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Augmented Reality—Reality for the SAF

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ABSTRACT

For the Singapore Armed Forces (SAF), training is an essential function to ensure that it remains a strong and respected force in the region. It has often relied on technology in training to overcome manpower and land constraints. The Multi-Mission Range Complex (MMRC) is one such innovation conceptualised to provide training realism while overcoming these constraints. With its emphasis on technology, the SAF is at the forefront of simulation training. Augmented Reality (AR) is a technology that can benefit the training community by improving not only the competencies of already skilled personnel, but also that of trainees who may lack knowledge and experience. Popularised by Pokémon GO, it is one of the technologies that have been identified to have a significant impact in 2017. AR enhances what we see, hear, feel and smell by adding graphics, sounds, haptic feedback and smell to the natural world as it exists. With the technological barriers of AR decreasing, it has become an attractive technology that the military can consider in training and operations. This essay explores the possibilities of adopting AR for military training. It will first delve into AR and then look into the advantages offered in the area of training. It will next explore AR uses for the military before focusing on how we can make AR a key enabler for Army maintenance training by considering 'Man', 'Methods' and 'Material'.

Keywords: *Simulators; Training Realism; Augmentations; Continued Serviceability; Tactile Training*

INTRODUCTION

> *"It's going to be one of those cases where, when you put a piece of new technology we haven't had in the past, it's going to generate a lot of new ideas."*
>
> – COL Walt Yates,
>
> Marine Corps Systems Command (MCSC)[1]

For the SAF, training is an essential function to ensure that it remains a strong and respected force in the region.[2] It has often relied on technology in training to overcome manpower and land constraints. The Multi-Mission Range Complex (MMRC) is one such innovation conceptualised to provide training realism while overcoming these constraints. Our Army has continuously employed various simulators to form a Live -Virtual-Constructive (LVC) training system that has enabled the SAF to overcome space constraint and cut cost (see *Figure 1*).[3] With its emphasis on technology, the SAF is at the forefront of simulation training.[4]

AR is a technology that can benefit the training community by improving the skills of already skilled personnel as well as trainees who may lack knowledge and experience.[5] Popularised by Pokémon GO, it is one of the technologies that have been identified to have a significant impact in 2017.[6] AR enhances what we see, hear, feel and smell by adding graphics, sounds, haptic feedback and smell to the natural world.[7] In a January 2016 analyst note, Goldman Sachs predicted that the Virtual Reality (VR) market will outpace the TV market in annual revenue by 2025 (see *Figure 2*).[8] While earlier VR attempts in the early 1990s had flopped and set expectations way too high compared to what early 3D graphics could deliver, computers nowadays are powerful enough to make AR a reality.[9] In addition, the persistent use of smartphones has made AR peripherals comparatively cheap to manufacture. Thus, with the technological barriers of AR decreasing, it has become an attractive technology for the military. This essay explores the possibilities of adopting AR for military training. It will first delve into AR technology and then

