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Augmented Reality
Collaborative and Analytical Tools
for ISR Operations

by

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VR-ARTF

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Biography

Colonel Brendan Cook is assigned to the Air War College, Air University, Maxwell AFB, AL. Colonel Cook joined the Royal Canadian Air Force in 1991. He obtained his Bachelor of Science degree in Oceanography and Earth Observational Science from Royal Roads Military College in Victoria, BC (1995), and his Master of Physics in Underwater Acoustics from the Royal Military College in Kingston, ON (2005). He is an Air Combat Systems Officers with operational tours flying the CP-140 Aurora, a long-range maritime patrol aircraft based on the P-3 Orion. His flying tours include 407 Maritime Patrol Squadron, the Maritime Proving and Evaluation Unit, and 405 Long Range Patrol Squadron, during which he accumulated 2275 hours of flying time. He has served in staff capacities at the Acoustic Data Analysis Centre (Pacific), the Joint Command and Staff Program at the Canadian Forces College, the Strategic Joint Staff at NDHQ Ottawa, and most recently within the Director of Air Requirements where he served as DAR 3 responsible for Maritime Air Requirements. He deployed to Afghanistan in 2009 and served as the Long Range Patrol Detachment Commander for Op IMPACT Roto 0 from 2014-2015 conducting operations over Iraq. He was the Commanding Officer of 405 Long Range Patrol Squadron from 2014-2016. Colonel Cook and his wife Cathy have two children, Beth and Liam.

Abstract

Intelligence, Surveillance and Reconnaissance (ISR) operations have experienced explosive growth in recent years, leading to an exponential increase in collected data. Yet despite this wealth of ISR data, individuals, teams and decision-makers are often not able to develop the individual and collective situational awareness (SA) of the operational environment they need. Augmented Reality (AR) technologies offer one potential solution to this dilemma. Using visual, auditory and haptic clues AR technologies have the potential to deliver new opportunities for collaboration and analysis, which will enhance individual and collective SA. This paper aims to charting a path for the development of AR tools for collaboration and analysis in ISR operations. It explores the current state of AR technology to clarify the key definitions, the taxonomy of systems, and the current research into effective uses. It also examines the cognitive and learning theories that underpin situational awareness to understand what role, if any, AR can play in developing SA. These theories were found to support the increased use of AR technologies to improve SA and collaboration, and eight design criteria that AR technologies must address to promote SA were identified. If these design criteria are respected, AR technologies can be anticipated to improve learning performance, increase user motivation, and enhance user engagement/interaction and collaboration. Additionally, gains in spatial understanding and long-term memory retention are foreseen. Despite this potential, three primary risks were identified that must be appropriately managed in AR system design: channelized attention; distraction in system management; and user customization. If these risks are managed and the design criteria respected, then developers of collaborative and analytical tools for ISR operations will be able to unlock the bright future offered by AR.

Augmented Reality Collaborative and Analytical Tools for ISR Operations

> *Hours before sunrise, a Special Forces team is en route to their objective, an enemy strong point deep in an urban area. As they approach, ISR assets verbally alert them to a threat approaching from the south, but over a hill and out of sight they cannot assess if it is threat. Seeking to avoid contact the team reroutes but stumbles into enemy sniper fire. In the ensuring exchange, the snipers are neutralized but the enemy is now alerted. The team presses on working to correlate ISR data with what they can see. Time is short, carrier-based strike aircraft are incoming. Analysts cannot match the ground and ISR observations to their own data. Unable to collaborate effectively with operators, they must provide multiple contingencies to the strike aircraft, introducing additional confusion. Suddenly, communications intercepts indicate a high-value target that was inbound has turned away from the objective having been alerted; an opportunity lost. Back at C2 it is clear a well-planned operation is beginning to unravel. Unable to effectively collaborate, the resulting strike is uncoordinated. Key enemy leadership slips away in the mayhem of the battle. The mission has failed.*

This vignette paints a grim picture of the present, but it does not have to be our future. Intelligence, Surveillance and Reconnaissance (ISR) operations, aimed at addressing the issues in this vignette, have experienced explosive growth in recent years, leading to an exponential increase in collected data.[1] Yet despite this wealth of ISR data, operators, analysts and decision-makers often cannot reap the benefits of the doctrinal role of ISR, which is to get the "resulting information to the right person, at the right time, in the right format."[2] As a result, individuals, teams and decision-makers are often not able to develop the dynamic understanding of the operational environment they need.[3] Recognizing this, the ISR enterprise is searching for strategies and technologies to improve collaboration and, in doing so, also improve individual and collective situational awareness (SA). Augmented Reality (AR) technologies offer one solution to address the tsunami of ISR data. Using visual, auditory and haptic clues AR technologies have the potential to deliver new opportunities for collaboration and analysis, which will enhance individual and collective SA. In order to assess the potential of AR technologies, this paper will first explore the current state of AR technology to clarify the key definitions, the taxonomy of systems, and the current research into effective uses. The cognitive and learning theories that underpin models for situational awareness (SA) will be examined to establish the critical challenges that AR technologies must address. This will chart the path toward a brighter future employing collaborative and analytical AR tools in ISR operations.

