Augmented Reality (AR) Training Systems for First Responders

Market Survey Report

January 2024

Science and Technology

NUSTL®
NATIONAL URBAN SECURITY TECHNOLOGY LABORATORY

Approved for Public Release

SAVER-T-MSR-45

The “Augmented Reality Training Systems for First Responders” was prepared by the National Urban Security Technology Laboratory – in conjunction with DAGER Technology, LLC – for the U.S. Department of Homeland Security’s Science and Technology Directorate pursuant to 70RSAT18CB0000049/P00006.

Photos included were provided by the National Urban Security Technology Laboratory, unless otherwise noted. The report’s cover photo is licensed from Kitreel/Shutterstock.com (photo ID 1417378334).

FOREWORD

The National Urban Security Technology Laboratory (NUSTL) is a federal laboratory within the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T). Located in New York City, NUSTL is the only national laboratory focused exclusively on supporting the capabilities of federal, state, local, tribal, and territorial responders to address the homeland security mission. The laboratory assists responders with the use of technology to prevent, protect against, mitigate, respond to, and recover from homeland security threats and incidents. NUSTL provides expertise on a wide range of subject areas, including chemical, biological, radiological, nuclear, and explosive detection, personal protective equipment, and tools for emergency response and recovery.

NUSTL manages the System Assessment and Validation for Emergency Responders (SAVER) program, which provides information on commercially available equipment to assist response organizations in equipment selection and procurement. SAVER knowledge products provide information on equipment that falls under the categories listed in the DHS Authorized Equipment List (AEL), focusing primarily on two main questions for the responder community: "What equipment is available?" and "How does it perform?" The SAVER program works with responders to conduct objective, practitioner-relevant, operationally-oriented assessments and validations of commercially available emergency response equipment. Having the right tools provides a safer work environment for responders and a safer community for those they serve.

NUSTL is responsible for all SAVER activities, including selecting and prioritizing program topics, developing SAVER knowledge products, and coordinating with other organizations to leverage appropriate subject matter expertise. In conjunction with DAGER Technology, LLC, NUSTL conducted a market survey of commercially available augmented reality (AR) training systems for first responders. This equipment falls under the AEL reference number 04AP-08-SIMS entitled "Simulators."

SAVER reports are available at www.dhs.gov/science-and-technology/saver-documents-library.

Visit the NUSTL website at www.dhs.gov/science-and-technology/national-urban-security-technology-laboratory or contact the lab at NUSTL@hq.dhs.gov.

U.S. Department of Homeland Security

SAVER

System Assessment and Validation for Emergency Responders

POINT OF CONTACT

National Urban Security Technology Laboratory (NUSTL)
U.S. Department of Homeland Security
Science and Technology Directorate
201 Varick Street, Suite 900
New York, NY 10014
Email: NUSTL@hq.dhs.gov
Website: www.dhs.gov/science-and-technology/SAVER

TECHNICAL SUPPORT

DAGER Technology, LLC (DAGER)
45240 Business Court
Suite 300
Sterling, VA 20166
Email: info@dagertechnology.com
Website: www.dagertechnology.com

Authors:

Steve Miller, Urban Security Capabilities Lead, DAGER Technology, LLC
Eric Morefield, Counter-IED Capabilities Specialist, DAGER Technology, LLC

EXECUTIVE SUMMARY

Emergency response agencies use augmented reality (AR) training systems to train responders in routine, dangerous, or uncommon situations in a realistic, safe, and cost-effective manner. AR training systems for first responders require both hardware and software. The hardware can include smartphones, tablets, and/or AR head-mounted displays, and possibly a separate computer system, controllers, and other accessories. AR software integrates the hardware and accessories with training scenarios to produce AR training content. AR training systems for first responders can be commercial-off-the-shelf (COTS) training products. Most companies that produce COTS training products can also customize their products to meet specific customer needs. This report features both COTS and customizable COTS products. AR systems use see-through displays; therefore, some also have the capability to be used as operational tools for first responders.

Between January 2023 and May 2023, the Department of Homeland Security (DHS) Science and Technology Directorate's (S&T) National Urban Security Technology Laboratory (NUSTL), conducted a market survey of commercially available AR training systems for first responders through its System Assessment and Validation for Emergency Responders (SAVER) program. This market survey report is based on information gathered from manufacturer and vendor websites, internet research, industry publications, and a government-issued request for information that was posted on the System of Award Management website. The survey identified 10 products. For the purpose of this market survey report, additional criteria for inclusion were added to narrow the scope of the report to COTS and customizable COTS products. Prices vary widely based upon quantity and type of hardware included, software licensing, number of users, number of scenarios included, and customization.

While some of the COTS products can also be customized to meet an agency's training needs, specialized or agency-specific training may need to be custom-built. COTS training products may allow an agency to evaluate how AR training fits into their training plan in terms of effectiveness, acceptance, cost, and deployment at a lower cost than custom applications. Regardless of the product type selected, AR training software can provide first responders with the ability to safely learn and practice skills in a controlled, immersive, and interactive environment. AR training can be cost and time effective, scalable, easily accessible, variable, customizable, and used to improve and record performance. The products described in this report provide a wide variety of training experiences for police, fire, and emergency medical services. The choice of a particular training product depends upon the needs of the agency.

The purpose of this report is to provide emergency response agencies with information that will guide them in making operational and procurement decisions. Each agency should consider the overall capabilities, technical specifications, and limitations of AR training systems in relation to their agency's needs when making equipment selections. Agencies should also consider the impacts associated with integrating AR training systems into their information technology, policy, concept of operations, and maintenance plans.

The performance of the products and information included in this report has not been independently verified by the SAVER program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Public safety agencies can use AR training systems as a cost-effective approach to training law enforcement, fire and emergency medical responders for routine, dangerous, or uncommon situations in a realistic and safe manner. Trainees can exercise response procedures in a low-risk environment and receive immediate feedback on their performance from instructors monitoring and/or controlling the scenarios. AR training software is also adaptable to agency needs: scenarios can be freely repeated, multiple students can interact simultaneously, and sessions can be conducted remotely, for example.

Between January 2023 and May 2023, the SAVER program – run by S&T NUSTL – conducted a market survey of AR training systems for first responders. This market survey report focuses solely on AR training systems for first responders. A separate market survey report titled "Virtual Reality (VR) Training Systems for First Responders" is available on the SAVER website. This AR training systems market survey report covers 11 different commercially available products and is based on information gathered from manufacturer and vendor websites, internet research, industry publications, and a government-issued request for information that was posted on the System of Award Management website. Due diligence was performed to develop a report that is representative of products in the marketplace.

Products included in this report are first responder training solutions that provide multiple and varied immersive scenarios. Many can integrate with first responder agency learning management systems (LMSs) to track training and record progress or provide "see-what-I-see" functionality, which allows a training scenario to be assessed and reviewed. AR training products needed to fall into one of two categories in order to be included in this report:

- Complete, pre-packaged, scenario-based AR training systems validated for first responders
- Customizable COTS AR training solutions from companies with documented experience producing validated first responder AR training systems

2.0 AR TRAINING SYSTEMS FOR FIRST RESPONDERS

AR, VR, and mixed reality (MR) are subsets of "extended reality" (XR), which enhances user interaction with the physical world using digital media. XR spans from basic tools like computer-based digital maps to 3D digital representations, AR glasses, MR glasses, VR goggles, and sensory controllers. As the complexity of XR grows, these tools may further integrate a user's senses using various devices, leading to a fully immersive experience. AR overlays virtual elements onto the real world, enhancing user perception and interaction. It's accessible through devices like smartphones, tablets, and AR head-mounted displays (HMDs), also known as "smart glasses." AR allows users to move through the real world while interacting with both real and virtual objects, including elements like smoke, fire, victims, suspects, and non-player characters (NPCs).

AR first responder training has trade-offs with VR training. AR training allows agencies to use existing training spaces, while VR training allows developers to create entirely new virtual trainings spaces. However, VR does not allow users to see and move through the physical training space realistically and may induce motion sickness. AR training is best suited for scenarios that require real-world context, physical interactions, collaboration, and/or hands-on skills training.

AR training allows trainees to learn and practice techniques in real-world, physical environments while receiving digital overlays and enhancements from the AR device. For example, law enforcement officers could stage active shooter training against virtual avatars inside facilities like schools or theaters where they would be the unit called to respond if such an incident occurred. AR training is well-suited for team-based training and collaborative problem-solving tasks. AR allows trainees to naturally interact and collaborate with one another in the same physical space. AR companies are also deploying operational AR systems for use during actual emergency responses; for some systems, AR training may have the additional benefit of using the same or similar interface as operational AR systems.

While AR training may require a sizeable initial investment, it may still be cost effective overall, as activities can be repeated for low or no cost. AR training may also reduce or eliminate costs associated with travel, equipment, and training materials. AR training can be delivered through a variety of devices and can allow trainees to access training material anytime and anywhere. It can be scaled up to accommodate large numbers of trainees, customized to meet specific training needs, or tailored to individual learning requirements. AR training allows trainees to practice, repeat, and perfect their skills in a low-risk environment. The systems can track a trainee's performance and provide analytics on their progress. Yet, because AR allows designers to have control over training content, it also allows instructors to put trainees in highly dangerous or uncommon circumstances in complete safety. Instructors can assess trainees' actions or give trainees real-time feedback. Integration with LMSs and/or "see-what-I-see" functionality allows instructors to monitor trainees' progress and to provide feedback and support, interacting with them virtually and/or in the real world.

AR content can be delivered via various devices, each with advantages and disadvantages. Training content on smartphones and tablets can be easy to access and affordable since most trainees have smartphones or tablets. However, AR training on such personal devices would have a limited field of view (FOV), would likely restrict the trainees' use of their hands, and would lack the feeling of immersion. Using dedicated AR HMDs for AR training addresses these issues but comes with higher hardware costs; HMDs may also introduce eye strain, headaches, and/or dizziness for some trainees with prolonged use.

2.1 AR Head-Mounted Displays (HMDs)

Most AR HMDS, often called AR glasses or "smart glasses," allow users "native passthrough," that is, the ability to see the real world as though they are regular eyeglasses. AR HMDs provide an immersive experience by tracking the user's head movements and overlaying virtual content onto their real-world view. The ThirdEye X2 MR Smart Glasses (see Figure 2-1), Microsoft HoloLens 2 (see Figure 2-2), and Magic Leap 2 (see Figure 2-3) are examples of immersive AR HMDs.

Figure 2-1 ThirdEye X2 MR Smart Glasses

Image Credit: BANC3 and ThirdEye

To overlay digital information, AR HMDs use specialized optics, providing either monocular or binocular augmentation. To give the perception of depth, binocular AR HMDs project a slightly different image to each eye to create a stereoscopic image. This can be problematic, however. A person's eyes normally converge (cross slightly) as the distance from an object to their eyes decreases or diverge (uncross) as that distance increases. Simultaneously, the eyes also focus or "accommodate" according to the eye-to-object distance. In the real world, both vergence and accommodation occur at the same point, but in the virtual world, the vergence and accommodation points are often out of sync. While an object may appear to be five feet away, the screen the user's eyes must focus on is only one to two inches away. This disconnect is known as the "vergence accommodation conflict" and can cause headache, dizziness, nausea, and eye strain.

