Utilizing Augmented Reality for Air Force Maintenance Training

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ABSTRACT

In October of 2018, Secretary of Defense Jim Mattis issued a statement requiring the mission capable rate of key tactical aircraft within the Air Force and Navy to increase to 80% within a year. Aircraft maintenance is the key to reach this level of aircraft readiness. However, the 2014 drawdown, combined with the retiring workforce, have led to a shortage of proficient maintainers and a skill and knowledge gap. Providing the skills to new maintainers to efficiently, effectively, safely, and thoroughly service aircraft begins with creating robust training content to enable the development of critical expertise. A variety of organizations within the Air Force exist to create such content; however, they face challenges when it comes to authoring robust content on unavailable aircraft and capturing, preserving, and distributing expert maintainer knowledge. Innovative solutions are needed to accelerate the authoring of spatially contextualized training in the actual maintenance environment. One such organization in need of technology solutions is the 367 Training Support Squadron (TRSS). Despite their current ability to develop a variety of training products, they have no mechanism to capture and provide hands-free training material on actual equipment, or to provide high fidelity training on absent equipment. This paper evaluates Augmented Reality (AR) as a solution approach to the gaps in maintenance training content creation and details a content authoring use case by the 367 TRSS to incorporate an AR training authoring tool into their toolset. Generalized findings highlight where AR is best suited to support maintenance training, and discussion of how AR can support rapid content authoring.

ABOUT THE AUTHORS

Ms. Christina Padron is the Deputy Division Head of the XR Division at Design Interactive and has designed and evaluated multiple virtual assessment and training tools for the Office of Naval Research, Army Research Lab, and the Air Force. Her work focuses on the design, usability, and effectiveness of AR/VR/MR training and job aid solutions. Christina is currently leading multiple AR/VR/MR training system design and evaluation efforts under contract with the Air Force, Army, and Navy. She holds a Master's degree from Penn State University in Industrial Engineering with a Human Factors Option and a Bachelor's degree from Purdue University in Industrial Engineering.

Ms. Charis Horner is a Research Associate in the XR Division at Design Interactive. Her experience surrounds emerging technology delivery to diverse stakeholders, including the Office of Naval Research, the Air Force Research Laboratory, and the Department of Homeland Security. Her current work is centered around the design and delivery of XR technologies across the Department of Defense with a focus on driving user-centered design for scalable adoption of AR/VR/MR training and job aid solutions. She holds a Bachelor of Science in Industrial Engineering from the University of Central Florida with a minor in Engineering Leadership, where her focus included Human Factors.

Mr. Troy Westbrook is the Deputy Director for the 367 Training Support Squadron (TRSS). He entered the Air Force in 1983 and served over 21 years as a KC-135 Aircraft Crew Chief. He went on to serve as a Maintenance Qualification Training Program Instructor, retiring in the grade of Master Sergeant in 2005. He returned to the 367 TRSS as a civilian where he serves as the Deputy Director, continuing to support AETC's Continuum of Learning and virtual training initiatives. Mr. Westbrook achieved a Bachelor of Science in Computer Science from Park University, and an Applied Science degree in Aircraft Maintenance from the Community College of the Air Force.

Mr. Joshua Davidson is a Technical Sergeant in the United States Air Force and functions as his squadron's AR/VR subject matter expert. His experience includes 10 years as an aircraft maintainer working on C-130's and 5 years as a graphics artist developing training material for the Air Force maintenance community using mediums such as photography, videography, 2D illustration, and 3D modeling. With a Bachelor's of Science in Game Development, his skills and expertise are currently being utilized as the 367 TRSS Graphics Development Section Chief and Special Projects Team Lead focusing on training innovation in the realm of augmented and virtual reality.

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INTRODUCTION

Aircraft readiness is crucial to ensure airmen can fly, fight, and win in both air and space. Without deployable aircraft on hand, the ability to respond quickly to threats inherently suffers. The criticality of this issue has been made paramount by Secretary of Defense Jim Mattis, who issued a statement in 2018 requiring the mission capable rate of key tactical aircraft within the Air Force and Navy to increase to 80% within a year (Mehta, 2018). Considering the mission capable rates across the fleet in 2017 bottomed out at 49%, with an average of just 71.3%, the intended jump in readiness represents a sharp increase in the need to ensure the fleet is properly maintained to deploy when called (Mehta, 2018).

