An Architectural Overview of the Augmented REality Sandtable (ARES)

Nathan L. Vey
Natick Soldier Research, Development and Engineering Center (NSRDEC)
Orlando, Florida
nathan.l.vey.civ@mail.mil

Yasmina Raby
Army Research Laboratory (ARL)
White Sands Missile Range, New Mexico
yasmina.r.raby.civ@mail.mil

Christopher Markuck
Dignitas Technologies
Orlando, Florida
cmarkuck@dignitastechnologies.com

Charles Amburn
Natick Soldier Research, Development and Engineering Center (NSRDEC)
Orlando, Florida
charles.r.amburn.civ@mail.mil

ABSTRACT

The Augmented REality Sandtable (ARES) is a research project from the U.S. Army's Natick Soldier Research, Development and Engineering Center (NSRDEC) that is investigating novel techniques for visualizing and interacting with complex battlespace information. The system is being used in collaborative research studies with Department of Defense, academic, and industry partners to provide a Common Operating Picture (COP) at the Point of Need. The ARES architecture was initially developed to support a variety of end user modalities (e.g. physical sand tables augmented with low-cost, commercial technologies; mobile devices; and personal computers). NSRDEC is now expanding the existing architecture to begin investigating user interactions using augmented reality and augmented virtuality (AR/AV) technologies, floor projection of augmented information, and distributed collaboration and telepresence across the various modalities. This AR/AV research also encompasses interaction methods using Commercial Off-The-Shelf tracked controllers (e.g. HTC Vive controller), voice recognition, gesture recognition, and game controllers. Intuitive interfaces across the modalities allow users to create, import, or choose maps and terrains from external data sources; place and move tactical graphics; and interact with models (e.g. line-of-sight, route planning, radio, or CBRN [Chemical, Biological, Radiation, and Nuclear]) in real-time. These approaches offer novel platforms for training and operational planning in Multi-Domain Battlefields. Studied benefits of using the initial ARES prototype already include increased user engagement, decreased cognitive workload, and high utility perceptions.

This paper details the modular, Service-Oriented Architecture of ARES. Topics covered include how it provides a COP while conducting expeditionary Mission Command; how it extends the scope of traditional mission planning tools by leveraging models and simulations; and how it allows for third-party application development and integration. It also outlines successful use-cases and provides lessons learned for other system developers.

ABOUT THE AUTHORS

MR. NATHAN VEY is a Science and Technology Manager for the Advanced Modeling & Simulation Branch (AMSB) of the U.S. Army's Natick Soldier Research, Development and Engineering Center (NSRDEC) located at the Simulation & Training Technology Center (STTC) in Orlando, FL. He is a former Marine with operational experience in training Signal Intelligence (SIGINT) collection and analysis operations. Mr. Vey's military training consisted of Electronic Intelligence (ELINT), Electronic Warfare (EW), and Geospatial Intelligence (GEOINT). After joining STTC in 2015, Mr. Vey has lead the engineering efforts for the Augmented REality Sandtable (ARES) and is conducting research on integrating cyber warfare training into Army training simulation systems. He holds a Bachelor of Science (B.S.) in Electrical Engineering from the Milwaukee School of Engineering.

MR. CHRISTOPHER MARKUCK is a Senior Software Engineer at Dignitas Technologies. He has over 14 years of experience with a wide variety of software applications, all involving modeling and simulation, some for the Army and some for commercial game applications (Electronic Arts). Currently he is the Primary Principal Investigator and Technical Lead for the ARES (Augmented REality Sandtable) project which combines the military's traditional sand table with Commercial Off-The-Shelf (COTS) hardware (e.g. Projector, Kinect) to enhance the interactive nature of the sand table. He is leading efforts in computer vision (e.g. object recognition) using various sensors (e.g. Kinect, Leap Motion), Mixed Reality (Microsoft HoloLens) and a service-oriented architecture for delivering a platform for external developers to build applications for the sand table on.

MS. YASMINA RABY is a Computer Scientist for the Battlefield Environment Division's (BED) Decision Support Analysis Team (DSAT) at the U.S. Army Research Laboratory's (ARL's) Computational & Information Sciences Directorate (CISD). In this team, she works on the development of weather-based decision support tools for the web and mobile devices. She earned a Bachelor of Science in Computer Science and a Bachelor of Arts in English at New Mexico State University, where she is also currently pursuing a Master's of Science in Industrial Engineering.

