The Tactical Considerations of Augmented and Mixed Reality Implementation

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The U.S. Army, NATO armies, and other advanced nations actively seek to implement augmented reality (AR) and mixed reality (MR) support for their operational forces. These platforms are intended to improve tactical awareness, target acquisition, and situational awareness, and also to develop an information upstream for commanders to act upon.

The United States' example is the integrated visual augmentation system (IVAS), which provides an integrated suite of situational awareness capabilities to enable better decision-making and increase soldier tactical fighting ability.[1] In the light of rapid developments and hurdles faced in fielding for the United States and its allies, we would like to add to the Army discourse the need to identify potential operational weaknesses in the AR/MR systems. The operational environment will test any equipment's durability and reliability. A central question we investigate is the tactical value on the battlefield and whether the system losing full or partial functionality changes the system from a capability enhancement into something that obstructs or prevents mission success. We identify multiple areas and research topics for investigation in order for AR devices to become a combat multiplier.

The acquisition and fielding process for new Army technology has shifted from an eight-to-ten-year process down to thirty-six months for delivery due to the availability of commercial platforms.[2] The condensed

A soldier tests the Capability Set 3 militarized form factor prototype of the Army's Integrated Visual Augmentation System 21 October 2020 during a live-fire test event at its third Soldier Touchpoint at Fort Pickett, Virginia. (Photo by Courtney Bacon)

process—soldier-centered design (SCD)—is different from traditional acquisition processes such that it meets the needs of rapidly evolving technology. This is evident in the Army's efforts to mature technological products to the soldier in a twelve-month period of performance via the rapid innovation fund, which is a significantly shorter time frame compared to earlier technology deployments.[3] Rapid acquisition and deployment meet the demand for bringing the latest technology to the soldiers but with quick turnaround comes also the risk of embedding weaknesses that are not identified early in the process. The challenge in the research and development of these technologies is to follow a methodological approach that allows for the imperfection and experimentation of technology, a concept that is new in Army capability development.

Via the IVAS program, AR/MR is positioned to be the next integrated battlefield technology. The U.S. Army is placing a considerable amount of investment and capital—human, financial, and temporal—into its refinement and deployment while purchasing 120,000 headsets to field to the force.[4] Currently, IVAS prototypes are rolling out to larger user bases to evaluate effectiveness with different populations and echelons.

While early adoption of AR/MR is promising, integrating technology into military operations inevitably encounters challenges. In a 2020 article on the Army's synthetic training environment, augmented reality, cybersecurity, rendering data, and bandwidth and latency were all identified as key challenges facing the Army for training.[5] This work expands the existing literature to focus on visualizing uncertainty on the battlefield, as well as to address some of the already identified shortcomings of using augmented displays for military operations.[6]

Integrating new technologies into combat operations requires multiple testing and refinement iterations via SCD. SCD focuses on feedback from soldiers and is prioritized in the development of feature sets. Recent soldier evaluations using the Army's IVAS has shown the importance of gaining bottom-up requirements analysis to improve soldier operations and utility.[7] The combat force lauds the testing, implementation, and fielding of AR/MR systems, in particular IVAS. The IVAS system has reportedly collected eighty thousand hours of feedback, been tested in extreme weather conditions in Alaska and Puerto Rico, and has a suite of capabilities to include thermal imaging, integrated GPS, night vision, holographic maps, and the ability to see around corners using a weapon's sight.[8] The IVAS is based on Microsoft's HoloLens 2, and despite undergoing rigorous testing with a rapid fielding plan initially targeted to hit combat units by the end of 2021, the Army's fielding was put on hold due to technical concerns.[9]

AR/MR is in the initial stages of adoption by the Army, and even with the current delay, we believe now is the ideal time to consider the potential obstacles prior to integration. For the AR/MR systems, scalability and meeting the stated goals as the "next generation 24/7 situational awareness tools and high resolution digital sensors to deliver a single platform that improves Soldier sensing, decision making, target acquisition, and target engagement," focus cannot be at the individual soldier level but must be expanded to commanders and units up to battalion and brigade.[10] We do not fight at the individual or squad level; the ability to support commanders and scalability to higher echelons is key to success. If functional, the information advantage generated by aggregated real-time combat information to build an operational picture enables multi-domain operations, shorter decision cycles, and rapid engagement with cross-domain assets. These are considerations that need to be contemplated prior to use in combat; ignoring these considerations will potentially increase risk during combat operations.