Being able to comfortably wear an AR HMD is an important consideration for training. Weight, fit, padding, and adjustability can affect wearability and the level of comfort. Poorly fitting headsets may distract users, lessening the sense of presence in a scenario. There are a wide variety of AR HMD manufacturers and models.[1]

2.1.1 Stand-alone AR HMDs

Stand-alone HMDs have built-in computing power and storage, allowing users to experience AR content without the need for a separate computer or console. Since stand-alone HMDs are not dependent upon a connected computer, they offer greater mobility and convenience than computer-connected AR HMDs. Stand-alone AR HMDs typically use Wi-Fi and/or Bluetooth to transmit data and communicate with wearers' handheld controllers.

Figure 2-2 Microsoft HoloLens 2 AR HMD

Image Credit: MedCognition

[1] Additional information on AR HMDs and their specifications are available at vr-compare.com.

Because they rely upon a built-in processor and batteries, stand-alone AR HMDs are typically heavier than computer-connected AR HMDs. For example, the stand-alone Microsoft HoloLens 2 AR HMD (figure 2-2) weighs about 1.2 pounds with the head strap, while the computer connected Rokid Max AR HMD (not pictured) weighs 2.6 ounces. The Magic Leap 2 (see Figure 2-3) is classified as a stand-alone AR HMD but transfers the weight of the battery and some of its processing power to a wired "Compute Pack" that is worn on the hip. The batteries on stand-alone AR HMDs have a limited run-time before they must be recharged or changed out. The battery on the stand-alone Microsoft HoloLens 2, for example, is rated for two to three hours of active use before it needs to be recharged.

Figure 2-3 Magic Leap 2 AR HMD

Image Credit: Magic Leap

2.1.2 Computer-connected AR HMDs

Computer-connected AR HMDs are typically tethered to a smartphone, tablet, computer or gaming console through a cable(s). The power and data cable(s) can allow the use of more powerful computers than can be embedded into headsets. This also allows these AR HMDs to display high-quality, immersive AR content while maintaining a stable and reliable connection to the computer. While the cable connection tends to limit the user's freedom of movement, computer-connected AR HMDs are typically lighter in weight than stand-alone AR glasses.

2.1.3 Degrees of Freedom

HMDs include hardware to track the user's position, typically an inertial measurement unit (IMU) and a method of correcting for "drift" (a compounding error in IMU's estimate of the headset's position). IMUs contain gyroscopes, accelerometers, and sometimes magnetometers to estimate movement. In a three-axis HMD, the IMU tracks the yaw, pitch, and roll of the HMD, and the user's view changes accordingly (Figure 2-4). Three-axis systems are said to have "three degrees of freedom" (3 DoF): Looking left and right, looking up and down, and tilting left and right. The user remains stationary and can "look around" at AR features, but 3 DoF does not allow the user to physically walk around within a space and have those movements reflected in the virtual or augmented world. Any position changes within the virtual world must be facilitated by using external controllers.

Figure 2-4 Three Degrees of Freedom (3 DoF)

Image Credit: DAGER Technology, LLC

Six-axis systems track the yaw, pitch, and roll of the HMD, plus the user's X-, Y-, and Z-axis movements (also known as "sway," "heave," and "surge," respectively) within a training space (Figure 2-5). Six-axis systems are said to have "6 DoF." Unlike 3 DoF systems, 6 DoF systems allow users to walk, run, crouch, or jump in the real world and have their movements reflected within the virtual environment. External controllers are not required for basic movement in 6 DoF systems but may be used to facilitate extra features like tool handling and grasping virtual objects.

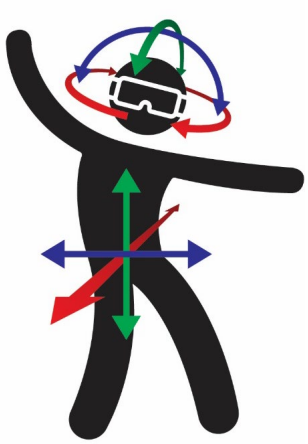


Figure 2-5 Six Degrees of Freedom (6 DoF)

Image Credit: DAGER Technology, LLC

2.1.3.1 Positional Tracking

Six-axis AR systems use a variety of methods to accomplish X-, Y- and Z-axis tracking, but all typically include IMUs plus cameras and/or infrared sensors. IMUs do much of the motion tracking in AR HMDs, but because of drift, they require a method to correct positional estimates. The cameras and other sensors used to correct drift may be mounted on the HMD, in the training space or both.

Inside-out tracking systems use cameras and/or other sensors mounted on the HMDs and controllers to look at features of the real-world external environment, monitor changes, and adjust the AR viewpoint accordingly. **Marker-based inside-out tracking systems** use fixed markers like QR code stickers, reflectors, or active-infrared beacons placed around the training space as reference points. To ensure positional accuracy when using marker-based systems, careful setup, calibration, and attention to marker placement is important so that the cameras will always have a view of multiple markers.

Markerless inside-out tracking systems use existing, unique features of the training environment to track the HMD location. Headset-mounted cameras monitor the environment and compare the viewpoint from frame to frame. The relative position of holographic content to existing physical features is then adjusted in the AR environment. Markerless systems do not require external hardware, so they are typically more portable than marker-based systems and are often found in consumer-grade HMDs. Markerless AR systems may require calibration prior to use to establish correlations between real-world and virtual objects. For example, prior to using some AR emergency medical services (EMS) training programs, trainers must designate reference points on a mannequin (and the surface on which the mannequin rests) using an AR HMD or instructor tablet to "anchor" the holographic patient to the mannequin while the program runs. Since markerless systems rely on unique features in the real world, however, they may struggle with open-floor areas and featureless walls and may be less accurate than marker-based systems in settings with these characteristics.

Outside-in tracking systems use external cameras and other sensors to track the user's HMD. The HMD usually has infrared LEDs or other markers mounted on the headset, which are tracked by the external cameras and sensors. These systems can be more accurate than inside-out tracking HMDs; however, outside-in systems require carefully installed and calibrated hardware.

2.1.4 AR Displays

2.1.4.1 Display Technologies

There are three primary see-through AR display technologies: Bug-Eye, Birdbath, and Waveguide.

Bug-Eye technology uses a one-way mirror to reflect an LCD image onto a glass or plastic screen for the user to see. This type of AR display is the cheapest to manufacture but results in a large form factor. No first responder training systems referenced in this market survey report use this technology. **Birdbath technology** uses beam-splitters and lenses to redirect and focus an LCD or organic LED screen's content, allowing for a greater FOV and a smaller form factor compared to a Bug-Eye display. However, a Birdbath display's (see Figure 2-4) multiple lenses tend to lose much of the light transmitted from the display, which necessitates darker external lenses, and may cause "ghosting," a form of double images that can make content seem blurry. Birdbath lenses are more expensive to manufacture than Bug-Eye displays, but not as expensive as Waveguide lenses.

Figure 2-6 RealMax 100 AR HMD

Image Credit: RealMax via worldviz.com

Waveguide technology utilizes mirrors, lenses, and/or prisms to guide light from the outside world and the HMD's display into the user's eyes simultaneously. Waveguide systems provide the highest visual clarity, less ghosting, and the smallest form factor of the three AR display technologies, but at the highest cost: most waveguide HMDs cost several thousands of dollars. [1] The ThirdEye X2 MR, Microsoft HoloLens 2 AR, Magic Leap 2 and HMDs pictured above use waveguide technology (see Figures 2-1, 2-2, and 2-3 respectively).

2.1.4.2 Display Attributes

There are several additional attributes to consider when choosing an AR headset, including resolution, FOV, refresh rate, latency, brightness, comfort, and tracking.

- The **resolution** of the AR HMD, which is often referred to as resolution per eye, determines the sharpness and clarity of the virtual images displayed. Higher resolution displays provide more detail and a more realistic experience. Resolution may be expressed in common screen pixel dimensions like 2160 x 2160, or in pixels per degree (ppd), which denotes the number of pixels found per degree of FOV. Human vision can typically resolve around 60 ppd.
- **FOV** is the observable area of AR content projected within the AR HMD. The average horizontal FOV for a person is around 200 degrees. A larger FOV for an AR HMD contributes to a more immersive experience. AR HMDs typically have a more restrictive FOV than VR HMDs because AR HMDs have to detect and overlay digital information on real world objects. The accurate matching of digital information with the real environment across a wider FOV is more technically challenging and costly than VR rendering.
- The **refresh rate** of an AR HMD shows how frequently the display updates the holographic elements. Refresh rates are expressed in hertz (Hz), which is cycles per second. Thus, a 90 Hz HMD will refresh the screen image 90 times per second. Higher HMD refresh rates can reduce motion blur and improve the feeling of immersion.

- **Latency** is the delay between a user's movement and the corresponding change in augmented graphic renderings. Latency can be affected by numerous factors, including refresh rate, graphics processing power, tracking technology, software optimization, and network latency. Low latency is important for reducing motion sickness and a natural-feeling AR experience.
- AR HMDs have clear lenses; therefore the **brightness** of the AR content being displayed must be intense enough to overcome the natural light levels of the user's environment. The brighter a display is, the clearer the images can be as light levels increase. Brightness is measured in nits. A light source with one nit of brightness equates to one candela (the SI unit for light visible to the human eye) per square meter. A typical AR headset has around 150-200 nits, with more capable headsets having around 500 nits. However, to use an AR headset outdoors in full sunlight, the requirement is around 1000 nits.
- **Weight, fit, and adjustability** can all affect wearability and the level of comfort. Being able to comfortably wear and use an AR HMD is an important consideration for training. A lightweight, comfortable, and well-fitted VR HMD will allow trainees to remain focused for longer periods and have a more seamless AR experience.

There are a wide variety of AR HMD manufacturers and models. Currently, there are over 60 models of commercially available AR HMDs, and their specifications are available at a VR and AR headset database located at vr-compare.com.

2.2 AR Controllers

At the core of the AR experience is the ability of users to interact with the AR environment. Unlike VR training, AR systems typically allow users to manipulate real objects while in their augmented environment, since they can still see these items through the AR HMDs. Users may also need to manipulate holographic AR content, which typically involves using handheld controllers. AR controllers often have a haptic feature to provide tactile feedback, usually in the form of vibrations activated when the user touches virtual objects in the AR world. Like video game controllers, AR controllers often have buttons, joysticks, wheels, or touchpads to allow users to pick up AR objects, manipulate AR controls, open AR doors, and perform similar functions. Controllers can also be built into props like hose nozzles, training weapons flashlights, tools, and other first responder equipment. In addition, a system may use AR beacons like wristbands, ankle straps, and even torso sensors that detect the body position of users to render their avatars visible to remote AR users within the simulation. This allows multiple users to interact with one another's avatars and manipulate objects cooperatively even from different real world training spaces.

2.2.1 Hand Tracking

Hand tracking allows for a natural and immersive virtual experience. Some AR HMDs feature hand tracking, which allows users to interact with virtual environments and objects using their hands, without the need for controllers. Hand tracking can allow users to use gestures to give simulation commands, manipulate holographic content as they would real objects, and build muscle-memory by practicing actions as they would in the real world. There are several different technological approaches to AR hand tracking, but they all capture and analyze hand movements that are translated to corresponding movements in the virtual world.

2.2.2 Eye Movement Tracking

Some AR HMDs can track the user's eye movements to determine where their attention is focused throughout a scenario or even to control user actions in the AR environment. Eye tracking (also called "gaze tracking") is typically accomplished via an internal HMD camera that monitors the movement of the wearer's eyes and may be aided by the projection of an invisible infrared point onto the user's cornea to measure the angle between this point and the center of the user's pupil. Eye tracking may be especially useful for law enforcement training scenarios to determine, for example, what areas a trainee is visually scanning during a room entry or to determine if an officer is watching a subject's hands during a traffic stop.