MR. CHARLES AMBURN is the Senior Instructional Systems Specialist for the Advanced Modeling & Simulation Branch (AMSB) of the U.S. Army's Natick Soldier Research, Development and Engineering Center (NSRDEC) located at the Simulation & Training Technology Center (STTC) in Orlando, FL. After obtaining both a Film degree and a Master's degree in Instructional Systems Design from the University of Central Florida, he began his Department of Defense civilian career at the Naval Air Warfare Center Training Systems Division (NAWCTSD) where he worked on special projects for the Navy and Marine Corps for 10 years. He then became the Lead Instructional Designer for the Army's Engagement Skills Trainer (EST) program where Mr. Amburn was responsible for several innovations in the way immersive training scenarios were created, experienced, and assessed. This drive to push the boundaries of what's possible in simulation and training is what led him to NSRDEC's STTC in 2011. Since joining NSRDEC, Mr. Amburn has led award-winning research that has spanned various domains including augmented reality, terrain visualization, and adaptive training systems.

An Architectural Overview of the Augmented REality Sandtable (ARES)

Nathan L. Vey
Natick Soldier Research, Development and Engineering Center (NSRDEC)
Orlando, Florida
nathan.l.vey.civ@mail.mil

Yasmina Raby
Army Research Laboratory (ARL)
White Sands Missile Range, New Mexico
yasmina.r.raby.civ@mail.mil

Christopher Markuck
Dignitas Technologies
Orlando, Florida
cmarkuck@dignitastechnologies.com

Charles Amburn
Natick Soldier Research, Development and Engineering Center (NSRDEC)
Orlando, Florida
charles.r.amburn.civ@mail.mil

INTRODUCTION

The United States Army utilizes the Mission Command Philosophy to conduct command and control. One of the key principles of the Mission Command Philosophy is to create shared understanding. A shared understanding incorporates aspects of both information synchronization and collaboration (US Army, 2012). Although the Army has been able to successfully conduct mission command throughout the most recent conflicts, it is reliant on complex, disparate systems with a large footprint will make it difficult to continue those same operations against a more sophisticated adversary. Future battles are expected to require commanders to conduct mission command while having little to no control over when or where they can setup an operations center. These principles and concept of the future were a driving force for the Natick Soldier Research, Development and Engineering Center's (NSRDEC's) Battlespace Visualization group to develop the architecture of the Augmented REality Sandtable (ARES) that supports real-time collaboration between various multimodal devices.

The ARES project consists of both development and applied research activities. Research aspects of the project are focused on human factors elements of information visualization, multimodal interaction, and human performance assessment (Garneau, Boyce, Shorter, Vey, & Amburn, 2018). These factors all play important roles in creating a shared understanding. Identifying the benefits and detriments of each modality and interaction method within relevant Army use-cases helps inform the project's development efforts. To date, multiple human subjects' research experiments have been conducted with Army users to include Soldiers from the 3rd Infantry Division and the Army's Maneuver Support Center of Excellence, Cadets from the United States Military Academy at West Point and university Reserve Officers' Training Corps (ROTC), and Reservists from the 143rd Sustainment Command. Several experiments were also conducted with general civilian populations. While this paper focuses on the development portion of the project, more information on the research activities can be found in Garneau et al. (2018).

ARES is composed of multiple modalities such as physical sand tables augmented with low-cost commercial technologies, mobile devices, personal computers, floor projections, and augmented- and virtual-reality (AR/VR) head mounted devices (HMDs). These modalities are depicted in Figure 1. Users can visualize and interact with tactical information laid onto maps through any of the aforementioned devices (or hybrids consisting of multiple modalities being used simultaneously) while collaborating with others who may be using a different device. This allows them to create a shared understanding of the operational environment; typically referred to as a Common Operational Picture or COP (Joint Chiefs of Staff, 2017). In addition to leveraging current technologies to modernize techniques that have been employed by

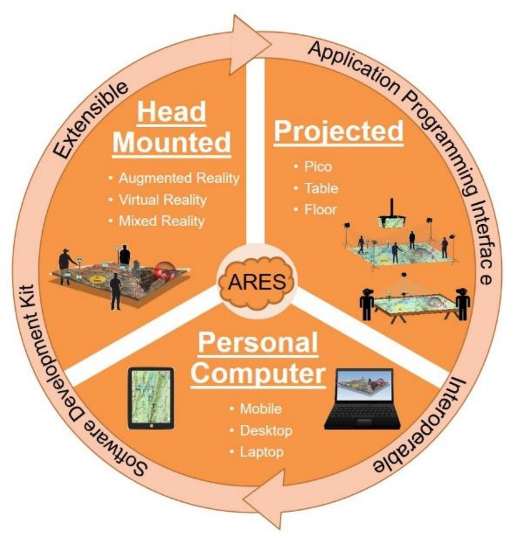

Figure 1: ARES Architecture Overview

militaries for hundreds or thousands of years, ARES supports the integration of models and simulations that are currently used by other systems (e.g. line-of-sight analysis, automated route planning, or visualization of radio signal propagation).