Human, Technological, and Environmental Considerations

Human factors inputs to AR/MR have traditionally focused on the display of information to enhance user comprehension. In the developed systems to support dismounted soldiers, researchers have shown evidence for egocentric views, overlapping displays, and multimodal communication methods.[11] In the tactical setting, an individual soldier must carry out the duties as a rifleman and team member. One of our immediate concerns is how the visualization and information flow distract from tactical awareness based on human senses and the interaction with the team. However, the difficult problem lies on two fronts: one is the appropriate technological support, and the other is switching between tasks to provide context-specific information.

Examining the technology, one of the biggest challenges is battlefield data verification. When directing troop movements on the battlefield, commanders need to be supported with data that is accurate, maintains integrity, and is current with the operational environment. Given the demands on AR/MR devices and even using current technology, there is a need to exchange a certain level of data back to a central compute-and-storage resource. However, as in the case of GPS location data, there is an underlying assumption that the data coming into an AR/MR device has not been manipulated and represents ground truth (e.g., it is not spoofed or jammed). Therefore, the approach to this needs to represent certainty or trust in the data and to understand how to tailor that data to each soldier's experience level.[12] Data manipulation and loss of integrity, or spurious data, will lead to subpar decision-making and, in the worst case, casualties. The soldiers trust the pixels with their lives, and if the technology is not reliable, it will no longer be used.

From a task perspective, soldiers must be able to switch between multiple tasks and roles without delay. For example, one minute a soldier could be firing at a distance, while the next moment directing supporting fires, seeking cover, hauling ammunition, or providing medical support to an injured teammate. While this is feasible, research shows that there needs to be appropriate information and context to support task switching within AR/MR.[13] Therefore, as technology develops, there needs to be an understanding of the primary tasks such that interfaces can appropriately support each. Support can be facilitated by obtaining soldier goals and breaking down task requirements accordingly.[14] In the event that an unknown event occurs, the interface needs to be cognizant and adjust to neither interfere with nor add to the soldier's cognitive burden.[15]

Overdependence on Technology

Soldiers train as they fight, and while an AR/MR system has many practical uses, its usage must be balanced to ensure that basic combat skills do not atrophy. For example, Army leadership has long acknowledged

Soldiers from the Old Guard test the second iteration of the Integrated Visual Augmentation System capability set during an exercise at Fort Belvoir, Virginia, in the fall of 2019. (Photo by Courtney Bacon)

the importance of conducting analog land navigation with a map, compass, and protractor.[16] While an AR/MR system is potentially effective for pre-mission training and objective familiarization, care must be taken to ensure that soldiers can still accomplish assigned critical individual and collective tasks without it for those occasions where it is unavailable. For example, the best electronics are worthless without a reliable power source, and even the best safety glasses and facial shields heavily degrade combat effectiveness once they fog up. An increased reliance on a digitized display of the environment and mission can lead to a loss of operation without the support of AR/MR. Overreliance on visual situational presentation to perform duties is not new or unique to AR/MR technology. Navy aviators use the term HUD-Cripple to describe the idea that a pilot becomes so reliant on technology that the individual is incapable of performing his or her tasks without relying on the technology.[17]

There is evidence that junior leaders are already falling behind on basic combat skills, so a deliberate effort must be employed to ensure that any fielded AR/MR system does not result in an overreliance on the given technology, thereby reducing combat lethality in its absence.[18] This will require more time for training in the field and garrison so soldiers can practice both AR/MR and nonaugmented iterations.

Unit and Soldier Experience Level

In research design, one seeks to explain as much as one can with as little as possible and without losing rigor. The same challenge goes for AR/MR, where rigor could be the information's validity and applicability. The information presented in the AR/MR tactical systems needs to be accurate, relevant, and timely, without creating a distraction or interrupting the information flow in the tactical setting. Units and soldiers have different experience levels, so information has a variation in value down to the soldier level. The variation in experience level can be significant, from war-fighting abilities, operating AR/MR equipment, to optimizing resource usage.

From a tactical perspective, a unit that utilizes AR/MR systems for command and information flow will only operate at a high level if it is restricted to key leaders, typically squad leaders and above. Combat engagements are fought at the four-member fire team level.[19] Directing individual members to engage known, likely, and suspected targets is the team leader's job. Whether it is clearing a singular room or clearing an entire town, the only difference is the number of teams engaged, but their individual tasks remain relatively unchanged.

