A Mixed Reality Platform for Enhanced Military Training

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ABSTRACT

Mixed Reality (MR), the next step in human, computer and environmental convergence, goes beyond VR and AR to incorporate a wide variety of advanced technologies to deliver high fidelity training in a richer, cost-effective environment.

The challenge to MR-based training implementation has been the integration of sight, sound, smell, and haptic senses into training courses that can be delivered at the point of need. One approach to resolving this issue is to develop a common platform that uses standards, orchestration and pre-integration to improve the quality, flexibility, affordability and speed to market.

The Kratos MR Platform integrates best-of-class COTS devices with advancements in gaming, display and similar technologies to achieve a fully immersive solution. COTS action requests (i.e.: initiate senses - sight, smell, sound, haptic, etc.) are communicated to the platform's shared central memory module where Kratos-developed software triggers the desired action automatically.

The platform is not constrained by shape or size of the environment. Its light source panels can be configured to accommodate various sizes and shapes—from rotary aircraft cabins, to air traffic control towers, to the turnkey Kratos Holodeck.

Now being evaluated by DoD for air traffic control and infantry tactics training, course developers can rely upon the pre-integrated platform to speed development and easily incorporate new technologies.

This paper will describe the key elements of the platform – the COTS products/technologies, the integration engine and the delivery methodology – and how they are coordinated to create a holistic MR simulation platform.

ABOUT THE AUTHORS

Craig H. Clark is the CTO at Kratos Technology and Training Solutions (KTTS). Over the past 2 years Craig has directed business unit technologies from product operations improvements to research and development. Prior to being the CTO Craig was the Senior Software Architect for KTTS and designed the training application framework for the modeling and simulation baseline for KTTS.

Craig's primary mission is to improve current technologies, manage research and development, and create discriminators and market disruption to give Kratos a dominant role in their training solutions. Craig started his career in the Naval Nuclear Propulsion Program, U.S. Navy. He was a naval instructor and has spent plenty of time underway running propulsion systems. He is a graduate of UCF, which has the finest computer science school in the nation on simulation, synthetic design and training. He worked in telecommunications until 9/11 and then changed his work to defense and training. He became a Principal Architect for General Dynamics and designed an urban operation system that currently has trained over a million U.S. Army soldiers and still operates at facilities around the world at over 120 different primary military training centers.

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CHALLENGE

The overarching training problem the Department of Defense (DoD) and other government agencies are trying to solve is the ability to train better, cheaper and faster without sacrificing fidelity, content or safety. Kratos evaluated numerous alternative paths to accomplish those goals. One area of overwhelming interest is in the realm of mixed reality (MR) – replacing standard simulation methods with an immersive virtual environment that also incorporates real-world cues to enhance the ability to train.

Through years of research, development and testing, coupled with the maturity of COTS-based VR products and with customer feedback. Kratos, along with the DoD, have found that immersive virtual simulation products can be implemented as an effective and cost-savings means of providing DoD and government agency-wide training. As educators, within the military and beyond, are discovering, mixed reality (MR) technology— a step beyond augmented reality (AR) and VR— will help to achieve this goal as it facilitates the deployment of more realistic training to the point of need, be that at a base facility, combat training center or in the field.

A Mixed Reality Primer

MR is the result of blending the physical world with the digital world. It is the next evolution in human, computer, and environment interaction and unlocks possibilities that before now were restricted to our imaginations. It is made possible by advancements in computer vision, graphical processing power, display technology, and input systems. The term mixed reality was originally introduced in a 1994 paper by Paul Milgram and Fumio Kishino, "A Taxonomy of Mixed Reality Visual Displays." Their paper introduced the concept of the virtuality continuum and focused on how the categorization of taxonomy applied to displays. Since then, the application of mixed reality goes beyond displays to also include environmental input, spatial sound, and location.

