Exploring the Ability to Employ Virtual Entities Outdoors at Ranges Beyond 20 Meters

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ABSTRACT

The Army is procuring the Integrated Visual Augmentation System (IVAS) system to enable enhanced night vision, planning, and training capability. One known limitation of the IVAS system is the limited ability to portray virtual entities at far ranges outdoors due to light wash out, accurate positioning, and dynamic occlusion.

The primary goal of this research was to evaluate fixed three-dimensional visualizations to support outdoor training for fire teams through squads (9-12 personnel). Doing so required enabling target visualizations for 3D non-player characters or vehicles at ranges up to 300 meters. Tools employed to achieve outdoor visualizations included GPS locational data with virtual entity placement, and employment of sensors to adjust device light levels. This study was conducted in March 2022 with 20 military test subjects in three scenarios located on the NPS (Naval Postgraduate School) campus using a HoloLens II. Outdoor location considerations included shadows, background clutter, cars blocking the field of view, and the sun's positioning. Users provided feedback on identifying the type of object, and the difficulty in finding the object.

The results indicate GPS only aided in identification for objects up to 100 m. Animation had a statistically insignificant effect on identification of objects. Employment of software to adjust the light levels of the VEs aided in identification of objects at 200 m. This research develops a clearer understanding of requirements to enable the employment of mixed reality in outdoor training.

ABOUT THE AUTHORS

LTC John R. Morris is a native of Texas. A graduate of Texas A&M, (BS, Agriculture), and the Army's Command and General Staff College, (MMAS, Strategic Studies), he was commissioned in 2005 into the U.S. Army. He served as a fire support officer, battery commander in the 82d and 101st Airborne Divisions, and an observer, controller, trainer (OCT) at the Joint Readiness Training Center. He also served as a capability developer as part of the Integrated Visual Augmentation Systems training application development while in the Army's Synthetic Training Environment Cross Functional Team. He completed a Master of Science degree in Modeling, Virtual Environments, and Simulations in June 2022, and then reported to his current billet as the Operations Officer, US Army Pacific Joint Multinational Simulation Center - Indo Pacific.

Quinn Kennedy, PhD, is a Research Associate Professor in the Operations Research Department at the Naval Postgraduate School. Her work in behavioral science research focuses on optimizing human performance and decision-making and testing the effectiveness of new technologies on human performance and training. Dr. Kennedy received her PhD in Psychology and postdoctoral training from Stanford University.

Perry McDowell served as a surface warfare officer (nuclear power) in the Navy from 1988-2000. In 1995 Perry earned his Master of Science degree in Computer Science at the Naval Postgraduate School, where he was awarded the Grace Murray Hopper Award as outstanding computer science student. Upon leaving the Navy in 2000, he returned to NPS and joined the faculty, where most of his work has involved using games, virtual reality, and augmented reality to improve warfighter performance. Although he has served as a principal investigator. For a wide variety of projects in the MOVES Institute, from 2003 – 2012 he worked primarily as the executive director for the Delta3D open-source game engine. From 2012 to the present, he has taught courses in simulation for training and conducted research in the areas of training effectiveness and creating training systems.

Clay Gruenke MSCS, is a Research Faculty Associate in the Modeling, Virtual Environments, and Simulation (MOVES) Institute at the Naval Postgraduate School. His work is geared towards the challenges of adoption and use cases of augmented reality in operational contexts. Mr. Greunke has three patents in the mixed reality space and is entering the PhD program at the Naval Postgraduate School.

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INTRODUCTION

Background and Motivation

This research evaluated the challenges currently preventing the military from fully leveraging mixed reality (MR) outdoors to enable increased realism during training. During one of the author's experiences as a Field Artillery officer in light infantry brigades, he was often challenged to employ realistic, mobile targets for training engagements. This challenge also extended to tactical rehearsals without troops where leaders sought to visualize the training event during terrain walks at the actual training site. When deployed to locations such as a forward operating base, it is even more challenging to maintain live fire skills as trainees must practice engaging targets on installations smaller than a football field. Live fire training requires fixed targets such as tanks, which often disintegrate beyond recognition after approximately 100 direct artillery strikes. Engaging moving targets is impractical as the damage from one large munition can destroy the propulsion/rail system. Both types of targets are challenging to replace due to cost and safety concerns.

Ultimately, this work supports achievement of the Department of Defense Close Combat Lethality Task Force goal of "25 'battles' before the first battle begins" (Schogol, 2018, as cited in Roper, 2018, p. 5). Currently, the target audience for this goal is light infantry warfighters. However, as the technology matures, it will support all combat arms, to include armor, field artillery, and aviation, as well as key support warfighters such as medics and combat engineers. The research serves as a basis that improves upon existing training targets, whose complexity is limited to pop-up or fixed track moving targets engaged from fixed positions. Once the Army has the means to provide 3D outdoor and mobile targets, training realism will dramatically improve as gaming and virtual reality products can be used outside. This will yield improved realism in training which will reduce the shock of the first contact during combat and will increase warfighters' abilities to anticipate enemy actions prior to experiencing combat.

