Challenges of Scenario Design in a Mixed-Reality Environment

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ABSTRACT

The Infantry Immersive Trainer (IIT) is a mixed-reality training system designed to extend training capabilities for Marines across a wide range of military operations (ROMO) within a single training environment. This is accomplished with a cutting-edge mix of real and virtual technologies, with a configurable hardware and software system infrastructure, allowing training scenarios to be quickly modified to focus on different training objectives based on an incoming trainee group's specific needs and goals.

In this paper, we review our lessons learned in developing scenarios for this mixed-reality environment, In addition to traditional scenario design challenges, the experience involved new challenges focusing mainly on maintaining a realistic experience at locations where the physical system and the virtual system converged. Also, the effort involved using front end analysis to drive scenario design, early in the system development cycle, providing the opportunity for scenario design to inform the configuration of physical and virtual capabilities to support increased training value and modularity. Finally, we present a summary of our results of an initial theoretical training effectiveness evaluation for the whole system, which provides additional insights to the scenario design and system development process. We conclude with a recommended approach for future mixed-reality scenario design efforts.

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INTRODUCTION

In the spring of 2006, Lieutenant General Mattis formally recognized the need for an advanced training system that offers Marines an opportunity to become immersed in an Iraqi village without ever leaving U.S. soil (ONR, 2007). In response to this need, the Infantry Immersive Trainer (IIT) was developed. The key purpose of IIT is to allow Marines to train in a highly realistic environment to optimize their preparation time before deploying.

The system includes a cutting-edge mix of real and virtual technologies, or mixed reality (MR), that enables a wider range of military operations (ROMO) to be supported in a single training environment with increased realism. The configurable hardware and software system infrastructure enables training scenarios to be modified more quickly to focus on different training objectives based on a trainee group's specific needs and goals.

In this paper, we introduce the challenges for designing training scenarios that were encountered in creating the IIT. First, we provide a brief description of the IIT and the development process, given the unique constraints that affected scenario design.

The IIT System

Stimulating the Senses

The IIT facility was built in a large, abandoned tomato factory at Camp Pendleton. Although it is a vast and open building, when you enter the simulated town, the "roads" span about three people wide; each "road" or hallway does not go for more than twenty or thirty feet before ending at a wall of another "house." All along the roads, one-room "houses" have been constructed, with real doors and windows (see Figure 1).

Figure 1. Road within IIT

Inside, the houses are furnished with authentic furnishings, including tea sets, hookahs, and wall hangings (see Figure 2). Smells are pumped into the warehouse giving it a musky scent.

Individuals of Middle Eastern descent serve as role players. Some are stationed inside the houses as residents who might receive an unexpected visitor – the trainees (see Figure 4). Role players populate a marketplace that has been built at one end of the "town." The marketplace has several booths, citizens milling about in between booths and some calling out to passersby, trying to sell their wares. The warehouse comes alive as a mini-town direct from Iraq – from the sites, to the smells, to the faces, the Marines will enter a

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world that will introduce them to what they will encounter when deployed.

Figure 2. Room within IIT

Figure 3. Role Player within IIT

The IIT is a decision house that enables the individual Marine to significantly increase the tempo of his Observe-Orient-Decide-Act Loop (OODA Loop), the constant mental process during which a Marine is presented with a situation, develops courses of actions, makes a decision, and executes the decision. The IIT's realistic/virtual environment serves as a stress inoculation tool, designed to inoculate the Marine rifleman from the sights, sounds, smells, and chaos of close quarters urban warfare while enhancing his ability to make correct legal, ethical, and moral decisions under the stress of combat.

IIT SCENARIO DESIGN CHALLENGES

A rich simulation, whether it is physical, virtual, or mixed-reality simulation, alone is not enough to ensure effective training. An event-based approach to training (EBAT; Fowlkes, Dwyer, Oser, & Salas, 1998) is an approach to creating scenarios for training to provide opportunities to observe key behaviors explicitly linked to targeted training; additionally, linkages are made between performance measures representing trainee responses to these opportunities. An event-based approach supports presenting the appropriate content to trainees for selected training objectives.

Challenge 1: Training objective linkages

The first challenge encountered, linking training objectives to events in the scenario, is a common task in typical scenario design. In the case of IIT, making linkages was a challenge because of the wide range of training objectives (TO) the system was intended to target. The challenge focused primarily in identifying how target TOs were related to emerging field experiences (i.e. cues, objects and events). Many details of the operational events were based on Marine lessons learned from Iraq deployments, requiring translation of these operational events into training scenario events.

