Mixed Reality: A Tool for Integrating Live, Virtual & Constructive Domains to Support Training Transformation

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ABSTRACT (1894):

The art and science of simulation, interactive entertainment and experiential learning have converged to provide new capabilities that have the potential to melt the boundaries between the training domains of virtual, live and constructive simulation and to create the next generation of Mixed Reality. Pulling from the foundational research of augmented reality, Mixed Reality has been able to tap the latest science and technology to spark the imagination and emotions. Mixed Reality may be the missing component needed to meet the challenge of transforming combined/joint training into the future. Once fully developed and implemented, Mixed Reality must create a training environment that combines the visceral nature of live training, with the dynamic and non-linear characteristics of virtual and constructive simulation.

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INTRODUCTION

The purpose of this paper is to introduce the Trainer and the Warfighter to Mixed Reality and the possibilities for increasing the realism and effectiveness of live training, for the dismounted (as well as mounted) soldier, while merging with the virtual and constructive domains. Although the main recipient of mixed reality--as discussed in this paper—focuses on the Army's dismounted soldier, mixed reality is versatile enough to address training and operational needs across the military services.

First training transformation will be discussed, then an overview of how the integration of the live, virtual and constructive simulation domains would support transformation. Next, augmented and mixed reality will be presented, explained and considered as a promising technology for implementing the integration of the live, virtual and constructive domains. The technical challenges that lie ahead will be highlighted. Lastly, recommendations are suggested for ensuring that DoD keeps a focus on the development of augmented and mixed reality as a viable technology for enhancing military training.

TRAINING TRANSFORMATION

The number 2 priority on DoD's Top 10 Priority List (behind "Successfully pursue the global war on terrorism") is to ***Strengthen combined/joint warfighting capabilities***.[1] This includes exercises and training. Strong joint experimentation and joint training programs amplify the Joint Forces Command's (JFCOM) dedication to this important priority. Joint integration, experimentation and training means that there needs to be a distributed capability for facilitating these areas; particularly the overlap between training and mission rehearsal. In 2002, U.S. Secretary of Defense Donald Rumsfeld approved the strategic blueprint for the Pentagon's Training Transformation program. The burgeoning training transformation initiative includes the establishment of a Joint National Training Capability (JNTC). The capability will be built upon existing service training ranges and other infrastructure, to support joint, coalition, interagency and intergovernmental training. To bring this capability to fruition, the DoD will make a significant investment in resources, and it is expecting to take advantage of the global training systems industry's capability to supply networked architectures and other system components. The Pentagon will conduct these JNTC training scenarios in the *live, virtual and constructive (L-V-C),* or computer-generated, domains through the mission-rehearsal phase of a real-world mission—prior to the individuals and forces arriving in theater.[2]

The Strategic Plan for Transforming DoD Training requires an overarching, open-architecture environment that will provide plug-and-play interoperability in a full range of L-V-C training, as well as offer other critical knowledge assets (such as on-line interactive instruction, comprehensive digital libraries, and real-world C4ISR). This future integrated live and synthetic environment will provide the foundation for a new, adaptable joint national training capability, which creates joint warfighting conditions through a collection of networked training sites linked to real-world command and control systems. Department's near-term efforts will establish the operational-level policies, plans, and resources that will drive the longer-range Transformation effort. Mid-term actions will resolve many of the tough issues and help to ensure that systems interface properly. A deployable Joint National Training Capability and mission rehearsal capabilities must be demonstrated by October 2007.

