Augmented Reality for Skills Training: Industry Examples and a Combat Medic Use-Case

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ABSTRACT

Modern augmented reality (AR) is typically delivered via two categories of devices, Head Mounted Displays (HMDs) and mobile devices. Both modalities focus on processing the user's environment for realistic augmented object rendering and positioning. Mobile devices process the camera image in real time for predefined markers, dynamic surfaces, and lighting. HMDs such as HoloLens construct low-fidelity 3D models of its surroundings using depth cameras. We prototyped the use of both of these AR methodologies in Tactical Combat Casualty Care (TC3) skills training to demonstrate proof of concept. Because Marker-based mobile AR requires relatively simple image processing, it can run on most commercial mobile devices. We created a marker-based application providing didactic demonstrations of combat-medic procedures through videos and 3D models. When the user's phone or tablet camera recognizes a physical marker, it renders a video or model onto the marker. Marker-based AR limits the user's interaction with the environment with a clear divide between the real and augmented. As an example of high resource intensive AR mediums, we developed a HoloLens application that renders a scene with a patient and medical instruments in an optimal, fixed position in the user's environment. The user can navigate the application through a defined set of spoken commands and apply a learned medical procedure by selecting a tool and a region of the patient. HoloLens provides a dynamic platform with natural interaction that visually blends the real and augmented within the scene. In this paper we discuss design considerations when deciding on the appropriate AR modality for training applications and our teams specific experience with deploying both of these AR modalities in a combat-medic training use-case.

ABOUT THE AUTHORS

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INTRODUCTION

Since their introduction, Tactical Combat Casualty Care (TC3) protocols have had a profound effect on the survivability of severely wounded war fighters (Kotwal et al. 2013). Combat Life Saver training along with advances in Tactical Field Care (TFC) training and equipment have greatly reduced the number of preventable battlefield deaths (Eastridge et al. 2012), and allow combat medics to perform increasingly complex procedures as part of TFC. These skills are desperately needed because treatment time is commonly measured in minutes and evacuation time in heavy combat areas can still sometimes be measured in hours (Kotwal et al. 2013).

While TC3 medical training mannequins have provided valuable hands-on training, TC3 classroom settings in the field they are not always available, can be difficult to maintain, and place limits on the number of trainees that can access limited physical devices. Moreover, an analysis of a Tactical Combat Casualty Care course at the Naval Medical Center Portsmouth (NMCP) found mannequin anatomical landmarks are not always pronounced, which is a grave deficiency in many medical procedures such as cricothyroidotomy (CRIC). The NMCP working group found "Very poor anatomical landmarks (e.g., thyroid notch, thyroid cartilage, CM, cricothyroid cartilage) across all airway mannequins reviewed." (Bennett, Cailteux-Zevallos, & Kotora, 2011). Augmented reality holds the potential to provide additional methods for TC3 instructors to enhance medic training and fill these training deficiencies.

While Augmented Reality (AR) has shown to provide engaging and promising learning experiences within civilian applications of the technology (Tang et al., 2003; Yoon et al, 2017), there are limited comparable research studies involving similar applications within military training programs. Moreover, few Training Effectiveness Evaluations (TEEs) have been conducted to date to systematically evaluate AR's role in military training, and those that have been performed have produced mixed results (Livingston et al., 2005; Livingston & Ai, 2008; Champney et al., 2015). Thus, more research is needed to translate growing success in the use of AR for commercial applications to those in the military.

AR BACKGROUND

Put generally, AR is the augmentation of the real world with digitally-generated sensory inputs – ranging from audio to visual stimuli – that provide an enhanced perceptual view of the real-world. Regardless of the specific AR use-case, the primary requisites to apply the technology can be distilled down to four essential elements:

- Computing device: required to compute and manage a virtual visual scene that can be correlated to a real-world view that must take into account the position of the observer with respect to the scene;
- Tracking system: required to obtain and record the user position and orientation in space to properly align the virtual scene onto the real-world image, in a process termed pose estimation;
- Display device: his is used to render the composited scene to the observer, can take the form of a mobile computing device such as a phone or tablet, or a Head Mounted Display (HMD) such as the MS HoloLens by Microsoft (MS); and
- Control devices: although optional, many AR applications include hardware-based control devices that enhance the user experience, such as the HoloLens remote.