Targeted training objectives were provided via the Predeployment Training Package (PTP), outlining the range of operations for which Marines should prepare. For example, the PTP spans from convoy operations to mechanized assault, cultural interactions and information gathering missions. As a first step, we performed a structured query with Subject Matter Experts (SMEs) from the fleet to identify and validate the specific operations and TOs that should be included in the design of the IIT. As a next step, we created linkages between the objectives and events by utilizing extensive SME interviews to gather details to balance breadth with depth.

After the linkages were created, another aspect of the challenge was to ensure that the initial set of scenario designs supported other training objectives. SMEs were again utilized to identify and validate the core set of scenarios that would be delivered with the system. Then, capabilities of the system, particularly virtual actors and behaviors, were identified, in order to support additional scenarios that instructors could utilize later to create new scenarios.

With emerging enemy tactics and new environments, lessons learned from the field require detailed SME input to drive both cue patterns and linkages between training objectives and scenario events.

Challenge 2: Scenario control

Control over the scenario as it unfolds is limited in a mixed reality system. First, the nature of the mixed reality environment is such that only a fraction of the whole environment can be controlled in real-time. Role-players are briefed prior to a scenario run with instructions about how to adjust their behavior depending on how Marines behave in the system. Second, the virtual characters are controlled, (in IIT currently by a human operator), and the loop which is made between trainee actions and virtual character reactions is not highly dynamic. In the IIT, the operator-controller relies on instructor-observer verbal communications in many cases to adjust virtual character behaviors. In response to shots from trainees, though, a shot-detection system was implemented to enable immediate virtual character interaction.

Exchanges between interactive scenario components and trainees must be carefully planned to ensure that accurate cue pattern assessment and situation awareness are developed. Briefs given to live role-players should include all the information they will need to appropriately adjust as the scenario unfolds; the behaviors the operator must control in the virtual characters should be easy to find and utilize on the control station and a means for quickly communicating the trainee actions in the room to the operator in the control room.

Challenge 3: Virtual and real interactions

In traditional virtual reality training systems everything in the "world" is virtual – even the trainee (represented by an avatar in the virtual world itself). In a MR system, virtual characters are projected onto walls in the physical world and thus exist "in" the same physical world that the human trainee exists (see Figure 4).

The main challenge with designing scenarios for MR is designing virtual characters in such a way that they afford realistic *inter*actions. For example, placing a virtual terrorist behind a couch is not as simple as projecting the character on the wall above a physical couch in the room. This becomes an issue with how Marines use their own movement to gain better perspective as to potential threats. In the instance above, where potential threats are positioned behind an object such as a couch, Marines train to sweep around the person to both maintain a continuous view of the individual as well as achieve a more complete view. In the case of a virtual character, a Marine can make the sweep, but the virtual character occupies no physical volume. With this, the Marine will see the back edge of the couch meeting the wall, but not a better view of the character.

Figure 4. Mixed Reality in IIT

Furthermore, the virtual characters are limited to the space of the projection area. Their behaviors are constrained to approximately a five foot by five foot square surface. This means virtual residents cannot walk "around" their house realistically, at least not with a single projection per character.

*The **seamless immersion** is most vulnerable at points where the virtual and the physical meet, especially **where trainees interact with virtual characters**.*

Challenge 4: Virtual indoors versus virtual outdoors

Initially, when training objectives and situations for the core scenarios were first identified, both inside and outside virtual situations were considered. In MOUT operations, Marines encounter potential threats, such as hiding terrorists, inside of the rooms and buildings they clear. They also encounter threats outside of the buildings they clear (such as through windows) – also known sometimes as "fatal funnels," which are openings into a room that create vulnerability to the occupants from outside threats. Both doors and windows are examples of fatal funnels because they frame occupants, allowing them to be more easily targeted from threats at a distance outside of the opening.

Initial planning gravitated towards developing scenarios that depict outside threats, projected as a perspective looking from a window out into a marketplace or field. These potential scenarios would require Marines clearing a room to manage potential threats both inside and outside of the room, particularly by assessing outside activity for potentially threatening behaviors such as a vehicle borne improvised explosive device (VBIED) driving erratically towards the building the Marines occupy.