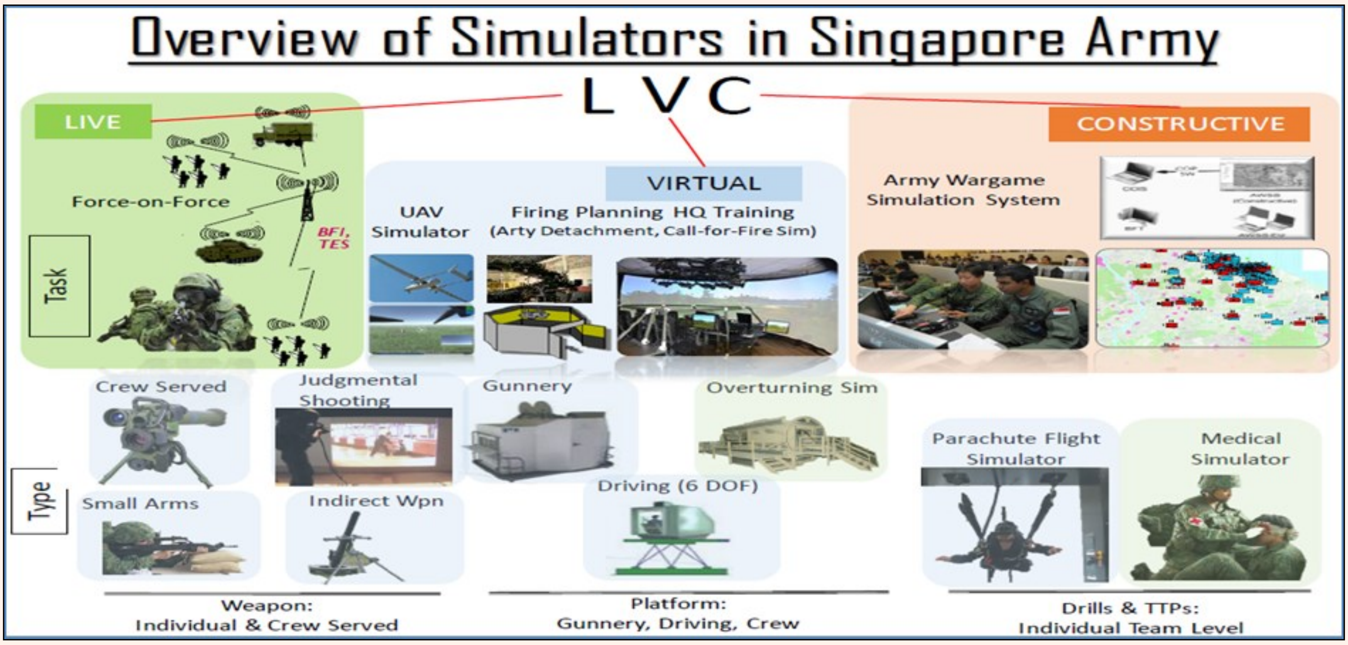

Figure 1: Overview of Simulators in the Singapore Army.[10]

look into the advantages offered in the area of training. It will next explore AR uses for the military before focusing on how we could make AR a key enabler for military maintenance training by considering 'People', 'Methods' and 'Material'.

AUGMENTED REALITY

AR is derived from VR in which users are completely immersed in an artificial world. In VR systems, users are not able to interact with objects in the real world. However, using AR technology, users can interact with mixed virtual and real worlds in a natural way.[11] Instead of a completely virtual world, AR users are still present in reality, but that reality is augmented with computer-generated information to enhance the user's experience of the world. AR users don goggles which offer real-time supplemental information (like statistics, Global Positioning System (GPS) data, sounds and graphics) about the world around the user.[12] Personal Computers (PCs), mobile phones, and tablets are active platforms for AR, but smartglasses, and their hands-free use, are driving the next wave for AR. AR is part of a broader landscape of emerging trends and approaches that bridge the physical and digital experiences. This landscape includes AR, Mixed Reality (MR), VR and Extended Reality (ER) (see *Table 1*).[13]

ENHANCING TRAINING WITH AUGMENTED REALITY

So how can AR actually enhance training? AR can potentially improve the speed and quality of training. A research study by Columbia University concluded that