Using these elements, AR systems superimpose computer generated images, such as graphics and text, onto objects in the real world. AR has been increasingly leveraged for a variety of purposes, ranging from recreational applications that help guide patrons through amusement parks to sophisticated applications that help surgeons perform complex surgical procedures more safely. AR can be a powerful visualization enhancement tool, providing a range of potential benefits across of range of industries.

Examples of AR Implementation in Medical Skills Training

Augmented reality can provide virtual models along with realistic visual and tactile feedback in the training of cognitive skills required for effective decision making, and psychomotor skills such as cutting, grasping, needle insertion, suturing, and direct manipulation of the patient (e.g., palpation, checking for a pulse). Moreover, as Mazurek and Burgess (2006) point out, decisions regarding casualty treatment are made based not only on the special knowledge of injuries but also on the understanding of the environment, current location, resources available and other 'meta-factors'. Thus, leveraging all aspects of augmented reality technology – including mixed-reality aspects such as haptics and audio – has the potential to reinforce learning beyond those that visual AR depictions alone can provide.

For example, the applicability for using AR to train lay-persons in the procedure for administering an ECG test was demonstrated out of the University of Naples, Italy. Their AR system visually guided learners through the structured procedures for applying leads and collecting ECG data. This system worked with both medical training mannequins as well as live standardized patients. Results showed promise, as results for subjects (n=7) demonstrated that they were able to apply and administer the test within 8 minutes and with acceptable accuracy (3mm-7mm) (Bifulco et. al., 2014).

Figure 1. AR to Train ECG Test Procedures

Also in the medical field, AR has been used for skill-acquisition of surgical skills, such as laproscopic surgery. A pilot study showed a reduction in procedure completion time by providing visual information that provided depth and spatial information to the learner (Wagner & Rozenblit, 2017).

A study to examine the potential for AR and VR to be used to train structural anatomy examined three variants of delivery including AR, VR (using the Oculus Rift), and a tablet to determine if these modes enhanced student learning. While there were no statistical differences in post-test scores nor, participant feedback indicated high levels of engagement with the material (Moro et al., 2017).

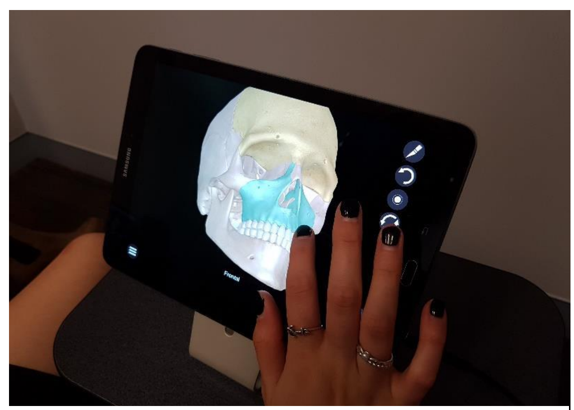

Figure 2. AR Example of Anatomy Training

A study to examine novelty and retention of AR learning systems (Smith & Keebler, 2014) was conducted that exposed participants to three variants of anatomical structures of the human heart, including: AR with labels, AR with no labels, and the control condition of a traditional physical human heart model. Overall, results indicated that participants reported that the AR variants were more enjoyable, curiosity inducing and easier-to-use than traditional fiberglass models. Further, the use of labels in the AR-with-labels conditions boosted post-training scores.

Augmented Reality Modalities

As discussed above, AR is typically deployed via either mobile platforms or via HMDs, with various tradeoffs between these platforms. For mobile AR, hardware costs are low, but devices provide minimal blending between real and virtual objects. With HMD AR, hardware is uncomfortable and expensive, but virtual objects blend seamlessly with the real world. When considering which deployment modality to choose for a given AR application, designers must weigh learning objectives, resources, and options carefully when building AR applications. These AR modalities are described and analyzed in the following subsections.