Eye tracking cameras can also automatically detect and adjust parameters for interpupillary distance, allowing for a quick and accurate calibration process when a user dons a headset. Eye-tracking cameras may also be used for biometric identification, allowing shared headsets to instantly recognize a trainee, load their profile, adjust their optical settings, and continue their training where they left off.

2.3 Haptic Feedback

Electronic devices have traditionally provided most feedback to users via visual and auditory signals. With the ascent of video gaming, developers sought to provide more immersive experiences by adding additional signals to stimulate the human sense of touch, known as haptic feedback, often shortened to "haptics." The human somatosensory system can detect multiple types of input data including pressure, pain, temperature, hair movement, joint position, muscle stretch, and vibrations. Haptics have migrated into AR training technology. The simplest haptics include control buttons designed to "click" when depressed or phone screens that vibrate when touched, simulating a button press. At an advanced level, some training systems allow a user to explore a real environment augmented with virtual haptic stimuli. For example, medical students can palpate a virtual tumor inside a real mannequin using a haptic AR system to practice conducting a cancer screening. Alternatively, AR systems can use real-world objects with AR overlays: for example, allowing EMS students and trainees to physically touch a real-world mannequin while treating a holographic patient who has been mapped to that mannequin.

2.4 AR First Responder Training Software

One benefit of AR training systems is providing first responders with the opportunity to learn and practice skills in a controlled environment. The training experience should be immersive and interactive, cost and time effective, scalable, easily accessible, varied, customizable, and used to improve and record performance. AR training systems use branching logic to create interactive and engaging training experiences that simulate real-life decision-making scenarios. Branching structures allow for flexibility and the ability to provide personalized guidance, instruction, and feedback to trainees. Branching can help trainees navigate through the scenario, make choices, and allow for variation in scenario play and outcome. The types of branching used depends upon the complexity of the training and the desired functionality.

2.4.1 Customization

AR training hardware and software for first responders varies drastically in the level of customization available. The selection of the level of customization often depends on the purpose of the training, the funding available, and the level of specificity needed. COTS training products may be more suitable for training based on national standards (like basic life support), equipment, or common processes (like conflict de-escalation). Custom-designed training may be more appropriate for specialized equipment and procedures, departmental policies, and virtual models of local infrastructure and assets. Some simple training setups feature basic scenarios that use COTS HMDs and their corresponding controllers to navigate the scenes. These are often pre-packaged training systems and do not allow for customization; however, new content can be downloaded from vendor libraries or open-source online repositories.

Alternatively, agencies can elect to create their own training content using "no-code" AR software. These feature pre-programmed content such as avatars, rooms, backgrounds, objects, and actions that can be brought together using simple menus and "drag-and-drop" functionality, eliminating the need for computer programming knowledge. However, the content that can be created in this manner is often limited in its complexity and realism.

At the next level of sophistication are COTS systems that allow agencies to insert "digital twins" of environments or objects. Users may scan actual local venues using high-resolution 360-degree cameras to create a realistic training space. Unique objects like improvised explosive devices (IEDs) or particular weapons may also be scanned using optical photogrammetry or laser scanners or built from scratch in computer-aided design (CAD) programs. These twins can then be placed into the AR environment or even virtually manipulated by trainees, e.g., an IED subjected to a render-safe procedure, or a supportive device used in emergency medical training. As the complexity of the training scenario increases, the requisite knowledge of the scenario developer increases as well and may require vendor assistance. Most AR companies selling COTS public safety training systems offer custom development at an additional cost.

AR training can also be developed entirely from the ground up, allowing agencies to have full control over training content. This typically requires hiring programmers skilled in the use of AR creation software suites and multiple computer programming languages. Top-quality simulations may also require script writers, video editors, and graphics artists. Most agencies that take this approach elect to outsource this work to vendors, who then work with an agency's training experts to achieve the desired results.

At the forefront of current AR training design are systems that feature adaptive and realistic scenarios that can also be easily customized by trainers using agency-provided content, like building scans or scans of an agency's duty weapons. As another version of adaptive training design, some EMS training allows instructors to assemble AR scenarios with patient "symptom blocks" using drag-and-drop flowchart software. The AR patient then reacts appropriately to trainee "treatment" interventions or the lack thereof. AR training developers are also beginning to leverage artificial intelligence (AI) technology for content programming and to control NPCs, enabling trainees to develop flexible skillsets. AI NPCs can react to trainee actions and change their behavior on-the-fly, for example, allowing trainees to repeat training without experiencing the exact same timeline or character behavior.

2.4.2 Interactions

AR training systems can have many different types of interactions available to trainees in the virtual world, including interactions with real-world objects, controllers and digital twins of tools and objects, as well as other trainees, role players, instructors and NPCs.

Figure 2-7 After-training review and feedback

Image Credit: InVeris Training Solutions

AR interactions differ from VR training interactions since AR technology allows users to see, pick up, and use real-world objects. For example, AR users may have the benefit of using a real tablet computer to look up information on the internet regarding a virtual hazmat spill displayed in their HMD. Likewise, trainees may be able to use their hands to manipulate the controls on a physical fire engine pump control panel during an AR fire. EMS users may load a physical mannequin onto a stretcher and load that stretcher into a real ambulance, all while an AR trauma patient visualization is overlain on the mannequin.

Like VR training systems, controllers in AR training systems allow trainees to move through and interact with the virtual objects; however, AR training systems allow users to pick up, move, rotate, and manipulate virtual holographic objects in the real world. Interacting with digital twins in AR training sessions allows trainees to learn how to maintain and operate equipment or learn their way around new venues. This may be especially useful for training on delicate, expensive equipment or in locations that have limited availability to be used for training. Controllers can also be used to emulate specific tools or equipment in the virtual scenario. First responder AR training systems sometimes replace standard AR handheld controllers with specialized first responder controllers, such as fire hose nozzles or weapons.

NPCs are computer-controlled characters programmed to interact with the trainees in the virtual world. NPCs help with scenario storytelling, populate the AR world to contribute to realism, and interact with trainees in the simulation. NPCs may use pre-scripted behaviors, branching logic, AI algorithms, or a combination of these. Advances in AI have enhanced AR experiences by enabling more natural and realistic interactions with virtual characters. AI-powered NPCs respond to user actions in intelligent and nuanced ways, making the augmented environment feel more lifelike.

Some AR training systems allow trainees to interact with other trainees, role players, and instructors within the simulation via avatars. Interaction with other trainees and trainers adds realism to the scenario as well as building teamwork, collaboration, problem-solving and conflict-resolution skills. The use of non-trainee role players in training scenarios can add human-to-human interaction between trainees and characters in the scenario, such as victims, hostages, and subjects. Depending upon the sophistication of the simulation, instructors can modify role-playing avatar actions, change environmental conditions, and vary the scenario outcome based on trainee actions.

2.4.3 Instructor Observation and Evaluation

Despite technical advancements in AR, skilled instructors remain vital for enhancing trainees' abilities. Although basic, computer-directed AR instruction is available, advanced training relies on instructors understanding trainees' AR experiences. Most AR first responder training systems feature "see-what-I-see" functionality. This allows instructors to display trainees' views on screens and visualize the trainees' interactions in the real world, also allowing them to provide post-training evaluation or real-time guidance. Instructors can directly communicate with trainees or use Voice-over-Internet Protocol via HMD earphones, which is also useful for remote training. Performance data available to instructors includes shot accuracy, vital signs, scene views, gaze tracking, and past performance. Recording sessions for review is common; some systems can also auto-evaluate trainee performance and offer feedback. Certain AR training systems allow instructors to customize scenarios based on past performance. AR systems' third-party LMS integration capabilities vary; basic AR systems often support LMS integration while more complex ones usually track training dates internally due to data complexity.

2.5 Operational Considerations

Unlike VR, AR systems can also be used in real-world operations. AR users, through their HMDs, can view a response scene that is augmented by real-world data from sources like thermal cameras, chemical sensors, radiation meters, structural maps, or personnel trackers. For instance, a fire commander could use structural mapping to visualize the location of firefighters inside a burning building.

AR technology can also enable remote collaboration with experts, who can see what responders see and make AR annotations on items or areas of interest. For example, a responder in a clandestine laboratory could consult with a hazmat chemist, who could highlight or circle dangerous chemicals or evidence items. These annotations persist in the responders' view as they move around the scene.

2.6 Emerging Technologies

Many people speculate that AR HMDs will be the technology to replace smartphones in the future. [2] Human beings are designed to work in three dimensions, and AR HMDs can layer three-dimensional data over the already three-dimensional world. For AR HMDs to become a vital part of our daily lives, AR technology must overcome many challenges, including privacy concerns, image quality, optics, battery life, sensors, haptics, and neural interfaces. Improvements in optics and image quality will allow the next generation of AR HMDs to generate "high-quality holograms of avatars onto the real world." [3] Technologies are emerging on several fronts to overcome the vergence accommodation conflict to produce a more natural AR visual experience at any distance. These technologies include varifocal displays (displays that can vary their focal depth to adjust what the user is looking at), retinal beam scanning (a laser directly paints an image on the user's retina), and others. [4] Developers are working on neural interaction technology using wristbands and gloves to interact with AR HMDs. A wristband is being developed that can sense the user's neural signals and track the user's intentions without any motion by the user. [5]

Others speculate that the future of AR is screenless and does not involve HMDs, tablets, or smartphones. AR and VR HMDs just move the screens that we have today closer to our faces. A different approach is being used in a protype AI assistant shirt-mounted device that uses audio feedback in conjunction with laser projections of data onto users' hands or nearby surfaces. [6]

Developers are working on AR systems that stimulate the users' sense of smell. Trainees may be greeted by the smell of natural gas if they're virtually arriving at the scene of an explosion, or the smell of smoke while virtually investigating a report of a chimney fire.

2.7 Relevant Standards

Because the majority of AR and VR headsets have so much technology in close contact with the user's head, the VR/AR Association created, adopted, and published American National Standards Institute/Controller Area Network/UL Standards and Engagement 8400 (ANSI/CAN/UL 8400), "Standard for Virtual Reality, Augmented Reality and Mixed Reality Technology Equipment." This standard is for the "safety of electrical and electronic equipment within the field of virtual reality, augmented reality and mixed reality technologies." In addition to general product safety requirements, it includes requirements related to see-through visual functions, flicker, skin compatibility, eye exposure to thermal energy, biomechanical stress, mechanical robustness, enhancing spatial perception, safety and warning instructions, and functional safety. [7] Additional standards to consider are detailed in Appendix A.

When exploring AR systems for use in emergency medical training and/or operations, special consideration must be given to how the systems may be impacted by the Health Insurance Portability and Accountability Act of 1996. [8]

2.8 Cybersecurity Considerations

Ensuring that the software is implemented, maintained, and backed up in a secure manner is a key aspect of consideration when looking at various products. Backing up and protecting the training scenario software is vital due to the time and financial investments AR requires. When installing training software and connected devices, follow the Federal Bureau of Investigation's (FBI) Criminal Justice Information Services (CJIS) Security Policy, which is available for free download online at le.fbi.gov/cjis-division/cjis-security-policy-resource-center. *[9]* .

Installing software on a network carries some cybersecurity risks, depending on the requirements and implementation of the software, as well as the environment on which it is installed. Specific risks include security vulnerabilities that could allow the software itself to be exploited or allow a bad actor to gain a foothold in the network. An unauthorized person gaining access to the software itself could result in the disclosure of sensitive information such as first responders' CONOPS.

HMD devices that are connected to host-based operating systems should use proper PC hardening security practices. All stand-alone devices listed in this market survey report can install a mobile device management solution to help secure these end point devices.

