Developing Augmented Reality for Interactive Visualization of Mission Data

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ABSTRACT

Modeling and simulation industry has been pioneering augmented reality (AR) capabilities for operational use in the defense industry. Examples of this technology include, fighter aircraft heads-up displays, and use of this technology across training use cases. This paper discusses advanced capabilities for data visualization and novel interactive experiences in AR. We present an approach for tailoring data-driven AR experiences enabling exploration of Intercontinental Ballistic Missile (ICBM), radar transmitter-receiver, and other technical baseline and mission data. Providing DoD customers with technical solutions in the AR space is empowering future systems engineering, modeling simulation & analysis, design, manufacturing, and visualization of the operational digital twin.

We develop AR software using C# and the Mixed Reality Toolkit for the Microsoft HoloLens 2. Utilizing the Unity3D game engine, we integrate ICBM mission data in a secure computing environment to explore interconnected data sources, such as Risk, Cost, and Performance data. These capabilities are built using a GitLab Continuous Integration/Continuous Deployment (CI/CD) pipeline, configured to satisfy the DoD CIO DevSecOps Reference Design.

This work enables maintenance personnel to train on any number of virtual configurations without impacting operational equipment, limiting mission readiness, or threatening human safety. AR provides freedom to explore technical engineering models and data. These tools and techniques provide our manufacturing and maintenance teams, and our nation's warfighter with new and significantly improved capabilities to more effectively complete their mission requirements.

ABOUT THE AUTHORS

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Figure 1. Dissection of sample assembly in AR
Source: Microsoft

Augmented Reality (AR) superimposes a computer-generated image on a user's view of the real world providing a composite view of digital and physical real-time images as shown in Figure 1. It is a technology that is headlining conversations across commercial and consumer industries. Recent advances in hardware and software capabilities are enabling numerous new potential applications of AR for the U.S. Department of Defense. The importance of this technology for future missions cannot be overstated. In February of 2022, the Office of the Under Secretary of Defense for Research and Engineering called out Human-Machine Interfaces and "Mixed Reality" (A term which represents a spectrum of technology including Virtual and Augmented Reality), as one of the critical technology areas for the Department of Defense.

ENABLING INFORMATION SUPERIORITY FOR THE WARFIGHTER

Proven Technology from the F-35 and Typhoon Programs

In the past, a pilot's helmet was nothing more than something to protect their head during a crash and a walkie-talkie to communicate with a flight tower and peer aviators. Today, militaries in countries such as the US and UK are incorporating AR into operational missions with heads-up displays (HUD) and helmet-mounted displays (HMD) used by air crews and pilots. AR integrates with platforms and provides customizable views of highly dynamic flight and sensor data, which is intended to enhance the pilots' situational awareness, and improve weapon system effectiveness. On the latest generation fighter, the F-35, the HMD worn by pilots displays sensor input from the aircraft's external cameras which provide a "see-through" experience around the airframe. The technology allows a pilot to assimilate data within a 360° display as opposed to a 8x8" HUD. It also automatically identifies allies from advesarial targets as noted in Figure 2. The HMD integrates the six embedded cameras on the skin of the fighter allowing the pilot to see everything of concern on the ground as if they are looking directly through their legs and undercarrage of the plane. Additionally, the HMD has a digital night vision capability enhancing a pilot's ability to perform after dark. This technology provides F-35 pilots asymmetrical advantage over an adversary. In a very real sense, the use of AR has enhanced the air superiority of the USAF.