Answering the call put out by Secretary Mattis to increase aircraft readiness starts with ensuring consistent aircraft maintenance, which begins with having experienced maintainers at the ready to perform crucial servicing tasks. Having such personnel on hand, however, is anything but trivial. In 2014, the Air Force drawdown saw a reduction in close to 20,000 airmen throughout the enterprise, resulting in decreased aircraft readiness and personnel burnout (Losey, 2017). The loss of experienced airmen is further aggravated by the retiring workforce of the Baby Boomer generation, which led to a shortage of maintainers and a skill and knowledge gap (Green, 2016). Although the maintainer shortage has been closed in terms of manning, a significant experience and knowledge gap remains as junior maintainers attempt to fill the shoes left by highly experienced maintainers (Everstine, 2019). The lack of an efficient method to store and transfer knowledge from expert maintainers and effectively train less experienced maintainers has resulted in increased personnel training costs as well as unplanned downtime, keeping the Air Force from pushing the boundaries of readiness.

Training maintainers to efficiently, effectively, safely, and thoroughly service aircraft begins with creating robust training content to enable the development of critical expertise. To this end, the Air Force has a variety of squadrons dedicated to creating training products. These Training Support Squadrons (TRSS), such as the 367 TRSS, or “the Griffin” out of Hill Air Force Base (AFB), liaise with partners within other Air Force units (e.g. Maintenance Groups) to identify and validate training gaps and develop custom solutions to meet training needs. The 367 TRSS develops, publishes, and maintains products to support continuation training programs for the Air Force’s maintenance enterprise. This unit is the largest interactive multimedia instruction unit in the Air Force, with operating locations at Langley AFB, Virginia and Scott AFB, Illinois, and is geographically separated from higher headquarters of the 982d Training Group and 82d Training Wing, Sheppard AFB, Texas. The 367 TRSS applies proven industry Instructional System Design techniques, (e.g. Analysis, Design, Development, Implementation, and Evaluation, [ADDIE] model) and Project Management techniques to develop products by “beginning with the end in mind” (Kirkpatrick, 2015). They start by identifying and validating the training gap, establishing customer needs and product requirements, creating a development and evaluation strategy including individual and group testing with the intended audience, product publication, and last, establishing a Life Cycle Management schedule.

The TRSS are being asked to “develop ten years of expertise in one year of training” with the training products they create to accelerate readiness. This is no easy feat, as it takes significant time to author, test, and distribute instructionally rich content, partially due to the difficulty in capturing training assets from distributed systems. Beyond this, despite the Griffin’s current ability to develop a variety of training products, they face a few challenges. For example, they currently have no mechanism to capture and provide hands-free training material to supplement hands-on training on the actual equipment. Another significant training authoring challenge surrounds how to develop “hands-on” training for physical assets which are not present at the training site or accessible in the necessary training state. Innovative solutions are required to meet these needs and provide the Air Force TRSS the tools to rapidly author robust training content to accelerate development of expertise. Augmented Reality will be evaluated as an approach to develop the innovative solution or solutions needed by the Air Force Training authoring ecosystem.

Augmented Reality Solution Approach

Augmented Reality (AR) is an interaction between the real and virtual worlds. The user experiences a real-world environment enhanced by virtual assets across multiple sensory modalities. Within augmented environments, users are able to register spatial and contextual information simultaneously, introducing new possibilities for conveying knowledge beyond conventional methods. The augmented stimuli are intended to enhance perception of and action on the real world through a merging of reality and virtuality (Milgram & Kishino, 1994). Through its enhancement of the natural world with interactive virtual content, AR is well-suited for training in both the classroom (Ibáñez & Delgado-Kloos, 2018; Wojciechowski, R., & Cellary, 2013) and operational environments (Hamza-Lup, Rolland, & Hughes, 2004; Webel et al., 2013).

Augmented reality is thought to be particularly well-suited to supporting learning of contextually rich tasks, as training programs are most effective when the original learning context is representative of the desired performance context (e.g., Tulving & Thompson, 1973; Smith & Vela, 2001). This is of particular value in the aircraft maintenance field, as maintainers need the ability to train new personnel independent of their location, whether on the flight line, in a hangar, or in a classroom environment. The abilities of AR to introduce virtual holograms and position them in contextually appropriate locations allows maintainers to visualize components, thereby accelerating and increasing the efficacy of training and reducing cost by eliminating the need to house physical components. Authoring and incorporating this type of training into the Air Force maintenance community has the potential to accelerate the development of junior maintainers.