Ongoing Research

The United States (U.S.) military, specifically the Army and Marine Corps, has pursued many routes to add features that occur in real operational settings that cannot be safely replicated during live training. A relatively early effort sought to incorporate virtual reality into dismounted infantry training with the development of the Dismounted Soldier Training System (DSTS) (Bymer, 2012). In the early 2010s, infantry units were provided a few DSTS units, but they were largely rejected by the users due to their limited mobility, which confined the system to a small indoor environment. However, it is worth noting that some infantry units accepted the system and used it. Furthermore, analysis of DSTS user feedback suggested that augmented/mixed reality would assist in solving capability gaps presented by the system (Reitz & Seavey, 2016). In the mid-2010s, the Navy and Army conducted market research through a phase-3 Small Business Innovative Research contract with Magic Leap Horizons, which validated the potential for mixed reality headsets to support training. In 2018, Microsoft bid and won a two-year research and prototyping contract valued at approximately $480 million to develop the Integrated Vistal Augmentation System (IVAS), which is based on the HoloLens mixed reality heads up display (HUD) (Haselton, 2019). The Army approved the IVAS contract to provide a tool to help train Soldiers to achieve combat overmatch. The Close Combat Lethality Task Force study defined close combat overmatch as "the ability of a squad-sized unit to impose its will on a similar sized opponent under all conditions and operational environments" (Mattis, 2018, as cited by Roper, 2018, p. 2).

As of Spring 2021, both live and virtual training lack the ability to employ virtual three-dimensional (3D) targets outdoors at ranges beyond 30 m (Aycock, 2021). The Army has sought this capability to increase realism during training and rehearsal events. Recently, it was explored under the IVAS prototyping effort, which is based on the

Microsoft HoloLens mixed reality hardware. The prototyping effort developed new hardware and software based on the HoloLens for night vision, thermal vision, navigation, rehearsal, and training. While the IVAS prototyping effort successfully executed a proof of concept for outdoor employment, as of fall 2020 it lacked the ability to support engagement at ranges beyond 30 m and dynamic occlusion. Due to the delay in hardware development and limited follow-on time within the prototyping contract, the outdoor capability has not fully matured.

Challenges

The challenges identified from previous prototyping research and the IVAS program are as follows. Practitioners and subject matter experts have identified similar challenges:

- The IVAS system has difficulty handling the occlusion of 3D virtual entities by real world objects which frequently move, such as tall grass.
- HUDs do not consistently present objects in the same location for all users when there are holes in the spatial map. This happens when one user places a VE on a flat table, and another user sees the object "floating" above the table.
- Non-player characters (NPCs) are unable to conduct advanced AI-driven navigation. Current behaviors are limited to a one or two step prescribed navigation sequence, making behaviors predictable.
- Significant changes in light levels within the user's field of view can significantly degrade the quality of virtual entities (VEs) at distances beyond 30 m.

RESEARCH QUESTIONS AND HYPOTHESES

There are two research questions and an exploratory question based on variables that were observed to determine their effectiveness in improving visualizations of outdoor entities.

Research Question 1: To what extent can employing global positional data be used to support navigational mesh development to enable placement and identification of 3D virtual objects at distances of 50, 100, and 200 m?

Prediction 1:

1. 90% of subjects will be able to identify 3D virtual objects under most conditions at ranges less than or equal to 50 m.
2. 75% of subjects will be able to identify 3D virtual objects under most conditions at ranges less than or equal to 100 m.
3. 25% of subjects will be able to identify 3D virtual objects under most conditions at ranges less than or equal to 200 m.

HA1: Application of GPS in tandem with a MR viewer will enable identification, on average, identification of 3D virtual NPCs and objects in the MR viewer less than 90%, u => .90 of the time at distances of 50 m, 75%, u => .75 of the time at 100 m and 25% of the time at distances of 200 m, u=>.25.

Research Question 2: Can employing animation of 3D VEs enable improve identification of objects at ranges greater than 20 m?

Prediction 2: Animation of 3D virtual objects will improve positive identification scores compared to objects at the same range, 90% of the time.

HA2: Across subjects, animation of 3D entities at distances up to 200 m within the parameters defined, on average, will result improve identification when compared to similar objects at ranges, 90% of the time, $\mu > .90$.

Exploratory Question 1: To what extent can adjusted light levels of 3D entities support identification at ranges of 20 – 300 m?

METHODOLOGY

This section provides an overview, discusses the study design, reviews participants, and questionnaires. The study began with background research, followed by pilot testing, then the completion of an observational study.