With further SME direction, training objectives were prioritized, and it became clear that inside situations should be targeted in the core set of scenarios delivered with the system. Primarily, the vision was a flexible system that supports reconfiguration, and the use of virtual characters depicted as "indoor" characters to free up live resources for other roles, such as crowds in the marketplace.

To some degree, though, technical challenges encouraged the decision to initially develop indoor scenarios. Developing scenario content for an outdoor scene requires the following to maintain immersion:

1) Coordination of virtual space and physical space – when you look out of two different windows onto the same scene, you should see similar objects, from different perspectives. So for example, if buildings are beside each other and have windows facing the same direction, if two completely separate scenes are depicted – say a busy urban marketplace scene from one window, it would not make sense physically for an empty rural field to be depicted from the other window.

2) Maintaining the integrity of the perception that something depicted "outside" the window actually looks like it is beyond the frame of the window. This requires coordination with the physical set to encourage perception of depth from the inside walls of the room to the space depicted outside. In the case of the initially considered outdoor scenarios, to maintain this consistency between real and virtual environments, a terrain database was required that could be correlated to the physical world. In other words, the physical house in which the outside scene was projected needed to have its own presence in the virtual world, and similarly, the contiguous physical areas to that house must be represented in the virtual world.

3) Maintaining the integrity of the interaction between the Marine (specifically the Marine's rifle), and the window, when the Marine takes cover with the wall and aims the rifle out *through* the window – the rifle barrel may stick out of the window some, not lie flush with the sill.

4) Lastly, the mechanism for detecting shots fired by the simunition rifles is a plane co-located with the projection surface and requires a minimum distance of separation between the origination of the shot. For indoor situations, the distance between a Marine's rifle barrel and the target is naturally the few feet required by the detection system. Whereas, Marines seeking to shoot *out of* the window will likely approach the window, even rest the barrel on the edge of the window, and thus be a mere inches from the detection system although many feet (or even thousands of feet) away from the virtual target.

Although indoor scenes were prioritized higher by SMEs, the goal of extendibility guided us to include one location in the facility that supported outside scenes. For the depth reasons listed above, a false-window was created for one of the projection areas; the projection physically existed a few inches beyond the plane of the wall on which the window was depicted. The room was designated as a Call for Fire (CFF) room, which is a specific mission/skill Marine training objective. CFF missions do not typically involve Marines using their rifles, and thus the constraint of maintaining a distance from the detection system was mitigated.

The coordination of physical and virtual realities is complex and requires notable planning. Coordination of ***outdoor realties*** *can be particularly* ***complex****.*

EVALUATION RESULTS

Once the scenarios were designed, implemented, and delivered, it was time to train. Marines first started using the system in the fall of 2007, around November. An evaluation was conducted in December to validate the training utility of the system, particularly the training scenarios. The evaluation sought: 1) trainee responses to the system (do they feel it's useful?), and 2) a theoretical evaluation of the fidelity of the system (did the completed system accurately represent the cues and functions it was designed to capture?).

The purpose of presenting the training utility evaluation results here is to reinforce the usefulness of the challenges and lessons learned that are the primary focus of the paper. The procedure and results are briefly reviewed here and reported elsewhere (Eitelman, Milham, & Carroll, 2008).

Procedure

The effort involved a two-part evaluation of the IIT training program to examine the degree that current hardware and software installations support targeted training goals as listed in the Pre-deployment Training Package (PTP). The results include: 1) trainee reactions to IIT utility and 2) theoretical cue fidelity and interaction capability evaluation (i.e., whether the fidelity of hardware/software systems is high enough to support training objectives).

Both evaluations were conducted at the IIT facility at Camp Pendleton from December 5 to 6 2007, with Day 1 dedicated to collecting reactions data through the questionnaires, and Day 2 dedicated to the cue and interaction fidelity evaluation.

Trainee Reactions

Data was collected from two operational units and a subject matter expert (SME). The operational units provided data for the trainee reactions: an infantry unit recently returned from Iraq at the time of the evaluation (noted as "experts") and a Military Transition Team (MTT) unit that had not been deployed together (noted as a "specialty" team). After each group went through the system, the trainees completed questionnaires that asked how well they felt the system facilitated training across various measures, including specific PTP TOs, teamwork, communication, and preparation for Mojave Viper and an assigned area of operation (AO) in theater.