AR Basics: Definitions, Configurations and Types

Augmented reality technologies are systems that "allow for combining or 'supplementing' real world objects with virtual objects or superimposed information but not restricted only to the sense of sight; it can be applied to all senses such as hearing, touch and smell."[4] They differ from Virtual Reality (VR) systems in that they are not fully immersive because the user continues to interact with the real world while employing AR systems.[5] The concept of using AR technology in military operations is not new. Its origins can be traced to the Second World War when systems such as the Norden bombsight, cued bombardiers with the correct aim point for bomb drops. These systems evolved into the first-generation of Heads-Up Displays (HUDs) employed initially in military aircraft cockpits. Over time, these traditional HUDs have become ubiquitous in the commercial airline industry with companies such as Boeing, Airbus, Bombardier and others including these systems as standard cockpit equipment.[6,7,8] The technology is also being fielded in the automotive industry with HUDs being made available in the new Mazda3, BMW 7 series, and aftermarket systems.[9]

Outside of a HUD application, the first commercially available AR system was Google Glass. Announced in 2012 to much fanfare, Google Glass was hyped as a revolution in wearable technology and was even named the "Best Invention of the Year." Despite this hype it quickly fell from favor. It was plagued by technical issues, and the integrated camera raised privacy concerns based on fears the public could be surreptitiously recorded.[10] By 2015 Google Glass was pulled back into the laboratory until it could be perfected: an inauspicious ending to AR's first encounter with the public. The general public's next encounter with AR came in handheld form on 6 July 2016 with the launch of the viral smartphone gaming app *Pokémon Go*. The app combined standard technologies built into smartphones (location tracking and cameras) to create a game in which digital content was overlaid on the real-world through the smartphone screen, in effect, turning a smartphone into a handheld HUD.[11]

Given these impressive advances in HUD technology it is not surprising that the next logical evolution was the integration of the HUD into a visor configuration. This innovation enables pilots to have access to the augmented data regardless of where they look. The F-35 Gen III Helmet Mounted Display System produced by Rockwell-Collins is one of the most recent examples of this technological step, providing context sensitive information for the pilot depending on where they happen to be looking at any time.[12] Like the traditional HUDs, as costs have come down, even head-mounted displays (HMDs) are beginning to enter the civilian aerospace market with companies such as Thales fielding the TopMax system in 2015, a monocular system for civilian business jet applications.[13] Beyond aerospace, companies such as Google, Microsoft, Magic Leap and others are developing more immersive forms of AR by employing HMDs for the presentation of information in gaming and other applications.[14,15]

Advocates for AR and VR technologies, like Charlie Fink, author of *Metaverse: An AR Enabled Guide to VR & AR*, have argued that the latest step in the technology, immersive HMDs, justifies the creation of the term Mixed Reality (MR) to describe the new generation of technology, a term which Microsoft has even trademarked.[16,17] However, from a user's perspective the distinction between AR and MR is somewhat arbitrary as it only represents different configurations for delivering the augmented experience: HUD, hand-held device, or HMD. For some users the traditional HUD or hand-held (aka smartphone-like) systems will be the preferred method to augment their reality with additional data, while others will benefit more from the new generation of immersive HMDs. Consequently, for the purposes of this paper the broader term AR will continue to be used to apply to all technologies that augment a user's reality with digital information; however, the focus will be on the hand-held and HMD configurations.

Regardless of the AR system configuration, the objective is for virtual and real-world objects to seamlessly coexist for the user. For this to occur the AR system must situate the augmented digital content in the graphical overlay for the user. There are three types of methods for overlaying graphics: marker-based, location-based, and marker-less.[18] Marker-based AR systems were the first to be developed because they do not require highly accurate location tracking or large supporting cloud databases to function. Instead these systems employ various types of markers such as bar codes, Quick Response (QR) codes, or even simple user-entered number codes to cue the system to provide on-demand digital content. Bacca et al conducted a meta-analysis of 32 published studies on AR systems over a ten-year period (2003-2013) and found that marker-based AR systems are by far the most widely employed in educational environments (59.4%).[19] This preponderance of marker-based AR systems in educational environments is no doubt due, at least in part, to the fact these systems were the first to evolve and are technologically the most robust. Location-based AR systems evolved after marker-based systems and are the second most used in education (21.9%) and typically employ GPS, 3-axis accelerometers and digital compasses to properly position digital content.[20] *Pokémon Go* employed location-based systems and since the launch of this game many smartphone applications now employ this technique. Marker-less systems are the latest evolution of AR. They rely purely on object recognition to determine what content to display and where to display it based on the user context, but are more difficult to field as the Google Glass experiment showed.[21] They require an embedded sensor system and recognition algorithm to sense the environment and objects within it, as well as a point cloud database of the environment to support 3D localization of the device. The point cloud database must also include relevant data about the environment and objects within it for the call up and display of augmenting data. Given these challenges, marker-less systems are currently the least employed in education applications (12.5%).[22] These systems exist in limited applications today such as *Living Wine Labels*, which recognize wine bottles and labels to provide a digital experience to users;[23] however, significant development is required before marker-less AR systems can be fielded widely. Mixed approaches that use a combination of location-based and marker-less graphics overlay could offer a promising approach to address these challenges.