Visibility Ratings by Scenario and Distance

The study's target population were military students at NPS. Volunteers were excluded from participating if they were not fluent in English (to avoid the difficulty that would arise in interpreting the visual descriptions), were prone to cyber sickness, and/or whose vision acuity test yielded less than 20/20 vision with correctable lenses. There were 20 total participants, 19 of whom were active-duty military, and one who was serving in the Naval Reserve. The mean age was 34.1 with a standard deviation (SD) of 4.45 and the gender breakdown was 18 males and 2 females. The service breakdown is as follows: Army: 8, Navy: 4, Marines: 7, Coast Guard: 1. The training background of personnel included 16 who received enemy/target identification training, and 18 who have experience with augmented and virtual reality (AR/VR). The experience and diversity of the test subjects is almost ideal, though greater representation of females to reflect the armed services population would have been preferable due to differences in sensory perception (Barber, 2020).

Identification Tasks and Scenarios

We used three sites to allow for a diverse set of terrains. At each site, subjects saw virtual images overlaid upon the real world at either two or three different ranges (50, 100, 200 m). Each site presented at least two of the following images: HMMWV, jeep, a Soldier, animated civilian in a fixed location, and a medical tent. The max range was intended to be 300 m, but occlusion and varying differences in elevation beyond 200 m made it difficult to lock the VEs to the ground. For example, when the scenario was tested, the object would appear 10 feet above the ground, then the next time the scenario was tested, the object would appear below the ground, so for ease of experimentation, we did not place targets at greater than 200 m. For each image, the user was asked to determine the type of object portrayed in the image, how confident they were in their classification, and if they could identify a defining feature of the object. The intent was to support statistical blocking if required. Participants were debriefed upon completion of the study. Figure 1 shows the locations of the three sites used as well as the directions of gaze.

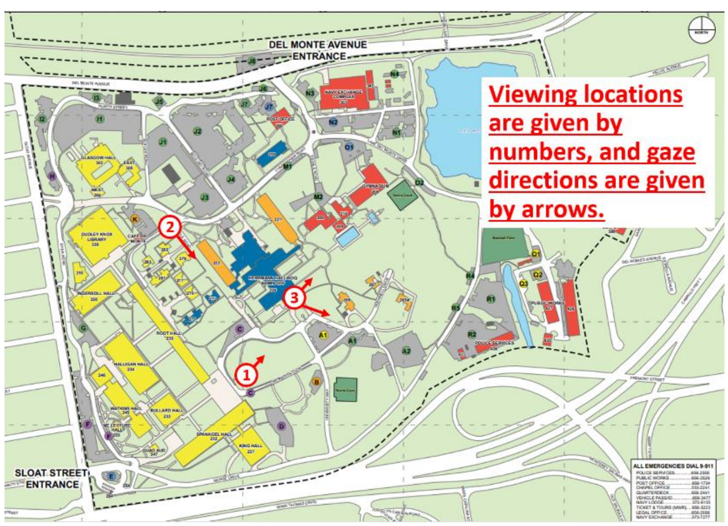

Figure 1. NPS Campus Map Showing Site Locations

1. Scenario 1 (Figure 2) was located on the southwest side of Hermann Hall and included two VEs. The test subjects viewed the scenario looking slightly northwest. The first VE was a man who was walking in place on a sidewalk, approximately 50 m from the test subject, wearing traditional Middle Eastern clothing. The second VE was a tan HMMWV parked in the grass, approximately 100 m from the test subject, who viewed the vehicle from its side. The environmental features included trees, dense shade, an open field, and a road.

Figure 2. SW side of Hermann Hall, facing NE (Site 1 in Figure 1) (VEs circled)

2. Scenario 2 (Figure 3) was located at the northwest side of Hermann Hall along a blocked off road and three VEs were visible. The test subject viewed the scenario looking southeast. The first virtual object was a man who was walking in place on a sidewalk, approximately 50 m from the test subject, wearing traditional Middle Eastern clothing. The second VE was a tan Jeep parked along an unused road, approximately 100 m from the test subject, and offset to the left of the man walking down the sidewalk. The third VE, a green Alaskan medical tent, with a red cross on the front, was 200 m from the test subject, and offset to the left of the Jeep. All VEs were viewed from their front by the test subject. The environmental factors included consistent shade provided by Hermann Hall and the trees on each side of the road, and little shade between the test subject and the first VE, 50 m away.

Figure 3. NW Side of Hermann Hall Looking SE (Site 2 in Figure 1) (VEs circled)

3. Scenario 3 (Figure 4) was located to the south of Hermann Hall and three VEs were visible. It was viewed from the fourth-floor tower of Hermann Hall. The test subject viewed the scenario looking southeast, and to the south. The closest VE was an inanimate soldier wearing military gear and holding a weapon approximately 50 m from the test subject. The second VE was 100 m from the test subject, and offset to the northwest, was a green Alaskan medical tent, with a red cross on the front. The third VE was a tan Jeep, approximately 200 m from the test subject, offset to the north of the tent and was placed upon the roof of a building. The environmental factors included shadowing provided by trees onto the VEs, standing water, and light washout from the sun.