This enhanced training environment (JNTC), which will optimize the use of existing military testing areas, training ranges and other critical assets must provide the most realistic joint mission experience possible in a training situation. Through involvement in enhanced exercises, participants will gain a global, network-centric capability that strengthens military transformation efforts to promote Warfighter effectiveness.[3] Inevitably training transformation must consider and overcome obstacles that prevent the *full integration* of the live, virtual and constructive training domains. This sounds like a tall order; however, according to, undersecretary of defense for personnel and readiness, David S. C. Chu, this plan is not an invitation to spend large sums of money, "It's a summons to use current resources in a more clever fashion," and "Above all, it's an invitation for innovative ideas, especially for the unusual combination of ingredients."[4]

DISTRIBUTED TRAINING ACROSS SIMULATION DOMAINS

Currently there's no effective, real-time solution for integrating and/or overlaying critical information about the merged L-V-C environment and presenting this information in a realistic manner to the *live dismounted and mounted soldier*. Imagine a unit of soldiers moving across the training range at one of the Army's combat training centers (CTC). Part of the scenario calls for the use and coordination of indirect fires. At this point in time, the way to simulate the impact of the rounds is for "smoker" vehicles to drive to the designated coordinates and pop canisters of smoke. There's the possibility of negative training, as opposing forces observe the smokers driving to their destinations and adjusting their maneuver, long before it's time for the coordinated barrage. Besides the obvious, another short coming with this particular method of live simulation is that the use of fires could be limited by the number of training support personnel—usually civilian contractors—and how quickly they can move and position themselves around the battlefield and initiate their effects (pop their smoke). The cost for providing this and increased levels of support could surely escalate for high operating tempos (OPTEMPO).

In order to train effectively, along with their distributed, virtual counterparts, the live participant needs to operate in an ***augmented world or environment***. The virtual player operating from Ft. Rucker, AL or Ft. Bragg, NC in an aviation combined arms trainer is completely immersed in a virtual representation of the battlefield that a unit of dismounted soldiers is physically operating on in perhaps Ft. Hood, TX or Ft. Lewis, WA—this is the new paradigm of transformation training. The technology and techniques exist for presenting the pilots operating in the virtual domain with an effective and integrated view of the battlefield. However, what about the dismounted (or mounted) units operating in the live, physical environment? How do they view an accurate virtual portrayal of aircraft as well as the battlefield effects caused by the pilots operating in this distributed training environment?

Deputy Secretary of Defense Paul Wolfowitz states that jointness is part of [a] cultural change, . . . the idea is to create a U.S. global military capability where individuals and units will receive training and experience in joint operations at the strategic, operational and tactical levels . . . the overall goal is for the armed services "to train as we fight - as a coherently integrated team."[5] As such, the individuals and units operating in the live environment must be able to see and sense, in real-time, what is going on in the overlapping synthetic environments and not be told by an observer-controller (OC) that these entities are out there. That means realistic 2/3-D virtual objects simulating explosions and smoke, vehicles and aircraft, urban areas/terrain, OPFOR, etc.

Can augmented/mixed reality be the window or portal for training participants operating in the live environment to access the joint, integrated training environment? Is it possible to inject virtual objects and graphical overlays into the live participant's field of view, thus *melting the boundaries between the live, virtual and constructive domains?*

MIXED REALITY – MELTING THE BOUNDARIES BETWEEN LIVE, VIRTUAL AND CONSTRUCTIVE

Introduction

The idea of MR and the emergent technologies needed to support it is a natural progression towards pulling the live participant into a transformed, joint L-V-C training environment. In addressing topic of transformation, the DoD's Director of Force Transformation, Arthur K. Cebrowski stated that new *equipment can catalyze new behavior and make new tactics possible, and that's laudable. But it's the behavior that counts - new tactics, new processes,* *new doctrine, new organizational structures, new information flows. That's where the transformation is,* ***and it all involves people advancing new ideas*****.**[6] The time has come for the further advancing of the idea of a larger role for augmented and mixed reality in the world of transformation training.

What is Mixed Realty?