While most of the focus in early AR technology development centered on employing graphical overlays, more recent work has looked at the integration of the sense of touch and hearing, by employing haptic and spatial audio cues in AR systems. Numerous studies have found that in the “initial stages of learning, especially with a complicated motor task, haptics may significantly improve learning by allowing the participant to more easily make a connection between the instructions and the motor requirements.”[24] Haptics have the potential to improve kinesthetic, embodied and tactile knowledge, which has clear applications in learning physical tasks. However, “hands on” training with abstract data and concepts also appears to generate “minds on” experiences allowing users to develop a deeper understanding of them.[25] Many gaming applications in both AR and VR employ haptic feedback to create a more immersive experience and to provide specific cues to users. Similarly, developers are increasingly integrating spatial audio into AR systems to enable users to track objects in AR and to create a sense of proximity in the virtual environment.[26] Spatial audio can "increase awareness of surroundings, cue visual attention, and convey a variety of complex information without taxing the visual system."[27] As haptic feedback and spatial audio are further developed these technologies can be expected to provide additional avenues to improve AR's potential.

AR in Learning

In recent years several studies have demonstrated the promise of AR technology to improve learning outcomes. Bacca et al's meta-analysis assessed the uses, advantages, limitations, effectiveness, challenges and features of AR technologies in educational settings.[28] Their study also included a review of findings from four other meta-analyses. Together these studies have concluded that the use of AR has improved learning performance, user motivation, user engagement/interaction and collaboration.[29] Additionally, augmenting the real-world with contextualized data improved spatial understanding and long-term memory retention.[30] These results have been replicated by other studies in other fields. Lin et al compared the use of traditional 2D simulation technology versus 3D AR simulations in teaching physics concepts and concluded that students who used "the AR system showed significant[ly] better learning achievements than those who learned with the traditional 2D simulation system."[31] Jenkins et al developed and tested AR technologies to support improved situational awareness of the space domain. They found that AR provided unique options to display spatial geometries that cannot be easily accommodated in a typical 2D display, improving spatial awareness for operators.[32]

Despite these encouraging results, these studies have also identified a few challenges for the employment of AR technologies. Most significantly, AR applications can lead to channelized attention on the augmented data, resulting in a decrease in situational awareness overall. Additionally, some of the AR applications were difficult to use, as the interfaces are still in development. These usability difficulties had the potential to offset any gains in learning and performance due to the distraction caused by the system. Lastly, while AR technologies offer the potential for personalization of the experience, the level of personalization was often insufficient to meet the needs of users. Consequently, while there is great potential in employing AR systems in a broad range of applications, to achieve this potential AR must be fit for purpose.

Individual Situational Awareness

To better understand how to develop and employ AR technologies to enhance individual and collective situational awareness in ISR operations it is important to understand the cognitive and learning theories that underpin it. Situational awareness (SA) is a term that was originally conceived in the 1980s and 90s from the study of aviation accidents as a way to describe a pilot's understanding.[33] It is now broadly understood to be "the term used in Human Factors (HF) and ergonomics to describe the level of awareness that people have of the situation they are engaged in; it focuses on how people develop and maintain a sufficient understanding of what is going on and what is likely to go on in order to achieve success in task performance."[34] Historically, research into improving SA has largely focused on cognitive processes at the individual level.[35] Mica Endsley's three layer model, one of the most widely cited works in the field, established the cognitive processes to achieve situational awareness: perception, comprehension, and projection.[36] Individuals perceive elements of their environment, achieve comprehension of the current situation, and then project into the future to predict events. Endsley demonstrated the utility of employing the concept of SA beyond the cockpit from large scale operational systems to tactical and strategic systems, and how it could be scaled from the individual to a team.[37] According to Endsley, team SA is a function of "the degree to which every team member possesses the SA required for his or her responsibilities."[38] To achieve this, team members build their own SA and then share information to develop the same SA across shared requirements.[39] Any team member who does not have the SA to meet all their requirements becomes the weakest link.[40] Given each team member possesses some elements of information that the others require to establish their own SA, the ability to communicate these elements efficiently and effectively becomes a critical factor.[41] Studies have shown that high-performing teams often communicate less than low performing ones, but when they do communicate, they do so both efficiently and effectively to ensure team members have the shared elements they need.[42] Durso and Gronlund later built on the early work of Endsley and others to refine the concept of SA and developed criteria to consider when using automation to assist in developing SA. Their work established four design criteria for automation to support individual SA. It should: (1) enable operators to perceive and comprehend the information presented to develop SA and project into the future to predict events; (2) reduce operator workload, but ensure the operator is in the loop for key tasks; (3) ensure the operator is aware of the system mode and can predict what the system will do next; and (4) keep track of relevant information so the operator can take over when necessary without a deficit in SA.[43] Ensuring that AR technologies employed in an SA system meet these criteria would ensure that they assist in building individual SA from a cognitive perspective.