Figure 4. Balcony of Hermann Hall, Looking NE (left) and SE (Site 3 in Figure 1) (VEs circled)

Surveys

The study used two surveys: a demographic survey and a post-task survey. The intent of the surveys was to gain an understanding of the research audience background, to identify health concerns, and to gather insight into their experience. The demographic survey collected basic data concerning the participants' age, gender, military service, and AR device experience. This survey allowed the research team to conduct a final screening of the participants to ensure they did not meet any exclusion criteria as well as seeing if any background factor affected their feedback concerning image visualizations. Participants recorded their answers on paper which were stored in a secure container. The feedback/ post- test survey attained user feedback on how they identified each object, and their professional opinion regarding the technology's ability to support outdoor training.

Software and Equipment

This study used one computer and one HoloLens II device. The computer used for this study is an older Alienware Aurora R4 with an NVIDIA GeForce GTX690 video card was used to input survey data and create scenarios for loading onto the HoloLens. The HoloLens II utilized Virtual Reality Rehab (VR Rehab) HoloWarrior software and HoloNav system. The system was supported by an external global position system (GPS) with a Bluetooth wireless connection. It also employed a sun visor and attachable sunglasses to dim the effects of bright sunlight.

Procedures

The detailed procedures/flow of study went as follows:

1. Approximately one-half hour before the experiment time, we validated the device and equipment were in working condition, including verifying all batteries were charged.
2. The subject arrived at researchers' offices in Watkins Hall. Upon arrival, the subject reviewed the consent form, and signed. Once complete with the consent form, the subject filled out the demographic survey.

3. The subjects' vision was validated using a standard vision test to ensure 20/20 vision. This ensured the subjects' performance was not due to deficiencies in their near/far vision.
4. Upon completion of the vision test, the researcher and subject walked to observational test site 1 southeast of Hermann Hall. There, it took us approximately 10 – 15 minutes to open the scenario and acquire a GPS signal, then five minutes to complete the first scenario.
5. Once the first scenario was complete, the researcher and subject walked to the observational test site 2 at the northwest side of Hermann Hall where they executed the second scenario. It took approximately 5–10 minutes to open the scenario, and five minutes to complete the second scenario.
6. Once the second scenario was complete, the researcher and subject walked to Hermann Hall's Tower Room balcony overlooking the NPS campus flagpole and Roman Plunge pool, which was 40 feet above the ground. The scenario took five minutes to open and adjust, and five minutes to complete.
7. Upon completion, the group then walked back to Watkins Hall. At Watkins Hall, the post-test scenario was completed, and results were locked in a file cabinet.

Data Analysis

This study incorporates two sets of data. This first set of data comes from the demographic survey and post-test survey. The second set of data is derived from subject feedback during the observational study. Survey data and user feedback were inputted into Microsoft Excel and checked for errors prior to being exported to JMP Pro 15.1 for statistical analyses.

The statistical methods used for hypothesis and exploratory analysis are the Chi-square tests of homogeneity and independence and one-proportion *Z*-tests. The Chi-square methods allowed for testing of Likert scale ratings from user feedback (ordinal variable) by distance (ordinal variable) and scenario type (categorical variable). An alpha level of .05 was used for all hypothesis testing. The data sample is random in respect to military background and experience. Assumptions for the Chi-square Test were checked. Because the user feedback data did not meet the expected values assumption, data from the Likert ratings was condensed to two rating levels, visible and not visible. Original Likert ratings of 1 – 3 were classified as visible, original Likert ratings of 4 – 5 were classified as not visible. After this reclassification, the assumptions and conditions were met.