Figure 2. F-35 HMD identifying three allied aircraft noted by red triangles.
Source: Collins Aerospace

The same type of technology is employed in the Typhoon Strike fighter which boasts that its "latest weapon isn't something slung under the wing – but a system with 'brains' that sits on the pilot's head." The "Helmet Mounted Symbology System" shown in Figure 3 is a highly sophisticated helmet and support system that lets the pilot 'see' through the body of the aircraft, giving them a vital advantage when it comes to split-second decision-making. Sensors on the helmet 'talk' to fixed sensors on the aircraft so the Typhoon always knows exactly where the pilot is looking. Weapons sensors on the aircraft track enemy aircraft and missile information and feed it into the brains of the plane. Data from these sensors (and from base operations) can then be fed into the mix to give the pilot the ultimate view of the action around him. In an environment where split seconds could mean the difference between life and death, assimilation of data to make an informed decision is absolutely critical. In the past, pilots needed to look at the terminal at the front of the cockpit to interpret data from the planes sensors. Like the F-35, the AR integrated into the HMD reduces the required movements and increases the pilot's ability to perform.

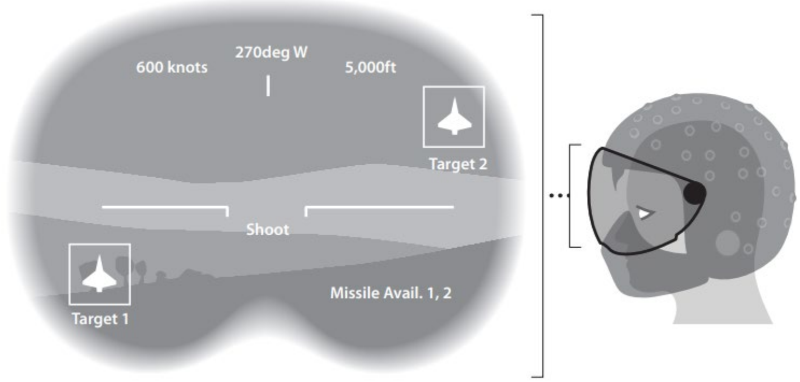


Figure 3. Simplified view (as seen by the pilot) on the inside of the visor of the Helment Mounted Symbology System
Source: BAE Systems

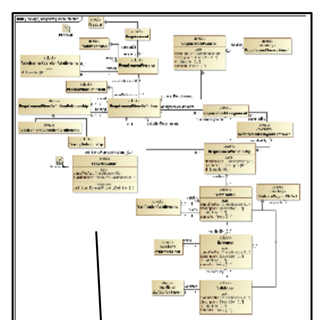
Extending AR to USAF Intercontinental Ballistic Missile (ICBM) Applications

Demonstrated Capabilities

Leveraging the lessons learned and capabilities gained from the F-35 program, the USAF has also expressed interest in extending the utilization of AR for applications within the ICBM community by investing XXX towards prototype development. Initial prototypes of ICBM data accessible from AR display units have opened up a world of possibilities with the technology.

AR experiences are comprised of 3D content projected on top of what the user can see naturally. Convincing holographic experiences require varying degrees of accuracy in the portrayal of life-like objects, for example the more realism an object is rendered with, the more convincing the experience is to the user. This concept applies as well to the usefulness or value proposition of AR for DoD applications. For instance, an AR experience might include an animation of a rocket motor static test firing or an adversary's newest combat drone. This experience on its own possesses varying degrees of usefulness, depending on the fidelity and integrity of the data behind the scene. This is demonstrated where low quality data is only able to represent a simple cartoon animation of a rocket test vs. high quality data in the form of professionally engineered finite element analysis and/or computational fluid dynamics analysis simulation producing a life-like animation rendered in AR.