The purpose of this paper, therefore, is to identify specific needs in developing Air Force maintenance training content for which AR is directly suited and to revolutionize their training capabilities to provide effective training where and when it is needed. Details will include how the 367 TRSS began to integrate AR into their training program to support knowledge capture from retiring experts and facilitate knowledge transfer to fellow maintainers.

AIR FORCE MAINTENANCE TRAINING - CURRENT STATE

Training currently authored by the TRSS span the gamut of traditional methods as well as a variety of emergent technologies. These training products include PDF documents (ePubs) of technical orders embedded with 3D objects displayed on a 2D tablet to provide trainees with views of airframe components dynamically. Other products include: interactive schematics (e.g. electrical/environmental, fuel/hydraulic plumbing, component function), hands-on training for engine operation and emergency shutdown, interactive multimedia instruction task training, targeted training videos (e.g., YouTube), information/technical posters, and on-the-job formal lesson plans. The Griffin hopes to add more interactive training product options, including 2D/3D interactive training products such as Augmented Reality, Virtual Reality and Mixed Reality, to the list. The training specifically provided by the Griffin supports the entire Air Force Aviation Maintenance Fleet (i.e. fixed/rotary wing aircraft, munitions/missiles, Aircraft Ground/Support Equipment). At present, the Griffin has 243 training products they have created, supporting approximately 108,000 Airman and civilian personnel. Users accessing the Griffin's products have completed 136,453 courses over just twelve months. Thus, the 367 TRSS is a vital organization well primed to champion the adoption of emergent technologies within authoring and consuming training content for maintenance.

Authoring Process

To provide quality training content to maintainers at the point of need, the Griffin's current training development model follows a robust process in which they elicit and validate training needs, analyze and establish training tasks, select the appropriate training medium, author content, iteratively test the product, and scale training roll out while monitoring validation. This process is followed to ensure the right solution is delivered, tailor-made to meet the specific needs of the training request. These training solutions need to be intuitive and easy to teach to instructors, as educators will be on the front lines of delivering content to trainees. The needs elicitation and task analysis leads to the selection of a proper training medium; however, situations arise where the limitations of available training mediums can make it difficult to meet the needs of the training request. Furthermore, when a training medium is identified, the task of authoring content can have a variety of bottlenecks which prevent content from being quickly delivered to the point of need, delaying the opportunity for maintainers to train quickly and efficiently on their needed tasks.

Limitations of Current Training Technology

Instructional Technology Units, such as the 367 TRSS, are often tasked to author create novel training solutions to meet specific training needs, but they are limited by the currently available technology mediums. Attempting to train personnel to maintain three-dimensional (3D) equipment using two-dimensional (2D) technology can be challenging. Even using a 3D perspective within a 2D screen (whether handheld or desktop-based) does not provide the amount of real-world context desired to efficiently learn maintenance tasks. A computer-generated 3D perspective may be useful for understanding the shape of objects because it can integrate the three dimensions into a single view and provide natural depth cues (St. John et al., 2001). Conversely, these 3D views can also impair perception of the relative positions of equipment because of projective opacities and distortions (St. John et al., 2001). This can cause difficulties in creating a mental model of a 3D object when the only reference available is two dimensional even if the perspective is 3D. Consequently, it may be more useful to train fully in three dimensions by using augmented physical equipment or virtual 3D models. This allows the trainees to maintain the use of their hands while still consuming the content. Training on these types of 3D systems ultimately shorten the time required for trainees to reach a basic level of proficiency increasing the efficiency of training opportunities (Ashraf et al., 2014).

It can also be difficult for a trainee to cognitively navigate many of these maintenance procedures during training. With the current technology, they are required to first mentally position a given task in a 2D model of the environment and then correctly translate this to identification of this location in the physical world (Henderson & Feiner, 2009). Without the ability to be hands-on, this can be particularly difficult. Hands-on training is critical to learning the maintenance of complex systems, such as those found in aviation. However, movement in and around these systems can be complicated by their sheer size or by structural characteristics that restrict a maintainer's view and freedom of movement (Henderson & Feiner, 2009). Requiring a maintainer to transport a bulky technical manual or even a smaller, but still potentially obtrusive hand-held device is not ideal. Also, maintenance procedures in these types of systems typically span dozens of tasks involving notionally unfamiliar objects dispersed within a given area, making carrying anything cumbersome. These limitations of traditional training techniques make them ill-suited for the future of maintenance training.