Results

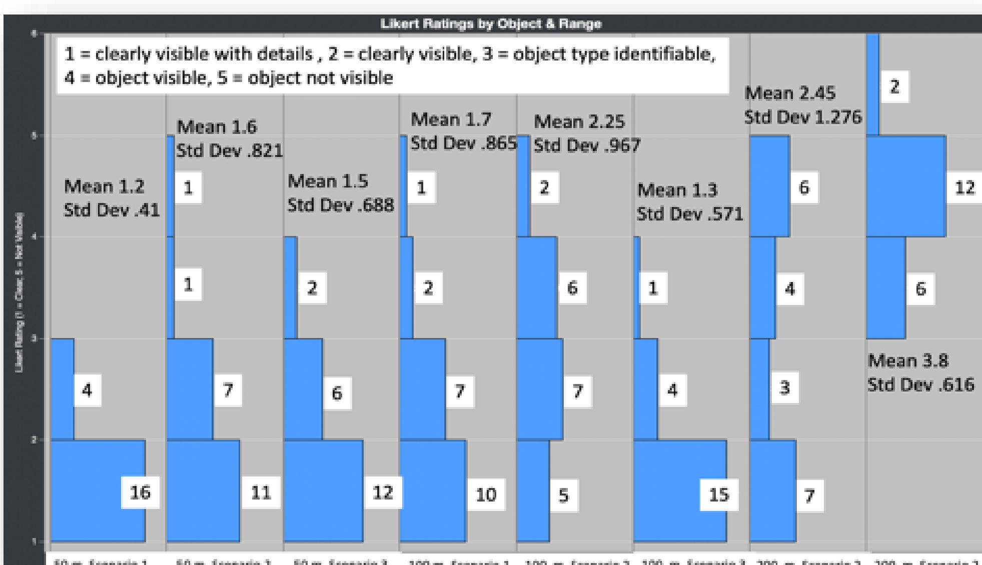

Figure 5. Likert ratings by object and range

Hypothesis 1: Application of GPS in tandem with MR will enable the user to identify 3D virtual NPC's and objects 90% of the time at 50 m, 75% of the time at 100 m and 25% of the time at 200 m.

To test the hypothesis, the team employed a Chi-square analysis and one-sample *Z*-test at ranges of 50, 100, and 200 m. To generate the analysis, all scores three and below were assigned to one (identifiable object type), and all scores four or more were assigned a two (unidentifiable object type).

We were unable to conduct a Chi-square analysis for the overall data as there was one near-perfect score (59 of 60 VEs identified, Figure 6), so the data did not meet expected values count for Chi-square. Researchers then analyzed users' ability to identify virtual entities at 50 m. The VE identification results were better than predicted (z = 2.15, p = 0.0315, 95% confidence interval (CI), 0.95 to 1.02). Thus, we rejected the null hypothesis at 50 m.

Contingency Table

Scenario	Count / Total % / Col % / Row %	Rating 1	Rating 2	Total
1	Count	20	0	20
	Total %	33.33	0.00	33.33
	Col %	33.90	0.00	
	Row %	100.00	0.00	
2	Count	20	0	20
	Total %	33.33	0.00	33.33
	Col %	33.90	0.00	
	Row %	100.00	0.00	
3	Count	19	1	20
	Total %	31.67	1.67	33.33
	Col %	32.20	100.00	
	Row %	95.00	5.00	
Total	Count	59	1	60
	Total %	98.33	1.67	

Figure 6. Contingency. Analysis for scenario by distance, 50 m

The second set of data analyzed was users' ability to identify virtual entities at 100 m. These entities included a HMMWV, Jeep, and a medical tent. The raw results indicate in 48 of 60 samples subjects identified the VE's (Figure 7). The one-proportion *Z*-Test results yielded z = .894, p = 0.3711, and a 95% CI of 0.69 to 0.90. Therefore, we retain the null hypothesis at 100 m.

Contingency Table

Scenario	Count / Total % / Col % / Row %	Rating 1	Rating 2	Total
1	Count	17	3	20
	Total %	28.33	5.00	33.33
	Col %	35.42	25.00	
	Row %	85.00	15.00	
2	Count	12	8	20
	Total %	20.00	13.33	33.33
	Col %	25.00	66.67	
	Row %	60.00	40.00	
3	Count	19	1	20
	Total %	31.67	1.67	33.33
	Col %	39.58	8.33	
	Row %	95.00	5.00	
Total	Count	48	12	60
	Total %	80.00	20.00	

Figure 7. Contingency. Analysis for scenario by distance, 100 m

Last, subjects' ability to identify virtual entities at 200 m was analyzed. The entities included a medical tent and Jeep. The results indicate 10 of 40 samples subjects identified the VEs (Figure 8). The one-proportion *Z*-Test results yielded z = 4.472, p = 0.00001, and a 95% CI of 0.35 to 0.65. Thus, we rejected the null hypothesis at 200 m.

Contingency Table

Scenario	Count / Total % / Col % / Row %	Rating 1	Rating 2	Total
2	Count	10	10	20
	Total %	25.00	25.00	50.00
	Col %	100.00	33.33	
	Row %	50.00	50.00	
3	Count	0	20	20
	Total %	0.00	50.00	50.00
	Col %	0.00	66.67	
	Row %	0.00	100.00	
Total	Count	10	30	40
	Total %	25.00	75.00	

Figure 8. Contingency analysis for scenario by distance, 200 m

Hypothesis 2 (HA2): Across subjects, animation of 3D entities at distances up to 200 m within the parameters defined will improve identification when compared to similar objects at ranges 90% of the time.

To generate data for the Chi-square analysis, all scores three and below were assigned to one (identifiable object type), and all scores four or more were assigned a two (unidentifiable object type). The analysis indicates that animation did not aide users in a statistically significant manner (Chi-square (1) = 0.819, p < 0.3654). We retained the null hypothesis. Only 2.5% more users could identify the virtual entity when it was animated versus when it was not animated (Figure 9).