This paper will focus on the modular architecture and how it supports the Army's Mission Command Philosophy through providing a shared COP via various modalities, how models and simulations are incorporated to expand the capabilities, and how third-party developers can utilize the system to develop or integrate their own applications or extensions.

MODALITY SUB-SYSTEMS

Mission command is a complex task for which no single tool can fit every need. Likewise, military operations are typically conducted in austere environments with limited resources. Because of the complex nature and variety of individual tasks that could benefit from the ARES system, the previously mentioned modalities (physical sand tables, floor projections, personal computers, mobile, and AR/VR devices) were developed. Each mode allows Soldiers to view the same data in the COP and even interact with users that have different modalities. In addition to using any of the modalities individually, they can be combined to form hybrid modes (e.g. using AR to augment a floor projection). This section will explain each of ARES modalities and identify some of the potential use-cases when they may be used.

Mobile Android Devices

The Tactical Planner is an Android based application that provides users an intuitive, familiar interface to control information that is shown in any of the other ARES modalities. For example, the Tactical Planner is what allows users to change the scenario, add tactical graphics, and enable the models that are shown on the physical sand table, floor projection, or AR modalities. A screenshot of the Tactical Planner's main map interface is shown in Figure 2.

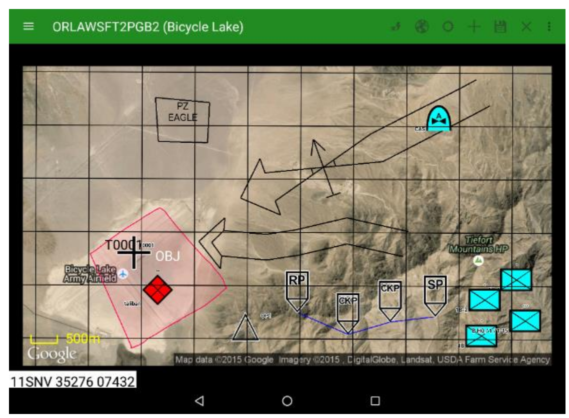

Figure 2: Tactical Planner Android Application

For use-cases when users are unable to use any of the other ARES modalities (e.g. dismounted Soldiers), the Tactical Planner offers a capability to maintain a shared understanding of the battlespace. When there is no network connectivity, the Tactical Planner can operate as a standalone device wherein users can still build and edit scenarios based on locally stored data that can later be shared with other modalities once connectivity is restored.

The Tactical Planner app allows users to conduct individual or collaborative mission planning or the development of Courses of Action (COA) using familiar toolsets (e.g. MIL-STD-2525 symbols and graphics). Once a scenario or mission is planned or a COA is developed, that information can be sent to other users via typical digital sharing methods (e.g. e-mail) or presented using another modality for a final brief. Current practices involve planning missions using paper maps, inputting those plans into complex computer systems that require specialized training, and then constructing a terrain model or slideshow to brief the missions. ARES allows these steps to be consolidated so that the plan can be built once and that data is then available to support the other tasks without any re-formatting or additional data entry.

Augmented Reality

The AR modality (currently based on the Microsoft HoloLens) is most useful when a physical sand table is not an option or when visualizations in the space above a physical surface are required. However, the AR modality does not offer a tangible element (such as the sand). In AR, users are able to see a holographic representation of a networked physical sand table (Figure 3**Error! Reference source not found.**) or real elevation data that is overlaid with their chosen map. After loading a region of interest, symbols and graphics can be added using the Tactical Planner app and manipulated through either the Tactical Planner or the HoloLens.

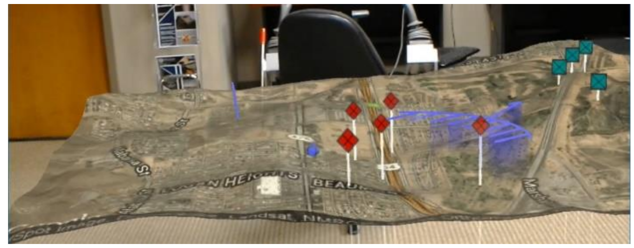

Figure 3: Holographic Sand Table Represented in AR

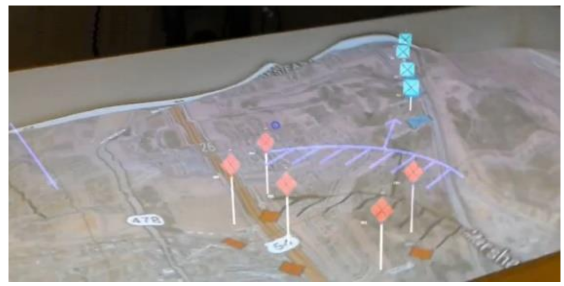

Figure 4: Hybrid Modality using AR and Physical Sand Table

Operationally, it is expected that the AR modality would suit best for command posts where there are not large numbers of people involved in the mission command process, individual leaders such as a higher headquarters Commander that is interested in a quick mission brief or a Platoon Leader conducting Troop Leading Procedures from the field. Likewise, any combined arms missions that require synchronization and de-confliction between ground-based and airborne assets would benefit from using AR (**Error! Reference source not found.**).