Distributed Situational Awareness

The three-layer model for SA and criteria for automation to assist individual SA are reflected widely today in system design. However, both approaches are often critiqued because they were developed by looking at SA from a bottom-up perspective, from the individual to the collective through a sharing process. These critics argue that this approach becomes problematic in collaborative environments because by its nature teamwork is inherently complex.[44] In distributed and complex systems, individuals perform two types of tasks. “Teamwork tasks” are directly important to team goals, whereas “taskwork tasks” are important to the individual’s role but only indirectly support the team goal.[45] Therefore, while individuals do require an appreciation of the SA of the other team members they do not necessarily need to develop shared SA to be an effective member of the team. Rather, individuals may need to view and use information differently than other team members and therefore shared SA is not as important as being able to communicate the appropriate information, to the right person at the right time.[46] Thus while attention must be paid to the considerations derived from these approaches, they must be balanced with approaches more conducive to collaborative systems.

An alternate approach proposed by critics like Salmon et al, employs a top-down perspective to focus on cognitive processes but at the collective level. It does so by considering the team, their associated network, and the interactions within that network at the outset.[47] According to Salmon et al, “SA arises from the interactions between operators and between operators and the technology that they use; it is associated with individual agents[,] but it may not reside within them as it is born out of the interactions between them.”[48] In their view, good team performance is facilitated not by shared SA, but rather by each member having compatible SA, which may be different than other members because individuals experience situations in different ways, defined by their experience, training, knowledge, skills, and roles. This compatible SA is then built up via SA transactions amongst the team to meet individual requirements, and through this process Distributed Situational Awareness (DSA) emerges as a systemic property rather than as a sum or product of each individual’s SA.[49] The implication of this approach is that DSA is highly reliant on how individuals display and interface with the information they have access to and that they require to fulfill their team role. Moreover, given that individuals have different roles, it is essential that they not be inundated with redundant or irrelevant information. From this work, four criteria can be identified for displays and interfaces to effectively support DSA. In addition to the four criteria for individual SA already noted (criteria 1-4), systems that support DSA should: (5) be tailored to the individual user; (6) present only the information that is required in a timely manner; (7) associate the new information with other information with which it will be likely used; and (8) facilitate SA transactions and collaborations between users.[50] AR technologies that meet these criteria would, therefore, be well-suited to supporting DSA within a collaborative network. The criteria for individual SA (1-4) noted earlier, coupled with the DSA criteria (5-8), then define the eight criteria AR should address to meet the cognitive requirements for building individual and distributed SA.

Situational Awareness as Learning

To validate these criteria further, it is worthwhile to examine the problem from another perspective. Learning theory can offer this secondary perspective because situational awareness is a product of learning about the environment. The three main branches of learning theory, behaviorism, cognitivism and constructivism, are all centered on the concept that learning occurs inside the individual. These theories do not consider the learning that occurs outside of the individual nor how learning happens within an organization.[51] As was already noted, the research into DSA has identified the importance of looking beyond the individual to teams and to the broader organizations of which they are associated. Connectivism is an emerging learning theory that looks at this broader, organizational perspective and is one which was developed to better explain the changes to learning brought on by the digital age.

Connectivism holds that learning in a digital age is no longer an internal activity isolated within an individual. Rather it is a process that occurs at the organizational level as information is acquired and new connections are drawn between old and new information.[52] From a connectivist point of view, “knowledge that resides in a database needs to be connected with the right people in the right context in order to be classified as learning.”[53] While individuals make each connection, it is their ability to serve as a node within a learning network, sharing connections to other nodes, that enables an organization to learn more.[54] Successful learning is achieved when all nodes in the network are engaged and exchanging information throughout to find solutions to problems and tackle issues employing multiple perspectives.[55] Consequently, with respect to individuals, connectivism values the ability to recognize patterns in information, to distinguish between the important and unimportant, and to identify and adjust to new information that has shifted the landscape.[56] Within organizations, connectivism values the creation, preservation and utilization of information flow as a key learning activities.[57]

While connectivism is a relatively new learning theory, having been first published in 2005, it has already gained traction in practice. It is being applied to many applications spanning the development of: Massive Open Online Courses (MOOC);[58] collaborative teaching and learning environments;[59] mobile learning applications;[60] and small-scale learning objects for inclusion in multidisciplinary approaches to learning.[61] The core concepts of connectivism and its diverse applications make it a learning theory with a high level of applicability to ISR operations. These operations are characterized by the employment of high-end digital technologies in order to collect, manage, analyze and display large and diverse data sets, so that both analysts and operators can collaborate and make connections across the data in order to build individual and distributed situational awareness. More significantly, the aim of connectivism, to connect the content of databases to the right person in the right context, closely mirrors the aim of ISR, to deliver information to the right person, at the right time, in the right format.