Advancements in sensors and processing are giving rise to a new area of computer input from environments. The interaction between computers and environments is effectively environmental understanding, or perception. Environmental input captures things like a person's position in the world (e.g., head tracking), surfaces and boundaries (e.g., spatial mapping and spatial understanding), ambient lighting, environmental sound, object recognition, and location.

Now, the combination of all three – computer processing, human input, and environmental input – sets the opportunity to create true mixed reality experiences. Movement through the physical world can translate to movement in the digital world. Boundaries in the physical world can influence application experiences, such as game play, in the digital world. Without environmental input, experiences cannot blend between the physical and digital realities.

Figure 1. Summary comparison of VR, AR and MR

BEYOND AR/VR

The key differentiator of MR is that it enables digital content and real-world content to interact with each other in real-time, in ways beyond augmented reality (AR) and virtual reality (VR). AR and VR platforms can't simulate the dirt, dust, and sweat of combat. They can't simulate the impact of external friction on the warfighter or their platforms. That is one of the biggest criticisms of synthetic training platforms. MR helps solve the friction challenge, providing the warfighter a truly immersive experience that mimics the combat environment.

The effects of tactile, audio, and visual sensory cues on a participant's sense of presence in a virtual environment and on their memory for the environment and the objects in that environment directly correlate to the success of training. Results strongly indicate that increasing the modalities of sensory input in a virtual environment can increase both the sense of presence and memory for objects in the environment. In particular, the addition of tactile and auditory cues to a virtual environment increased the user's sense of presence and memory of the environment.

A PLATFORM APPROACH TO MR-BASED TRAINING

The greatest challenge to effective and affordable MR-based training today has been incorporating the variety of products and technologies for sight, sound, smell, haptics, etc. into self-contained training courses that can be delivered in a variety of places, situations and environments. As technology professionals in other disciplines such as communications and IT have discovered, the answer to fully capitalizing on new technologies is by integrating them into a common platform that uses standards, orchestration and pre-integration to improve the quality of outcomes, as well as flexibility, affordability and speed to market.

A mixed reality simulation platform needs to have the ability to unite best of class commercial technologies and enable delivery of courseware to the point of need. Educators can design courseware and other training materials quickly and affordably, utilizing the best technologies, content development strategies and the widest range of delivery scenarios for the most immersive solution— far faster and more affordably than using one-off techniques. To be clear, the platform is not a development environment or toolkit. Instead it is a complete, turnkey training delivery foundation that allows educators to apply the most realistic, advanced MR technology to achieve training objectives.

Mixing the Real with the Virtual

For over a decade VR systems have been used to model all aspects of military training, including ballistics, air, ground and maritime systems models as well as human behavior. Now, MR is taking training immersiveness to new heights. MR merges real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time. It is best suited to training applications that would benefit from:
1) enhanced sensory perception beyond simple visuals, or 2) where training in a real environment can be enhanced by introducing virtual elements. For example, unlike AR or VR, with MR a Humvee driver trainee will experience the initial feel of all vehicle controls, smells and vibrations in environments ranging from a desert to urban streets, all while sitting in a schoolhouse, holodeck or the cab of a stationary vehicle. MR reduces the costs and eliminates

the risks associated with live training, while providing heightened realism that better prepares trainees for the live training exercises to follow.

Sensory Perception & Reaction: MR's Baseline Technologies

One such example of a platform approach to delivering MR training solutions is that developed by Kratos. It is comprised of three parts: 1) a select group of best-of-class hardware and software Commercial-Off-the-Shelf (COTS) technology products that create, drive and manage sensors and sensory inputs; 2) an Integration Engine that unifies the inputs, outputs and operations of these technologies so they can behave in a coordinated way, and 3) flexible, versatile lighting technology that allows MR courseware delivery in virtually any suitable environment.