Floor Projection

Large, printed maps are often used on the floor in order to facilitate briefings to large groups. Some common uses for these large maps are Rehearsal of Concepts (ROC) Drills, Combined Arms Reviews (CARs), or large-group After Action Reviews (AARs). All of these examples pertain to use-cases wherein many people with different tasks are all involved in the same operation or mission and synchronization is required between groups. Using many of the same commercial technologies as the physical sand table, the floor projection can display maps and mission overlays directly on the floor. The size of this modality is only constrained by the size of the floor or the cost of the components. The current prototype system is using 2 projectors to cover an area of approximately 16'x 9'. Using two projectors to cover the same space from opposite sides allows the projected imagery to remain visible even while shadows are created from users walking over the projection surface. Future research will seek to expand the size of the projection through a template of projector/camera pairs in order to accommodate any desired size of display. The goal will remain to utilize low-cost, commercial items and allow end-users to setup and calibrate the system without seeking additional technical support.

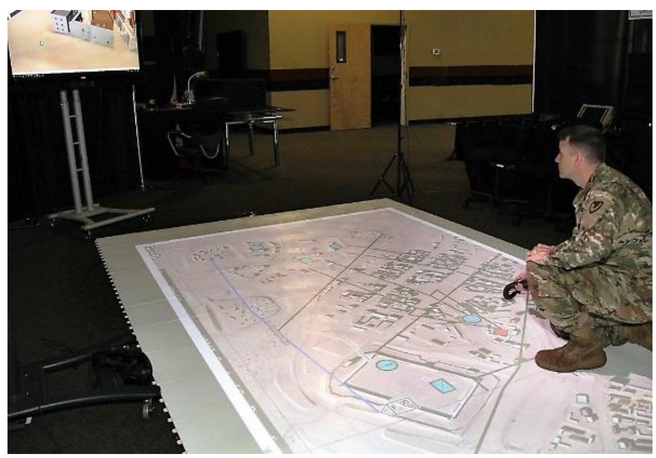

Figure 5: Soldier using ARES Floor Projection Coupled with a Virtual Model of the Terrain

Since the floor projection is restricted to two dimensions (2D), this mode can be combined with other capabilities that allow users to perceive height. For example, this can be achieved through using the augmented reality modality on top of the floor projection (similar to that shown in **Error! Reference source not found.**) or by using a tracked controller that is paired with a virtual, 3D rendered model of the terrain shown on a peripheral display (shown in Figure 5). In both of these cases, the map of the 2D floor projection can be correlated through simple, end user calibration methods to match the 3D data that is provided by the other modes.

Physical Sand Table

Sand tables are still prevalent throughout the Army today. They are sometimes used to conduct Sand Table Exercises (STEX), mission briefs, and After Action Reviews (AARs). By adding a few low-cost, commercial technologies (e.g. projector, depth sensor, and computer) to existing sand tables, end users can create an ARES system that expands the range of tasks they can do while also decreasing the amount of time that is needed to shape the sand and overlay the tactical elements (Hale, Riley, Amburn, & Vey, 2018). A photo example of the physical sand table is shown in Figure 6.

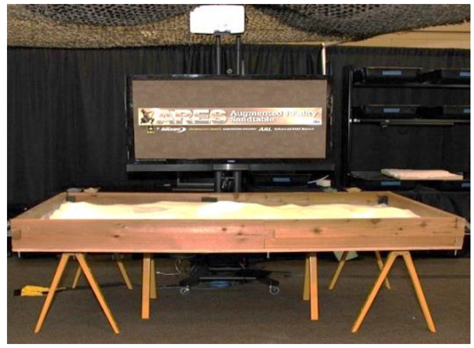

Figure 6: Physical Sand Table Modality

Currently, there are physical, ARES sand tables in use across the country (e.g. Ft. Benning, Ft. Stewart, Ft. Rucker, Ft. Leonard Wood, and West Point). Many organizations have realized the added benefits of digitizing their age-old technology with low-cost equipment and have constructed their own systems that use the Government Off-the-Shelf (GOTS) ARES software. They are using their systems to teach and discuss concepts such as land navigation, terrain model construction, briefing Operations Orders (OPORDs), and planning missions. In addition, several users have integrated their other simulation training systems with ARES to provide a command and control view on the sand table during virtual training rehearsals.