Both connectivism and DSA emphasize that learning in the digital age occurs when individuals collaborate within a network. They stress that individuals in the network will use information differently and that developing shared awareness of knowledge is not the overall goal of the network. Rather, individuals need to build the awareness that they require as well as contributing to an awareness of the overall knowledge that is compatible with the others in the network. This compatible awareness then enables individuals to more effectively complete their function as a node within the network, creating connections that enable the sharing of knowledge to those who need it. Through this process knowledge is created within the network itself and individuals can draw on this overall knowledge to conduct their appropriate taskwork and teamwork tasks in support of the overarching team's goals. These two approaches emerge from different initial perspectives on how to build situational awareness, cognitive versus connectivist, and yet they arrive at very similar conclusions on how to build situational awareness. Consequently, the eight design criteria established for developing individual and distributed situational awareness will provide a rigorous framework to evaluate the potential for AR technologies in ISR operations.

AR in Individual Situational Awareness

As determined earlier, design criteria 1-4 focused on optimizing individual SA. The first criterion was to enable operators to observe and comprehend information to develop individual SA and then to use that information to predict future events. With respect to increased operator perception and comprehension the research by Bacca et al and Jenkins et al provides strong evidence that AR technologies can improve learning performance and spatial awareness particularly in cases where 2D displays of data are inadequate to properly represent data. Military and civilian employment of HMD systems have also demonstrated that AR systems allow operators to perceive and comprehend the information in a context sensitive fashion enabling them to develop individual SA and then project into the future to predict events. However, the research by Bacca et al also shows that while these systems can assist in the perception and comprehension of information, there is a risk that operators will channelize their attention on the augmented data, resulting in an overall loss in SA. The launch of *Pokémon Go* provides an interesting case study in this effect. Within 148 days of the introduction of the game, researchers identified a disproportionate increase in vehicular crashes, injuries, and fatalities in the vicinity of PokéStops, locations in in the game where users can replenish their "weapons." A significant factor in this increase was found to be channelized user attention during game play.[62]

Much like the civilian users of *Pokémon Go*, users of AR systems in aerospace applications must be careful to not succumb to channelized attention. This has been the focus of significant research by the aerospace industry. When designed correctly to avoid channelized attention, HMD devices have been found to decrease operator workload by enabling the monitoring of key systems without the pilot having to direct their attention "inside" the aircraft. Moreover, by integrating system status, warnings and alerts into the HMD displayed data, the pilots can be cued when their attention is required for key tasks. This example satisfies the second design criterion for developing individual SA, that is to reduce operator workload while keeping the operator in the loop for crucial tasks.

The third criterion was that operators will remain aware of the system mode and can predict what the system will do next. Here again, pilots using HMD displayed data were able to adhere to this criterion. It was only with the fourth criterion, keeping track of relevant information, that Bacca et al caution that in managing this wealth of the data, the AR interface must be easy to use, or the performance gain risks being offset by the distraction caused in managing the system. Nevertheless, well designed AR systems have demonstrated that they can provide spatial and tactical data in their appropriate context so that operators can keep track of relevant information, particularly when automated systems are in control. In doing so, AR systems have shown the potential to enable operators to intervene, when necessary, without a deficit in SA. As one would expect given the proliferation of HUD technologies in aerospace and other fields, the design criteria for building individual SA can easily be met by AR technologies. The key challenges in meeting these criteria are addressing the risks of channelized attention and distraction due to usability difficulties.

AR in Distributed Situational Awareness

The first four design criteria centered on individual SA, whereas the latter four criteria (5-8) focus on building distributed SA (DSA). Given that DSA requires multiple users to be able to collaborate effectively it is more challenging to satisfy these criteria. The fifth criterion targets developing DSA in collaborative systems by ensuring they are easily tailorable to the individual user. As noted in the studies by Bacca et al, while AR technologies appear capable of fulfilling this criterion in theory, in practice this has not always been borne out in the system design. The current designs of HMDs do not fit all users equally well, as a result, some users are not able to align certain HMDs for optimal viewing.[63] Even the simple functionality of integrating with prescription eye-wear is not always as simple as might seem. For instance, the Microsoft HoloLens can be worn over prescription eye-wear, but this affects the fit of the system.[64] Other systems like the Magic Leap One are slightly more functional because they can accommodate prescription inserts. Beyond the HMD form and functionality, the applications for commercially available AR systems only provide limited ability to tailor the content and display of information for individual users. However, this latter aspect is mostly related to the current state of development of applications and not a true reflection of the future potential. With appropriate software development one can easily imagine a future in which the current 2D physical displays for a weapon system are replaced by software defined displays projected within an HMD. Operators would then be able to generate one or multiple displays in their 3D AR workspace to display the information in a manner that best suits their task and individual traits.