Care should be taken with any software that requires an active internet connection to function or receive updates. Some software is also cloud-hosted, requiring an active internet connection to function, and some software requires additional network resources to function and is not meant to be installed in a stand-alone environment.

2.9 Use of Grant Funds for Certain Telecommunications and Video Surveillance Equipment or Services

The John S. McCain National Defense Authorization Act for Fiscal Year 2019 (NDAA), Pub. L. 115-232, Section 889 (NDAA) prohibits the use of federal funds, including loan and grant[2] funds, to obtain or acquire certain telecommunications technologies manufactured by certain entities or to enter into contracts with entities that use those technologies. The Office of Management and Budget (OMB) published regulations at 2 C.F.R. § 200.216 to clarify the application of the NDAA to the use of federal grant funds to procure or obtain certain telecommunications equipment or services.

Effective August 13, 2020, federal grant recipients and subrecipients (i.e., **non-federal entities**) are prohibited from obligating or expending loan or grant funds to procure or obtain[3] the following "covered telecommunications equipment or services":

- Telecommunications equipment produced by Huawei Technologies Company or ZTE Corporation (or any subsidiary or affiliate of such entities)

For the purpose of public safety, security of government facilities, physical security surveillance of critical infrastructure, and other national security purposes, video surveillance and telecommunications equipment produced by:

- Hytera Communications Corporation
- Hangzhou Hikvision Digital Technology Company
- Dahua Technology Company
- or any subsidiary or affiliate of such entities
- Other entities identified by the Secretary of Defense

The restriction also applies to systems that use the covered equipment or services as a substantial or essential component, and to subsidiaries or affiliates of those listed above[4]. See www.federalregister.gov/d/2020-17468/p-877https://www.federalregister.gov/d/2020-17468/p-877.

Costs associated with covered equipment and services are "unallowable" for grant funding. Grant recipients are responsible for ensuring funds are used only for allowable costs, and would be obligated to refund the government for unallowable costs. The Federal Emergency Management Agency (FEMA) issued FEMA Policy #405-143-1, Prohibitions on Expending FEMA Award Funds for Covered Telecommunications Equipment or Services (Interim) for further guidance on the Section 889 prohibitions. Additionally, OMB issued frequently asked questions (FAQs) on the topic.

For **federal** entities, FEMA published interim rules amending the Federal Acquisition Regulation[5].

[2] This also includes cooperative agreement funds.
[3] Nor may they extend or renew a contract to procure or obtain or enter into a contract to procure or obtain the covered equipment or services.
[4] As well as telecommunications or video surveillance services provided by entities or using equipment described above.
[5] www.federalregister.gov/documents/2019/12/13/2019-26579/federal-acquisition-regulation-prohibition-on-contracting-for-certain-telecommunications-and-video and www.federalregister.gov/documents/2019/08/13/2019-17201/federal-acquisition-regulation-prohibition-on-contracting-for-certain-telecommunications-and-video.

3.0 AR TRAINING PRODUCTS FOR FIRST RESPONDER TRAINING

This section provides information on 10 products that offer first responder focused-AR training. All products are complete, pre-packaged scenario-based AR training systems for first responders. All of them are from developers based in the United States and offer wearers 6 DoF. The training solutions in this market survey report provide multiple, varied immersive scenarios. All of them either integrate with first responder agency LMSs to track training and record progress and/or provide see-what-I-see functionality to allow for assessment and review of the training scenario.

Table 3-1 provides baseline characteristics and specifications of the products, which are listed first by responder discipline (i.e., EMS, fire, law enforcement) and then alphabetically by manufacturer. Dual discipline products, however, are listed between the applicable disciplines. Please note that while cost is not included in Table 3-1 due to varying pricing models, pricing information is included within the individual product sections that follow, if provided by the manufacturer. The information in Section 3.0 has not been independently verified by the SAVER program.

Below are definitions of the product information in table 3-1, listed in column order.

Training Target refers to the primary first responder group for which the product is intended, whether EMS, fire or law enforcement (LE).

AR HMDs refers to the model(s) of AR head-mounted display used by the system.

Smartphone or Tablet refers to the operating system or type of device(s) that can be used to view and interact with the AR simulation.

Multi-Trainee Collaboration refers to whether more than one user can participate simultaneously in an AR training session and collaborate.

Operational Use refers to whether the system has the capability to be used by first responders operationally.

Table 3-1 Product Comparison Matrix

Manufacturer and Product	Training Target	AR HMDs	Smartphone or Tablet	Multi-Trainee Collaboration	Operational Use
BANC3, Inc./ThirdEye, Respond Eye	EMS	ThirdEye X2 MR	Android	✓	✓
Design Interactive, AUGMED	EMS	Microsoft HoloLens 2	Android and iOS	--	--
GigXR, Inc., HoloScenarios: Basic Life Support	EMS	Microsoft HoloLens 2	Android and iOS	✓	--
MedCognition, PerSim	EMS	Microsoft HoloLens 2	Android	✓	--
ARCortex, Emergency Response Information System (ERIS)	Fire	Lenovo A3, Microsoft HoloLens, Magic Leap 2	Android and iOS	✓	✓
JHB Group, Inc., FiAR Fire Extinguisher Training System	Fire	None	Apple iPad	--	--
Avrio Analytics, AR Police and Fire Training Solution	Fire, LE	Magic Leap 1 & 2, HTC XR Elite, Pico 4	Android	✓	--
InVeris Training Solutions, Simulated Reality for Collective Experience (SRCE)	LE	Magic Leap 2	--	✓	--
Ti Training, RECON Simulator with RealMax 100 AR Training Glasses	LE	RealMax 100	--	--	--
Sphere Technology Holdings, Inc., Sphere	Fire, EMS, LE	Microsoft HoloLens 2, Magic Leap 2, Lenovo A3	Android and iOS	✓	--

-- Indicates that the product does not have this feature

3.1 BANC3, Inc., and ThirdEye, RespondEye

The ThirdEye X2 MR HMD provides hands-free training experiences by overlaying digital information onto the real-world view of the user. RespondEye software is designed for emergency medical response. Together this solution can be used for training responders in emergency care capabilities. They can also be deployed operationally and may be particularly useful in remote or disaster areas by connecting responders with remote medical professionals who can guide and support them through AR visuals. ThirdEye X2 MR HMDs and RespondEye software run on open-source Android OS and have a modular design to allow future integration with a variety of hardware components and other software.

Figure 3-1 RespondEye

Image Credit: BANC3 and ThirdEye

The ThirdEye X2 MR HMD is self-contained, allowing trainees to move freely within the training environment untethered and offering wireless functionality. The HMDs are stand-alone devices with Bluetooth and Wi-Fi capabilities, offering portability and compatibility with other hardware devices such as laptops, tablets, and smartphones. The X2 MR has 500-nit-brightness see-through displays that allow it to be used indoors or outdoors. ThirdEye headsets come pre-loaded with RespondEye software.

RespondEye utilizes AR for a hands-free, see-what-I-see live telehealth platform that allows field EMTs and paramedics to remotely connect with trainers and/or physicians in nearby emergency departments. RespondEye functions include taking photos, videos, screenshots, making on-screen annotations, and allowing conference calls with multiple participants as well as providing multiple headset interconnectivity. The user interface controls are voice-, motion-, and gesture-based. It also has a desktop application.

The X2 MR headset also offers third-party integrations. The HMD can integrate with FLIR One Pro Thermal Sensor to provide users with hands-free access to FeverVision (for medics to view patient body temperatures) and live thermal camera heat mapping accurate to ±3 °C. ThirdEye'sX2 MR headset can also connect to DJI-brand small, small unmanned aircraft systems (sUAS) through their DroneEye software. BANC3 can provide similar functionality for other sUAS if needed.

The AR and MR training solutions provided by BANC3 and ThirdEye enable a variety of trainee interactions. Trainees can view training videos through the HMDs. Remote subject matter experts can guide trainees with AR visuals, such as freeform drawing and 3D models overlaid on the wearers' real-world view. Digital twins can also be incorporated into training scenarios. Trainees have the freedom to move around and explore the training environment while receiving real-time guidance from instructors. The HMDs also support the use of haptic glove feedback for enhanced interaction and realism.

Integration with LMSs is possible, allowing incorporation of AR training progress and evaluations into existing training programs. Instructors can provide real-time feedback and guidance to trainees during the training sessions. The solutions have been validated through pilot programs and offer user training, instructor training and development training options for creating custom content.

BANC3 and ThirdEye emphasize that their solution is Health Insurance Portability and Accountability Act of 1996 (HIPAA)-compliant for the protection of personal health information. The AR HMDs come with built-in EMS protocol viewers to guide first responders; further, the connection to remote medical specialists is secure. The system is also compliant with Section 899 of the NDAA.

BANC3's healthcare solutions require the ThirdEye X2 HMD at a cost of $2,450, a SLAM tracking module for an additional $799, and a RespondEye software subscription for $49.99 per month, per headset. Extra battery packs cost $89.99 each, a hardhat connector is $99, and prescription vision inserts are available for $19.99 per pair. The thermal vision package costs an additional $799.99 per headset. BANC3 provides 24/7 customer and technical support with the subscription. These services are primarily offered remotely, but in-person support is possible if travel expenses are covered. A two-year extended warranty is available to cover accidental damage during normal use for $39.99 per month per headset with a $199 deductible.

3.2 Design Interactive, AUGMED

AUGMED is a COTS, interactive AR training solution designed for Tactical Combat Casualty Care (TCCC). The product can also be used for training EMS and police responders to treat trauma victims. AUGMED is designed to provide TCCC instruction for both classroom and refresher training. While AUGMED can be used in a VR environment, it is optimized for AR interactions. When used as an AR tool, casualty avatars can be overlain on sensor-enabled mannequins, live role players, or virtual patients. This gives trainees the ability to physically feel the "victim" and enables the victim to give feedback on the efficacy of treatment. For example, in some scenarios, sensors in a mannequin will detect when enough pressure has been applied to a tourniquet to control bleeding, and the wound in the AR view will reflect this incrementally as pressure is applied.

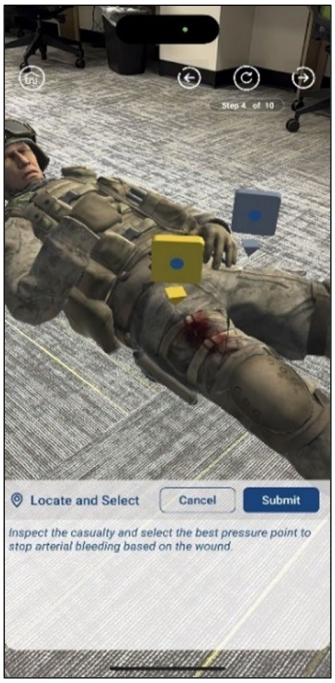


Figure 3-2 AUGMED

Image Credit: Design Interactive

AUGMED is completely portable, can be set up in minutes, and requires a small room to operate. AUGMED can run on various headsets, tablets, and mobile phones (Android and iOS), but is optimized to run on the Microsoft HoloLens 2 HMD. The system is wireless and does not require a computer or handheld controllers. Interaction with victims and menus is accomplished via hand recognition when using a Microsoft HoloLens 2. On simpler devices, interactions with victims and menus are done with touch screens. Interactive menus allow trainees to make decisions, develop treatment plans, or apply various treatment options.