Marker-Based Mobile AR

Marker-Based Mobile Augmented Reality (MB-MAR) provides a low cost solution for cases where user access is important. Users can practice outside the classroom with virtually any smartphone or tablet device. MB-MAR works by processing the device's camera stream for a specified image (i.e., a fiducial marker). When the image is detected, a virtual object appears on the camera display over the image marker, matching the pose (i.e., orientation of the user and the virtual objects to be projected onto the real-world scene) to the marker. As the image moves and rotates within the real world, the virtual object continues to match its pose. A marker can be printed onto paper or displayed on a second device. The natural interaction of manipulating the marker allows the user to focus on the training material and less on application interaction.

Because MB-MAR virtual objects are tied to markers existing in the physical world, application designers only have to consider object placement relative to the marker and do not have to worry about factors such as cluttering or occlusion. However, designers should be aware that most marker tracking software limits simultaneous tracking to five or six images.

Marker tracking quality highly depends on the image characteristics, typically requiring high-contrasting edges rather than round edges and non-repeating patterns. If application designers expect close inspection of 3D models within the application, the following design considerations will make the experience as smooth as possible:

- A variety of factors influence AR performance such as the choice such as marker tracking software used, available device sensors such as the gyroscope, and computational power of the device, marker tracking performance will vary, and poor performance will cause frustration with the end-user as the AR app 'loses track', causing disruption in the AR display.
- Virtual objects should roughly match the size of their respective marker images. The device will lose track of the marker if the user tries to inspect a virtual object too closely outside the bounds of the marker.
- The minimal distance between mobile device and physical marker is roughly three to four inches when using a five inch by seven inch marker. Virtually dividing the target image into smaller subsections within the software will allow a shorter minimal distance of about an inch or two. Minimal distance highly depends on the quality of the device camera and the size of the marker.

Head Mounted Display AR

Head mounted displays or AR headsets typically require computationally heavy environment tracking to build models of the environment for proper placement and lighting of virtual objects. Users wear the headset that contain a see-through heads up display. Headsets contain sensors for environment modeling, lighting modeling, gesture recognition, voice commands, and eye tracking in newer headset iterations. After the headset builds a complete model of the environment, virtual objects can be dynamically placed within environment boundaries with proper lighting and scale. Object permanence is enabled by the headset saving and recognizing environment models. Because developers have no control over the environment, the application design should consider all possible environment scenarios (e.g., elements within the environment that could move etc.).

Below we briefly enumerate some general issues and constraints with commonly available AR headsets that affect application design:

- Limited field-of-view adds frustration and difficulty for the user to find virtual objects.
- Headset ergonomics cause discomfort after long use.
- Battery life limits the amount of time the user can walk around with the headset freely.
- Hand gestures are predefined.
- Headset sensors can only track objects within line-of-sight, so the user's range of motion is limited. Users select virtual objects by rotating their heads, holding their hands within sensor range, and using the selection hand gesture; therefore, text input should be limited. As a solution, voice commands provide low error rates but requires explanation or instructions for the user to reference.

IMMERSE USE-CASE: AN AR-BASED SKILLS TRAINER FOR COMBAT MEDICS

Under the direction of the Office of Naval Research, CHI Systems in collaboration with our research partner George Mason University conducted research to establish the technical feasibility of applying augmented reality to combat medic training. Our goal was to build a foundation for the development of a pedagogically sound TC3 training system focused on instructing combat medics in levels of care that include care under fire, tactical field care, and casualty evacuation. Our vision for IMMERSE is to provide a bridge between classroom training and field (i.e., 'lane') training. The former provides didactic instruction and skills labs, and the latter presents highly immersive training but at a very high cost for a limited number of scenarios. Thus, the niche we targeted for IMMERSE was to provide a bridge between these two existing forms of training.

Our research program was divided into three consecutive phases, including (1) conducting a *domain analysis* to determine the specific set of TC3 skills which we would utilize to design and develop the initial prototype, (2) conducting a *training design* to identify the specific skills and learning objectives to be modeled in the prototype as well as the overall user experience to support those skills, and (3) *implementing* a demonstration of the prototype in order to garner feedback from stakeholders. These three phases are described below.