Contingency Table

Animation	Count / Total % / Col % / Row %	Rating 1	Rating 2	Total
N	Count	39	1	40
	Total %	65.00	1.67	66.67
	Col %	66.10	100.00	
	Row %	97.50	2.50	
Y	Count	20	0	20
	Total %	33.33	0.00	33.33
	Col %	33.90	0.00	
	Row %	100.00	0.00	
Total	Count	59	1	60
	Total %	98.33	1.67	

Figure 9. Contingency analysis of animation by distance, 50 m

This finding is confirmed when we reviewed the grouped mean for both animated virtual entities (n = 40, mean = 1.4) versus the non-animated VE (n = 20, mean = 1.5). This indicates an improved score of only 0.1 in the ability to identify the VE when 50 m from the observer (subject) using the MR device.

Exploratory question: To what extent can adjusted light levels of 3D entities support identification at ranges of 20–300 m?

As the observational study began, a delayed software update prototype became available, and was available shortly after commencing observational test. After the first 10 test subjects, the updated software was employed for observational testing. This software allowed for the light levels and angle of lighting for all VEs and people to be updated simultaneously by the researcher. The software did not allow for individual entities to be updated. A Chi-square test was conducted to determine if there was an improvement in subjects' ability to identify VEs at 50, 100, and 200 m.

The analysis indicates that software did not aid users in a statistically significant manner at 50 m Chi-square (1) = 1.403, p = 0.2362. About 98% of the subjects were able to identify the type of VE at 50 m regardless of the type of software employed. All the subjects identified the virtual entities when software version 2 was employed, which was a 3.33% improvement over software version 1 (Figure 10).

Contingency Table

Software	Count / Total % / Col % / Row %	Rating 1	Rating 2	Total
V1	Count	29	1	30
	Total %	48.33	1.67	50.00
	Col %	49.15	100.00	
	Row %	96.67	3.33	
V2	Count	30	0	30
	Total %	50.00	0.00	50.00
	Col %	50.85	0.00	
	Row %	100.00	0.00	
Total	Count	59	1	60
	Total %	98.33	1.67	

Figure 10. Contingency analysis for software version, 50 m

Feedback from the subjects when viewing the at 100 m was nearly the same as when viewing the virtual entities at 50 m, but software version 2 performed 6.67% worse than at 50 m (Figure. 11). The overall ratings slightly decreased, dropping from 98.33% of all subjects who were able to identify the virtual entity to 95%, regardless of software type. When comparing the two software types, software version 1 was statistically equivalent to software version 2 (Chi-square (1) = 0.357, p = 0.5500).

Contingency Table

Software	Count / Total % / Col % / Row %	Rating 1	Rating 2	Total
V1	Count	29	1	30
	Total %	48.33	1.67	50.00
	Col %	50.88	33.33	
	Row %	96.67	3.33	
V2	Count	28	2	30
	Total %	46.67	3.33	50.00
	Col %	49.12	66.67	
	Row %	93.33	6.67	
Total	Count	57	3	60
	Total %	95.00	5.00	

Figure 11. Contingency analysis for software version, 100 m

The difference in software performance at 200 m was statistically significant, with a Chi-square (1) = 6.583, p = 0.0103. 30% of the subjects using version 2 of the software were able to identify the type of object versus 70% of the subjects who were able to identify the type of object using version 1. It should be noted that 50% of the subjects, regardless of the software version, were able to identify the virtual entities at 200 m (Figure 12).

Contingency Table

Software	Count / Total % / Col % / Row %	Rating 1	Rating 2	Total
V1	Count	14	6	20
	Total %	35.00	15.00	50.00
	Col %	70.00	30.00	
	Row %	70.00	30.00	
V2	Count	6	14	20
	Total %	15.00	35.00	50.00
	Col %	30.00	70.00	
	Row %	30.00	70.00	
Total	Count	20	20	40
	Total %	50.00	50.00	

Figure 12. Contingency analysis for software version, 200 m

Demographic and Post-Task Survey

We explored the relationship between survey feedback and the subjects' observational test results. First, we examined a potential correlation between user enemy identification training and feedback. Next, we discuss post-task survey results regarding MR application in training. The post-task results specifically focus on feedback regarding strenuous training use and factors which complicated identification of VEs.

The post-task survey solicited subjects' feedback to identify challenges and recommendations. The questions specifically asked about characteristics of the VEs which were used for identification. It also explored the ability to identify VEs in stressful, physically demanding situations. The researchers solicited feedback on environmental factors such as bright light and background clutter. Last, the survey asked if MR can be used to improve training and if there were any health issues such as eye strain.

After examining the post-task survey, we noticed that subjects trained in identifying enemy vehicles or personnel appeared to provide a lower response rating, indicating an inability to clearly identify the VE compared to the other subjects. In order to gain greater insight into this observation, we conducted a Chi-square analysis. This analysis differed from previous analysis in this study as we kept the original Likert ratings (1-5), with 1 being "clearly visible," and 5 representing "not visible." The original ratings were maintained as it provided nuanced insight when we ran the Chi-square analysis. Approximately 20% of the subjects had not previously received vehicle or enemy recognition training. When comparing the enemy identification training effect on user feedback the analysis indicates (Chi-square = 1.064, p = 0.9000) the results were not statistically significant.