AUGMED software features branching logic that can be tailored to the level of the trainee, so more basic trainees can be given simple ladder-like steps to follow when treating victims, while more advanced trainees can be given scenarios with multiple potential branching outcomes to complicate treatment. Failure to choose proper treatment options can result in the death of the AR victim. AUGMED lessons are aligned with a trainee's current and evolving performance, measured via AI-generated algorithms to accelerate proficiency. The scenarios are designed for a single trainee to interact with a patient and do not feature multi-player interactions; however, instructors have see-what-I-see capabilities and can provide guidance and feedback to trainees. The software uses "spatialized learning assessments" throughout the scenarios.

Haptic feedback is accomplished using mannequins or live role players that have an AR "victim" overlay. Digital twins can be introduced into scenarios with vendor assistance. Currently, customization of scenarios can only be done by Design Interactive. AUGMED does not integrate with outside LMS systems.

AUGMED software can be stand-alone, without connecting to cloud-based servers. Users can manually retrieve updates when the company notifies customers they are available. As a U.S. Department of Defense (DoD) system, the software has been granted a U.S. DoD Authority to Operate and Risk Management Framework Compliance certification.

Pricing and licensing depend upon agency size, contracted services, and equipment. AUGMED comes with a one-year warranty, which includes maintenance and online support. Continuing product support is available as an annual subscription.

3.3 GigXR, Inc., HoloScenarios: Basic Life Support

HoloScenarios is an AR emergency medical training solution that allows trainees to simultaneously engage with each other and holograms representing patients and equipment. From separate locations, trainees can share in these simulations wherein their collective decisions and actions impact the patient's improvement or deterioration. The simulations have many stages with branching logic that allows trainees to have varied outcomes even when playing the same scenario. Facilitators can monitor the training and alter a scenario's stages, creating hundreds of outcome permutations.

Figure 3-3 HoloScenarios: BLS Module

Image Credit: GigXR, Inc.

HoloScenarios software is completely portable and runs on either the Microsoft HoloLens 2 HMD or Android and iOS mobile devices. There are no predefined space requirements, but HoloScenarios does require an internet connection (Wi-Fi, LTE, or 5G).

GigXR currently offers three HoloScenarios; Respiratory Module, Basic Life Support (BLS) Module (see Figure 3-3) and Advanced Cardiac Life Support Module. HoloScenarios allows for a "HoloPatient" to be layered over an actual mannequin. Any mannequin can be used, and the software features sizing tools to adjust the hologram to the size of the mannequin. Trainees can interact with the HoloPatient, for example, giving it chest compressions. These AR patients also feature realistic animations that can provide intricate and subtle visual and auditory cues. The hologram patients react to trainees; for example, an AR patient can eye-track a human user's avatar. HoloScenarios software allows trainees to prescribe and administer medications, choose the right dose and delivery mechanism, and spawn medical equipment that would be expensive in real life. Digital twins of all equipment needed are included in a library of more than 100 medical tools and equipment. The user can further expand the digital twin library.

The training aims to provide learners at all levels with a realistic emergency event simulation in a safe-to-fail environment. This allows lay medics and other healthcare practitioners to review and practice their skills. In the HoloScenarios: BLS Module, trainees can use an automated external defibrillator or take a leadership role on a resuscitation team. HoloScenarios runs a custom physiological engine that corresponds to medical data. For example, when applying an oxygen mask, a user must choose the right flow rate for the oxygen or else the patient will not improve. Up to 40 trainees can collaborate on one scenario. There is an option for an instructor to participate and guide the training. Every action taken by every user in the simulation is monitored and recorded. The system tracks which tools were used and what actions users have taken.

The cost of HoloScenarios is based on how the system is hosted: either on the agency's servers or on the cloud. Costs include a one-time platform deployment fee, a fixed recurring platform hosting license, a recurring application license, a recurring fixed platform cloud-managed services fee, and a recurring fixed support fee. Information on pricing is available upon request from the company.

GigXR provides user and instructor guides, which explain how to deploy the training curriculum. GigXR also provides training on how to use their software development kit so that the user can build their own immersive applications. GigXR provides customer support by email, call back support, and scheduled meetings with an account manager from 9:00 a.m. to 8:00 p.m. Eastern time on all business days.

3.4 MedCognition, PerSim

PerSim is a prepackaged AR-based simulation tool that incorporates a holographic patient for training EMS professionals (see Figure 3-4). PerSim uses pre-scripted blocks of symptoms to be displayed by the patient avatar. Instructors can build scenarios by sequencing these blocks or creating alternate symptom branches that the instructor can trigger at the appropriate decision points.

Figure 3-4 PerSim

Image Source: MedCognition

PerSim is designed to be portable: the entire kit for one trainee fits into a single hard-sided transport case, which weighs less than 35 pounds. This allows trainees to practice patient care in any setting, including classrooms, emergency rooms, or the backs of ambulances. The only requirement is a flat space large enough to display the virtual patient. The system is completely wireless, using Microsoft HoloLens 2 HMDs. The system includes an Android-based tablet that serves as both virtual vital signs monitor and as a simulated defibrillator. No other controllers are required.

The software can map the AR patient to a mannequin to provide trainees with a physical patient with which to interact. PerSim has over 10,000 combinations of case simulations, with capabilities for team training and multi-patient training, but also allows users to create new scenarios using pre-designed tools. Trainers can use an instructor tablet to select pre-defined cases or use the tablet to build a custom scenario using the available blocks of symptoms for a variety of emergency medical conditions. There are also options for adult, pediatric, obstetric, and geriatric patients. Instructors can control various factors for each stage of the medical case, including signs like cyanotic skin, labored breathing, or sweating. Once satisfied with the case flow and symptoms, the instructor wirelessly loads the case to the trainees' AR HMDs. Trainees then interact with the holographic patient and optional mannequin to complete the training. Trainees interact with patients via voice commands, triggering feedback, such as audio of lung sounds or heart rhythms. The system does not require an electrical power source or internet access to run training sessions but does require internet connectivity to install updates and add additional medical content.

The PerSim instructor tablet has see-what-I-see capability, allowing trainers to see the trainees' viewpoint, and supports casting an HMD's view to external monitors for the benefit of other trainees. This capability requires a computer with Windows 10 and a Microsoft Display Adapter or a television capable of receiving a Miracast stream.

The PerSim system is available for purchase starting at $10,000 for one base package. Every base package includes a Microsoft HoloLens 2 HMD (additional headsets available for purchase), an Android tablet for instructor-based operations, an Android tablet for virtual patient monitoring by the trainee, a battery-powered wireless router, an equipment charging station, and a software license to manage PerSim. The base system includes male and female adult virtual patients and a broad selection of common medical conditions such as shortness of breath, seizure, chest pain, and altered mental status. A monitor-defibrillator simulator that supports advanced cardiac training is also included. The base system does not require additional fees; a PerSim Plus subscription is available, however, for advanced content like major trauma, multi-patient capability for up to four patients simultaneously, male and female models of different ethnicities, advanced adult illness, and pediatric models including neonate, infant, and school-age children.

3.5 ARCortex, Emergency Response Information System (ERIS)

ERIS is an AR situational awareness training and/or operational solution for firefighters. ERIS can provide 3D mapping and scene intelligence to commanders while enroute and on scene. ERIS allows commanders to track personnel, visualize the area, and display building information. The system's AR overlay shows the location of firefighters, building floor plans, and internet of things data from sensors to provide information on interior conditions. ERIS's AR overlay can be displayed on smartphones and tablets (both Android and iOS) or via AR HMDs.

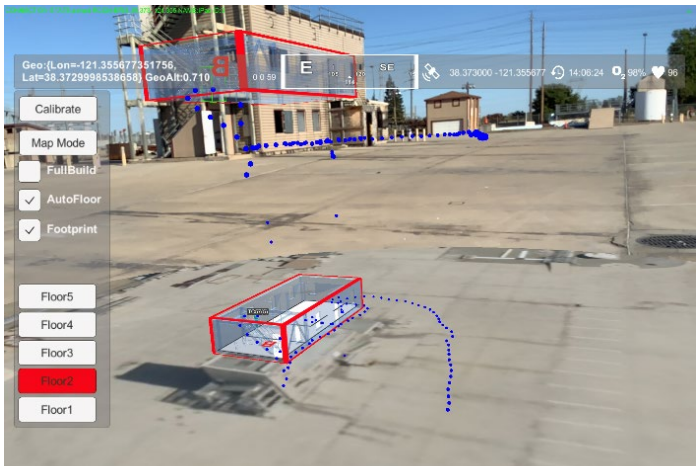


Figure 3-5 ERIS

Image Credit: ARCortex

ERIS can also simulate real emergencies for training and has four types of AR training scenarios: fire, flood, transit, and active shooter. ERIS training includes for virtual victims as well as simulations of smoke and fire propagation. Buildings and areas can be viewed in first-person AR View or in "model view," which allows a 3D model of the building or area to be rotated and viewed from any angle. Multiple users can see the same content from their own perspective. Up to 16 users can collaborate in a scenario. Scenario editing and customization, including adding 3D maps and objects, can be done either by ARCortex or the end-user via the "scenario editor." ERIS does not currently integrate with LMS but does allow for an instructor to participate in the training and make training injects.

ARCortex can package hardware and software together or can provide software to agencies that have the appropriate AR hardware. ERIS runs on AR-capable smartphones, tablets, and AR HMDs. ERIS currently supports Lenovo A3, Microsoft HoloLens, and Magic Leap 2 AR HMDs. ARCortex can add other OpenXR compatible headsets for an additional cost, if needed. Information on pricing, warranty, and customer support, is available from the company upon request.

3.6 JHB Group, FiAR Fire Extinguisher Training System

The FiAR Fire Extinguisher Training System is a fully interactive training system that integrates AR technology with a physical fire extinguisher to create customizable real-world training scenarios with varying physical information for fire extinguisher types, fire types, fire behavior, and participant movement The FiAR system uses a physical fire extinguisher to provide realistic weight, hand placement, and actions during training.

Figure 3-6 FiAR Fire Extinguisher Training System

Image Credit: JHB Group

The FiAR system is fully portable and can be set up in less than one minute. No headsets are associated with FiAR. Visualization of the scenario with control and tracking of extinguisher deployment are conducted through the FiAR fire extinguisher hardware and extinguisher-mounted Apple iPad. Scenario setup can be done by using the quick start scenarios, which use provided magnetic QR codes for various types of fires, or full scenario setup and mapping on the FiAR iPad app. Scenarios can be customized by using the iPad Pro's lidar to create a 3D map of the training space, adding a fire by size and type, and/or dropping in selected 3D objects. The FiAR application offers see-what-I-see capability, but the app cannot be guided by an instructor and allows only one trainee to use the system at a time. FiAR does not integrate with LMS but provides a scorecard with feedback at the end of each scenario.

The FiAR Fire Extinguisher Training System is on the General Services Administration (GSA) Schedule (47QSWA20D000N) for $13,842 and includes the FiAR Fire Extinguisher, iPad Pro, proprietary FiAR app, carrying case, shear pins, and QR code magnets for quick start training. FiAR is compliant with Section 899 of the NDAA. The FiAR Fire Extinguisher Training System comes with a one-year warranty and 24/7 phone and web technical support.

3.7 Avrio Analytics, AR Police and Fire Training Solution

The AR Police and Fire Training Solution provides scalable AR training for high-risk/low-occurrence events faced by first responders. The Avrio platform can be set up in minutes and incorporates real-world surroundings into training scenarios. Avrio scenarios can transition from strategic policy-level training to tactical drills or dress rehearsals. Avrio can use multiple types of AR headsets, Android phones or tablets with at least 4 GB memory or Windows computers with at least 16 GB memory. Avrio currently supports the Magic Leap 1, Magic Leap 2, HTC XR Elite and Pico 4 AR HMDs.