Emergent technology such as Augmented Reality and Virtual Reality can bridge the gap between the limitations of the previous training technology, such as videos and interactive multimedia instruction (IMI), and fully supported on the job training. Augmented reality provides a halfway point between true hands-on training and a simulator, as it can deliver hands-on virtual content in an actual environment where the task is completed. AR specifically closes this gap by merging real world scenarios with simulated input, providing trainees an environment in which to become proficient while eliminating the danger of the true task at hand. Therefore, there is an opportunity to utilize emerging technology, such as AR, to solve some of the challenges with current mediums, increasing the efficacy of the training solutions.

Training Content Authoring Challenges

Once a medium for training is identified, the challenge becomes to develop the most effective training content within that medium by authoring the content. This training needs to accurately represent the relevant equipment, content, and environment, and it must coexist with the environment in which training is occurring, whether it be a classroom environment or on the flight line. The training content created may contain a variety of elements from disparate sources and capturing those training media can be challenging for the Griffin, and other similar squadrons. Further, the availability and accessibility of aircraft and their various components can provide a challenge when developing training to be delivered directly on them.

Capturing Media for Training

A crucial component of training content authoring is the capture of media to incorporate into training content. The media content may be a photo, technical order, video of the procedure being completed, or other visualizations which are then added into training courses. Often, this media capture becomes a bottleneck for the creation of training content, as the central location where media need to arrive for training content assimilation is not the location where the physical performance task occurs. Currently, overcoming this involves back and forth communication between the training content authors and the experts or squadrons requesting training. The training content authors must coach on how to properly capture usable training media, communicate which systems are needed, then receive the media back, edit it, and incorporate it into the training. The alternative to this is for training authors to travel to the airframe location to capture the data. This process is expensive and time consuming, as schedule coordination, travel plans, accommodations, and further delays occur while awaiting the ability to travel. Additionally, when traveling to collect media, authors must obtain proper security clearance and ensure classified or secret information is not in jeopardy of being misused. This typically involves liaising with public affairs and obtaining authorization to bring cameras or other media capture equipment to the location. Each specific piece of media capture equipment must be cleared by each location housing the equipment in order to use it to obtain training content. This again lengthens and complicates the media capture process. Another media capture dilemma ties closely to the challenge posed by aircraft and component availability, as described in the subsequent section.

The proper capture and documentation of training media lengthens the time needed to create quality training content. With the current process of centralized media creation, training authors need to wait until an aircraft is available, obtain proper clearance, travel to its location, and use the current technology available to capture assets. During these delays, junior maintainers must continue to wait for the training content they need to accelerate their proficiency, continuing to delay their ability to become experts. The current process inherently creates bottlenecks when equipment/airframe is not available. Thus, a need exists to have a simple mechanism to decentralize media capture and allow maintainers to directly create the media needed for their training, rather than training authors needing to coordinate and wait on the equipment.

Aircraft, Component and Maintainer Availability

Often, the equipment on which trainees need to practice tasks is not accessible to complete through training, which poses a challenge when determining how to best author training content. For example, to train on repairing a broken aircraft component, ideally one would have a physically broken aircraft component. Obviously, breaking currently functional equipment for the sole purpose of training is a subpar and unfeasible solution, due to the inherent risk and cost. This equipment would be out of commission during the training time, would be at risk of being irrevocably damaged, and would pose safety concerns as new trainees are more likely to make errors which could harm themselves or the equipment. Similar concerns arise with instruction on individual equipment components, as disassembling existing equipment is not cost effective, safe, or feasible in many scenarios. Both these situations must be considered when authoring content, as content created must allow trainees to practice and become proficient at these tasks, while in the absence of the physical view of the component.

In another use case, aircraft may not even be present at the physical training site where trainees will consume authored content. The active inventory of aircraft in the Air Force vary significantly, with some models having twelve or less active aircraft force wide (Mehta, 2018). Temporarily grounding these aircraft for the purpose of training or training content creation, even for small periods of time, immediately decreases the readiness of the fleet, contradicting the original intent of training creation. Therefore the challenge becomes, how do Air Force training authors create content for aircraft which are not even present?

Authoring of these types of training will typically come through two dimensional formats such as illustrations or videos, or three dimensional images displayed on two dimensional mediums as the visual renderings allow trainees to see interior parts. However, these solutions do not allow trainees to visualize the information spatially in the environment. Perhaps a trainee has a physical aircraft in front of them and is viewing a two dimensional rendering of an interior inaccessible part. The lack of spatial orientation reduces the fidelity of this type of training scenario. Even more divorced from reality is training of this type when an aircraft is not present. How can the trainees visualize the scale and complexity of the craft and its related components when the rendering provided through training lacks the dimension of the actual craft? Therefore, a need exists to improve the ability to author contextually rich, spatially oriented content for situations where the aircraft or aircraft component is inaccessible.