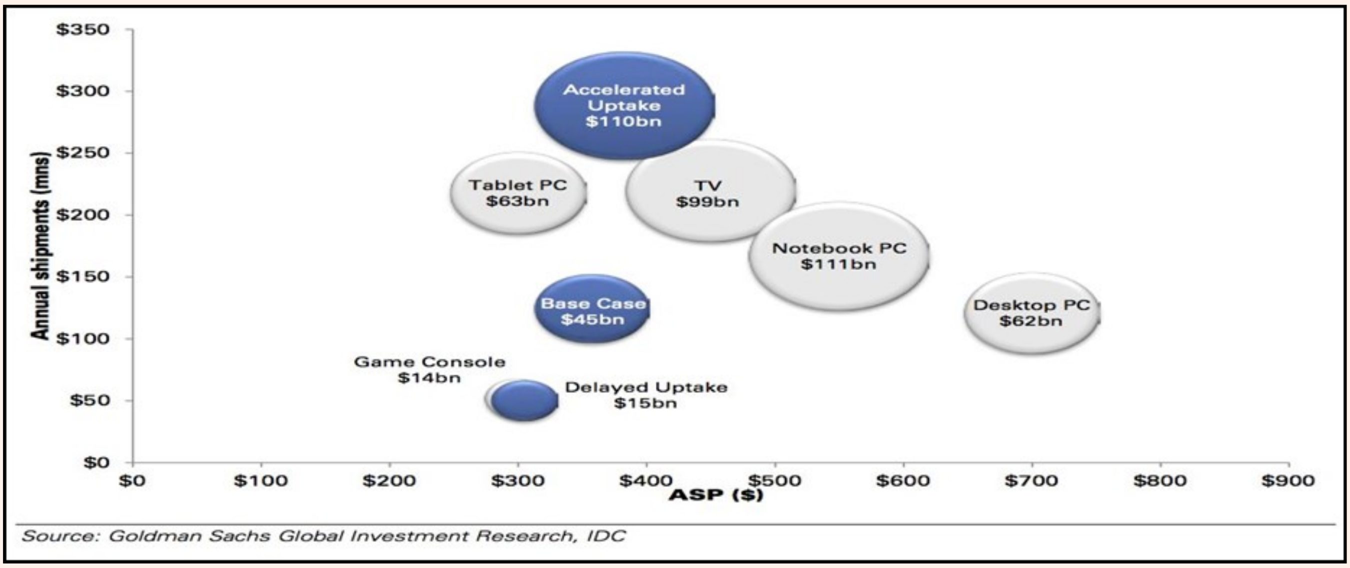

Figure 2: VR/AR HMD Market.[14]

Table 1: *The key characteristics of the various emerging technologies that blend the physical and digital worlds*

Feature	Augmented reality (AR)	Mixed reality (MR)	Virtual reality (VR)	Extended reality (ER)
Presence: The user is at the location of the experience	Yes	Yes	No	No
Real time: The user is interacting in real time with the environment	Yes	Yes	Yes and No	Yes
See-through capability	Yes	Yes	No	No
Movement: The user can physically move in the environment	Yes	Yes	No	No
Time horizon of enterprise adoption	2 to 4 years	3 to 7 years	2 to 4 years	Already in use

Table 1: Emerging technologies that blend the physical and digital worlds.[15]

users guided by AR complete the same task in 53% of the time and more accurately than previous forms of instruction.[16] Users also found AR-based training to be a more natural and intuitive way of learning. The delivery mechanism of AR-based trainings can be handhelds such as phones and tablets. It is easy to implement hands-free AR learning as solutions can also be developed on custom-built head-mounted devices. In terms of cost, Information Technology (IT) research and advisory company Gartner had predicted that 'by 2018, the total cost of ownership for business operations will be reduced by 30% through the use of smart machines and industrialised services.'[17]

A huge advantage of using AR for training is that trainees can interact with real world objects and simultaneously access the virtual information for guidance. Thus, trainees are able to perform an actual task while accessing additional training material, and that way learning is facilitated. With reference to Fitts and Posners' model of skill acquisition (see *Figure 3*) this denotes that AR enables the trainee to learn the basics of the task by observing the augmented instructions and trying to perform the instructed sub-task, to develop behaviour and movement patterns when performing the sub-tasks, and to redefine those motor patterns in repeated performances of the task (i.e. during training).[18] Given that AR may one day become an operational tool, using it for training follows the goal for the military to 'train as you fight'. AR allows for more realistic interaction among multiple trainees, since they see each other through their natural vision, as opposed to an avatar representing a particular person. Furthermore, instead of using actual personnel to take the roles of potential adversaries or having trainees learn against empty space, a warfighter could train against customised avatars.[19]