The trainees responded to questions targeting their perceived utility of the IIT facility for training value across several aspects of training. Trainees indicated how well they felt the IIT facility provided training:

- For selected TOs from the prioritized PTP TOs
- Compared to traditional training approaches
- For training teamwork
  For training communication skills at different levels of command
- To prepare for Mojave Viper training (an established pre-deployment training exercise)
- To prepare for an assigned AO while deployed

Cue Fidelity

The theoretical evaluation involved interviewing a SME while walking through the facility. To develop the interview questions, we identified a SME-validated set of 31 TOs, considered high priority within the scope of the IIT vision, of 95 total unique TOs across the blocks of the PTP matrix. The 31 selected TOs spanned five of the six TO areas of the PTP matrix: 1) Enduring Combat Operations, 2) Combined Arms Operations, 3) Military Operations in Urban Terrain, 4) IED Defeat, and 5) Cultural Training.

For each of the selected TOs, cue fidelity requirements were identified for each scenario. The interview questions evaluated the degree that these requirements were met. Cues were ranked by the degree that the instantiation of the cue facilitated training on that TO.

One example of cue utility evaluations was whether the current level of fidelity could support training. In the case of evaluating the virtual doors, they were rated as usable, even though they were in a different form. With this, the doors were usable as cues to support a realistic training environment, but the form of the doors in the facility had some insignificant differences, with respect to training, from those found in country. The SME explained that the doors were basically the right size and shape as those found in Iraq, based on his experience. However, he pointed out some subtle differences that weren't considered critical for training value, such as the shape of the handles (sphere in IIT) were not the same as those in country (D/L-Shape).

In another example, 'clutter and outside rubbish' was present but not with high enough fidelity to support training on anomaly detection. The SME reported that the facility did not have a notable amount of trash and rubble scattered in the streets. There was some clutter in the 'outside' of the town buildings, but there was not the same quantity and types of clutter and rubbish that would sufficiently support training anomaly detection (e.g., emplaced IED) for Observation while on Patrol.

Results

Trainee Reactions: Utility to train TOs

Both training groups indicated that the IIT facility was "useful" for training five out of eight (63%) of the selected training objectives (see Table 1; scale from 1 ("not useful") to 5 ("extremely useful")). Applying Rules of Engagement (ROE) and Escalation of Force (EOF) procedures was ranked highest between the two groups, both of which are TOs largely facilitated by scenario design (versus physical fidelity, for example).

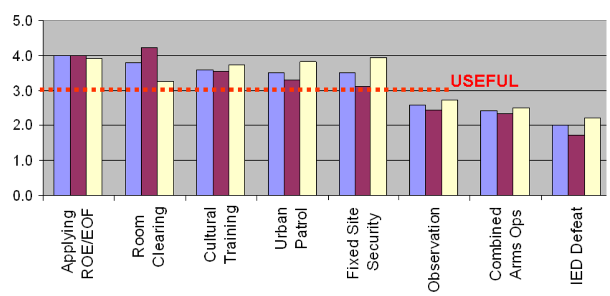

Table 1. IIT Training Utility Results

IED Defeat was ranked lowest. However, at the time of the evaluation, the full IED simulation system was not online. The SME reported that an IED simulation system was anticipated to arrive that would provide more realistic IED capabilities in the facility. The key aspects to the IED Defeat TO are to 1) advance skills of preventatively identifying IEDs, and 2) inoculate Marines to the effect of IEDs so they can continue the mission as events unfold. The primary advantage of having a pyrotechnic IED simulation system is to support inoculation. However, with the IED simulation system in place, scenario design can further support the TO by including events surrounding the IED that exercise Marines maintaining situational awareness and performing quick-reaction decision making.

Also, Combined Arms Operations ranked second lowest, however the Joint Fires and Effects Trainer System (JFETS), which was the display provided in the CFF room, was operational but facility personnel had not yet been trained to use the system at the time of the evaluation. For both trainee groups, the JFETS system was not used in any of their training runs.

Trainee Reactions: Value over Traditional Training
The groups reported that the IIT facility was more valuable than traditional training approaches. The expert group reported that, as compared to other more traditional training approaches, the IIT facility is "extremely useful" (see Table 2; scale from 1 ("not useful") to 5 ("extremely useful"))

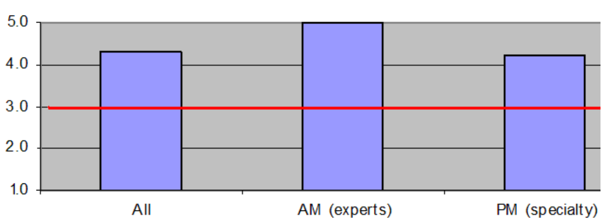

Table 2. IIT Value Over Traditional Training

Trainee Reactions: Utility to Train Teamwork
Both groups reported that ***the IIT facility was "very useful" for training teamwork***, and they agreed that the system was "very useful" for training teamwork skills (see Table 3; scale from 1 ("not useful") to 5 ("extremely useful")).