The most interesting and ambiguous Likert rating is "3." It is defined as "visible, difficult to determine object." The rating was awarded by 14% of those who received the identification training, and 12.5% of the personnel who had not received identification training. When exploring the poorer ratings, Likert rating 4 (visible, could not determine object type) and 5 (not visible) were awarded by 15% of subjects who received enemy identification training, whereas 12.5% of subjects who did not receive the training awarded the ratings. When examining the best ratings (1 = clearly visible, 2 = visible under most conditions), a lower percentage of trained subjects provided a 1 (46.8%) or 2 (23.4%) versus untrained subjects who provided a 1 (50%) or 2 (25%).

Anecdotally, subjects' comments suggested that personnel trained in enemy identification were more discerning in evaluating the quality of the VEs presented.

For MR to be effective as a training tool, Soldiers must be able to use when conducting normal maneuvers. Therefore, we want to gather the users' opinions about the potential of MR during intense training. We asked subjects, "How well do you think you will be able to recognize the image during a physically demanding training event?"

The general feedback regarding the technology's potential in an actual training environment shows that future users are receptive to the technology (Table 1). The two respondents who selected "poor" serve in the sustainment and maneuver/combat arms fields. The respondent who chose "very well" serves in the sustainment field.

Table 1. Rating Technology's Potential

Very Poor	Poor	Average	Well	Very Well
0	2	6	10	1

Another factor affecting how MR can be used in live training events is how it performs in a wide range of environmental and viewing conditions. We asked subjects about common factors which are encountered when MR is used outdoors. The most common complicating factor was bright light, followed by camouflage/background clutter, and then shadows. Bright light tends to dissipate the strength of the image the user is viewing (Table 2). Camouflage/Clutter tends to allow the VE to blend into background objects, which may not be a negative concern since they are unlikely to be seen in real world events. Shadows can sometimes obscure the VE if it is a darker image.

Table 2. Users' Rating of Factors Affecting the Viewing of Virtual Objects

Bright Light	Camo/Clutter	Shadows
10	8	2

DISCUSSION

The primary focus of work was to explore technologies that seek to overcome two major challenges for practical outdoor application of MR. Specifically, we focused on inconsistent anchoring and light washout of VEs beyond 20 m. Employment of GPS was intended to address the inability to consistently anchor a VE at ranges beyond 20 m. Researchers also explored the effects of animation in users' ability to identify objects in the hope it may alleviate challenges presented by high light levels.

High light levels were initially addressed through the employment of a visor and sunshades placed over the HoloLens II field of view. Shortly after the observational study commenced, software became available to adjust the brightness and angle of light on each virtual entity. During development of the IVAS Squad Immersive Virtual Trainer capability, animation was considered as an aid to assist the trainee in acquiring the target outdoors as distant ranges complicate target identification. Consequently, researchers sought to explore if animation may aide in virtual target identification outdoors.

We used the NPS campus as our environment because of its diverse terrain. It included forested and urban terrain and was within 200 – 300 m of the ocean and freshwater streams. This environment had frequently shifting light levels due to the capricious California Coastal Fog and conducting experiments at various times throughout the day (between 9:00 a.m. – 4:30 p.m.). One scenario was conducted from the 4th floor of a building, while another occurred along an abandoned road, with limited obstructions to the field of view, and another in a lightly forested park. Consequently, challenges such as morning dew, strong shade, foot/vehicular traffic, buildings, communication antennas, and elevation introduced real-world challenges into the research environment. Therefore, future research in using MR outside should include a wide range of terrains and environmental factors that will be encountered by military users employing the systems.

Recommendations and Observations

There are many capabilities which must be matured to enable practical outdoor use of MR for robust military training. Challenges mentioned earlier, such as tackling dynamic occlusion, are helpful, but we do not believe it is absolutely necessary. There are three areas tied to the research discussed in this work, which would make outdoor MR application possible. First, the HoloWarrior software must support highly detailed maps to enable efficient and tactically accurate scenario development possible. Second, outdoor, entity, class, or grouped based scenario editing must be available to refine issues tied to VE drift that occurs during bright sunlight. Last, the ability to adjust lighting levels by VE, or by class of objects, must be available.