A squad is comprised of two teams and this provides the squad leader a slight degree of separation from the immediate fight. This separation enables the squad leader to focus on directing the individual teams and maintaining communication with platoon leadership to ensure that the squad remains nested in the platoon mission.[20] Any disruption as two soldiers lose connectivity to the AR/MR system would directly impact the dynamic and the efficiency of the squad, especially for fire team members. Those junior soldiers make up the bulk of combat forces—the increased data provided by an AR/MR system has the potential to overwhelm and confuse, resulting in sensory overload and reduced combat effectiveness. Even though AR/MR offers the potential to distribute information to the individual soldier level, the appropriate level for distributing information needs to be carefully considered. Filtering and retaining information at the squad leader level frees team leaders to focus on maneuvering and employing their soldiers without encumbrance by further distractions.

As these devices see more frequent use across echelons, there are potential research areas that can be explored. One option is to provide the appropriate levels of information to the person viewing that information. This will require understanding the critical information elements that a decision-maker needs to be able to have access to. In previous research, this is known as providing separate or specialized views for different categories of users.[21]

Sensor Integrity

As previously mentioned, accepting wearable AR/MR devices for tactical information and communication depends on trust. From a soldier's perspective, he or she has to trust that his or her equipment functions as intended. Soldiers should not doubt the equipment's basic functions performance under combat conditions. For example, the Naval Department of Ordnance's failure to acknowledge the deficiency of the Mark 6 torpedo in the early years of World War II negatively affected submarine captains' willingness to engage targets.[22] If the sensor's data integrity is dubious, the lack of trust will force commanders to refrain from using AR/MR.

AR/MR devices and sensors are invariably constructed with general purpose computing hardware and will inherit the operating system and hardware's innate vulnerabilities. Although these lessons can

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be applied in the abstract to all AR/MR devices, the Army's IVAS is based on the HoloLens 2 and provides poignant, recent examples. Not only does the HoloLens 2 run on Windows 10 (and thereby inherits its vulnerabilities), but components tweaked for the HoloLens can also introduce new integrity issues. An early HoloLens patch fixed a vulnerability in which a remote device got the HoloLens to execute arbitrary code simply by sending malformed Wi-Fi packets, which is the HoloLens's most common form of communication with other networked devices.[23] While "[the] HoloLens 2 security architecture was designed and engineered from the ground up to be free from legacy security issues … creating a minimized attack surface," security vulnerabilities are still (naturally) being discovered.[24]

A technologically advanced adversary will certainly devote research during peacetime to develop simple, inexpensive, one-time use, tossable devices that can—in close combat—create spurious sensor data. Such an adversary will also be inclined to invest the time and resources into gaining unauthorized access into AR/MR devices in order to manipulate the effectiveness of the device and to negatively influence the wearer's decision-making cycle.

Electromagnetic Signatures

The last few years have seen a revival of spectrum and electronic warfare (EW), where all major military forces seek to degrade and disrupt utilization of the electromagnetic spectrum (EMS).[25] We consider the challenges facing AR/MR systems from both the radio frequency (RF) and infrared (IR) perspective. The AR/MR worn systems are dependent on access to networked communication using the EMS to carry data traffic, even to reach local resources.[26] While the transmission range to maintain high-quality Wi-Fi connectivity is relatively low (100–200 m), the detectable range is far greater. With increased contention over control of the EMS, electromagnetic signatures of the worn AR/MR systems can alert hostile forces that friendly forces are present in an area.[27] The constant streaming of data effectively makes each AR/MR worn system a uniquely identifiable beacon, even if the traffic itself cannot be deciphered.

Infrared emissions provide an adversary with another identifiable signature. The AR/MR-worn system's IR camera provides a tactical advantage as the thermal imaging can visualize camouflaged hostile forces and detect still-warm equipment, such as machine guns that have recently fired, electronic equipment, engines, and generators. However, commercial-worn AR/MR rely on IR light to sense hand movements and other nonverbal instructions for the system. The IR light emission is detectable, especially in an environment with no or limited light, conflicting IR emissions.

In the growing contention over the EMS, fixed sensing equipment is no longer the only threat for detecting AR/MR emissions. For example, drones with the ability to conduct electromagnetic harvesting could detect the presence of worn AR/MR systems. The increasing presence of loitering munitions on the modern battlefield is another avenue for detection.[28]

The ability to detect the transmissions of worn AR/MR systems by either of these capabilities, combined with the challenge of detecting their presence especially during hours of limited visibility, demonstrates a real and growing threat vector. The need to share relevant and timely information must be balanced with the need to minimize the detectability of soldiers using AR/MR equipment.