In simple terms, augmented reality is the overlaying of graphical information or virtual entities over the real (usually a video representation of the live environment). An augmented reality system generates a composite view for the user. It is a combination of the real scene viewed by the user and a virtual scene generated by the computer that augments the scene with additional information.[7] For example, while watching a televised football game, you're likely to have noticed from time to time, a yellow line that appears across the field from sideline to sideline. This graphical overlay represents the spot or yard marker where the offense has to advance the ball for a first down. Fans in attendance at the game can view the sideline officials holding the first-down marker at any time; however, the selected camera angles that the television audiences view may deny this information. This simple augmentation provides the viewer at home with additional information that helps place him on a somewhat equal footing—maybe even a greater footing--with the fan that is live at the event, at least in this area. Other examples of augmented realty can be found in telecommunications, manufacturing and entertainment industries.

Going beyond simply augmenting or overlaying of graphical data, *mixed reality* (MR) is more dynamic in nature, as it strives to merge or blend the physical and digital worlds without any perceived difference between the two. MR is a natural extension of augmented reality; however, unlike the first-down marker example, MR would strive to heighten the experience of the participant by melting the boundaries between the live, virtual and constructive domains. This level of reality would go beyond simple augmentation. Mixed reality would be multi-modal in its performance and presentation, stimulating a full range of senses (visual, auditory, etc.) and transporting the participant into a scenario that is realistic, forceful and compelling.

Unlike football fans sitting at home, most practical military uses of MR would require the employment of some form of wearable computers. In the book "Fundamentals of Wearable Computers and Augmented Reality," Barfield and Caudell make a distinction between augmented reality systems and wearable computers. They see augmented reality systems as technology that enhances human senses, but is immobile and tethered to large computing platforms, while the term "wearable computers" signifies freer movement about and throughout a given environment. Considering the various potential military uses for MR, the capability to freely move about and throughout the training and operational environment, while receiving and processing critical information is certainly a key to this technology's acceptance and application, especially for use by dismounted soldiers. For the purposes of this paper, the term mixed reality (MR) will be used to encompass all the attributes of a stand alone augmented/mixed reality system, with the mobility of a wearable computer system.

Technical Challenges

In its current stage(s) of development, MR falls short of providing a robust capability that can be used immediately for integrating the synthetic and real, particularly for the live training participant. Much of the work accomplished within the Army thus far has been focused on the presentation of virtual objects into an MR environment and observations of the participants' reactions and perceptions of those objects, along with associated auditory cues and special effects. (See section entitled, *MR MOUT Innovation Testbed at STTC*) The bulk of this work has been done indoors. This is because several technical challenges are simpler to deal with. However, for an MR system to be useful to the Joint Warfighter in a future transformation training scenario, it must be capable of operating not only indoors, but outdoors as well.

It has been pointed out in the last several AR/MR/VR conferences that there are two main difficulties preventing AR from being successfully used in custom applications: lack of good tracking and lack of a good HMD.[9] However, from a military training perspective, this list would have to be expanded and include the following four (4) areas:

- Position Tracking and Environment Sensing
- Image Registration and Occlusion
- Individual Head Mounted Display Technology
- Wearable Computers (Size, Weight, Power, Ruggedization)

Position Tracking and Environment Sensing. In order to be successful in merging virtual objects into

the live setting (of the live participant's field of view), the position and orientation of the participant relative to the real environment must be known and tracked. In an indoor, controlled environment this can be successfully achieved using inertial sensors attached to head mounted displays (HMD), with its position data improved and corrected using acoustical sensors mounted over-head. While sufficient for indoors, limited mobility purposes; this approach would have limited to no use in an outdoor, mobile training and operations environment. The outdoor environment is difficult, if not impossible to control and would require a mix of techniques and equipment to provide the necessary fidelity; including GPS, inertial, magnetic, optical and/or acoustic sensors.
Solving the issue of equipment mix, corrective of drift errors and latency issues is necessary for 360 degree, real-time coverage of the soldier's movements.