The maps available on the HoloWarrior did not support accuracy beyond 10 m. The software allowed for minor adjustments in the placement of all objects simultaneously but did not allow for adjustment of each object. The ability to access and employ detailed maps, with up to 1 cm accuracy, to include recently generated maps, are required to prevent the trainer from spending too much time editing the scenario, is critical. The ability of the software to ingest maps captured the day of training would also reduce some occlusion challenges tied to movement of large objects such as dumpsters. The GPS capability must also be integrated into a scan of the training environment to create an occlusion mesh and head tracking map. These maps can be integrated together to refine inaccuracies in the map data. The most frequent inaccuracy is elevation data. Challenges were frequently experienced in our ability to anchor the VEs to the ground as the elevation data ranged from one – two m above or below the ground. This forced us to manually adjust the elevation of each virtual entity. GPS anchoring/fixing of each object or critical objects is necessary to ensure alignment with the ground. It will be nearly impossible to develop a perfect outdoor MR training scenario solely on a laptop, but the integration of detailed, accurate maps is crucial to ensuring only minor refinements are required, preventing a barrier to training due to poor maps.

The HoloWarrior editing capability, which resides on the HoloLens II must become amenable to entity or class level changes. As discussed earlier, the software only allowed for refinement to the comprehensive scenario. This meant that when environmental factors moved a virtual entity at a specific range by three meters, we had to move all entities simultaneously to ensure they were properly positioned. This also forced us to completely re-edit the scenarios to ensure we had space in the physical world to adjust the VEs. This limitation dramatically reduces the trainer's ability to adjust scenarios. Future software development should allow for micro-editing outdoors, while wearing the HoloLens II. The ability to move each virtual entity in elevation or its position on the ground maximizes the available training area. we recommend this capability be explored using both an X-Box controller, and hand gestures, such as tap and hold, gaze, or the laser pointer. This editing capability will be required to ensure quick scenario refinements, even when the GPS and maps are improved.

The effects of high light levels at ranges beyond 100 m are difficult to overcome without further improvements to the HoloWarrior software. The software must allow the trainer to have the option to adjust lighting levels at a macro level, and also a micro level, similar to what was described when discussing the movement of VEs. These two light adjustments are required as the sunlight crosses the line of sight of the user leading to users perceiving the location of each virtual entity differently. This ability to adjust both the lighting angle and the brightness level for each VE is critical to ensuring visibility at ranges beyond 200 m. This capability should also be assessed at near ranges, as the research in this work suggest lighting levels had minimal impact at 50 m, and a degrading impact at 100 m.

Because most of our subjects had prior training in enemy identification and, although it did not rise to the level of statistical significance, they appeared to be more discerning in their ratings than those without such training. This observation is consistent with the findings of Frank (2022) who found that models which met the needs of most military members did not work for training geospatial analysts. The models used to train these Soldiers required a greater degree of fidelity to improve performance on recognition tests. This implies that any MR system developed must be geared towards the specific task Soldiers are performing, and that a system acceptable for one group may not be acceptable for another.

Specific Challenges Encountered in this Study

The acquisition of a GPS signal proved challenging at times, as buildings with multiple antennas seemed to prevent acquisition of a consistent signal. Consequently, MR employment for training which requires GPS must consider electromagnetic interference. The challenges tied to GPS and supporting maps used for scenario design inhibited implementation of complex scenarios with animation. The ability to upload maps from government websites such as the National Geospatial and Intelligence Agency, whose Geospatial Repository and Data Management System includes training maps, is critical. This capability will enable the trainer to create detailed scenarios and ensure centimeter level accuracy in virtual entity placement.

The inability to place VEs at ranges beyond 200 m was both a software and physical terrain challenge. It was challenging to find an unobstructed field of view beyond 200 m on the ground at NPS. In order to overcome this challenge, one observation site was placed on the fourth floor of Hermann Hall. The low fidelity maps inhibited our ability to place virtual entities beyond the boundaries of NPS. We were unable to confidently assess and decipher critical details regarding terrain needed to accurately place the virtual entities. When assessing distances beyond 200 m, the trainer must understand the change in elevation, the field of view from the intended engagement and observation locations, and the characteristics of the physical objects to ensure scenario realism. The change in terrain elevation is especially important because a change in elevation of more than five feet may obscure the ability for a trainee to see a VE at 200 m.

CONCLUSION

This research informs the next steps necessary for enabling outdoor employment of MR for training. It is an invaluable tool to enable outdoor training and understand employment techniques. Furthermore, it can assist in bridging the gap until unsupervised machine learning algorithms can yield results which enable dynamic occlusion within an occlusion mesh. The results of the research are modest but do suggest that both GPS employment and software enabled lighting of VEs can improve the ability of trainees to see holographs at distant ranges outdoors. Further research and development which enables trainers to refine each object, and enables incorporation of high-fidelity terrain data can enable outdoor training using MR. Consequently, this capability can enhance realism, reduce training related cost, and most importantly, enhance warfighter lethality.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help of VR Rehab who provided the software which drove the HoloLens II for the experiment that we ran. We would also like to thank the engineers from the IVAS team at PEO STRI, to include Donnie Palmer, Blake Aycock, Neil Pinto, and Jimmy King for providing access and expertise.

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