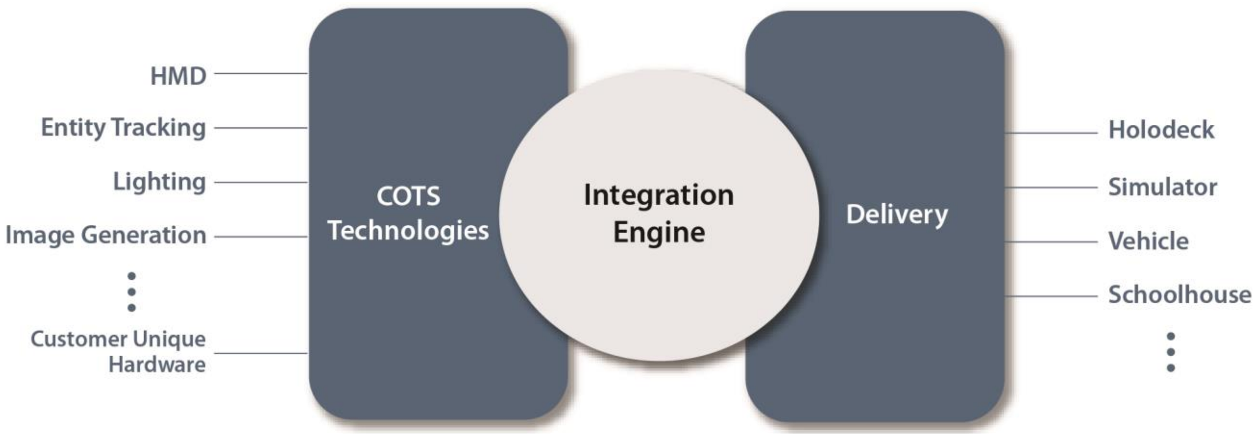

Figure 2. Basic Components of an MR Platform

The platform employs the latest in commercial-off-the-shelf (COTS) technologies including (but not limited to):

- HMD technology
- High Definition camera and sensor technology
- Entity Tracking system
- Lighting technology
- Image generator (IG) and Rendering Engine
- Operating system(s)
- Proprietary color spectrum keying algorithms

Integrating the many technology elements required to create an MR environment can be a challenging undertaking, requiring specialized software to integrate the myriad of components listed above into an immersive, holistic experience.

TECHNOLOGY + INTEGRATION: THE HEAT OF THE PLATFORM

The Kratos Platform integrates technology advancements in the gaming and similar markets to achieve a fully immersive MR solution. Internally developed algorithms and software integrate the COTS technologies to create the most realistic training environments.