AR also offers practical advantages over the use of virtual environments. Embedding virtual training applications in existing live-action training facilities can reduce modelling requirements and other infrastructure costs. Modelling an accurate virtual environment and the unknown fidelity requirements of such a model makes it expensive to create immersive virtual environments. Furthermore, this AR facility would maintain the natural haptic cues one gets from walls and other real objects. Virtual environments often require unnatural navigation methods such as with a joystick while AR allows the user to walk normally. There is added realism as soldiers can run or crawl and feel tired, but still react to generated avatars.[20] As explained by Young et al., 'One advantage of AR … is that it can create a training environment without major modifications to the operating interface, or without having to create expensive simulation facilities.'[21]

USES OF AUGMENTED REALITY IN THE MILITARY

AR research is of major interest in several domains and the potential applications of AR systems include medical visualisation, manufacturing and repair,

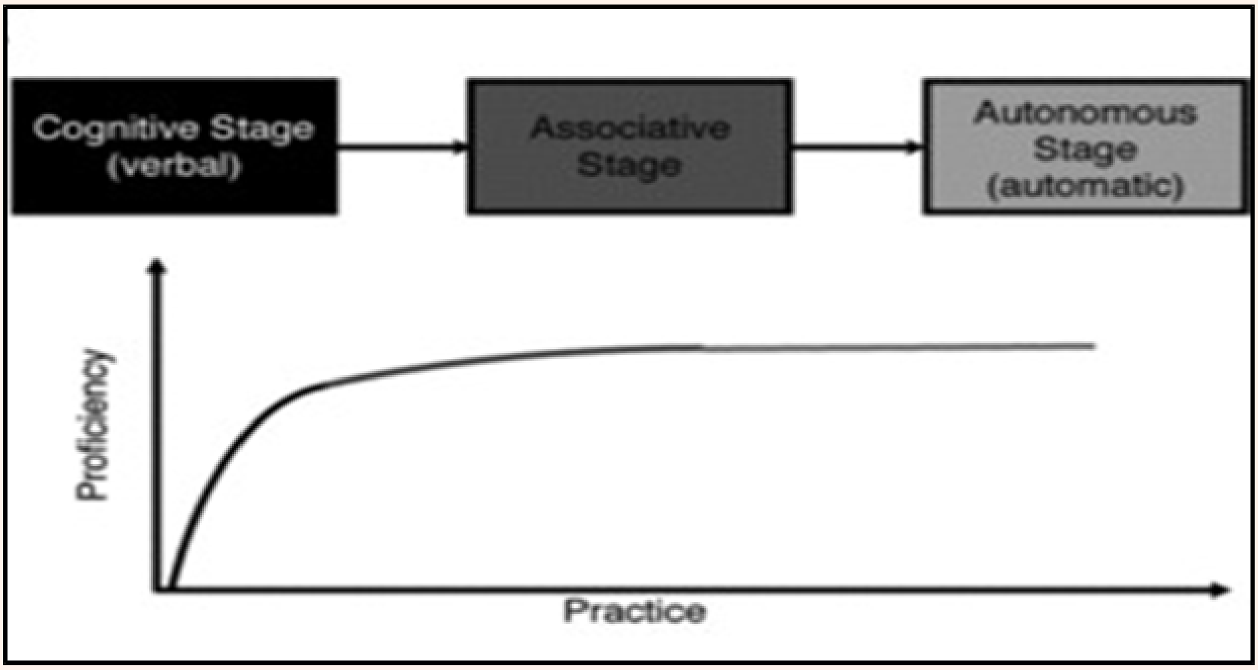

Figure 3: Fitts and Posners' Model of Skill Acquisition.[22]

robot path planning, entertainment and military aircraft.[23] Two examples of how AR is being pursued militarily are as follows:

Improved Situational Awareness

United States (US) Soldiers are set to get a Google Glass—like AR system designed for the battlefield. Called Augmented Reality, Command, Control, Communicate, Co-ordinate (ARC4), it allows commanders to send maps and other information directly to the soldier's field of vison. The gadget attaches to a military helmet, and can even be integrated with weapons control system. The firm behind it, Applied Research Associates (ARA), says the system was developed as part of a six-year project with substantial investment from the US Military's Defense Advanced Research Projects Agency (DARPA) unit. Rather than looking down at a two-dimensional (2D) map or chest-worn computer, the soldier sees virtual icons overlaid on their real-world view. 'You are able to perform your mission with high awareness of their surroundings, with enhanced safety, speed, and in close co-ordination with team members.' ARA claims.[24] 'This state-of-the-art technology provides heads-up situational awareness for the military—allowing soldiers to perform their jobs with enhanced safety, speed, and mission effectiveness,' the firm said.[25] However, it can also be used in logistics and even by the public. The ARC4 software renders AR information on any wearable see-through display--including Night-Vision Devices (NVD), making it easy to integrate with existing products.[26]

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Improved Training Realism

AR is emerging as a game changer for Marine Corps training as they seek to develop simulated training solutions for the Marines. Currently, VR falls short while live-fire training is expensive. The biggest advance is a project it calls Augmented Immersive Team Training (AITT).[27] The system is designed to get Marines out of physically limited trainers and simulator facilities by projecting realistic training scenarios into their field of vision, wherever they are. The AITT system addresses gaps faced with VR by combining realistic virtual elements like fixed and rotary-wing aircraft, and targets like tanks and people, with a real-world scene that Marines view through head-worn tactical binoculars. With the help of technology that automatically adjusts brightness and contrast, the result is a real-feeling battlespace with very little to distinguish simulated effects from authentic ones. COL Walt Yates who is the programme manager for the MCSC's training systems said that he foresaw the Marine Corps fielding the system to 'members of the squad and company fire support team that are eyeballs and sensors on the battlefield,' including forward observers, forward controllers, joint terminal attack controllers and scout observers.[28] But eventually, he said, the technology can be adapted for those training with Light Armoured Vehicles (LAV), Amphibious Assault Vehicles (AAV) and tanks, or even Unmanned Aerial Systems (UAS) training.[29]

AR research is of major interest in several domains and the potential applications of AR systems include medical visualisation, manufacturing and repair, robot path planning, entertainment and military aircraft.

TAILORING AUGMENTED REALITY FOR MAINTENANCE AND TRAINING

Currently, maintenance is probably the most active research field in AR for industry and there are a large number of studies covering the benefits of using AR for maintenance. Some benefits include faster maintenance interventions with fewer errors and more efficient and safer procedures. Remote guidance and supervision from an expert is also possible by means of AR. The military has also started to actively research the use of AR technology not only for training and maintenance but also for simulation of actual military operations.[30] The use of AR is advantageous for training involving complex work such as that for technicians. Some of the tasks performed by technicians involve a staggering number of steps and can lead to mishaps due to human errors. AR makes it more practical and speedier to train technicians to perform complex tasks and ensure that they don't forget something along the way.[31] By accessing augmentations while performing task training, trainees become partially skilled. Hence, their skill levels start to develop when they perform the real task for the first time. This would see benefits in our Army, especially so when our technicians have to train on many different Army systems. Coupled with the fact that many of the technicians are conscripted, it is important that they get the maximum time allotted for training and execute maintenance tasks during such training. The following paragraphs discuss some ways in which AR can be used for Army maintenance.