The use of software defined, user configurable displays would also provide a path to address the sixth criterion in system design: to present only the information that is required by the user in a timely manner. At present, systems such as the Thales TopMax monocular display and F-35 Gen III HMD are already designed to provide context specific and time-sensitive data to users. The TopMax system will provide standard HUD type data and track data for air contacts when an operator is looking out of a cockpit, but blank out such data or display other required data when an operator is looking internally.[65] In this way, the operator is provided with the key navigation and flight deconfliction data when required, and not distracted by such data when performing other tasks.

With respect to the seventh design criterion, AR systems also have the potential to associate new information with other information by employing the three methods for overlaying of graphics (marker-based, marker-less, and location-based). In particular, the marker-less and location-based methods, when fully developed would enable operators observing a geographic point or an object to be able to display additional ISR data associated with that location or object from historical databases. One can envision an operator observing an enemy strongpoint to be automatically provided amplifying data regarding the last observed enemy disposition at that location or the latest predicted disposition based on intelligence assessments. Alternatively, ground forces approaching a strongpoint could be provided with the latest 3D model of the location for the conduct of tactical planning to assess viable approaches or potential sightlines for anticipated sniper positions. In each of these cases, new information could be visually associated with other information with which it will be used.

Perhaps the most promising aspect of AR technologies is demonstrated by their ability to satisfy the eighth and final design criterion by facilitating SA transactions and collaborations between users. Already, systems such as the F-35 Gen III HMD and TopMax systems can pass tactical information between platforms for visual comparisons of tracking information to resolve the ambiguities in the operational environment.[66] Future applications could enable ISR assets to provide real-time, geo-referenced and orthorectified imagery to land forces for viewing on their AR HMDs from their perspective, rather than the "bird's eye view" currently provided by airborne ISR assets. Lastly, air, land and naval forces would be able to benefit from real-time intelligence updates being pushed or pulled to their AR HMD devices to improve their understanding of the environment or elements within it. In doing so, operators and analysts would be able to exchange real-time ISR data and conduct collaborative analysis in time-sensitive scenarios to improve individual and distributed SA.

The Future of AR in ISR Operations

AR technologies have a strong potential for use in developing analysis and collaboration tools for ISR operations. In all three configurations – HUD, hand-held and HMD – AR systems are already providing useful tools. Future developments in visual, haptic and auditory cuing, and improvements in marker-less and location-based methods for graphical overlays will only enhance AR's capability. Both cognitive and connectivist theories support the increased use of AR technologies to improve situational awareness and collaboration. From these theories eight design criteria that AR technologies must address can be identified. If these design criteria are respected, AR technologies are anticipated to improve learning performance, increase user motivation, and enhance user engagement/interaction and collaboration. Additionally, gains in spatial understanding and long-term memory retention are foreseen. However, three primary risks were identified that must be appropriately managed in AR system design. First, both individual and distributed SA models indicate that channelized attention (users focusing on the augmented data) is a significant risk that could result in an overall decrease in SA. Second, if the implementation of the technology does not ensure usability then operators could become distracted in the management of the system, resulting in the potential to rapidly offset any potential gains. Third, the systems must be capable of being customized to the individual user, both in terms of fit and software defined displays. However, if these risks are managed and the design criteria respected, then the previous grim picture of the present will give way to the bright future offered by AR collaborative and analytical tools for ISR operations.

> *En route to their objective the Special Forces team receives spatial audio and visual cues on their AR HMDs to alert and orientate them to a threat approaching from the south. Over a hill and out of sight, the team leader receives real-time video on his HMD to assist his tactical analysis. An analyst located half-way around the world, reports the "threat" is a delivery van on its normal early morning route. Nevertheless, seeking to avoid contact the team leader provides new routing data to his team's HMDs. Just outside the objective, ISR identifies two enemy snipers blocking the approach and passes visual targeting information and wind data to AR-enabled rifle scopes used by the team. Undetected, the enemy snipers are neutralized. The team moves into their final position and identifies targets for the incoming carrier-based strike aircraft. Analysts conduct collateral damage assessments and push targeting data and weapon selections recommendations to the HMDs of the strike aircraft. Suddenly, communications intercepts identify a high-value target approaching the compound, an unexpected windfall. Their HMDs display visual cueing to locate and validate the assessment, and in collaboration with ISR assets they redistribute monitoring tasks. Back at C2 analysts compute the arrival time of the high-value target, while strike assets receive updates and new weapons selections on their HMDs. When the target arrives, they unleash controlled mayhem in a coordinated air and ground assault. As buildings are reduced to rubble and the enemy reacts, HMDs display updated*

sight lines, threat vectors and target designations. Minutes later, the objective is overrun, the mission a success. Miles away, a second AR enabled operation is about to strike….