Image Registration and Occlusion. The process of placing virtual objects in the correct relationship to the real is the registration problem. Ensuring that virtual objects, passing in front of real objects, obstruct the participant's view of that real object or vise versa is the problem of occlusion. These issues are firmly connected to tracking, as the system must know where the participate is positioned and oriented, as well as sense the location, shape and size of key terrain features in the environment. It's in between these two entities—the live participant and the backdrop of the live environment—that the tools of registration and occlusion are used to layer virtual images into the live participants field of view. Some issues that are being addressed by the University of Central Florida include presenting a high level of detail (LOD) for trees and forested terrain, the movement and characteristics of fire and the casting of virtual shadows on real objects and vice versa. These areas of computer science are important to providing a realistic rendering of mixed reality that will strain the soldier physiologically.

Individual Head Mounted Display Technology. There are two basic technological approaches used for HMDs: video see-through and optical see-through. The video see-through HMD replaces the wearer's view of the surrounding environment, with small video cameras that are mounted in the HMD, to capture these images. On the inside of the HMD, the video image is played in real-time and the graphics are superimposed on the video. The optical see-through displays employ optical combiners in front of the wearer's eyes. These combiners let in light, permitting the wearer to observe the actual environment and they also reflect light from monitors displaying graphical information. The result is a combination real and virtual world drawn by the monitors.

As the video see-though type of HMD obstructs the natural view of the wearer, some sort of optical see-through approach would be more useful for the live, dismounted training applications. Unfortunately, most product lines that had optical and video see-through type of HMD are not yet in full production or have discontinued production (Sony has not gone out of business). The advantage of video see-through mixed reality is that its functionality is not limited to head mounted applications simulation and can be applied where video technology is currently being used. These training applications would include tele-operation of robotics, security observation or training observation and evaluation that already employ video technology.

Other factors affecting the development of a suitable HMD are size, ruggedness and cost. One promising solution for the future may be the use of retinal-scanning displays. These systems would use light to paint graphical images directly onto the retina of the eyeball—providing an "artificial vision."[i] Artificial vision may be the answer to the size issue. Either way, wide-spread use of HMD technology among gamers and others is probably necessary to eventually provide cost effective HMD solutions suitable for the military training environment.

Wearable Computers (Size, Weight, Power, Ruggedization). War and other military operations are mobile. Warfighters are mobile. Live training is mobile. Therefore, systems that support these activities must be mobile. This is certainly true with regard to the dismounted soldier. Soldiers carry large amounts of equipment on their back and system developers should at all possible, avoid increasing that load. Therefore, the implementation of MR capabilities must be embedded onto existing or planned system components, rather than fielding separate stand-alone systems. While it's acceptable to wear a lap-top computer strapped to one's back in the R&D environment, it's not acceptable for use by troops, low crawling through rough terrain. Program managers—particularly for the Future Force Warrior ensembles—must design scalable systems using computer/graphical processing and memory resources that will accommodate future augmented and mixed reality capabilities. That means less size and weight and with the MR capability residing on the operational system, ruggedness is addressed. This issue requires close coordination of the technology R&D/acquisition transfer strategies that support ongoing weapons systems acquisition programs.

Broad Technological Objectives. A few important overarching technological objectives that must guide the development of MR include:

- Embedded. In order to develop an effective mixed reality solution, future requirements must stress the integration of a number of technologies. These solutions have to be infused into a light-weight, robust and embedded system for use by mounted and dismounted soldiers operating in the live environment.

- Real-Time. The system must render virtual and live participants operating together in real time. Delays caused by latent anomalies and technical limitations within a distributed system should be reduced as must as possible. We need to understand what the possible impacts are and how they can be minimized and eventually overcome.

- Multi-Modal (visual, auditory, etc.). The system must provide a compelling and realistic training experience; the full range of the participant's senses must be challenged, just as they would in combat. Not only should a training scenario provide visual (sight) stimuli, but the auditory, olfactory, etc. In other words, the full spectrum of sights, sounds and smells of the battlefield should be represented and presented for the soldier's training benefit.

- Non-linear and Adaptable (based on training objectives and requirements). The system must be flexible and challenging. The *trainer* should have the capability to create demanding training scenarios that are unpredictable and fully tax the soldier's capabilities. As real world missions change, the training system must be accommodative and permit the timely development and implementation of suitable and relevant training. In other words, change and develop on the fly.