Figure 3-7 Size-up 360's, First On-Scene

Image Credit: Avrio

Avrio COTS AR-based training scenarios are designed for both law enforcement and fire departments, with several applications used across both groups. "StratScape" is Avrio's tabletop exercise (TTX) application used by fire, police, and emergency management. Fire-specific training includes "Size-up 360" (see Figure 3-7)- and "Triage Trainer." Police-focused training includes active shooter and de-escalation training (see Figure 3-8). Participant profiles in the active shooter training can be modified to allow fire and EMS response to train on the same incident. The active shooter training and TTX scenarios can also be modified to add hazmat response.

Figure 3-8 Avrio Active Shooter

Image Credit: Avrio

By using AR, TTX exercises can address situational awareness through immersive 3D scenarios, realistic simulations, and adapting participant information based on role to enhance responder communication. The AR allows elements of real life human-to-human interactions to be maintained (such as body language), while also supporting the participation of remote participants. The Rescue Taskforce/Active Shooter scenario allows responders to tactically train in the locations that first responders might be called upon to protect.

The Size-up 360's "First On-Scene" AR training allows firefighters to practice reporting and scene assessment skills using AR and physically accurate scenarios. The de-escalation AR training scenarios use AI NPCs and natural language processing to remove the limitations of branch-based scenarios, instead allowing for tens of thousands of training iterations without ever seeing the exact same context twice.

Avrio, a third-party vendor, or the user can customize Avrio training parameters, scenarios, maps, and objects. Digital twins can be added using smart phones or other scanning technology to upload images to the system server (which is user controlled and requires no vendor intervention). Users can interact with real physical objects (e.g., doors and tools) alongside virtual objects. Bluetooth weapon attachments, less-lethal weapons and other tools are also available to be used with the system. Fifty or more users can collaborate in scenarios without the need for all users being co-located. Remote users are represented with avatars for collaboration with those trainees who are physically onsite in the AR environment. The training simulations change and adapt through Avrio's AI NPC technology. Avrio scenarios are supported by fire physics, radiation physics, and real-time cognitive analysis to adapt content dynamically to the individual trainees.

An instructor can guide the training but is not required. All scenarios are fully interactive with AI-based feedback that considers all users actions and interactions in forming the outcome. The see-what-I-see function allows for both live and recorded monitoring and critiques of training sessions. The training system displays and tracks objective performance metrics, such as shots fired, actions taken, time to complete, and tactical movements. Avrio Analytics supports LMS integration.

Avrio's product is completely portable and can be set up in 2 to 10 minutes. The training room must be illuminated to a moderate level. Avrio needs a minimum space of 25 ft^2 and can accommodate a maximum training area of around 10,000 ft^2. A computer is included with the system as well as the other hardware and software necessary for creating new content. The Avrio system with two HMDs and the instructor system fits in a carry-on-bag-sized Pelican case.

Avrio is a stand-alone application that does not need to be connected into agency networks. A lease agreement for software for up to 1,000 users is $7/user per month and includes 10 Magic Leap 2 headsets. Additional headsets can be added at an additional cost. The lease covers headset access for all users, all user access to computer TTX applications, one instructor tablet, Pelican cases, agency documents, an in-person train-the-trainer session, a walkthrough of the platform for custom content creation and the uploading of all agency-supplied 3D CAD files. Customer service is included, as are system updates and device warranties. Customer service hours are available from the company upon request.

3.8 InVeris Training Solutions, SRCE

The Simulated Reality for Collective Experience (SRCE) tactical AR training program is designed for law enforcement agencies. It enables users to engage in high-repetition training scenarios and mission simulations in 3D with after-action review (AAR) and performance assessment features.

SRCE allows interactive training and mission rehearsals to take place between users in various locations and during short windows of training opportunity. The system uses wired HMDs but supports free movement via user-worn backpack computers. Body-worn sensors monitor a trainee's heart rate, breathing, gaze, and other biological signs in real time. Up to four users can simultaneously participate and interact in a scenario.

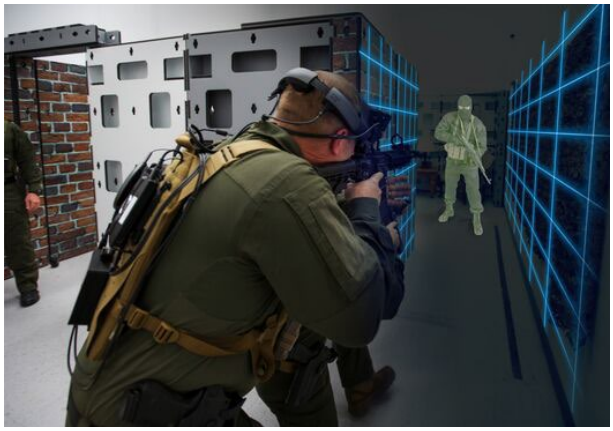
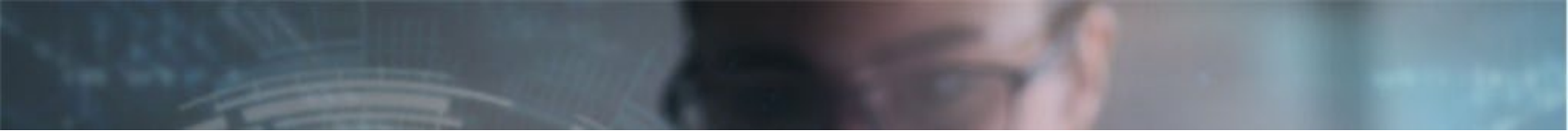


Figure 3-9 SRCE

Image Credit: InVeris Training Solutions



Trainees have a view of their actual physical environment; however, hostile suspects, decoys, hostages, and other individuals are all delivered digitally through AR. The system's Magic Leap 2 AR headsets allow users to see their own hands, weapons, teammates, and surroundings while incorporating computer-generated elements such as virtual avatars and obstacles. Instructors can control interactive avatars, providing new scenarios each time by moving them within the scanned environment. Avatars can be modified based on age, sex, race, body type, and clothing style.

The SRCE system is designed to be flexible and portable. SRCE's standard package is optimized for tactical shoot-houses but can be customized to any indoor training facility, supporting areas up to 100 ft × 100 ft. SRCE also allows mission rehearsals in actual target locations (schools, arenas, government buildings, etc.) or digital twin environments, which can be created through near real-time scanning and replication technology using a tablet or other device with a high-resolution camera. The environments can be customized to emphasize specific training techniques or scenarios. SRCE comes with "BlueFire" AR-platform M4A1 carbine kits, and has available optional Glock 17 or Sig Sauer M17, M18, or P320 pistols. These weapons are air-powered and feature recoil, magazine replacement, weapon cant (the angle at which the weapon is being held) sensing, lock-back, and instructor-controlled simulated failures.

Trainees and instructors can be geographically separated but still interact via internet connection as if they were together. SRCE supports see-what-I-see monitoring and multi-viewpoint AAR, allowing instructors and trainees to assess individual and team performance during and after a training session. Trainees can walk through previous sessions, seeing every element played back around them as a visualization to review operational performance. The system records and assesses various performance metrics, including shot placement and eye, head, and muzzle tracking.

SRCE comes with a four-person team kit, which includes an Instructor Operator Station comprising a laptop, a calibration wand, proprietary location scanning software, and a network/wireless router. Large training areas may require a mesh network with additional wireless hotspots/routers, which are sold separately. The four-person team kit also includes a travel case that holds four AR HMDs with tracking cameras and four fully equipped AR tactical kits, each with a compact wearable micro-PC, a networking hub and a USB rechargeable battery power pack. The battery packs support up to eight hours of training time. SRCE also includes two spare trainee kits, including two HMDs with tracking cameras and two fully equipped AR tactical kits, to allow for successive training and battery charging. The four-person team system also comes with four USB weapon dongles, four infrared weapon trackers, and four weapons (choice of pistols or rifles). A one-year warranty is included. A recurring warranty fee and cloud access subscription fees (to access updates and upgrades, which are sold separately) are required from year two of using the system and forward. InVeris offers the optional pistols listed above as well as accessories, such as their BlueFire fill station with air tank (to support simulated weapons). InVeris is not on the GSA Schedule but is compliant with Section 899 of the NDAA. Pricing on a four-person team system varies based upon features and can range from $150,000 to $400,000.

3.9 Ti Training, RECON Simulator w/RealMax 100 AR Training Glasses

RECON simulators are COTS products designed to provide an immersive training experience for law enforcement officers through multi-screen simulations. Ti Training has added an AR component through their RealMax 100 AR Training Glasses. These HMDs do not obstruct trainees' view of the simulator screens of training environment, but adding AR elements like patrol cars, cover and concealment objects, fire, smoke, or rain to create more realistic scenarios. All RECON systems include the ability to develop custom scenarios by uploading user-produced video and designating "hit zones" on the video images.

Figure 3-10 RECON Simulator Training Solution

Image Credit: Ti Training

RECON simulators include surround sound, HD projection screens, low light and adjustable light conditions, automatic self-calibration, and environmental control options such as light bars, strobe lights, fog machines, and fans to produce wind. The RECON Core system supports up to eight screens working independently or together with a single instructor. Multiple trainees wearing AR HMDs can see both the screen-based scenario and any AR objects within their fields of view simultaneously. Users can interact with the scenarios via various simulated or real weapons, including long arms, pistols, pepper balls, batons, beanbag launchers, and conducted-energy weapons. Ti also offers the custom-built RECON SimHouse with two to 24 screens, which can be assembled in a small space or spread through a shoot house and can support either live fire or marking cartridge systems. In either configuration of the SimHouse, participants move through the reconfigurable walls of the simulator as overhead projectors turn on and display the next portion of the scenario in either that room or successive rooms.

RECON training is delivered using an LCD instructor monitor and a menu on the instructor screen. An instructor can cue events and have AR objects or avatars react to the trainees' actions in real-time. An optional return-fire cannon is also available. The instructor can track the trainees continuously via cameras that show the location of every participant in real-time. The RECON simulator's debrief features include zoom-in controls during debrief, picture-in-picture capability, a customizable trainee report generator, and slow-motion, pause, frame forward, and frame back controls for debrief replay.

The RECON Core single-screen system is portable and packs into two hard-sided cases, weighing less than 60 pounds each. The system can be set up in conference rooms or any typical classroom space with a large screen or blank wall. The RealMax 100 AR Training Glasses are wireless and self-contained, housing an internal battery and processor; they provide a 100-degree FOV through the lens and can be worn over personal eye wear. The HMDs have a battery life of up to three hours. The RECON Core system includes over 800 pre-loaded scenarios, skill-builder shooting drills, and scenario updates for the life of the system.

Ti Training offers multiple variations of the RECON system, with costs increasing as additional screens, cameras, and features are added. The three-screen RECON 180, which costs approximately $30,000, includes a professional-grade CPU and hardware, Windows OS, Microsoft Office compatibility, a lightweight flat-panel LCD instructor monitor, Ti's Scenario Creation and Editing Interface, and Ti's Instructor Interface for scenario control and debrief. The system comes with a keyboard, optical mouse, and all necessary wires, cables, and connectors, and it includes a full warranty with 24/7 technical support.

3.10 Sphere Technology Holdings, Inc., Sphere

Sphere is an AR training solution for various industries, including law enforcement, fire, and EMS (see Figure 3-12). Sphere software is designed to be hardware agnostic, supporting devices such as the HoloLens 2, Magic Leap 2, Lenovo A3, smartphones, tablets (Android and iOS), and Windows PCs. The system is portable and supports wireless and stand-alone AR devices, which enable full visibility and usability outdoors. Most of the training scenarios are available for use with HMDs, enabling trainees to view life-size content in real environments.