Notes

[1] Isaac R. Porche et al., eds., *Data Flood*, Helping the Navy Address the Rising Tide of Sensor Information (RAND Corporation, 2014), http://www.jstor.org/stable/10.7249/j.ctt6wq8rr.9.

[2] "B-GA-401-002/FP-001, Royal Canadian Air Force Doctrine: Intelligence, Surveillance and Reconnaissance" (Royal Canadian Air Force Aerospace Warfare Centre, November 2017), 2–1, http://www.rcaf-arc.forces.gc.ca/assets/AIRFORCE_Internet/docs/en/cf-aerospace-warfare-centre/b-ga-401-002-fp-001-royal-canadian-air-force-doctrine-intelligence-surveillance-and-reconnaissance-accessible.pdf.

[3] Stew Magnuson, "DoD Making Push to Catch Up On Artificial Intelligence," *National Defense*, July 2017, 22, https://aufric.idm.oclc.org/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=mth&AN=124363553&site=ehost-live&scope=site&custid=airuniv.

[4] Jorge Bacca et al., "Augmented Reality Trends in Education: A Systematic Review of Research and Applications," *Educational Technology & Society* 17, no. 4 (2014): 133.

[5] Charlie Fink*, Charlie Fink's Metauniverse - An AR Enabled Guide to VR & AR*, ed. Robert Fine (United States: Cool Blue Media, 2018), 18.

[6] "Innovative 787 Flight Deck Designed for Efficiency, Comfort, and Commonality," accessed January 21, 2019, https://www.boeing.com/commercial/aeromagazine/articles/2012_q1/3/.

[7] "Airbus Cockpits," *Airbus*, accessed January 21, 2019, https://www.airbus.com/aircraft/passenger-aircraft/cockpits.html.

[8] "Bombardier Global 6000 Description," *Bombardier Business Aircraft*, August 1, 2017, https://businessaircraft.bombardier.com/en/aircraft/global-6000.

[9] Ronan Glon, "Head-up Displays Bring Fighter-Jet Tech to Your Car in the Name of Safety," *Digital Trends*, June 22, 2018, https://www.digitaltrends.com/cars/best-head-up-displays/.

[10] Nick Bilton, "Why Google Glass Broke," *The New York Times*, January 10, 2018, sec. Style, https://www.nytimes.com/2015/02/05/style/why-google-glass-broke.html.

[11] Nick Wingfield and Mike Isaac, "Pokémon Go Brings Augmented Reality to a Mass Audience," *The New York Times*, December 21, 2017, sec. Technology, https://www.nytimes.com/2016/07/12/technology/pokemon-go-brings-augmented-reality-to-a-mass-audience.html.

[12] "F-35 Gen III Helmet Mounted Display System," accessed January 22, 2019, https://www.rockwellcollins.com/Products-and-Services/Defense/Avionics/Displays-and-Controls/Helmet-Mounted-Displays/F-35-Gen-III-Helmet-Mounted-Display-System.aspx.

[13] "Thales Unveils Revolutionary Head-Worn Display System for Business Jets | Thales Group," accessed January 22, 2019, https://www.thalesgroup.com/en/worldwide/press-release/thales-unveils-revolutionary-head-worn-display-system-business-jets.

[14] "Mixed Reality at Microsoft," *Mixed Reality at Microsoft*, accessed January 22, 2019, https://www.microsoft.com/en-us/mixed-reality.

[15] "Magic Leap," *Magic Leap*, accessed January 22, 2019, https://www.magicleap.com/.

[16] Fink, *Charlie Fink's Metauniverse - An AR Enabled Guide to VR & AR*, 19.

[17] "Mixed Reality at Microsoft."

[18] Bacca et al., "Augmented Reality Trends in Education: A Systematic Review of Research and Applications," 142.

[19] Ibid.

[20] Ibid.

[21] Ibid.

[22] Ibid.

[23] "Augmented Reality Wine - Living Wine Labels," accessed January 22, 2019, https://www.livingwinelabels.com/en-us/augmented-reality-wine.

[24] James Minogue and M. Gail Jones, "Haptics in Education: Exploring an Untapped Sensory Modality," *Review of Educational Research; Washington* 76, no. 3 (Fall 2006): 332, http://search.proquest.com/docview/214115027/abstract/A73A825E415A4C5BPQ/1.

[25] Ibid., 336.

[26] Fink, *Charlie Fink's Metauniverse - An AR Enabled Guide to VR & AR*, 66.

[27] Hale, Kelly S. and Kay M. Stanney, eds., *Handbook of Virtual Environments : Design, Implementation, and Applications*, 2nd ed. (Boca Raton, FL, USA: CRC Press, 2014), 89, http://web.a.ebscohost.com.aufric.idm.oclc.org/ehost/ebookviewer/ebook/bmxlYmtfXzgzNTY1OF9fQU41?sid=8d0f0614-ae52-4b3c-adec-37ad5ae667c1@sessionmgr4006&vid=0&format=EB&rid=1.