In these applications, the most life-like data is derived from Digital Engineering systems and tools which provide Authoritative Source of Truth and include Model Based Systems Engineering (MBSE) data (Figure 4). These modern tools transact in data formats compatible in AR such as 3D computer aided design (CAD), building information modeling, product lifecycle management, customer relationship management, and others. In these environments, engineers develop and design platform and systems, and share that data through digital threads, which enable other application programming interfaces (APIs) to transact with that data



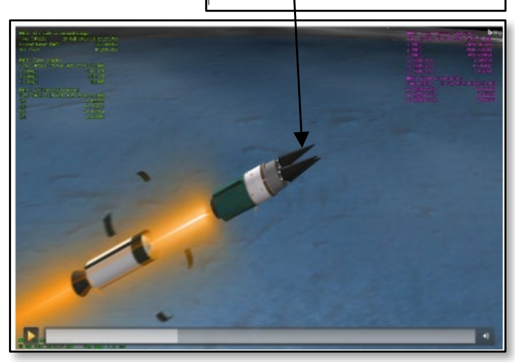


Figure 4. Weapon System MBSE and CAD Model linked in Digital Engineering
Source: BAE Systems

to provide additional capabilities such as AR. Understanding the complexities of this data, including what is required to integrate capabilities, and to build secure applications for end users such as enhances development of AR and other visualization tools. DE and MBSE will never be a “freshly baked cake” just handed to a customer to go use. These engineering processes must mature within organizations by careful growth to meet each organizations needs and requirements.

A small team of BAE engineers have been able to rapidly link a Microsoft Hololens to ICBM 3D models. Once a 3D model existed within the HUD, software developers connected other relevant databases such as piece part information, risk, drawings, technical orders, and requirements to enhance the user’s experience as shown in Figure 5. Capitalizing on several COTs software capabilities allows the user to create an exploded view of the sub-assemblies for an ICBM.

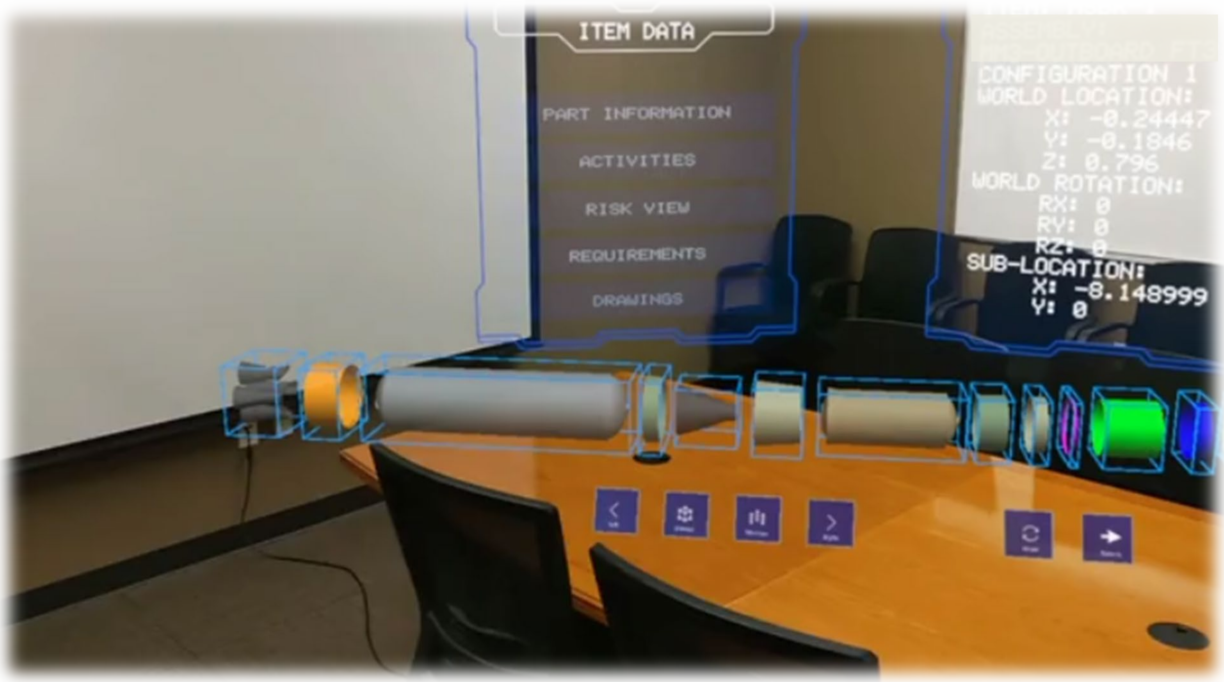


Figure 5. Exploded view of a generic ICBM missile inside a Microsoft Hololens Source: BAE Systems

