see Figure 15).

Figure 15: Screen shot of user's virtual workspace with surrogate outlines.

With the guidelines, users were able to return surrogates to their original positions, thus avoiding tangled cables

Stereoscopy

While the HMDs integrated in the CFFT-AV system are binocular, the initial design was monoscopic: identical video signals were delivered to the displays in each eye. However, with the user's need to view real-world objects through voids in the scenegraph, alignment of the voids relative to the object became an issue.

In Figures 16A and 16B, a user looks through a monoscopic binocular display. As the scenegraph voids are in identical positions in each eye, eyes positioned on the voids serve to align ocular parallax for distant real-world objects as the sight lines through the voids are near-parallel. On a nearby object, however, with the voids in the same lateral position in the monoscopic scenegraph, as the user's eyes attempt to align on a real-world object at arm's length through the scenegraph voids, the user will "see double". As the user's eyes adjust for parallax, his view of the scenegraph will crisscross (Figure 14A). Alternatively, if the user tries to align visually on the scenegraph voids, (Figure 14B), the real-world object will appear double as the vision for both eyes is combined.

Figure 16A: User aligns on voids in the scenegraph; disparity in retinal images results in "seeing double" (simulated view)

Figure 16B: User aligns on real world object. Misalignment of scenegraph voids results in a portion of the scenegraph obscuring the object in one eye. (simulated view)

While there is some debate over the variability in adult interpupilary distance (IPD)[8], 63 mm is a defensible mean. With a stereoscopic view and simulation viewpoints set 63mm apart, visual artifacts are eliminated (Figure 17). More research is required to determine whether users at the limits of the typical adult range (i.e. 50-75 mm) will require an IPD adjustment in the simulation application to refine the distance between simulation viewpoints to avoid distracting parallax-related visual artifacts.

A further benefit inures from a stereoscopic implementation: objects in the scenegraph have the illusion of depth, making them appear more realistic. As real-world objects seen through voids in the scenegraph have depth arising naturally from the user's parallax viewpoints, stereoscopy supports a more seamless and immersive experience in CFFT-AV.
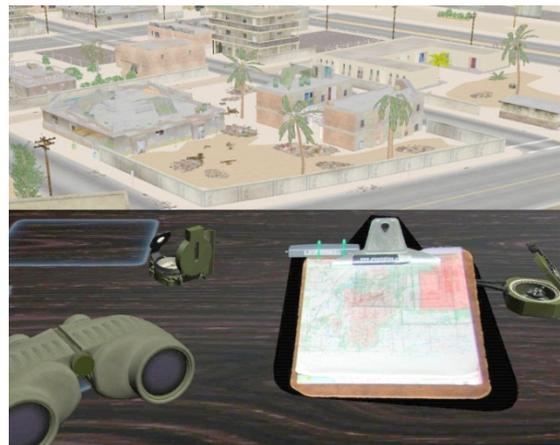

Figure 17: Stereoscopic display allows user to align on voids and objects without artifacts (simulated view)

CONCLUSION

To the authors' knowledge, CFFT-AV is one of the first augmented virtuality training implementations attempted by the U.S. Department of Defense. The concepts in CFFT-AV appear to have been validated in terms of the technology that the system demonstrates, offering a superset of functionality found in dome simulators at a reduced cost and footprint requirement. The approach is not without limitations (e.g. the need for controlled lighting conditions, tethered surrogates etc.) but offers advantages over established alternatives. Ultimately, the user community will determine if CFFT-AV is a useful, practical and valid solution.

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REFERENCES

1. Stevens, CPT L. L. (1983). One Mean Screen, *Field Artillery Journal, July-August,* 26-29
2. United States Joint Forces Command, Standardization Team/Joint Terminal Attack Controller Simulator Accreditation Team, 30 May 2007, 13 August 2008, 10 December 2008, 1 March 2009, 18 November 2009, 10 June 2010, 23 July 2010, *Joint Close Air Support Simulator Evaluation Reports*
3. Paul, C.; Thie, Harry; Reardon, E; Prine, D. W. (2006). Implementing and Evaluating an Innovative Approach to Simulation Training Acquisitions, *RAND National Defense Research Institute* pg 28-31
4. *JCAS AP MOA 2004-01 Joint Terminal Attack Controller (JTAC) (Ground)* 1 Sept 2010
5. Milgram, P; Takemura, H.; Utsumi, A.; & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum *SPIE – the International Society for Optical Engineering*, *Telemanipulator and Telepresence Technologies, vol. 2351,* 282-292
6. Dougherty, MAJ James F. (2011). The Aviation Combined Arms Tactical Trainer: Update, *Army Aviation, July 31, 2011,* 24-26
7. eMagine Corporation, http://www.emagin.com/oled-microdisplays/
8. Dodgson, N.A. 2004, Variation and Extrema of Human Interpupillary Distance, *Proc. SPIE* vol. 5291, "Stereoscopic Displays and Applications XV"