MIXED REALITY INNOVATION TEST BED AT STTC, ORLANDO, FL

One of the main projects emerging from the augmented reality side of the ETDS STO is the Mixed Reality MOUT project (also known as Mixed Reality Innovation Test Bed). MR MOUT was created to investigate and better understand the challenges and obstacles in applying mixed reality to future combat systems.[11] The test bed consists of a re-creation of an urban courtyard, within the laboratory, surrounded by architectural details that pose as potential threats to the soldier in all directions. The structure contains embedded tracking and observation technology similar to an instrumented MOUT site. Interoperable Commercial-Of-The-Shelf (COTS) technology is networked and programmed to simulate a multi-sensory combat simulation with 3D surround sound and special effects.

Interchangeable HMDs can be utilized for experimentation to apply augmentation of virtual multiplayer and data representations. Presently, the Canon Coastar Video see-thru, stereo scopic HMD is used in order to leverage the dual camera computer vision (stereo vision) and the ability to provide various degrees of virtuality from all real to all virtual. 3rd person views are provided to the trainer via either observer cameras with mixed reality views or a virtual camera views, used to obtain the view of virtual characters.

A centralized story engine is in testing to produce scenarios that provide self-generating variations through interactive non-linear scripting techniques. The same engine is able to capture a subject's performance and replay in 3D for novel After Action Review (AAR) presentations, analysis and comparison with other subjects. Using this authoring capability, human performance psychologists will be able to design unique scenarios to evaluate different variables within the environment. Such evaluations would include threats, stress elements, representations of multi-modal data on Heads Up Displays including audio, visual, haptic, directional, spatial and graphic. In addition, the simulation format will be able to be adjusted to provide alternative platforms for evaluating performance, including desktop, VR HMD, AR HMD, MR HMD, and flat panel video displays.

Ongoing and planned human performance research activities, conducted by the Research, Development & Engineering Command (RDECOM), Army Research Institute (ARI), University of Central Florida (UCF) and other institutions, using the MR MOUT Test Bed includes,

- Multi-Modal Cues. Evaluate the effectiveness of multi-modal (audio, visual, haptic) cues spatially, directionally, etc.

- Team Leader Decision Making. Time pressured decision-making with 3D spatially registered visual cues.
- Mixed Reality Training Effectiveness
- Mixed Reality Audio Perception

The forthcoming results of these human performance experiments and analysis will assist the army in determining cognitive impacts of mixed reality, including when and where its use is most appropriate and effective.

As the world center for cutting edge experiential entertainment (theme parks, video games, simulation rides and location based entertainment) as well as Modeling, Simulation and Training (M&ST), Orlando has a unique perspective on the enhancement of both the virtual and real world simulation.[12] Complementary research was integrated from both military training and entertainment to emphasis the compelling nature of simulation.[13] It has since gained additional support from the Naval Research Laboratory under the Research in Augmented and Virtual Environment (RAVES) project, from Canon Inc.'s Mixed Fantasy project developing research in experiential entertainment.

CONCLUSIONS

Preliminary stages of development lead researchers to believe that there's potential for the use of augmented and mixed for military applications, particularly for implementing and enhancing training and mission rehearsal tasks. Not only for the live, dismounted participant--an important area for the Army--but also for other services and agencies training needs. The payoff for the Warfighter includes:

- Heightening the trainee's experience
- Improving the Trainer's ability to develop and present scenarios.
- Enhancing the After Action Review (AAR) capability

RECOMMENDATIONS

As the DoD continues to move toward the goal of joint transformation, distributed training systems/environments and a Joint National Training Capability, Mixed Reality must be recognized as a potential key component. Joint Forces Command, the various services training commands, systems acquisition program managers and others should aggressively address the challenges facing the maturation of these technologies and strategies for their transition into existing and planned training and operational systems.

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