These elements are then accessible for further interrogation of an element such as a booster nozzle. AR units provide a user with an augmented world to explore views of a piece part in any orientation desired simply changes by “grabbing” the object and rotating the element with the physical motion of a user’s hand as demonstrated in Figure 6. Here, maintenance records, technical orders, requirements, and associated drawings can be queried and brought up into the HUD for a user to assimilate various views of data within a single place. A user is then able to physically walk around this augmented reality with as many digital displays as desired. Alternative methods of simultaneous displays of information like this would require multiple monitors, but would not quite measure up to the immersive data experience.

Sub-assembly components that require a detailed investigation can be broken out from the model, placed virtually on a table, and expanded to investigate the individual configuration item level components or lower (eg. screws, nuts and bolts). A user has the ability to virtually assemble an item without stepping into a factory or dismantling a physical unit. This experience is, perhaps, the next best option to handling a 3D printed mockup.

Figure 6. Exploration of a generic ICBM sub-assembly piece part within a Microsoft Hololens possible with physical gestures.
Source: BAE Systems

Figure 7. Notional Digital Twins of an ICBM system placed in a virtual shopping cart.
Source: BAE Systems

A "digital twin" is a virtual representation of an actual or intended real-world physical system that can be used for practical purposes, such as simulation, integration, testing, monitoring, and maintenance. Since information is granular, the digital twin representation is determined by the value based use cases it is created to implement. The digital twin can and does often exist before there is a physical entity. The use of a digital twin in the create phase allows the intended entity's entire lifecycle to be modeled and simulated. A digital twin of an existing entity can, but must not necessarily, be used in real time and regularly synchronized with the corresponding physical system.

As digital twins of fielded hardware make their way into this augmented reality environment, the individual components of link with cost data. This allows the user to isolate various components of the system and segregate them for purposes of replacement parts. A virtual shopping cart can then be assembled as a user is building an estimate for a repair. This idea is demonstrated in Figure 7 where several pieces have been placed in the cart.

Augmented reality technology has also been coupled with artificial intelligence (AI) software where voice recognition engines are able to recognize and respond to commands from a user. Coupling these two technology streams expands the user's ability to interact with the model. Physical interactions such as moving a hand to press a digital button or grab onto a piece part can be clunky. The three dimensional mapping of data from cameras at a single point near the head are sensitive to several line of sight errors and the technology for rendering high fidelity 3D locations may be nearing the limitation of the sensors.

Simple commands such as opening models and exploding to piece parts have already been demonstrated within the BAE environments where simple hand gestures have started to be replaced by voice commands. With advances in AI in platforms like ChatGPT from OpenAI, the ease and speed at which data from the model is acquired, analyzed, and assimilated is limitless. In other words, we are just scratching the surface of the possibilities that we will discuss in more detail towards the end of this paper.

New Methods of Building AR Software for Classified Applications

DevSecOps is the integration of security practices and procedures throughout the software development and deployment lifecycle as represented in Figure 8. The goal is to seamlessly integrate security into the continuous integration and continuous delivery (CI/CD) pipeline in both pre-production (dev) and production (ops) environments. In September of 2022, DoD CIO released an updated DevSecOps Reference Design and the Software Modernization Strategy. These documents describe the new methods and architectures intended for DoD software and operating environments that are to be secure in the age of continuous growth and sophistication of cyber-attack. Our small team is developing a secure method of building and deploying AR experiences. Our workflow implements elements of the architecture, process, and tools described in these DoD CIO strategy documents. Our approach to AR development is based on our practical, hands-on experience establishing a certification process for commercially available AR hardware (Microsoft HoloLens 2) to transact and process Controlled Unclassified Information (CUI) across networks (including GovCloud) compliant with Risk Management Framework (RMF), National Institute of Standards and