Remote Maintenance Guidance

Equipment faults can arise from various causes, such as random failures, operating under extreme conditions, or from combat damage. Although technicians may be trained to perform a requisite level of repair, not all technicians possess the necessary experience or specialised skills for more complex repairs. When such cases arise, technicians in the field may require help from maintenance bases or engineers in Headquarters (HQ) to guide them in performing advanced repairs. AR allows a maintenance expert's knowledge to be spread across the battlefield, reaching to the frontlines where vehicles are damaged or broken down. Through high bandwidth networks, Subject Matter Experts (SME) with specialised knowledge can provide diagnostic and repair assistance over the air with the help of AR.[32] With a live feed from the field, the SME can create labels, arrows and instructions on his user interface that will appear on the technicians' AR devices and guide them through the required steps to troubleshoot and repair the equipment. Instead of being physically at the frontline, where he can only tend to only one unserviceable equipment at a time, the SME can now be virtually transported to many locations to augment a few technicians simultaneously.

Maintenance Information

Corrective action is required when components malfunction or are damaged through abnormal use, thus affecting the functionality of the main equipment. As failures are random and varied, troubleshooting and diagnostics are required and complex repair processes may be necessary, forming the bulk of the technician's workload and the equipment's down time. Often, technicians have to refer to repair manuals or work instructions, but still require their hands to be free to work on the equipment. Boeing, one of the world's largest aircraft manufacturers, uses wearable AR technology to keep their technicians' hands free to carry out the assembly of aircraft wire harnesses, while

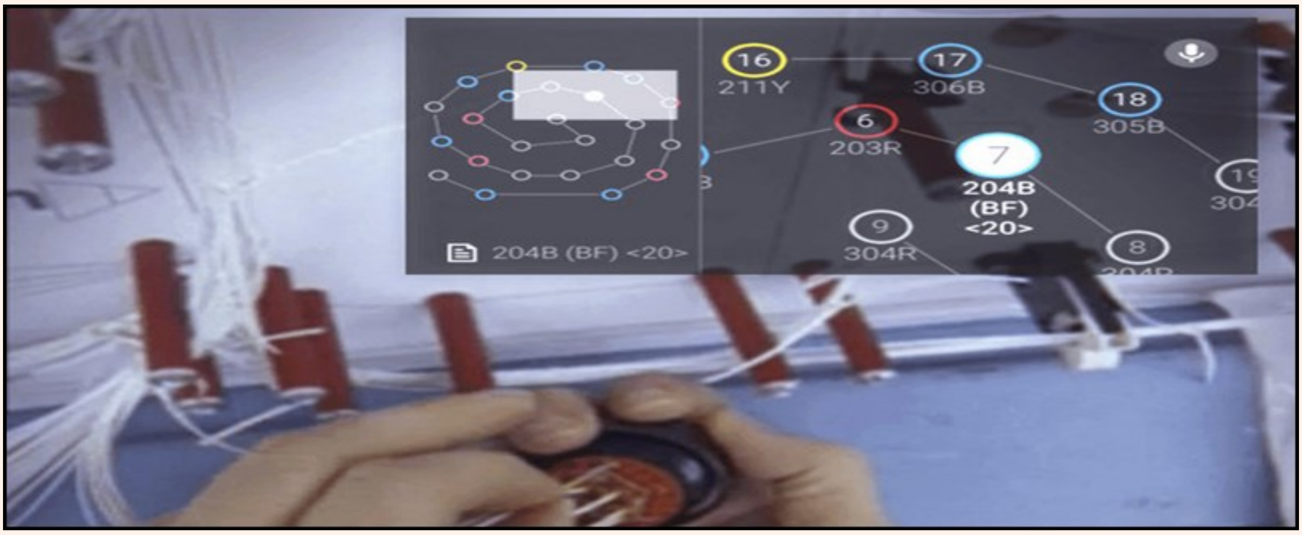

Figure 4: A Boeing technician working on a wire harness using Google Glass and the Skylight App.[33]

following the detailed work instructions displayed on their individual devices (see *Figure 4*).[34] The company achieved notable reduction in mistakes made on the highly complex and intricate wire harnesses, thanks to the ease of access to manuals on their AR devices.