SYSTEM ARCHITECTURE

In order to maintain a common software baseline that enables interoperability across all of the modalities, ARES adheres to a Service Oriented Architecture (SOA) design philosophy that fosters a flexible, extensible, and robust tool suite suitable for future adaptation (Erl, 2005). A service-oriented decomposition enables platform independent deployment, flexible network topologies, independent and reusable services, sensor independence, and simple adoption of third party additions to the platform. The loosely coupled architecture allows all contributors to develop a feature for the ARES platform independently without being concerned about other features or components that were also independently developed.

The ARES system is composed of several core applications that are made available to developers via Advanced Message Queueing Protocol (AMQP) and Representational State Transfer (REST) Application Programming Interfaces (APIs). These core applications include the Depth Streamer, Table Manager, Viewer, MilSymJava, Tactical Planner, and AR/VR. The Depth Streamer is responsible for streaming depth and camera data (obtained from a sensor such as a Microsoft Kinect or Intel RealSense) over the ARES message bus when a physical sand table is used. Data received from the depth sensor is filtered to reduce noise and then sent to consumers subscribed to the message bus. The Table Manager manages the core applications that compose the ARES system, ARES services (e.g. REST API), and a web interface. MilSymJava is an open source project that renders the MIL-STD-2525 B and C tactical symbols and graphics used with ARES. The Viewer is responsible for handling the visualization aspects of the sand table and floor displays. It can display maps, MIL-STD-2525 tactical symbols and graphics, basic geometries (e.g. lines or polygons), sand-based height data (e.g. contour lines and/or hypsometric colors), and visualizations of various models or simulations (e.g. line-of-sight, signal propagation, route planner, sand-based area of indivisibility, chemical/biological plume concentration, etc.). Tactical Planner is an Android application that provides a mobile interface for interacting with any of the modalities. The Tactical Planner can also be used as a standalone application with all features available except for ones requiring services (e.g. line-of-sight) from other core applications. The AR/VR application works across multiple AR/VR devices (e.g. Microsoft HoloLens, HTC Vive, tablets, smartphones) and provides different experiences tailored to the device. For example, the HoloLens application can display a virtual version of the sand table or synthetic terrain or can be used in conjunction with a physical sand table or floor projection to visualize information above the map (e.g. air assets, terrain, cyber effects, chemical/biological plumes, etc.). For VR, the Vive allows users to interact with a fully virtual sand table that they can "jump into" for a 1st person point of view from inside the sand table.

Communications between the core applications are handled over RabbitMQ or REST. RabbitMQ was chosen for the message bus since it can ensure message delivery and uses publish/subscribe and request/reply patterns. It also officially supports a wide variety of developer tools and has many mature and well-documented community plugins (e.g. Java, C#) which simplifies integration efforts. Using RabbitMQ with AMQP allows us to provide transparency for the architecture using an open standard that fosters third party interfaces. REST is used as an alternate interface to ARES for devices/services. For example, a service or device may only want to get a depth frame when it needs it and does not want the overhead of subscribing to depth frame events from RabbitMQ; in this case, they can use the REST API to retrieve the current depth frame. Figure 7 depicts a high-level overview of the core applications and the message bus that connects them.

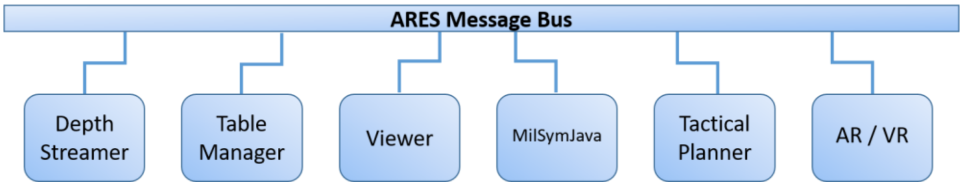

Figure 7: Core Applications of ARES Architecture

ARES uses Google Protocol Buffers (Protobuf) for serializing/de-serializing data sent via AMQP or REST. Using Protobuf provides us with self-documenting, language-neutral definitions that can be used with several major languages (e.g. C++, Java, Python, C#). It also supports several output formats (e.g. binary, JSON, text) which allows ARES to support applications that might not have Protobuf support. For example, Protobuf JSON is utilized to synchronize responses from our REST interface with the data being sent over RabbitMQ. In situations involving large datasets (e.g. streaming depth or image data) when performance was a priority, custom data structures were preferred over Protobuf. The flexibility of using Protobuf or custom messages with RabbitMQ allows new devices to be added to the system without making any modifications to the core system. The relationship between the core applications and the message bus through which they use AMQP and REST is shown in Figure 8.