[28] Bacca et al., "Augmented Reality Trends in Education: A Systematic Review of Research and Applications."

[29] Ibid., 146.

[30] Ibid., 134.

[31] Tzung-Jin Lin et al., "An Investigation of Learners' Collaborative Knowledge Construction Performances and Behavior Patterns in an Augmented Reality Simulation System," *Computers & Education* 68 (October 1, 2013): 314–21, doi:10.1016/j.compedu.2013.05.011.

[32] Dr Michael Jenkins, Geoffrey Catto, and Les Bird, "Increased Space Situtational Awareness through Augmented Reality Enhanced Common Operating Pictures," in *2018 Technical Papers* (Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), Maui, USA, 2018), 9, https://amostech.com/TechnicalPapers/2018/Poster/Jenkins.pdf.

[33] Francis T Durso and Scott D. Gronlund, "Situation Awareness (Chapter 10)," in *Handbook of Applied Cognition*, ed. Francis T Durso et al. (Hoboken, New Jersey: John Wiley & Sons Ltd., 1999), 283.

[34] Paul Salmon M. et al., *Distributed Situation Awareness: Theory, Measurement and Application to Teamwork* (Ashgate Publishing Limited, 2009), 1.

[35] Durso and Gronlund, "Situation Awareness (Chapter 10)."

[36] Mica R. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," *Human Factors: The Journal of the Human Factors and Ergonomics Society* 37, no. 1 (March 1995): 32–64, doi:10.1518/001872095779049543.

[37] Ibid., 33.

[38] Ibid., 39.

[39] Salmon et al., *Distributed Situation Awareness: Theory, Measurement and Application to Teamwork*, 212.

[40] Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," 39.

[41] Mica R. Endsley and Daniel J. Garland, *Situation Awareness Analysis and Measurement* (CRC Press, 2000), 10.

[42] Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," 39.

[43] Durso and Gronlund, "Situation Awareness (Chapter 10)," 303.

[44] Salmon et al., *Distributed Situation Awareness: Theory, Measurement and Application to Teamwork*, 206.

[45] Ibid., 212.

[46] Ibid.

[47] Salmon et al., *Distributed Situation Awareness: Theory, Measurement and Application to Teamwork*.

[48] Ibid., 207–8.

[49] Ibid., 208.

[50] Ibid., 213.

[51] George Siemens, "Connectivism: A Learning Theory for the Digital Age," *International Journal of Instructional Technology and Distance Learning* 2, no. 1 (January 2005): 3, http://www.itdl.org/journal/jan_05/article01.htm.

[52] Richard Bair and Timothy Stafford, "Connected and Ubiquitous: A Discussion of Two Theories That Impact Future Learning Applications," *TechTrends: Linking Research & Practice to Improve Learning* 60, no. 2 (March 2016): 132, doi:10.1007/s11528-016-0021-z.

[53] Siemens, "Connectivism: A Learning Theory for the Digital Age," 5.

[54] Siemens, "Connectivism: A Learning Theory for the Digital Age."

[55] Bair and Stafford, "Connected and Ubiquitous," 132.

[56] Siemens, "Connectivism: A Learning Theory for the Digital Age."

[57] Ibid., 5.

[58] Karl Steffens, "Competences, Learning Theories and MOOCs: Recent Developments in Lifelong Learning," *European Journal of Education* 50, no. 1 (March 2015): 41–59, doi:10.1111/ejed.12102.

[59] Neena Thota, "Chapter 5 - Connectivism and the Use of Technology/Media in Collaborative Teaching and Learning," *New Directions for Teaching & Learning* 2015, no. 142 (Summer 2015): 81–96,

https://aufric.idm.oclc.org/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=103364841&site=ehost-live&scope=site&custid=airuniv.

[60] Bair and Stafford, "Connected and Ubiquitous."

[61] M. Esther del Moral, Ana Cernea, and Lourdes Villalustre, "Connectivist Learning Objects and Learning Styles," *Interdisciplinary Journal of E-Learning & Learning Objects* 9 (January 2013): 105–24.

[62] Mara Faccio and John McConnell, "Death by Pokémon GO: The Economic and Human Cost of Using Apps While Driving" (Cambridge, MA: National Bureau of Economic Research, February 2018), 36, doi:10.3386/w24308.

[63] Based on user experiences and feedback from VR-AR Task Force participants employing the Microsoft HaloLens and Magic Leap One AR systems. Comparisons of commercially available VR HMDs yielded similar results, with no one system fitting all users equally well.

[64] Based on user experiences and feedback from VR-AR Task Force participants.

[65] Based Thales provided data and author's own observations during a demonstration of the Thales TopMax system conducted in 2016 for the Royal Canadian Air Force. For more information see http://onboard.thalesgroup.com/topmax-game-changer-2/

[66] Based Thales provided data and author's own observations.