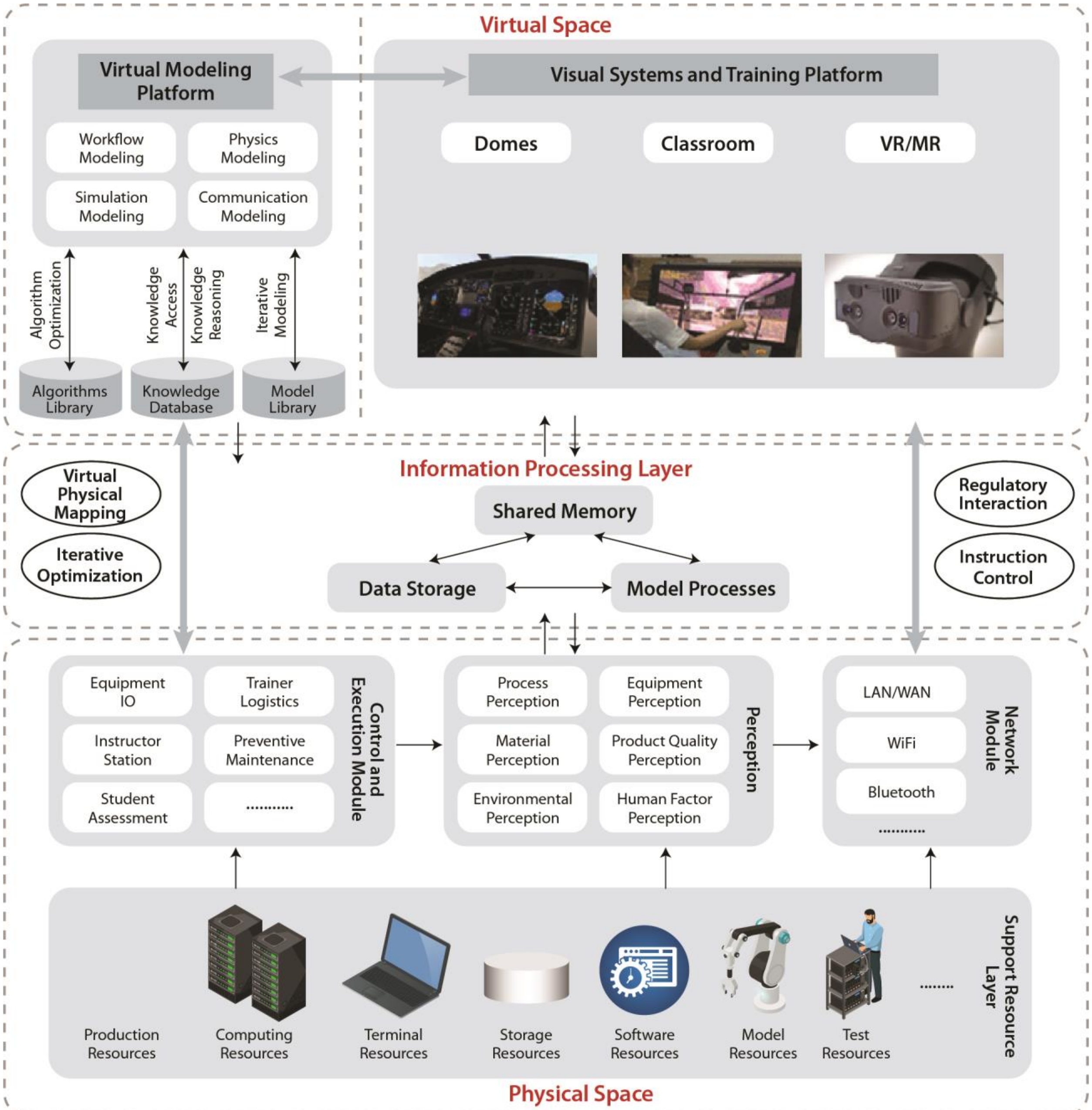

Figure 3. Open Architecture Design of MR System Maximizes Interoperability

The mixed reality system, as diagramed above, is designed with an open architecture to maximize interoperability, reuse and reduction in ownership cost. By using technologies like openVR we allow for several different COTS components and software solutions to be integrated into the system. This also prevents us from being tied to a specific product or vendor. The Information Processing Layer has an open API and allows for new systems to receive and transmit events and messages. Agnostic integration efforts were used specifically for allowing of modular and scale (size) flexibility.

The actions of each of these COTS devices are communicated to a shared central memory module where required actions are automatically triggered by the platform's software. For example, pine forest imagery in a simulated environment will trigger pine tree aroma; the pull of a trigger in a gunnery training scenario will trigger muzzle flashes, the turning of an HMD will trigger a change in the visual to track the changing head movement and resulting visual. What's more, the architecture of the platform is designed with the expectation of change. As COTS technologies and products continue to advance, the platform architecture has been designed to easily replace older forms with the latest updates without elaborate reengineering.

Delivering MR Training Anywhere

In a highly mobile world, training can no longer be limited to the classroom, and the greatest advantage of this platform-based strategy is that it enables MR-based courses to be delivered in virtually any suitable environment. Training increasingly needs to be delivered at the point of need. The key for the Kratos platform is unique lighting technology that can seamlessly cover any surface. Thus, the platform is not constrained by shape or size of the environment. Its light source panels can be configured to accommodate various sizes and shapes. There really are no limits to configuration—from rotary aircraft cabins, where aerial gunnery trainees can react to multiple battle scenarios via the latest in head mounted display (HMD) units—to air traffic control towers, marksmanship firing ranges to the turnkey Kratos Holodeck.