AUGMENTED REALITY CAPABILITIES

The goal, therefore, when incorporating AR as a training authoring and consumption tool, must be to meet the needs left by current authoring capabilities, such as providing the ability to author contextually rich, spatially oriented content for situations where the aircraft or aircraft component is inaccessible, to provide a simple mechanism to decentralize media capture and allow maintainers to directly create the tasks needed for their training, and to ultimately decrease the time to author such training.

Types of Augmented Reality and Selected Instantiation

Augmented Reality tools provide a variety of capabilities which can directly benefit the specific needs identified by the Griffin. When discussing AR tools, it becomes necessary to clarify the specific instantiation of AR being evaluated. AR can span a variety of modalities, the most distinct of which are AR applications within handheld devices and head mounted displays (HMDs). Handheld, or mobile, AR represents situations where digital content is layered on the physical world within a tablet, mobile phone, or other handheld device, allowing users to have reference information via the two dimensional surface of the device (Grubert, 2015). Uses of this medium can be limited by the need to hold or otherwise affix the device while consuming content displayed. This can pose challenges in maintenance due to the limited maneuverability of a maintainer's extremities as they are required to accommodate the device (e.g., Dey et. al, 2018).

Augmented Reality HMDs can be seen in two instantiations: the two-dimensional and the three-dimensional. 2D HMDs overlay information directly in the field of view, but do not spatially position and orient content on the user's environment (Qian et. al., 2017). In this way, 2D HMDs are not handheld, so they do allow the user to maneuver within the field, but they lack the ability to spatially deliver content at the point of need. 3D HMDs, in contrast, affix digital information spatially within the users' environment. They have the capability to perceive the real world objects at a user's location (e.g. tables, chairs, equipment) and use this information to directly tie content to the contextualized area in which a user is working. This type of spatial AR, sometimes also called "Mixed Reality", utilized through a 3D HMD does a more thorough job of navigating and directing users to the point of need by placing content directly in space (Qian et. al., 2017). Parts and assets can be created virtually and placed realistically in the environment with enabled user interaction. 2D HMDs and non-spatial applications cannot do this, meaning if there is no asset, training is limited to classroom based environments. For these reasons, the training instantiation chosen to be evaluated is AR using three-dimensional head mounted displays.

Training Authoring System Capabilities

The capabilities of 3D HMDs allow the users to have hands-free manipulation of content in real, 3D space, where content can be virtually overlaid on a real environment. An example of this is a fuel line. Using 3D HMDs, a digital representation of the flow of fuel within a component can be seen overlaid on the actual component. Beyond virtual overlays, 3D models of absent components can be directly placed within environments where users can walk around them, manipulate, resize, and animate to encourage contextualized understanding. Additionally, instructional content can be tied to the contextual environment. Consider a situation where a maintainer is being trained on a crucial task where danger can be present if the safety protocols are not closely followed. Expert tips and notes can be directly tied to the location of that task, so that the trainee has a visual in their line of sight warning them of the danger present at this step and providing information on how to overcome it. A 3D HMD allows this type of information to be directly tied to the physical location of danger, rather than divorced from context in a 2D format.

The key to the success of this content lies in the authoring of the information and its placement within the environment. Using an AR authoring tool, delivered through a 3D HMD, experienced maintainers with no software development expertise can author procedures to directly be consumed by junior maintainers in AR. With a robust AR authoring toolkit, non-technical trainers or maintainers can spatially add digital assets to a trainee's real environment, inputting their tacit knowledge directly into the tool. The development cost drastically decreases with this approach, as software developers do not need to be in the loop to customize and edit material. In this training instantiation, Air Force maintainers are empowered to manage, edit, and update their own content without needing to employ additional technical skillsets and manage recurrent cost of software development and customization. These capabilities can address the needs enumerated by the 367 TRSS and Air Force maintenance training development at large. Explicit clarifications of how these capabilities can meet the needs are detailed below.