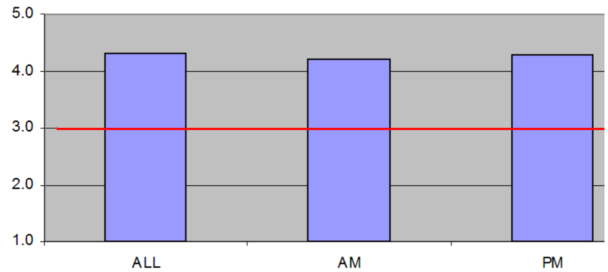

Table 3. IIT Teamwork Training Utility

Trainee Reactions: Utility to Train Communication
Both groups reported that ***the facility was "very useful" for training communications, particularly at the fire team level***. For higher echelons, the system's utility, as reported by the trainees, declined. Both units did report that the system was 'very useful' for training both fire team and squad level communications (see Table 4; scale from 1 ("not useful") to 5 ("extremely useful")).

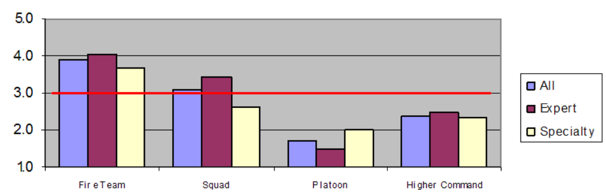

Table 4. IIT Teamwork Training Utility

Trainee Reactions: Utility to Prepare for Mojave Viper and Deployment
The IIT facility is envisioned to be a part of a pre-deployment training cycle that also includes the Mojave Viper exercises. Thus, it is important to consider the utility of the system with respect to its use with other components of the pre-deployment training cycle. Both groups reported the IIT facility as being "very useful" for preparation for Mojave Viper training. The expert group ranked it higher than the specialty group.

Ultimately the system aims to prepare Marines to successfully operate when deployed in an assigned AO. Having one group recently returned and one group in the stages of developing team cohesiveness, the data is particularly useful because it reflects these two divergent stages of a unit's development.

The specialty group was asked to report the utility of the system for preparing to a hypothetical assigned AO if they were preparing to deploy. They reported it would be useful to do so.

The expert group was asked to consider the AO from which they recently returned to consider the utility of the system for preparing for that *specific* AO. In other words, the expert group was asked to pretend that they were preparing for the AO from which they recently returned – now that they have the knowledge of their experience there – and evaluate the IIT for its value in preparing for that AO. The expert group ranked the IIT with the highest utility rating available, or "extremely useful."

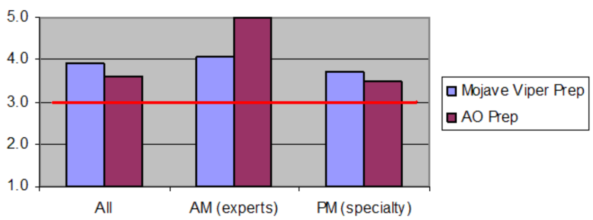

Table 5. IIT Utility for Mojave Viper & Deployment

Cue and Interaction Fidelity

Six out of eight (75%) high priority TO areas are more than 50% usable by the system at the time of evaluation see Table 6). That is, of the eight high-priority TOs, six of them support more than half of the required cues and functions required to enable a successful training experience.

Ultimately, higher usability of the cues indicates higher potential utility for training. The 50% threshold is subjective. Marines, however, are very adaptable and coupled with their positive feedback of the utility of the system across several measures, 50% usability seems a notable level for the early stages of the system.

Training Objectives	# Cues Critical	# Usable	Usable %
React to contact from sniper, ambush, IED	12	12	**100%**
Guardian Angel	2	2	**100%**
Iraqi Culture (101)	12	11	**92%**
Room Clearing	42	37	**88%**
Apply ROE / EOF	21	16	**76%**
Observation (Patrol)	29	17	**59%**
Observation (OP)	31	15	48%
Close Air Support*	46	22	48%

Table 6. IIT Cue Fidelity Results

LESSONS LEARNED

Next, we offer some lessons learned from our experience developing the scenarios for the mixed-reality IIT system that may facilitate scenario development for future mixed reality systems. We have grouped the lessons learned by the challenge listed above from which they were derived.