MR Applications

The Kratos Holodeck is comprised of COTS technologies that are utilized in many different applications. One application is an Air Traffic Controller (ATC) proof of concept and demonstrator. This ATC demonstrator allows students to utilize real ATC computers and physical components, while working in a virtual world. This system is networked to an Apache simulator so the student can interact with the pilot in the simulator as he approaches the ATC tower. The student looks down and picks up the physical microphone to communicate with the Apache as it flies closer to the runway. The student can look out the tower windows and see the Apache (simulator in the virtual world) flying. Combining the virtual world with the physical world that the student was utilizing is a true example of mixed reality.

Other examples in the simulation and training environments include gunnery trainers utilizing high fidelity weapons in the virtual world. We have developed V-22, UH-60, CH-47 gunnery trainers in mixed reality environments.
As the technology advances, research labs are discovering that they can use mixed reality to assist them with their evaluation of new technologies and products. Another customer is utilizing mixed reality to evaluate next generation technology and products for soldier lethality. They are advancing the mixed reality technology to include eye tracking, induced signal to noise ratios, picture-in-picture, overlays, higher HMD resolution and increase FOV. Once this is complete, the Holodeck will be integrated with new soldier equipment to assist in the evaluation and deployability of this equipment. Finally, integration of multiple larger size Holodecks will be used for soldier or squad level training.

The potential for MR to dramatically alter training is not limited to military operations. FAA training centers as well as metropolitan SWAT teams can benefit from ATC and soldier/squad training, respectively. This recent advancement of high powered wireless computers allows the system to grow exponentially, networking multiple individuals together to allow face-to-face interaction in a virtual world.

TECHNOLOGIES CRITICAL TO MIXED REALITY

Numerous technologies are required for a platform to deliver MR training. These include, but are not limited to, tracking, head mounded display (HMD), image generations, gaming engines and lighting technologies. As time precludes a discussion of each, this paper will focus on tracking and lighting technologies.

Tracking Technology Overview

Position and orientation tracking is very important towards achieving immersion and presence in virtual or projected training environments. Head tracking information is used to change the viewpoint of the generated image to reflect user movements inside the training area. For dome projected trainers, orientation information, although not as critical as in virtual reality training, is important to calculate the final eye-point in relation to the position of the head tracker. The value of the viewpoint offset is given by the distance between the head tracker and the viewpoint (for a projection system it is considered the point in between the eyes at the base of the nose). A close positioning of the head tracker (e.g., above the forehead) will minimize the offset induced by head rotation from looking perpendicular to the screen, thus a less accurate orientation sensor can be used.

In head mounted projection systems though, the positioning information needs to be accurate due to good assessment of discontinuities between the physical trainer cabin and the projected out-the-window (OTW) scene, versus the virtual system where everything is aggregated at the IG level and translations of the viewpoint in the scene are resilient to a higher measurement error.

There are several methods of tracking position, for the generic size of the training environment considered, the following were evaluated:

Magnetic Tracking

Magnetic tracking relies on measuring the intensity of the magnetic field in various directions. There is typically a base station that generates AC, or pulsed DC excitation. As the distance between the measurement point and base station increases, the strength of the magnetic field decreases. If the measurement point is rotated, the distribution of the magnetic field is changed across the various axes, allowing determination of the orientation as well.

Trackers using this technology: Polhemus G4, Polhemus FastTrack, Ascension trakSTAR
Pros: High precision, fast update rates, works in complete darkness, multiple receivers.
Cons: Subject to interference from conductive materials near emitter or sensor, from magnetic fields generated by other electronic devices and from ferromagnetic materials in the tracking volume. The positioning accuracy decreases with the cube of distance from the source, although multiple sources can be used.