3D Visualization for Aircraft and Components

The first specific requirement of the Air Force authoring environment is to mediate the need to have an aircraft or aircraft component while authoring and consuming contextually rich, spatially oriented content, as these assets are often inaccessible. AR authoring tools provide a chassis allowing authors to attach existing 3D models to a 3D medium, where trainees can view models of aircraft and components visually and spatially. When an author has added this 3D model to an AR authoring platform, trainees will have the ability to see a scaled model of the component or the craft directly in their field of view, spatially oriented in the environment. This AR view can accommodate the scale of a large component or craft, providing a mechanism to realistically visualize the focal point of maintenance. Beyond this, trainees are able to manipulate these models in space, sizing, and scaling to view with the level of detail needed to understand the task at hand. Utilizing 3D animation visualized in AR, trainees can deconstruct components of aircraft inaccessible in the real world. This allows trainees to visualize internal parts of a complex system which previously were opaque. Training content authors can use these capabilities to solve the need of creating training for broken components, internal components which cannot be deconstructed in training instantiations, or absent aircraft or components. An example of this can be found in below in Figure 1.

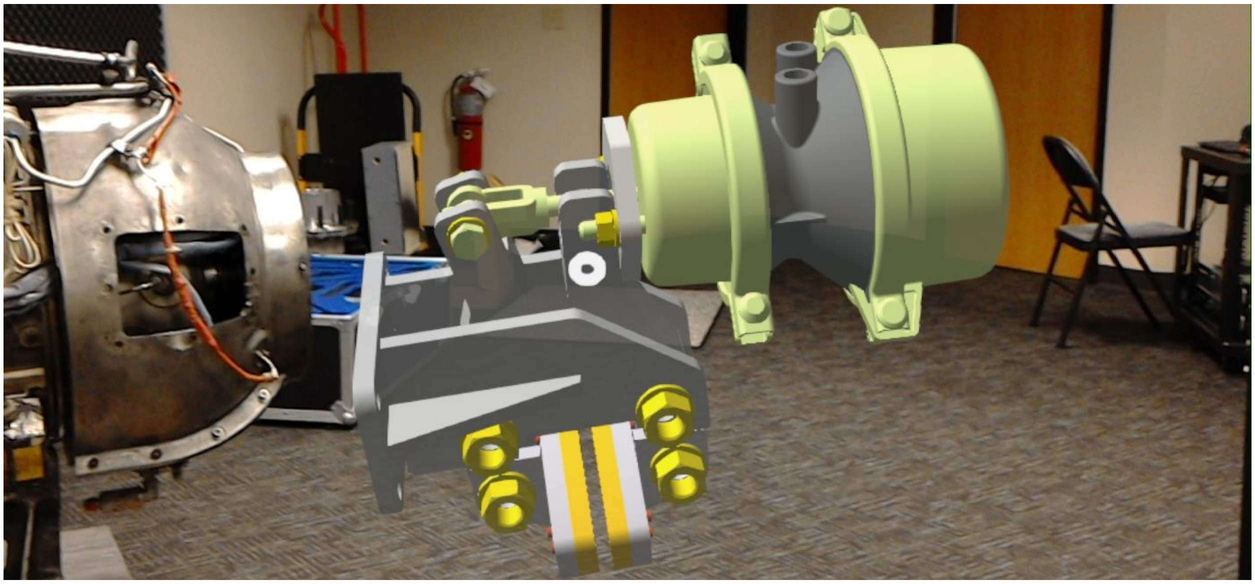

Figure 1: 3D Visualization of Part

Decentralizing Asset Capture and Reducing Time to Author

Another feature of AR authoring tools, if designed intentionally for scalability, is to allow end users who have access to equipment to become authors, capturing content where they are directly where the asset is located. If the AR tool allows end users to use 3D HMD AR hardware to capture training assets on the same tool on which training will be consumed, this eliminates the bottleneck created by centralized media capture. If designed with usability in mind, AR authoring tools can allow anyone, regardless of experience, to don a head mounted display, record the necessary content, and directly save it, automatically sending it back to the training authors. An example of this is seen in Figure 2, where an expert can use an AR authoring tool to capture media directly within their work space.

Figure 2: Media Capture in Training Context

Allowing maintainers on location to directly capture media through an AR tool can also mediate the challenges with obtaining security clearance for media capture. If the maintainer's location has an AR device on site which has been cleared a single time by the public affairs office, the repetitive process of obtaining clearance each time media capture is necessary becomes obsolete, as the single clearance provided to that device suffices. This empowers quick media capture by on-site maintainers, cutting through the red tape inherent in the current process. By eliminating the bottleneck of centralized authoring, the time to author the contextually rich training decreases. Authoring itself is faster, as it can happen directly within the AR tool used for training. This eliminates the need for the training authors to take the media captured and rework them into a different format for the training, getting rid of the non-value added step of editing content captured and translating it to a new presentation.