Figure 3-11 Sphere

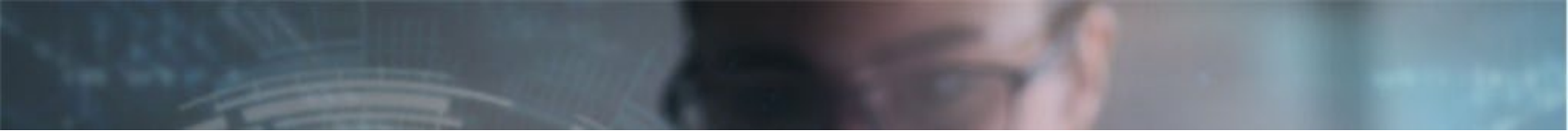
Image Credit: Sphere Technology Holding

The solution provides pre-packaged COTS scenarios that are customizable to meet specific training needs. The public safety training scenarios offered by Sphere include active shooter, public demonstrations involving violence, explosive hazard first response, and mass casualty incidents. Sphere offers training plans tailored to the customers' requests, which can be conducted online or on-site.

Sphere's AR training system allows trainees to have a see-through experience with no loss of environmental awareness. It provides the use of both real-life tools and holographic tools that can be uploaded into the environment. The system supports many digital twins file types. Digital twin content is loaded directly from the company's web management portal and can be placed in the environment using HMDs. The system enables a close-to-normal decision-making process while maintaining immersion and interaction with real-world objects. If MR devices are used, the application functions as a MR solution[6], preventing motion sickness by using external cameras on the HMD to project a real-world view into the headset. Currently, the training does not integrate AI components, but they can be added based on specific requirements.

The system supports up to 30 participants in a MR session and offers the option for instructors to participate directly in the AR experience with trainees. Fellow participants can be represented by AR avatars if not physically co-located for the training event. The system supports various types of feedback, which depend on the location and tools used for on-site training. Sphere can integrate with existing LMSs to generate detailed reports and track trainee progress.

[6] Mixed Reality (MR) is the blending of the physical and digital worlds. The main goal of MR is to combine the best aspects of VR and AR by, for example, using VR headsets that have external-facing cameras. These cameras can take imagery from the users' environment and blend it with virtual content, displaying both on the users' HMD screens simultaneously. [25]



The system's software licensing model requires AR or mixed-reality HMDs and an internet connection. The price of Sphere software depends on the number of licenses that are needed; volume discounts are possible. Sphere offers a "Ramp-up Package," which enables a department or location to use all functionalities of the software with an unlimited number of users for 6 months for a price of $2,900 per month. The company provides ongoing customer support and commits to responding to support requests within 12 hours during business hours. Warranty coverage is valid for as long as license fees continue to be paid.

4.0 MANUFACTURER CONTACT INFORMATION

Additional information on the AR training solutions for first responders included in this market survey report can be obtained from the manufacturers listed alphabetically in table 4-1.

Table 4-1 Manufacturer Contact Information

Manufacturer	Website	Address	Phone Number	Email Address/ Web Form
ARCortex	www.arcortex.com/solutions	14005 Palawan Way, #11B Marina Del Rey, CA 90292	650-714-1168	info@arcortex.com
Avrio Analytics	www.avrioanalytics.com	140 E Glenwood Ave., Unit 106 Knoxville, TN 37917	719-248-8870	info@avrioanalytics.com
BANC3, Inc.	www.banc3.com	300 Alexander Park, Princeton, NJ 08540	609-759-1900	marketing@banc3.com
Design Interactive	designinteractive.net/augmed	3501 Quadrangle Boulevard, Suite 150, Orlando, FL. 32817	407-706-0977	designinteractive.net/contact-us
GigXR, Inc.	www.gigxr.com	1318 Pacific Avenue Venice, CA 90291	626-893-4228	support@gigxr.com
InVeris Training Solutions	www.inveristraining.com	296 Brogdon Road Suwanee, GA 30024	(800) 813-9046	its-marketing@inveristraining.com
JHB Group, Inc.	www.jhbgroup.org	8545 Pyott Road Lake In The Hills, IL 60156	657-667-3473	team@jhbgroup.org
MedCognition	medcognition.com	1305 E. Houston Street Suite 401 San Antonio, TX 78205	210-960-0930	sales@medcognition.com

Manufacturer	Website	Address	Phone Number	Email Address/ Web Form
Sphere Technology Holdings, Inc.	sphere.tech	333 W San Carlos Street San Jose, California 95110	669-350-9306	sphere.tech/contact-us
Ti Training	titraining.com	4680 Table Mountain Drive, Suite 150, Golden, CO 80403	800-634-1936	info@titraining.com
Vizitech USA	www.vizitechusa.com	103 East Sumter Street, Eatonton, GA 31024	706-749-8099	csr@vizitechusa.com

5.0 CONCLUSIONS

Emergency response agencies use AR training systems to train responders in routine, dangerous, or uncommon situations in a realistic, safe, and cost-effective manner. AR training systems for first responders require both hardware and software. Hardware may include smartphones, tablets, and/or AR HMDs, and possibly a separate computer system, controllers, and other accessories. AR software integrates the hardware and accessories with training scenarios to produce AR training content. AR training systems for first responders may be COTS, customized COTS, or custom-built training products. (Most companies that produce COTS training products also customize their training products and can produce custom training.) COTS AR training systems can also give agencies an opportunity to evaluate the potential benefits of using AR operationally.

AR training software can provide first responders with the ability to safely learn and practice skills in a controlled, immersive, and interactive environment. AR training can be cost and time effective, scalable, easily accessible, variable, customizable. These products can be used to record and improve trainee performance. This report examines the commercially available training systems and identifies 10 products ranging in prices that vary, widely based upon quantity and type of hardware included, software licensing, number of users, number of scenarios included, and customization. The products described in this report provide a wide variety of training experiences for police, fire, and EMS. While some of these products can be customized to meet an agency's particular training needs, specialized or agency-specific training may need to be custom-built. Prior to incurring the costs of custom systems, these COTS products may allow an agency to evaluate how AR training fits into their training plan in terms of effectiveness, acceptance, cost, and deployment.

The purpose of this market survey is to provide emergency response agencies with information that will guide them in making operational and procurement decisions. Public safety agencies should consider the overall capabilities, technical specifications, and limitations of AR training systems in relation to their agency's operational needs when making equipment selections. The performance of these products and information included in this report has not been independently verified by the SAVER program. Agencies should also consider impacts associated with integrating VR equipment into their information technology infrastructure, data management processes, equipment maintenance cycles, and LMSs.

Appendix A. STANDARDS RELEVANT TO AUGMENTED REALITY

1. ISO/IEC 18038:2020, *Information Technology - Computer Graphics, Image Processing and Environmental Representation - Sensor Representation in Mixed and Augmented Reality* [10]

   This document defines the framework and information reference model for representing sensor-based 3D mixed-reality worlds. It defines concepts, an information model, architecture, system functions, and how to integrate 3D virtual worlds and physical sensors to provide mixed-reality applications with physical sensor interfaces. It defines an exchange format necessary for transferring and storing data between physical sensor-based mixed-reality applications.

   This document specifies the following functionalities:
   a) Representation of physical sensors in a 3D scene
   b) Definition of physical sensors in a 3D scene
   c) Representation of functionalities of each physical sensor in a 3D scene
   d) Representation of physical properties of each physical sensor in a 3D scene
   e) Management of physical sensors in a 3D scene
   f) Interface with physical sensor information in a 3D scene

2. ISO/IEC 23000-13:2017 [INCITS/ISO/IEC 23000-13:2017 (2021)], *Information technology - Multimedia application format (MPEG-A) — Part 13: Augmented reality application format* [11]

   This document specifies:

   a) Scene description elements for representing augmented reality content.

   b) Mechanisms to connect to local and remote sensors and actuators.

   c) Mechanisms to integrate compressed media (image, audio, video, graphics).

   d) Mechanisms to connect to remote resources such as maps and compressed media.

3. ISO/IEC TR 23843:2020, *Information technology for learning, education, and training — Catalogue model for virtual, augmented, and mixed reality content* [12]

   This document describes how to search for VR, AR, and MR content through a curriculum catalogue based on curriculum and achievement standards information.

4. ISO/TS 9241-430:2021, *Ergonomics of human-system interaction — Part 430: Recommendations for the design of non-touch gestural input for the reduction of biomechanical stress* [13]

   This document provides guidance on the design, selection and optimization of non-contacting hand and arm gestures for human-computer interaction. It addresses the assessment of usability and fatigue associated with different gesture set designs and provides recommendations for approaches to evaluating the design and selection of gestures. This document also provides guidance on the documentation of the process for selecting gesture sets.

   This document applies to gestures expressed by humans. It does not consider the technology for detecting gestures or the system response when interpreting a gesture. Non-contacting hand gestures can be used for input in a variety of settings, including the workplace or in public settings and when using fixed screens, mobile, VR, AR, or MR devices.

5. ISO/IEC 18039:2019, *Information technology — Computer graphics, image processing and environmental data representation — Mixed and augmented reality (MAR) reference model* [14]

   This document defines the scope and key concepts of MAR, the relevant terms and their definitions and a generalized system architecture that together serve as a reference model for MAR applications, components, systems, services, and specifications. This architectural reference model establishes the set of required sub-modules and their minimum functions, the associated information content, and the information models to be provided and/or supported by a compliant MAR system.

   The reference model is intended for use by current and future developers of MAR applications, components, systems, services, or specifications to describe, compare, contrast, and communicate their architectural design and implementation. The MAR reference model is designed to apply to MAR systems independent of specific algorithms, implementation methods, computational platforms, display systems and sensors or devices used.

   This document does not specify how a particular MAR application, component, system, service, or specification is designed, developed, or implemented. It does not specify the bindings of those designs and concepts to programming languages or the encoding of MAR information through any coding technique or interchange format. This document contains a list of representative system classes and use cases with respect to the reference model.

6. ISO/IEC 18040:2019, *Information technology — Computer graphics, image processing and environmental data representation — Live actor and entity representation in mixed and augmented reality* [15]*:*

   This document defines a reference model and base components for representing and controlling a single live actor and entity (LAE) or multiple LAEs in an MAR scene. It defines concepts, a reference model, system framework, functions and how to integrate a 2D/3D virtual world and LAEs, and their interfaces, to provide MAR applications with interfaces of LAEs. It also defines an exchange format necessary for transferring and storing LAE-related data between LAE-based MAR applications.

7. ISO/IEC 18520:2019, *Information Technology - Computer Graphics, Image Processing and Environmental Data Representation - Benchmarking Of Vision-Based Spatial Registration And Tracking Methods For Mixed And Augmented Reality (MAR)* [16]

   This document identifies the reference framework for the benchmarking of vision-based spatial registration and tracking (vSRT) methods for MAR.

   The framework provides typical benchmarking processes, benchmark indicators and trial set elements that are necessary to successfully identify, define, design, select and apply benchmarking of vSRT methods for MAR. It also provides definitions for terms on benchmarking of vSRT methods for MAR.

   Additionally, this document provides a conformance checklist as a tool to clarify how each benchmarking activity conforms to this document in a compact form by declaring which benchmarking processes and benchmark indicators are included and what types of trial sets are used in each benchmarking activity.