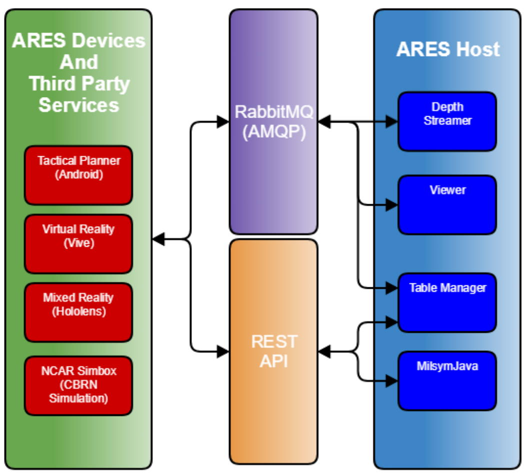

Figure 8: RabbitMQ Messaging Overview

In a networked configuration, the various ARES modalities can be connected to each other in a collaborative mode that allows users to share scenario data (e.g. maps and tactical overlays) with other users. To share this data, a server acts as the session host and forwards scenario update messages to other devices while also keeping track of the current state. Using a webcam, distributed users can also use video teleconferencing (VTC). WebRTC provides real-time communication either peer-to-peer or through a relay server when necessary. That approach provides a flexible mechanism for communication and allows it to scale from simple to advanced network topologies. ARES also supports Distributed Interactive Simulation (DIS) version 7 (v7) which enables interoperability with other simulation systems as a viewer only participant. Several locations that are using ARES now have used the DIS capability to connect to training systems such as One Semi-Automated Forces (OneSAF), Close Combat Tactical Trainer (CCTT), and Virtual Battlespace (VBS), amongst others.

The ARES system was designed as a platform with the intention that external users would be able to add custom functionality (e.g. models or plugins) to the Tactical Planner application and/or create custom applications that work on top of the ARES framework. The plugin framework provides development options to users that wish to create that customization. The plugin developer has the ability to create a custom interface linked to a specified tactical symbol(s) that allow end users to set model parameters and enable/disable functionality. Developers can create custom applications that use data (e.g. sand height data) from ARES and/or capabilities such dynamic projection mapping for displaying on the sand surface by using the ARES Software Development Kit (SDK) / API. More information about the SDK and API will be presented later in this paper.

A Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) plume simulation model was recently integrated into ARES. Figure 9 shows an example of how the SimBox CBRNE simulation system from the National Center for Atmospheric Research (NCAR) was integrated with ARES using the SDK/API tools. A plugin was added to the tactical planner to allow the user to specify the location and parameters for simulating a CBRNE release that would be sent to SimBox to start the simulation. While the CBRNE simulation is running SimBox generates plume concentration frames and sends them to ARES over RabbitMQ. The ARES CBRNE plugin renders a 2D image based on the concentration values provided by SimBox and publishes it to consumers over RabbitMQ. The ARES modalities (e.g. Table, Floor, Tablet, etc.) then have the capability to generically consume image frames from the message queue in order to visualize the plume simulation.

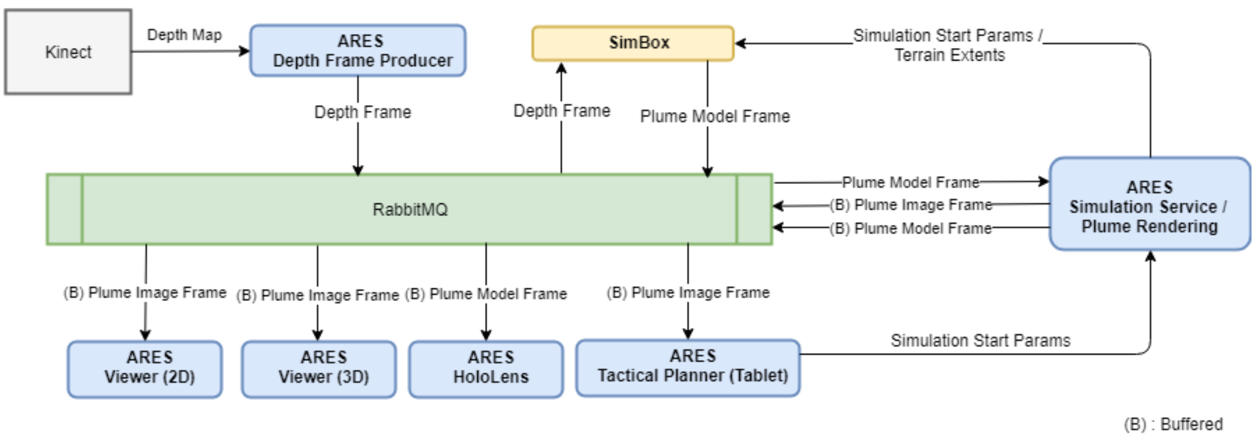

Figure 9: NCAR SimBox Integration with ARES Overview

DEVELOPER RESOURCES

ARES is designed to support development from contributors that may wish to add new features to ARES, whether they are new models or new front-end additions. The development of an API and SDK that allows for flexibility and extensibility is at the core of ARES design. The vision is ARES will act as a platform that resembles an "App Store," where contributors will be able to develop features and make them available to users who can enabled or disable them as needed. This allows ARES to provide a highly tailored experience depending on the use-case.