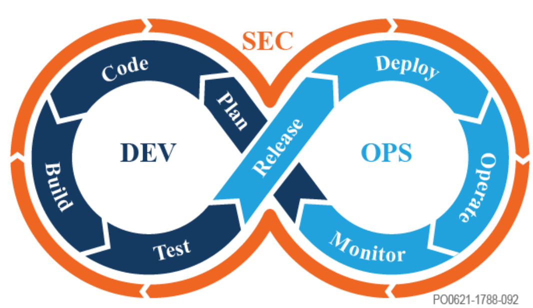


Figure 8. Figurative representation of the DevSecOps process.
Source: BAE Systems

Technology (NIST), and Defense Federal Acquisition Regulation Supplement (DFARS) requirements.

We apply principles from the Open Container Initiative which includes the same methods recommended by DoD Platform One. Our teams deploy similar capabilities into multi-level DoD cloud environments today, leveraging technologies (such as Kubernetes) for major DoD programs including the Sentinel Intercontinental Ballistic Missile ACAT-1D in the Air Force Nuclear Weapons Center. By applying modern agile software development practices, BAE Systems development teams develop secure code and deploy new AR capabilities to secure hardware up to 50% faster than traditional methods.

Augmented Reality is dependent on sophisticated hardware. State of the art wearable computers are integrated with advanced optical components. In order to render data as "holograms" light must pass through waveguides and end up in the wearer's retina. This precision physics is all managed in software and hardware, utilizing gyroscopes and pupil tracking cameras to ensure the projected image matches location with the user consistently. This is accomplished with integrated hardware such as sensors and emitters including; Wi-Fi, Bluetooth, microphone, or cameras which are typically not permitted in secure facilities that process classified information. For specific DoD applications, modifications can be made to the hardware device profile, physically and through software, to cyber-securely "harden" the platform in order to comply with most Approval to Connect (ATC) and Approval to Operate (ATO) requirements. In secure operations, AR will rely on logically adjacent continuous integration and continuous delivery (CI/CD) software pipelines. These pipelines will provide secure update of trusted and verified code and enable AR experiences to be deployed to the high-side devices.

The ICBM Augmented Reality Art of the Possible

The exploratory prototypes of AF ICBM AR applications has opened up the aperture of opportunities and possibilities that this technology can offer to the warfighter. The primary benefit noted in an augmented reality world is the coalescing of data into a single, easily accessible place. The largest and most relatable sensor, the human eye, captures visible pictures at 30 to 60 frames/second. AR HMD augment those pictures with either data from a database such as the 3D models demonstrated above, MBSE models, drawings, off board camera images, real-time telemetry, etc. The possibilities of data fusion into the AR world is limitless.

One such extension of the use of AR in ICBMs is that of training. There are plenty of training applications with the automotive, industry. While VR/AR training is not unique, the application within the highly sensitive ICBM field is unique. Currently the warfighters in the ICBM field, known as missileers (Figure 9), have very few places to learn how to operate and service the land based leg of the nuclear triad. It is also well documented that failures during routine maintenance like the 1980 Damascus Titan missile incident can have lethally high consequences. Using AR technology will decrease the time it takes for learning the ICBM system and servicing it. For instance, a missileer in a silo could use a headset that securely connects to engineering support near Minot AFB. With a set of technical orders to service a guidance system loaded onto the HMD, the user is free to use their hands as they perform the service and digest the orders. If additional information is needed, the missileer would have access to training videos, technical drawings, and CAD models without having to refer a tablet that is out of the line of sight. Like an F-35 fighter pilot, the missileer gains efficiency in having the augmented data in their field of view. Secure connection to engineering staff near the base allows the missileer collaborative expertise on-site further increasing efficiency and reducing errors to critical nuclear components. Using object recognition AR technology, the on-site missileer can pull up the digital twin of the item within the field of view and link that to the technical orders that have been given. Again, the probability of

Figure 9. Missileer maintaining fielded ICBM.
Source: NBC News

defects introduced by the maintenance process is reduced by overlaying the digital imagery with the items in the natural world.