8. ISO/IEC 23488:2022, *Information technology - Computer graphics, image processing and environment data representation - Object/environmental representation for image-based rendering in virtual/mixed and augmented reality (VR/MAR)* [17]

This document specifies an image-based representation model that represents target objects/environments using a set of images and optionally the underlying 3D model for accurate and efficient objects/environments representation at an arbitrary viewpoint. It is applicable to a wide range of graphic, VR and MR applications which require the method of representing a scene with various objects and environments.

9. ISO/IEC TS 23884:2021, *Information technology — Computer graphics, image processing and environmental data representation — Material property and parameter representation for model-based haptic simulation of objects in virtual, mixed, and augmented reality (VR/MAR)* [18]

   This document specifies physical and material parameters of virtual or real objects expressed to support comprehensive haptic rendering methods, such as stiffness, friction, and micro-textures. It supplements other standards that describe scene or content description and information models for VR and MR, such as ISO/IEC 19775 and ISO/IEC 3721-1.

10. IEEE 1589-2020, *Standard for Augmented Reality Learning Experience Model* [19]

    This standard defines two description languages for expressing AR learning experiences. This document shows how to represent activities conducive to developing or upgrading knowledge, skills, abilities, and other characteristics in a standardized interchange format. The interchange format links the representation of learning activities with their environment and context in the actual (or simulated) workplace, classroom, or other environment in which an AR-enhanced training system may execute them. The specification aims to lower entry barriers for authoring of learning experiences that involve interaction with the real world, sensors, computer vision, and web applications.

    This standard for augmented reality learning experience models (ARLEMs) provides an overarching integrated conceptual model and the corresponding data model specifications for representing activities, learning context, and environment (aka “workplace”), while linking with other data model components needed for AR-enhanced learning activities.

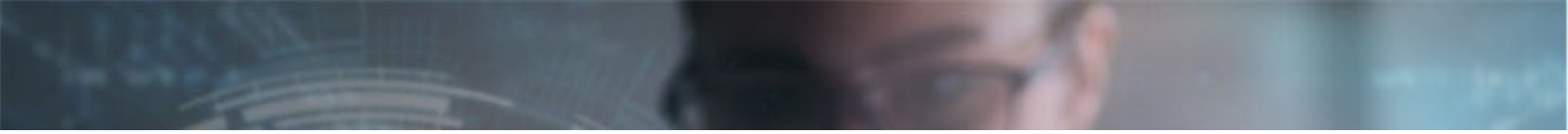
    The standard distinguishes slow-changing data for environment description from fast-changing data for step-by-step guidance. It defines the required data models and modeling languages and their bindings to Extensible Markup Language (XML; see XML 1.0) and JavaScript Object Notation (JSON; see ECMA-404).

    The purpose of this standard is to support the discovery, retrieval, transfer, and execution of AR-enabled learning content, thereby facilitating the creation of repositories and online marketplaces.

    Finally, the standard supports reuse and repurposing of existing (learning) content in “mixed” experiences that combine real-world guidance with traditional media such as instructional video material or existing web applications and widgets.

11. ANSI/CA/UL UL8400, *the Standard for Virtual Reality, Augmented Reality and Mixed Reality Technology Equipment* [20]

    This is a standard for the “safety of electrical and electronic equipment within the field of virtual reality, augmented reality and mixed reality technologies.” In addition to general product safety requirements, it also includes requirements related to see-through visual functions, flicker, skin compatibility, exposure of the eyes to thermal energy, biomechanical stress, mechanical robustness, enhancing spatial perception, safety and warning instructions, and functional safety.



12. Consumer Technology Association (CTA), CTA-2069-A, *Definitions and Characteristics of Augmented and Virtual Reality Technologies* [21]

13. ANSI/CTA-2087, Recommendations and Best Practices for Connection and Use of Accessories for XR Technologies [22]

    This document explores XR hardware accessories and their connections. The goal is to agree on common terminology and definitions for XR hardware accessories on a common connectivity standard, including device compatibility.

14. CTA-2013, *Best Practices for Diversity in XR* [23]

    This standard will establish a list of criteria that will provide considerations for the XR industry to build an ecosystem of content, hardware, and software to advance diversity and inclusion.

6.0 REFERENCES

[1] R. Delwo, "How Augmented Reality Headsets Work: Diving into Different Optical Designs," 8 May 2018. [Online]. Available: https://medium.com/@RDelly/how-augmented-reality-headsets-work-diving-into-different-optical-designs-50d6240933ef.

[2] N. C. Hughes, "Are AR glasses destined to replace smartphones?," Cybernews, 27 January 2023. [Online]. Available: http://www.cybernews.com/editorial/are-ar-glasses-destined-to-replace-smartphones. [Accessed May 2023].

[3] K. Jackson, "Meta to Release AR glasses in 2027, Report Said," CNET, 2023 March 1. [Online]. Available: https://www.cnet.com/tech/meta-will-reportedly-release-ar-glasses-in-2027. [Accessed May 2023].

[4] T. Sluka, "5 ways to Address AR's Vergence Accommodation Conflict.," AR Insider, 22 June 2022. [Online]. Available: https://arinsider.co/2022/06/22/5-ways-to-address-ars-vergence-accommodation-conflict. [Accessed May 2023].

[5] S. Stein and Q. Wong, "How Facebook Plans To Blend the Virtual and Real with Your Wrist," CNET, 18 March 2021. [Online]. Available: https://www.cnet.com/science/how-facebook-plans-to-blend-the-virtual-and-real-with-your-wrist. [Accessed May 2023].

[6] J. Kastrenakes, "Humane's new wearable AI demo is wild to watch – and we have lots of questions," The Verge, 9 May 2023. [Online]. Available: https://www.theverge.com/2023/5/9/23716996/humane-wearable-ai-tech-demo-ted-video. [Accessed May 2023].

[7] "New Standard Helps Guide Safe Development of Virtual Reality, Augmented Reality and Mixed Reality Devices," UL Standards & Engagement, 28 April 2023. [Online]. Available: https://ulse.org/news/new-standard-helps-guide-safe-development-virtual-reality-augmented-reality-and-mixed-reality. [Accessed June 2023].

[8] "The Use of Technology and HIPAA Compliance," The HIPAA Journal, [Online]. Available: https://www.hipaajournal.com/the-use-of-technology-and-hipaa-compliance. [Accessed 24 August 2023].

[9] Federal Bureau of Investigation, US Department of Justice, "CJIS Security Policy Resource Center," 14 September 2023. [Online]. Available: https://le.fbi.gov/cjis-division/cjis-security-policy-resource-center. [Accessed 15 November 2023].

[10] International Organization for Standardization., "Information Technology - Computer Graphics, Image Processing and Environmental Representation - Sensor Representation in Mixed and Augmented Reality (ISO/IEC Standard No. 18038:2020)," 04 2020. [Online]. Available: https://www.iso.org/standard/70720.html.

[11] "ISO/IEC 23000-13:2017 Information technology - Multimedia application format (MPEG-A) Part 13: Augmented reality application format," International Organization for Standardization, November 2017. [Online]. Available: https://www.iso.org/standard/69465.html. [Accessed 29 November 2023].

[12] "ISO/IEC TR 23843:2020 Information technology for learning, education and training," International Organization for Standards Catalogue model for virtual, augmented and mixed reality content, October 2020. [Online]. Available: https://www.iso.org/standard/77143.html#:~:text=This%20document%20describes%20how%20to,VR%20and%20MR%20content%20information. [Accessed 29 November 2023].

[13] "ISO/TS 9241-430:2021 Ergonomics of human-system interaction Part 430: Recommendations for the design of non-touch gestural input for the reduction of biomechanical stress," December 2021. [Online]. Available: https://www.iso.org/standard/80270.html. [Accessed 29 November 2023].

[14] "ISO/IEC 18039:2019 Information technology Computer graphics, image processing and environmental data representation Mixed and augmented reality (MAR) reference model," International Organization for Standards, February 2019. [Online]. Available: https://www.iso.org/standard/30824.html. [Accessed 29 November 2023].

[15] "ISO/IEC 18040:2019 Information technology Computer graphics, image processing and environmental data representation Live actor and entity representation in mixed and augmented reality (MAR)," International Organization for Standards, May 2019. [Online]. Available: https://www.iso.org/standard/70721.html. [Accessed 29 November 2023].

[16] "7. ISO/IEC 18520:2019, Information Technology - Computer Graphics, Image Processing and Environmental Data Representation - Benchmarking Of Vision-Based Spatial Registration And Tracking Methods For Mixed And Augmented Reality (MAR)," International Organization for Standards, January 2019. [Online]. Available: https://www.iso.org/standard/66281.html. [Accessed 29 November 2023].

[17] "ISO/IEC 23488:2022 Information technology Computer graphics, image processing and environment data representation Object/environmental representation for image-based rendering in virtual/mixed and augmented reality (VR/MAR)," May 2022. [Online]. Available: https://www.iso.org/standard/75718.html. [Accessed 29 November 2023].

[18] "Information technology — Computer graphics, image processing and environmental data representation — Material property and parameter representation for model-based haptic simulation of objects in virtual, mixed, and augmented reality (VR/MAR)," International Organization for Standards, December 2021. [Online]. Available: https://www.iso.org/standard/77278.html. [Accessed 29 November 2023].

[19] "IEEE 1589-2020, Standard for Augmented Reality Learning Experience Model," Institute of Electrical and Electronics Engineers, 17 April 2020. [Online]. Available: https://standards.ieee.org/ieee/1589/6073/. [Accessed 29 November 2023].

[20] "ANSI/CA/UL UL8400, the Standard for Virtual Reality, Augmented Reality and Mixed Reality Technology Equipment," ANSI, 2023. [Online]. Available: https://webstore.ansi.org/standards/ul/ansiul84002023. [Accessed 29 November 2023].

[21] "Definitions and Characteristics of Augmented and Virtual Reality Technologies (CTA-2069-A)," Consumer Technology Association, [Online]. Available: https://shop.cta.tech/products/definitions-and-characteristics-of-augmented-and-virtual-reality-technologies. [Accessed 29 November 2023].

[22] "Recommendations and Best Practices for Connection and Use of Accessories for XR Technologies (ANSI/CTA-2087)," Consumer Technology Association, December 2019. [Online]. Available: https://shop.cta.tech/products/recommendations-and-best-practices-for-connection-and-use-of-accessories-for-xr-technologies. [Accessed 29 November 2023].

[23] "Best Practices for Diversity in XR (CTA-2103)," Consumer Technology Association, November 2022. [Online]. Available: https://shop.cta.tech/products/best-practices-for-diversity-in-xr-cta-2103. [Accessed 29 November 2023].

[24] D. Purves, G. Augustine and D. Fitzpatrick, "Types of Eye Movements and Their Functions," Sinauer Associates, 2001. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK10991 [Accessed 14 November 2023].

[25] "Virtual Reality Augmented Reality and Artificial Intelligence Wiki," 22 March 2015. [Online]. Available: https://xinreality.com/wiki/Mixed_Reality#cite_ref-.E2.80.9D1.E2.80.9D_1-0. [Accessed 28 November 2023].

[26] "8. ISO/IEC 23488:2022, Information technology - Computer graphics, image processing and environment data representation - Object/environmental representation for image-based rendering in virtual/mixed and augmented reality (VR/MAR)," International Organization for Standards, May 2022. [Online]. Available: https://www.iso.org/standard/75718.html. [Accessed 29 November 2023].

[27] "Recommendations and Best Practices for Connection and Use of Accessories for XR Technologies (ANSI/CTA-2087)," Consumer Technology Association, December 2019. [Online]. Available: https://shop.cta.tech/products/recommendations-and-best-practices-for-connection-and-use-of-accessories-for-xr-technologies. [Accessed 29 November 2023].