Training Objective Linkages

Lesson 1: Plan for extensive TO analysis

One of the objectives of the IIT system was to target a wider than traditional range of military operations in the system; while mixed reality does not necessitate increasing the breadth of situations a system might support, the technology affords offering a wider set of situations. Thus, it is important to plan the front end analysis to drive the design process accordingly, including the resources to support the range of training objectives and/or situations the system should target.

Scenario Control

Lesson 2: Plan actions of both live role players and virtual actors in scenario design

Scenario design includes preparing role-players that will help maintain the integrity of the scenario to training objectives. As much as possible, scenario design should include selection requirements (e.g., fluent in a particular dialect for preparing for a specific AO) and briefing instructions for role-players. Selection requirements ensure critical cues and behaviors that support training objectives that target verbal/cultural interaction. Briefing must be sufficiently explanatory to live role-players to enable them to handle the different situations they may encounter based on varying trainee behaviors.

Lesson 3: Require quick control over virtual characters

The reaction of virtual characters must not break the trainee's immersion. Reactions delayed by a second, or less, may be noticeably artificial to trainees. Wherever possible, use technology to reduce the time it takes to perform a virtual reaction. This does not necessarily mean to remove the human from the loop – in cases where human decision making, such as by an expert instructor, are required to select responses, use technology to automate the deployment of those responses.

* The Close Air Support system, Joint Fire Effects Trainer System (JFETS), was operational but was not fully operable. Facility personnel had not yet received training on using the tool and so a limited set of effects were demonstrated for the cue fidelity evaluation.

Although realism of virtual characters in *virtual environments* has been studied and advances have been made, realism of virtual characters in *mixed reality environments* needs further study and development to ensure a truly immersive, and *seamless*, experience in mixed reality systems.

Lesson 4: Design meaningful interactions between trainees and virtual characters

Interactions between trainees and virtual characters are one of the main places where immersion may breakdown. Virtual characters should be placed in locations where their lack of depth is minimally noticeable.

Lesson 5: Acknowledge physical constraints on virtual characters during design

Plan virtual characters to perform behaviors that do not require more physical space than the screen on which they are projected, or when possible, require additional projection areas, as needed, to display naturalistic behaviors virtually in the physical space.

Virtual Indoors Versus Virtual Outdoors

Lesson 6: Coordinate virtual world and physical world development

More than a scenario design lesson learned, this is a lesson in the state of the art of MR technology. To maintain geographic consistency between virtual and physical worlds, the terrain database used to depict virtual scenes must reflect the design of the physical world, and vice versa. This is not necessarily a technical challenge; however it indeed has significant implications on the time and cost of development for outdoor scenarios.

Lesson 7: Plan to design and build transition interfaces

In many cases, the interface between trainee and the virtual world requires extra attention to maintain the seamless blend from physical to virtual. To encourage the perception that the scene "outside" of the virtual window is past the plane of the window itself, we built a false-window. Even a few inches of depth before the virtually-deep scene is presented seemed to help reduce the seam between the virtual and physical. Another MR system reviewed during IIT scenario design planning similarly placed furniture or rubble in front of the projection screen to encourage some distance between the trainee and the plane of the projection. "Transition interfaces," like the false window or carefully placed props, are important to maintain immersion and should be accounted for in scenario design.

SUMMARY

The Infantry Immersive Trainer is an advanced mixed-reality system that involves a cutting-edge mix of physical and virtual capabilities. It supports training of a wide range of military operations, larger than typical training systems. The system was designed and implemented in a short time frame; launched successfully and yielding positive results for training utility. From this experience, various challenges were encountered and consequently several lessons learned emerged.

The most prominent and unique challenge posed by designing scenarios for a mixed reality environment is blending physical and virtual worlds is to maintain ***seamless immersion.*** Several challenges were identified, many of which (all but the first) stemmed from this unique pairing of physical and virtual capabilities to create a new, immersive reality. The results indicate that the initial set of scenarios were successful. The lessons we offer include implications for planning the resources required for the scenario design process and several considerations for maintaining seamless blend of the virtual and physical worlds. Mixed reality is a promising modality for training systems of the future. We hope that sharing our challenges and lessons learned facilities future MR efforts, thereby supporting the advancement of this capability.

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