CASE ANALYSIS

In order to begin evaluating the efficacy of AR to meet the needs enumerated, the 367 TRSS tested an existing AR authoring solution called AUGMENTOR™ to determine how the authoring capabilities would fit into their existing toolset. The intent of this is to evaluate how well an AR authoring solution can meet the needs defined and to prepare the software to be implemented in a pilot program with aircraft maintainers. The results of the pilot program, where trainees utilize the content created, will be published at a later date. To test content creation within AR, the Microsoft HoloLens was used in conjunction with an integrated web portal to provide additional authoring capabilities beyond the head mounted display.

C-5 Super Galaxy Aircraft Content Creation

The aircraft selected for pilot program content creation was the C-5 Super Galaxy, the largest airframe in the fleet. Its 2017 readiness percentage was 60.25%, significantly lower than the target set by Secretary Mattis (Mehta, 2018). This particular craft comes with a variety of challenges, as it has many complex components and spans the length of 247 feet and 10 inches, with a height of over 65 feet (U.S. Air Force, 2018). The reasoning for choosing this airframe lies both in how well it is primed for improvement in readiness, and its inherent needs as one of the most sizeable aircraft in the force. It has the largest maintenance and air crew of any aircraft in the fleet and represents a significant target audience for a single airframe. Utilizing this aircraft for the content creation use case thereby provides a considerable target user group and resultant findings to test and prime for adoption AR training within the Air Force. It also offers noteworthy challenges in creating AR content, as the number of potential tasks and spatial context factors is inherently vast with the size and scope of the airframe itself. Essentially, if AR works for the biggest problem, it should work for smaller ones. Therefore this airframe was chosen as a springboard by which to evaluate the efficacy of AR training in the Air Force maintainer environment.

The specific chosen maintainer training context is that of "en route maintenance." In en route maintainer facilities, aircraft will fly in, pick up their needed materials and receive necessary services, and then depart. The maintainer community in this context have no assigned airframes, meaning no decommissioned craft is present on location. Therefore these maintainers have limited time to practice maintainer tasks before aircraft arrive, and they have a tight timeline to complete servicing tasks while the airframe is on the ground. Since no airframes reside long term in en route facilities, these maintainers inherently have limited access to systems on which to train, but they still must be prepared to view and service aircraft quickly and thoroughly. Therefore, the 367 TRSS has a need to create training which enables proficiency for maintainers to carry out tasks quickly, and to train on an airframe which is not present.

The en route maintainer group is a clear primary target audience for AR training. Due to the inherent limited ability to access systems for training and practice, training on virtual airframe components becomes incredibly valuable. It increases spatial contextualization in an environment where their previous capabilities would have been limited to 2D training and interfaces. Additionally, the time crunch inherent in the en route maintainer community means maintainers must be proficient on the tasks to be performed, as en route aircraft have limited amounts of time to be on the ground before needing to depart. Creating this type of content within AR allows the 367 TRSS to quickly provide training procedures to the maintainer community at the point of need.

The specific targeted tasks for this use case fall in to two categories. The first is ensuring the airframe is safe for maintenance, which involves confirming the aircraft is properly grounded, bonded, and safe to begin carrying out maintenance procedures. Included in the safe for maintenance are aircraft inspections, including pre-flight, post-flight, and thru-flight. These procedures encompass the entirety of the aircraft with a single piece of instruction. The second task category is powering on the electrical systems of the airframe in order to perform maintenance, which involves a variety of procedures to apply, control, and display electrical power, core processing electrical power, and disconnecting the core processing and external power once the maintenance is complete.

These specific tasks, safe for maintenance and inspections, as well as maintenance power to the airframe, were intentionally selected for training content creation with AR. As these tasks take place in a variety of locations around the airframe, having content which is spatially oriented to the exact location of a maintenance step allows maintainers to take full advantage of their environment while still having access to the information necessary to carry out a task. Additionally, the challenge of the vast amount of space needed to be traversed by maintainers carrying out these tasks, as they will need to travel the length of the airframe to complete a single procedure, will push the capabilities of an augmented reality tool to determine whether or not it is viable to be used in such a large space.