Acoustic Tracking

Acoustic tracking measures the time it takes a known acoustic signal to reach the receivers. Typically, multiple transmitters are distributed in the tracked environment and multiple receivers (microphones) are placed on tracked objects. If the receivers are aware when the signal was sent, the time to receive the signal can provide the distance from the transmitter. When multiple receivers (microphones) are present in a known position on a rigid object, the time difference between them can provide data about the orientation of that rigid object relative to the transmitters.

Trackers using this technology: Intersense IS900, Nexonar, Chirp Microsystems
Pros: Works in complete darkness, immune to electromagnetic interferences, multiple receivers.
Cons: Subject to audio interference, slow update rate, sensitive to occlusions.

Optical Tracking

There are different variations to perform tracking using optical technology, among these:

- The tracked object is outfitted with markers in a well-known pattern and two or more external cameras are looking for the markers in the common viewing area.
- The tracking object is outfitted with a camera and markers are placed in the environment. The size and geometry of the markers are used to compute the position and orientation.
- Infrared laser light scans the tracked volume with determined timing and photoelectric sensors placed on the tracking object identify the position of the object based on scan timing.

Pros: Less susceptible to noise from the environment, does not suffer from drift from inertial sensors, many objects can be tracked simultaneously.

Cons: Difficult to implement with NVG, track accuracy affected with multiple occlusions, or outside the trainer (e.g., out of the UH-1Y platform), and deploying multiple cameras to cover large volumes has a high cost.

Ultra-Wide Band (UWB) Tracking

UWB tracking uses low-power wide-band radio signals to measure time difference of arrival of a radio pulse from multiple sources to the receiver. Using at least four sources a precise position in the 3D space of the tracked object can be calculated.

GREEN SCREEN and LIGHTING TECHNOLOGY

Green/blue screens are based on the idea of chroma-keying. Chroma-keying, sometimes known as color-keying or keying, is the process of singling out a particular color in an electronic image and then using computer software, which can be just about anything you can imagine, to show through. The idea is that a specific color is chosen and replaced by a different color/background. Additionally, one of the most important aspects of shooting any type of green or blue screen project is the use of appropriate lighting.

Backlighting/Front Lighting

If the subject isn't lit correctly or the green/blue screen is too dark, too bright, or uneven, chances are you'll have problems. Several types of lighting systems and types, in different combinations, have been used to achieve the best results. The background must be evenly lit, otherwise the shadowed areas will be harder to key out. Improper backlighting can cause hot/cold spots and oversaturation of the screen material.

The subject you're keying out also needs to be far enough away from the green/blue screen so you don't get bleed-thru from the reflective light off the screen onto your subject. In addition, the subject in the foreground must be lit separately so you have control over the exposure and direction of the light source(s) you require for the scene.

Cloth

Green/blue cloth is a low-cost alternative to other materials used for the background. While it's easy to implement, it does present its own set of challenges; it can produce shadows and if the sheen of the cloth isn't matte enough, reflections can occur on the subject.

Electroluminescent (EL) Paint

Electroluminescent paint is a costly alternative to other green screen materials. While readily available and easy to implement, it doesn't provide a good uniformity of light.

Video Cards

The NVIDIA Quadro P6000 was released in October 2016 as the most advanced pure professional graphics solution ever created, combining the latest GPU, memory and display technologies that result in unprecedented performance and breakthrough capabilities. Professionals across a range of industries can now create their most complex designs, solve the most challenging visualization problems and experience their creations within the most detailed, lifelike and immersive VR environments.

The Quadro P6000 Pascal architecture GPU implementation, GDDR5X memory and DisplayPort 1.4 support synergistically deliver the best overall single precision FP32 performance and professional graphics solutions. The P6000 enables users to create large, complex designs, interactively render photorealistic imagery, and create detailed, lifelike VR experiences.

Light Tape®

Light Tape® provides a back light solution that evenly illuminates the green screen surface without diffusion and as the panels can be configured to accommodate various sizes and shapes the platform is not constrained by shape or size of the environment. There really are no limits to configuration. We believe it is the overall best solution for the Kratos implementation.