Extreme Weather, Energy Consumption, and Battery Life

The future operational environment for AR/MR includes extreme heat, cold, humidity, and other environmental conditions that can degrade electronic performance. The major powers (i.e., the United States, Russia, China, India, France, and the United Kingdom) envision future operational environments that range from the arid deserts of the Middle East and Africa to the cold weather-exposed high mountains of Southwest Asia and Europe and to the tropical jungles of the Indo-Pacific and South America. The varying environmental conditions will affect electronic equipment, increasing the likelihood of malfunctions and exacerbating the challenge to maintain sufficient power for system functionality. Dust, heat, humidity, and daily wear and tear can affect the sensors and the electronic equipment.

The battery life for the IVAS system, for which the base system is the civilian Microsoft HoloLens 2 headset, is currently eight hours.[29] A twelve-hour engagement would then require at least two sets of batteries or recharges. The risk is that the ongoing need to either replace batteries or recharge them impacts a unit's tactical performance.

Adding to the climate condition complexity, operations are likely to occur in desolate areas that lack infrastructure such as a robust power grid to provide power to charge batteries and maintain electronic equipment. The absence of infrastructure also impacts the logistic chain, which in turn affects the access to supplies for repair or replacement of faulty equipment such as electronic components.

The tactical units are equipped with an advanced battery charger, but generators on the battlefield are cumbersome and require constant resources of their own (e.g., fuel, unless solar power is available). Additionally, a generator creates sound and heat signatures, which increase the likelihood that the unit will be detected by an adversary.

Solar panels are not always suitable; high north (i.e., Arctic or Siberian regions) winters do not have sufficient daylight for adequate energy supply by solar panels the majority of the year. The preceding factors, combined with current battery technology, which does not hold the same charge when it gets colder, means that battery capacity can be reduced to half the expected output, and adds to the challenge.[30]

Battery power can be a limiting power for extended usage of the equipment. Even if equipment is tested in cold weather under limited time, the future special operations operational environment in great power competition with longer missions and with less support increase the stress and wear on the equipment. Exposure to frigid conditions can also make plastic components brittle, leading to discomfort for the operator. These usability concerns require future studies into battery technologies and functionality under extreme environmental conditions.

Network Reliance and Scalability

Seen from a division and brigade level, network connectivity becomes a single point of failure as the tactical unit's ability to fight using AR/MR is contingent upon the operational unit's ability to provide tactical connectivity at the point of contact. Potential near-peer adversaries focus on engaging EW capabilities at the operational level to suppress and degrade overarching networks. While this is concerning with regards to combat operations (e.g., indirect fires), it is even more concerning when attacking AR/MR networks, which are crippled without network connectivity. The AR/virtual reality (VR) systems rely on high-quality data with maintained data integrity through limited delivery channels using the unregulated 802.11 wireless frequency ranges.

From a friendly fire standpoint, the number of AR/VR systems deployed within a platoon area of operations would quickly overwhelm the limited available wireless bandwidth. Recent network studies have shown that the so called "last mile"—the Wi-Fi network where wireless devices connect to an access point—is still the single point of failure for delivering performant networked services.[31] The voluminous bandwidth required by dozens of AR/VR systems in a small area could quickly cause "friendly fire" incidents in the radio frequency RF spectrum, where the density of AR/VR systems creates denial of service for all local systems. This problem is compounded exponentially in an urban environment where AR/MR are most useful; rogue wireless transmissions

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(e.g., civilian home networks) will directly interfere with AR/VR systems' communications.

Operational orders have alternative routes as texts, voice, and data and could also choose different networks such as satellite communication (SATCOM), high-frequency radio (HF), and very-high frequency radio (VHF). There is a higher likelihood that operational orders, in an EW-saturated environment, reach the intended receiver compared to an undisrupted functional AR/VR system. From an adversary's perspective, which should be a part of our risk assessment, the AR/MR supporting networks are mission-critical and identifiable for targeting.

Conclusion

For tactical AR/MR systems to be a viable enhancement for soldiers and increase their fighting ability, addressing the areas presented in this article with a well-defined prioritization and additional research and testing is required. Each soldier has limited ability, like any human, to process information rapidly and sustain that ability over time so care must be taken to avoid information overload. The technical stability and reliability of AR/MR systems are pivotal to their successful implementation; any disruption or partial functionality could drastically reduce the effectiveness of the combat unit.

A fighting force is trained and drilled to coordinate movement, fires, and actions, which creates an all-or-nothing deployment of the AR/MR system. If the system does not work for a fraction of the unit, the whole unit has to fight without the AR/MR system to avoid misunderstandings and losing the advantage of unit cohesion and coordination. In future potential conflicts with near-peer adversaries, rapid adoption and integration of technology will be essential, but doing so requires a methodical approach to avoid creating new vulnerabilities for adversaries to exploit. ■

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