Application Programming Interfaces

ARES leverages a combination of AMQP and RESTful interfaces that provide commands for data storage management, managing elements of the ARES viewer, and application state management. Scenario and terrain data are managed via AMQP and RESTful persistent storage services, enabling applications to retrieve, modify, and create data as needed. Additionally, both the AMQP and RESTful interface supports commands enabling the user to modify the visualization output. For example, there are commands that can apply contour lines to the display, change the scenario/terrain currently displayed, as well as capturing a snapshot of what is being currently rendered. Peripherals such as Microsoft Xbox controllers and capturing images from the depth sensor are also managed using commands made available by leveraging both AMQP messaging and the RESTful interface.

Software Development Kit

ARES provides developers with an end state that allows contributors to add features to the platform in their desired language. The SDK supports development in Java, C++, C#, Unity, and Python that adds robustness to the architecture. Developers that have models or features currently written in these languages can easily incorporate them into ARES. Additionally, the plugin architecture for the Tactical Planner application offers flexibility in the interaction methods that developers can incorporate without having to modify ARES core platform code.

ARES Lite

ARES Lite is a developer-oriented, virtual ARES environment that provides developers a means to develop and test their projects without needing any hardware for the ARES modalities. ARES Lite gives developers an ARES emulator with detailed statistics and tools for simulating interactions with the AR/VR modalities. ARES Lite supplies users with a full implementation of the ARES server that accepts connections from mobile devices running the standard Tactical Planner application that works with all of the modalities. Through ARES Lite, developers can create and modify scenarios as though they were utilizing any of the ARES modalities.

ARES Lite is packaged with demonstration scenarios that also include terrain data. They can be loaded into the virtual environment using the Tactical Planner app or the built in ARES debug interface. Users can then see a virtual representation of the scenario in a window. Figure 10 shows an example of what the emulator may look like when a demonstration scenario is loaded in the virtual environment. The left side of Figure 10 shows some of the helpful statistics regarding the frame rate and rendering demands on the system that give developers the opportunity to understand how their plugins might impact the system when deployed.

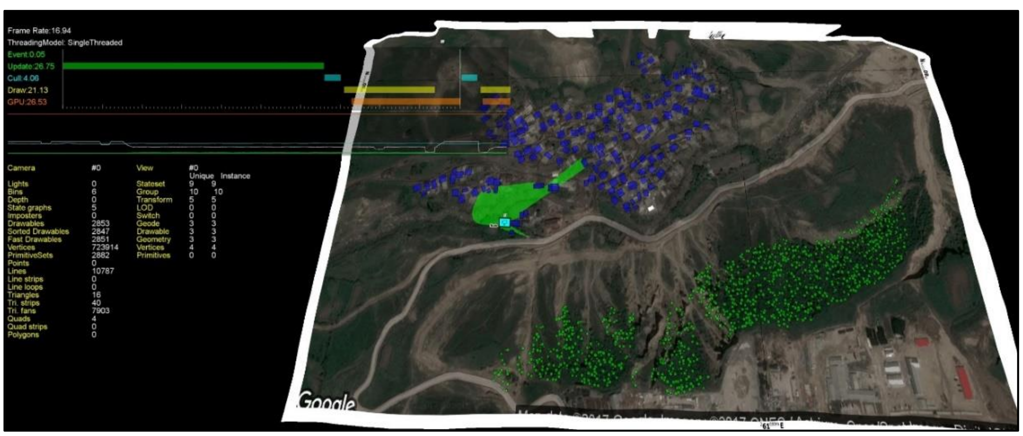

Figure 10: ARES Lite Visualization with Debug Statistics

Example Use

ARES developer resources have been successfully applied for various projects that have enabled developers to integrate with ARES. As mentioned in a prior section, NCAR's SimBox CBRNE simulation was developed using the ARES SDK and APIs. The effort required that starting parameters (time, weather parameters, and release point) and terrain data be captured and sent back to SimBox for processing. Once the model completed its processing, the output then needed to be sent back and displayed on the table over the course of a set simulation time duration. The details of this interaction are depicted in Figure 9. NCAR was able to successfully develop their application using the ARES developer resources while not having any ARES-specific hardware. The plume simulation model was then used in a study with the Maneuver Support Center of Excellence's (MSCoE) CBRN Captain's Career Course in which participants were able to carry out the Military Decision Making Process (MDMP) using ARES to plan scenarios and simulate CBRN releases (Abich, et al., 2018).