Mixed Blending

In augmented/mixed reality the occlusion between virtual and real objects needs to be managed correctly so users can look at the scene and rationalize that it's natural. In order to achieve this, the depth of the real-world has to be measured in real-time and from the user's viewpoint.

In Kratos' approach the virtual world is placed behind the physical world, whereas in other Augmented Reality systems the virtual elements are placed in front of the physical world. This is implemented by recording the physical-world layer with a camera and overlaying that video feed on top of the virtual video and providing a color-keying method to remove certain parts of the physical layer from the video feed. The Kratos Chroma-key solution is an application built using OpenGL for rendering and Shader code for image processing and blending. Initially, the method of capturing the video feed from the IG involved the use of capture cards and a processing PC to blend and process images and render them to the HMD. We have refined those methods, utilizing functions from the graphics cards to grab the frame buffer of the IG before it leaves the card. This method is significantly faster and streamlines the processing pipeline.

In our configuration the MR System consists of a COTS virtual reality headset paired with a stereoscopic camera system. Areas of the real scene that are desired to be replaced by the virtual scene will be colored in green. The stereoscopic camera device uses two wide-angle low-profile cameras to provide the video feed for each eye.

Table 1. Differentiates Mixed Reality and Augmented Reality characteristics.

Characteristics	*Mixed Reality*	*Augmented Reality*
Layers Order	Physical over Virtual	Virtual over Physical
Layers Separation	Particular color in the physical world is replaced by the virtual	A 3D model of the physical word has to be generated on the fly to determine occlusion areas where the physical world will be seen
Layers Capture	Virtual world – generated by IG Physical world – captured by cameras	Virtual world – generated by IG Physical world – seen by naked eye
Layers Visualization	Virtual world – HMD Real world – cameras on HMD	Virtual world – projected on a see thru display Real world - seen by naked eye
Field of View	110 degrees	Published Field of view of selected HMD
Layers Alignment	Precise head tracking and matched fields of view between cameras and virtual reality	Depth sensing cameras

CONCLUSION

The incorporation of reality-based technologies in the DoD and other government agencies improves the efficiency of the user for the selected application by leveraging technology to provide the means to train in the complex operating environment of the future, integrating technologies to optimize team and individual performance, and providing tough realistic training that is synchronized with live events and providing options for accelerated and sustained readiness.

The cost savings potential of a reality-based training environment far exceeds the operating cost of legacy training environments. Increased use of reality-based training could cut costs by lowering maintenance costs, avoiding costly trainee errors, and shrinking logistics costs associated with coordinating multifaceted exercises.

Reality-based solutions leverage the cost savings potential by meeting the readiness challenge in the new era of defense demands and reassessing how the military trains. In particular, it calls for further investigation into how the military can optimize its use of reality-based training to enhance readiness at lower cost. By taking concrete steps to determine the optimal balance between live and reality-based training and reality-based training's true return on investment, as well as investing in advanced simulation technologies, the military will find itself in a better position to ensure readiness.

Although the cost-savings argument is crucial to persuading those at the top to embrace reality-based training, the extent to which it can enhance training beyond current capabilities may be even more important. In many cases, reality-based training has been shown to outperform live training in skills and knowledge transfer to trainees. A review of studies on the effectiveness of computer-based simulation training concluded that, "computer-based simulations—assessed as an alternative to other means of training, as a supplement to other means of training, as a device to combat skill decay in experienced trainees, and as a means of improving performance levels as they stand prior to training—show positive results for knowledge transfer a majority of the time: in 22 out of 26 such studies, trainees demonstrated equal or superior knowledge transfer to the control group from simulations." (Going Virtual for a New Defense Era - the Promise of Virtual Training)

https://www.govexec.com/gbc/going_virtual_for_new_defense_era/#the-promise-of-virtual-training