Domain Analysis

Early on in discussion with TC3 stakeholders, we determined that the IMMERSE system should focus on Combat Life Savers (CLSs) in addition to combat medics. A combat lifesaver is a soldier who receives focused but limited medical training to provide care to injured soldiers on the battlefield when medics are not available, or to provide support to combat medics. CLSs are trained to treat blast injuries, amputations, severe bleeding, penetrating chest injuries, and airway management. An excellent use of the envisioned augmented reality system for combat lifesavers would be to provide stress exposure training (Driskell & Johnston, 1998). Simulation-based training is lauded for many types of tasks or task components (e.g., decision making, team coordination, procedures), but criticized for lacking affective task components (e.g., fear and other stresses). Representing these types of affective task components for soldier training is viewed as critical (e.g., Russo, Fiedler, Thomas, & McGhee, 2005) and recent literature and lessons learned have emphasized the need for addressing stress in soldiers. The IMMERSE system may be helpful to introduce stressful task components to TC3 trainees, providing a form of preparatory information. Preparatory stress training introduces trainees to the stresses that they will encounter in their jobs and educates them about the physiological and mental effects of stress and has been shown to reduce the effects of stress on task performance.

Based on both our review of doctrinal training publications and discussions with stakeholders, we selected a focus on Surgical Cricothyroidotomy as our primary use-case for IMMERSE prototype. Partially informing this prioritization was recent research results from the Medical Simulation and Information Sciences Research Program (MSISRP) published by Joint Program Committe-1 which resulted from an analysis of injury patterns from Operation Iraqi Freedom (OIF) as reported in the Joint Theater Trauma Registry (JTTR). Analyses from OIF indicated that the three leading conditions attributed to preventable death on the battlefield are airway compromise, tension pneumothorax, and hemorrhage from extremity wounds (Holcomb, et al., 2007; Kelly et al., 2008). Thus, we selected Surgical Cricothyroidotomy as the primary prototype use-case.

Training Design

During TC3 training, a variety of factors come into play including cognitive, perceptual, psychomotor, affective, and attitudinal factors, which were drivers of our training IMMERSE concept. We developed a learner-centric prototype model for leveraging AR to deliver TC3 training that could be integrated with existing modalities of training. At the same time, we laid the foundation for extending this model into a more sophisticated training platform that can provide rich training that integrates cognitive, perceptual, and other training variables while also providing a platform for performance measurement and assessment.

In addition to preparatory information, AR systems can serve to enhance the capability of training programs to support advanced learning of medical skills, which is particularly important for combat medics. Advanced learning can be defined as "acquiring and retaining a network of concepts and principles about some domain that accurately represents key phenomena and their interrelationships, and that can be engaged flexibly when pertinent to accomplish diverse, sometimes novel objectives…" (Feltovich, et al., 1994). Moreover, much of military training is founded on a building block approach which often means that there is insufficient time to address more complex skills, a deficiency which has been documented during opportunities to practice advanced skills in combined arms or joint training exercises (Rasmussen & Vicente, 1989). In such cases, training often must be pared back to more basic forms of instruction because instructors find that trainees have not yet developed proficiency in prerequisite skills and knowledge. An unfortunate consequence is that personnel must learn advanced skills on the job and *during* deployments when mistakes and misconceptions are much costlier.

Thus, based on factors such as those described above, our initial training concept for IMMERSE was to enhance classroom-based training and provide a bridge between classroom training (consisting of lecture and part-task hands-on training) and realistic immersive training such as lane training and field exercises. IMMERSE can provide opportunities to experience a series of short (approx. 10-15 minutes), immersive combat scenarios that support decision making and stress management when assessing casualties and TC3 tasks such as performing tourniquet application, needle chest decompression, and airway management. The training will provide systematic exposure to relevant TC3 scenarios related to combat medic training objectives.