If AR were not an option, the 367 TRSS would use other traditional training modalities in order to meet the needs of the C-5 en route maintainer community for these particular tasks. These would likely take the form of targeted training videos, where a maintainer can view a video of another maintainer carrying out this task prior to having to complete the task themselves. To create and deliver this content, the 367 TRSS would need to capture this video from an experienced maintainer, publish it in an accessible form to the trainee, and ensure the trainee is aware of the access to the targeted training video. Another potential content creation option for the 367 TRSS would be interactive multimedia instruction, such as an interactive PowerPoint presentation or a computer-based simulation. In the current environment, these training systems would need to be consumed via a personal computer. The most significant limitation of these two training instantiations is they are inherently tied to a computerized delivery modality. A trainee must walk away from the maintenance environment, sit at a computer screen, consume the training content (whether a targeted training video or an IMI), then return to the maintenance environment to practice or carry out the task.

Using AR instead of these traditional training methods for the en route maintainer organizations allows creation of content that can be consumed on command, on demand, and at the point of need. Maintainers have the ability to view and practice procedures on holograms of components in the very hangar where these airframe components will later arrive. When the plane arrives, the AR training tool can act as a job aid, providing the exact information needed to the junior maintainer in a hands-free modality while the maintainer carries out the task. AR can spatially orient the information needed to the exact point where it is needed. Rather than flipping through a technical manual to find the schematic of the specific component located on the back of the airframe, AR can overlay this specific schematic on the specific area where the maintainer will need to reference it, reducing the cognitive load and the need to switch between tasks. The maintainer in this context can focus on the task at hand, with the relevant information spatially oriented in their environment, available on demand and on command.

Results

As part of the pilot program currently underway, the content authors have created inspection tasks in AR and added videos, schematics, steps for the inspection, and reference holograms. Summative evaluations were conducted by content authors via user interviews. In their preliminary findings, authors discovered creating content for the C-5 Super Galaxy Aircraft with the AR tool decreased time to author by approximately 50% in comparison to traditional methods. If an IMI was created for these tasks, typically it would take content authors months to generate; use of the AR authoring tool vastly decreased this time. The authors perceived the content creation tool to be intuitive and easy to use, as learning how to create content in the tool took a matter of minutes with no prior guidance. This perceived usability extended to creating and editing content on both the web portal and within the HoloLens, providing the capability to leverage an intuitive system to train on C-5 tasks such as described in the case study.

Once content was created, it was showcased to 20 - 30 instructors within the Air Force. It took instructors a matter of minutes to get acclimated to the system, with little guidance, showing re-educating instructors to teach in this new medium is feasible within a short time frame with a well-designed application. The educators provided positive feedback, as they began considering additional areas within instruction where AR would be suited to enabling proficiency with maintainers. They saw this technology coexisting with current training modalities, as AR capabilities provide previously unavailable experiences for specific use cases. As an example use case, instructors envisioned using AR to upload technical data as an on demand, hands-free reference to maintainers while they train or carry out maintenance procedures.

Challenges seen by the content authors while creating AR content span two categories: hardware limitations and network connectivity. With the Microsoft HoloLens, the authors found the limited field of view (FoV) inhibited intuitive creation of procedures spanning large distances. Additionally, file storage limitations of the hardware made it difficult to upload a sufficient number of robust 3D models of airframe components. Beyond this, the limited network availability on location made uploading 3D models, creating content in the web portal, publishing it to the cloud, and downloading on to the HoloLens unpredictable. The content authors also found the specific AR instantiation is not suited to tasks which require other head mounted equipment, such as head or eye protection, as the HMD would interfere with safety. Therefore, there is opportunity to increase the FoV and storage capabilities, mediate network connectivity requirements, and create a HMD which can coexist with head mounted equipment.

CONCLUSION

The intent of this paper was to evaluate Augmented Reality within the Air Force training content creation environment, specifically to ease the process of capturing media for training, creating content for unavailable or inaccessible airframe components, and ultimately decreasing the time to author and disseminate quality training content. Through the case study initiation, it was found the AR authoring solution decreased time to author, provided visualization of inaccessible system components, and has the potential to decrease the complexity of media capture. However, limitations of the current hardware truncated the ability to add a wealth of 3D models and disparate spatial content, and the network environment provided challenges to quickly create content. Future work is necessary to fully run a pilot validation of the system in use by maintainers in an actual training environment, and to formally disseminate and evaluate training as delivered by Air Force instructors. The completion of the pilot program will enable these discoveries and be detailed in a future publication. The preliminary findings bode well for the future of AR within the Air Force maintainer content creation community, as creating hands-free, spatially contextualized content at the point of need adds crucial capabilities to the toolset of those on the front lines of increasing aircraft readiness and meeting the goal set by Secretary Mattis.

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