ARES developer resources will be further utilized in planned collaborations with academic institutions such as the University of Central Florida's (UCF) Florida Interactive Entertainment Academy (FIEA) and Orange Technical College. In this collaboration, students will get an opportunity to use these resources to create new or enhance existing projects in ARES as a part of their courses. Going forward, the ARES project will continue to invite developers to contribute through a robust and expanding set of developer resources.

LESSONS LEARNED

Through all aspects of research and development, we learned several lessons that helped us improve our project execution and scalability. In this section, we will highlight some of the major lessons learned during the development of the ARES architecture.

Commercial Off-The-Shelf (COTS) Hardware

Focusing on purchasing low-cost COTS hardware for ARES modalities was very beneficial for generating interest from stakeholders and potential collaborators across both the military and academia. Collaborators use a bill of materials and installation instructions to build their own ARES systems from low-cost hardware and require minimal support from our development team. This approach made it significantly easier for us to scale which, in turn, allowed us to gather feedback from a broad range of collaborators.

Messaging Architecture

Making a simple API and messaging architecture for collaborators was a high priority during development. Using open solutions, such as RabbitMQ and Google Protocol Buffers, that have support for multiple languages allowed us to easily add additional modalities (e.g. AR/VR), integrate with third party applications (e.g. NCAR SimBox) and scale the ARES system without significant changes. We were able to go from a single, local sand table to a robust, distributed system capable of supporting several ARES modalities across multiple locations with minimal development effort.

We created the SDK in response to some collaborators that had some difficulty integrating the ARES RabbitMQ client with their system. The SDK provides tools, examples, and a framework for developers to integrate their application easily into ARES with a low level of effort.

Research Studies and User Observations

As part of ARES research, we chose to put a large emphasis on conducting studies with users with the goal of collecting data to understand ARES uses cases, drive requirements for development, and assess system effectiveness for the warfighter. The data we have received from studies have been a significant help with developing the future direction of ARES. For example, we were able quantify the time savings of using the ARES floor projection versus a traditional floor-based model during a recent site visit to the U.S. Army's Maneuver Center of Excellence (MCoE). We also received a lot of feedback on improvements that would improve the efficiency of the system for mission planning. Some of these recommendations have resulted in development efforts that have become requirements for a future release of ARES or in research efforts that will further refine the knowledge base and potential benefits of a system like ARES.

CONCLUSION

Through its Service-Oriented Architecture, ARES and its various modalities lend well to both operational and training use-cases. The ability to conduct mission command with the aid of numerous devices that assist users' understanding of the complex battlespace is beneficial across all echelons of command. Increasingly complex battlefields present new challenges related to information fusion and mission synchronization. The ARES architecture allows users to visualize the same COP through any modality they have available. When new devices become available on the market, the inherent modularity and flexibility of the architecture will allow for the simple adoption of new modalities. If additional models, tools, or capabilities are desired for certain users or use-cases, developers can use ARES Lite along with the SDK and API to create their own applications or plugins. ARES is already being used in classrooms, simulation centers, and in support of field exercises within the Army. As further development will continue to press forward to bridge the distances between remote collaborators and seek to provide intuitive visualizations and interactions for complex subjects, so too will the human factors research efforts to exploit the critical items that lend to higher levels of situational awareness and decision making on the battlefield.

REFERENCES

Abich, J. I., Eudy, M., Murphy, J., Garneau, C., Raby, Y., & Amburn, C. (2018). *Use of the Augmented Reality Sandtable (ARES) to Enhance Army CBRN Training.*

Erl, T. (2005). *Service-Oriented Architecture: Concepts, Technology, and Design.* Upper Saddle River: Prentice Hall PTR.

Garneau, C. J., Boyce, M. W., Shorter, P. L., Vey, N. L., & Amburn, C. R. (2018). *The Augmented REality Sandtable (ARES) Research Strategy (ARL-TN-0875).* Aberdeen Proving Ground: US Army Research Laboratory.

Hale, K. S., Riley, J. M., Amburn, C., & Vey, N. (2018). *Evaluation of Augmented REality Sandtable (ARES) during Sand Table Construction.* Orlando: US Army Research Laboratory.

Joint Chiefs of Staff. (2017). *JP 3-0 - Joint Operations.* Washington, D.C.: Joint Chiefs of Staff.

US Army. (2012). *ADP 6-0 - Mission Command.* Washington, D.C.: Headquarters, Department of the Army.