Our training design was focused on methods to organize and present AR-based TC3 training content. We've specifically focused on the use of Dr. David Merrill's First Principles of Instruction (FPI) (Merrill, 2002) as a method to organize IMMERSE training content. Merrill's FPI breaks up training into successive/iterative phases, based on a set of principles, the core of which is that learning should be problem-centered since learning is promoted when learners are engaged in solving real-world problems. These principles include:

- **Activation**: Learning is promoted when relevant previous experience is activated.
- **Demonstration** (Show me): Learning is promoted when the instruction demonstrates what is to be learned rather than merely telling information about what is to be learned.
- **Application** (Let me): Learning is promoted when learners are required to use their new knowledge/skill to solve problems.
- **Integration**: Learning is promoted when learners are encouraged to integrate (transfer) the new knowledge or skill, which can include exercises such as reflection.

Merrill's FPI presumes learners begin with activation of prior knowledge and proceed through successive phases, each building upon the previous ones. One of the instructional concepts developed during was the use of an advanced organizer as a means to organize TC3 content onto a physical 'smart card' by connecting it to a larger cognitive structure that reflects the organization of the training content itself (Kirkman & Shaw, 1997). The IMMERSE smart card concept provides a visual presentation of high-level training content organized according to standard TC3 training doctrine. This concept was similarly applied by Ferrer-Torregrosa (2015) to utilize AR to teach medical concepts. Additionally, the IMMERSE smart card concept serves to encode fiducial markers for the IMMERSE application to trigger AR content.

IMMERSE Implementation

For IMMERSE, the training cycle was broken up into stages reflecting Merrill's First Principles of Instruction. The activation, demonstration, and integration phases were grouped together in a marker-based mobile augmented reality application while the application phase was implemented as a head-mounted display application deployed via the . MS HoloLens.

> To master a complex problem, students must first start with a less complex problem. When the first problem is mastered, students are then given a more complex problem. Through a progression of increasingly complex problems, the students' skills gradually improve until they are able to solve complex problems. (Merrill, 2002, p 46).

While the training process was broken down into increasingly complex stages, the training material was broken up by areas of operation. Because airway obstruction is a leading cause of preventable death, and limited anatomy review materials exist (Bennett, Cailteux-Zevallos, & Kotora, 2011), we implemented the surgical CRIC procedure across training phases. Learners begin training by selecting the region of interest and thus, the specific related procedures, shown in Figure 3.

Figure 3. Beginning a Training Scenario

We developed the IMMERSE demonstration with the Unity 3D game engine. Marker tracking was implemented using Vuforia for an Android device. We used the Microsoft HoloLens for the head mounted display.

Activation Phase

"The first phase of learning a new skill should be to provide three dimensional experience that they can use as a foundation for the new knowledge; too much instruction starts with abstract representations for which learners have insufficient foundation" (Merrill, 2002). Learners build their knowledge foundation on anatomical structures during the Activation phase. When users point their mobile device's camera at a printed marker, a 3D anatomical model with reactive labels overlays the marker. The learner can actively inspect the model from many perspectives by moving and rotating the marker, allowing learners to gain better intuition on the spatial aspects of these structures, as seen in Figure 4.

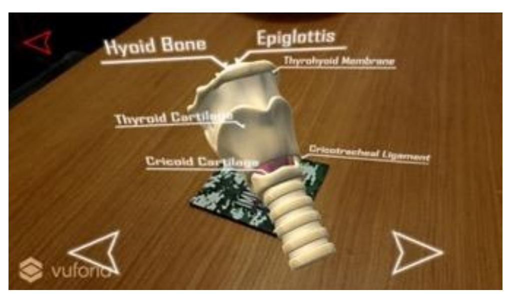

Figure 4. Virtual Anatomical Structure Overlaying a Physical Marker.

Demonstration Phase

The demonstration increases in complexity by showing how the previously learned anatomical structures fit within context and how the learner must perform a procedure. The models focus on a single region of the body, expanding the scale of the models used from the previous stage of anatomical structures. However, any close inspection of the details by the learner will happen near the focused anatomical structure, which matches the scale of the marker; therefore, the rest of the body can overflow off the marker without causing irritation to the user.