Figure 10. Collaborative planning using AR projects to save time and materials.
Source: CHEManager International

The use of multiple HMD in an effort to collaborate with Engineers, Program Managers, Customres and other interested stakeholders can also be applied to the ICBM effort. Companies like Holo-Light (Figure 10) have applied AR technology in a collaborative forum that has pulled engineers out of their desktops to a physical tabletop. Here the 3D model can be interrogated, explored, and visualized much the same way a physical demonstration is done. However, users can rotate between a commonly shared view of the model to their individualized view of the model like can be done with any other MBSE model. The immersive experience lays the ground work for future innovation and development as it provides looks into the design that are normally discovered after prototype or manufacturing. Design changes and enhancements that are often too costly to fix due to design changes or schedule slips.

The AR opportunities don't stop with the inclusion of the CAD models or the other things mentioned above. As processing power for the AR devices increases, high fidelity physics based models can be linked to the HMD. High fidelity 6-degree-of-freedom simulations which model the ICBMs flight path from the calibration and alignment phases, booster ignition, egress from the silo, stage separation, post boost vehicle maneuvers, Reentry vehicle release to target impact could all be displayed with the augmented world. Users could then, for instance, watch the missile launch from the silo and interrogate the margin of safety between the outer missile skin and the silo wall. Simulations can be paused during flight, analyzed, and cross-examined against other data on separate virtual displays. The advantages to this approach will be invaluable during flight test reconstruction fuzing multiple data sources to determine the best estimate of trajectory. It will also be tremendously helpful in root causing anomaly investigations when tests don't perform as intended. Anomalies that generally take tremendous effort and require aggressive deadlines to meet public inquiry and congressional committee demands.

The authors have been monitoring the industrial debate regarding the future of AR. It has been noted that Microsoft is set to layoff ~10,000 employees which includes its entire Mixed Reality Toolkit group and the AltspaceVR team, putting Microsoft's own Hololens project at high risk. This is likely due to the low ROI from AR related ventures. Congress denied the US Army's request for $400 million to buy more Hololens headsets citing that 80% of soldiers experienced "mission-affecting physical impairments" such as headaches, eyestrain, and nausea. In response to that experience, the Department of Defense's Office of the Inspector General warned that buying augmented reality systems without user acceptance "could result in wasting up to $21.88 billion in taxpayer funds to field a system that soldiers may not want to use or use as intended."

While that cost vs benefit debate continues, it is the author's belief that the proven time savings advantages from AR will ultimately come to Warfighter in one way or another. Innovations in the industry to deal with the challenges of physical impairment will find a solution.

SUMMARY

Incorporating advanced technology into DoD missions and effectively integrating in existing workflows is no small task as it can be challenging to understand the impact to mission and team that comes from introducing new methods of work. Within an Agile framework, developing software capabilities such as AR can be a low impact, high value, iterative journey. When this is combined with user centered design principles, and secure code development, the results are capabilities with high return on investment. AR is seeing massive investment across industry and DoD is poised to be on the receiving end of this transformative era. As a core technology explicitly named in the DoD Digital Engineering strategy, AR is now seeing a renewed focus from senior leaders as an enabling technology for America's warfighter. The next steps for this technology include further refinement of the hardware, increased computing capacity, high resolution displays, and more advanced integrated software capabilities. The authors are continuing to develop new AR experiences to empower customers across DoD to ensure the warfighter has the latest generation technology, which will enable information superiority and asymmetrical advantage in sea, land, air, space, and cyberspace.

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