Learners can then review demonstrations related to the CRIC procedure via an interactive AR model that can be viewed from multiple vantage points, animates the procedure being performed, and allows learners to review critical aspects of the procedure. The IMMERSE demonstration also provides static demonstrations of each procedural step that the learner can access based on their instructional needs, as seen in Figure 5.

Figure 5. Reviewing Interactive AR-Based Demonstrations

Application Phase

During the application phase of training, the learner should have a strong idea on how to implement the tested procedure and be ready to demonstrate skills. By implementing the application phase in a head mounted display, we were able to add complexity by allowing learners to demonstrate their skills in a more realistic scenario. In this phase, the learner is tasked with making key decisions regarding the CRIC procedure by stepping a simulated instructor through portions of the CRIC procedure (e.g., instrument selection, step ordering) via a 3rd-person perspective demonstrated in Figure 6.

Figure 6. Hands-On Patient Treatment Using MS-HoloLens

The learner receives feedback on key steps (e.g., omission/commission). The IMMERSE application utilizes speech interaction to enable the learner to interact with the instructor through verbal commands (e.g., ‘stabilize membrane’).

Integration Phase

Finally, learners can review components of the CRIC scenario procedure and are presented with checks-on-learning, which provide an opportunity for reflection to support knowledge integration. Users are shown the key elements of procedural video/animation and given questions at each phase to assess their knowledge. If they answer correctly, they can continue forward. If not, they review the information again, as demonstrated in Figure 7.

Because soldiers may not need to use their medic skills very frequently, the integration training application needs to be easy to access. By implementing the integration phase in the marker-based mobile AR applications, users can review material at their own leisure.

Figure 7. Checks On Learning as a Reflective Exercise

CONCLUSION

IMMERSE demonstrates how to apply augmented reality across a training cycle practically, maximizing training effectiveness and minimizing cost, in the context of combat medical training. Careful consideration of each AR technology and influence on training is important when balancing effectiveness and cost. A spectrum of AR fidelity technologies exist, correlate with cost, and offer unique benefits and drawbacks. For current mainstream AR technologies, marker based mobile AR exists as the lowest AR fidelity technology while AR headsets continue to push boundaries on the high end of AR fidelity.

Marker based mobile AR is a low end AR technology where environment tracking is limited to an image existing in the physical world. Because of the limited environment information, the virtual content is limited by the bounds of the image marker. Range of distance between user device and marker determines the freedom the user has to view objects outside the bounds of the marker before the device loses track. This freedom influences the allowable scale of a virtual object. Because of these factors, marker-based mobile AR works best for beginning phases of training where the material is simple. However, any case where AR is desired and ease of access is important, marker-based AR provides the most compatibility across devices than any other AR technology.

HMD displays, on the other hand, focus on immersion and blending between the real and virtual. Scenarios can add stress to learners by dynamically creating realistic factors that affect performance. Using the combat medic examples, a headset could create a high stress scenario with open fire happening in consideration of the user's environment. AR headsets give learners the opportunity to practice their skills in realistic scenarios and collaborate together in teamwork. A teamwork testing scenario example could include multiple learners enacting an augmented scene where injuries occur during combat, forcing learners to quickly decide who gives treatment and who covers the impromptu medic during battle.

Also along the spectrum between marker based mobile AR and AR headsets is marker-less mobile augmented reality. AR enabling software exists for android and iOS that can run on devices with powerful graphics and processing. Similar to headsets, these technologies model the environment for surfaces, points of reference, and lighting. Virtual objects are dynamically placed in the environment through the camera display. These technologies unlock a significant amount of content authoring abilities compared to marker AR but lack the immersion of headsets.

Beginning stages of learning require time and careful practice for first time absorption, so learners should have access to training outside the classroom. Similarly, refresher training is important throughout the lifetime of a learner's career, so ideally learners should have access to training material at any time. However, during stages of training that need to bridge the gap between classroom and real world scenarios, realism trumps access in importance. Using Merrill's First

Principles of Instruction, IMMERSE applied marker mobile AR to activation, demonstration, and integrations phases, which represent the first phases of learning as well as a refresh phase. HMD AR technology was applied to the application phase, opening the possibilities to realistic scenario authoring.

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