AR can help to shorten the time required to repair and reduce errors by providing promptly available details and contextual knowledge of the equipment.[35] The US Air Force (USAF), in collaboration with Columbia University, developed Project Augmented Reality for Maintenance and Repair (ARMAR) to display diagnostic information and procedural animations derived from repair manuals and overlaid on the screen of the AR device, which can be easily followed by the technician carrying out the repair. With advanced computer vision technology to detect a three-dimensional (3D) object's features, AR devices can identify the actual components to be replaced and their mounting points are highlighted to the user for action (e.g. removing the screws).[36] Once the component is removed, the AR device can automatically display the next action required. This way, AR helps to ensure that maintenance procedures are carried out properly and minimise wastage of time due to missteps. This is especially useful in enabling Full-time National Servicemen (NSF) technicians, who have limited time in active service and may lack the technical experience for more complex tasks, to work independently with minimal supervision. A potential AR-enabled maintenance workflow is shown in *Figure 5*.[37]

Maintenance Checklists

Preventive maintenance is a pre-determined regime that is carried out on the equipment at regular intervals to ensure its continued serviceability and prolong its operating lifespan. Using AR, a checklist of tasks can be overlaid on the actual locations or components of the equipment that requires action. In a

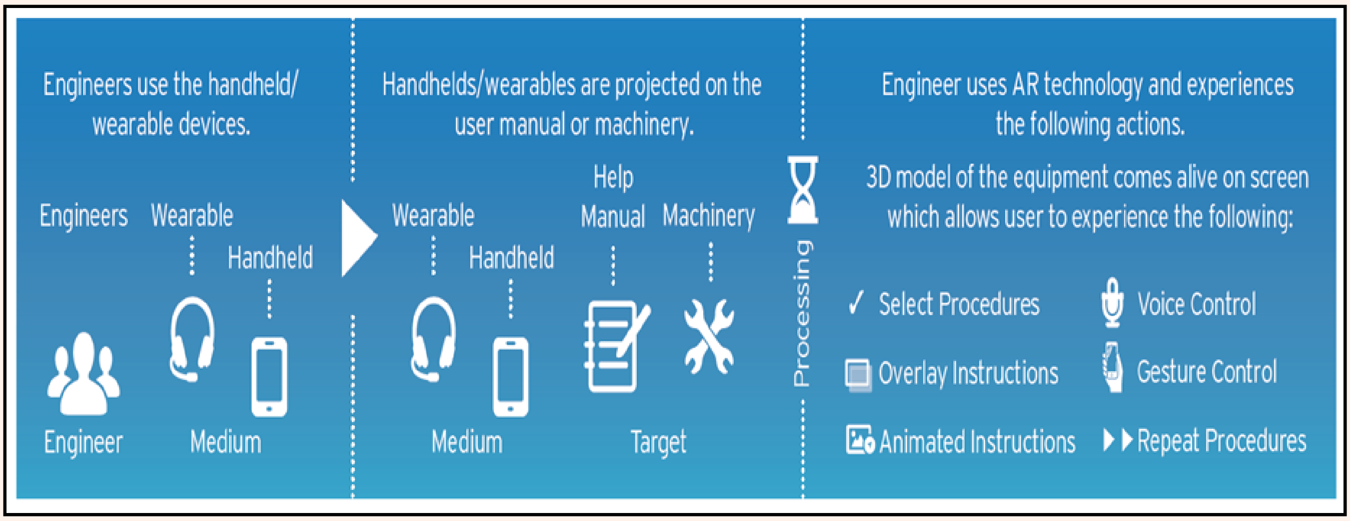

Figure 5: AR-enabled Maintenance Workflow (Left: Before, Right: After).[38]

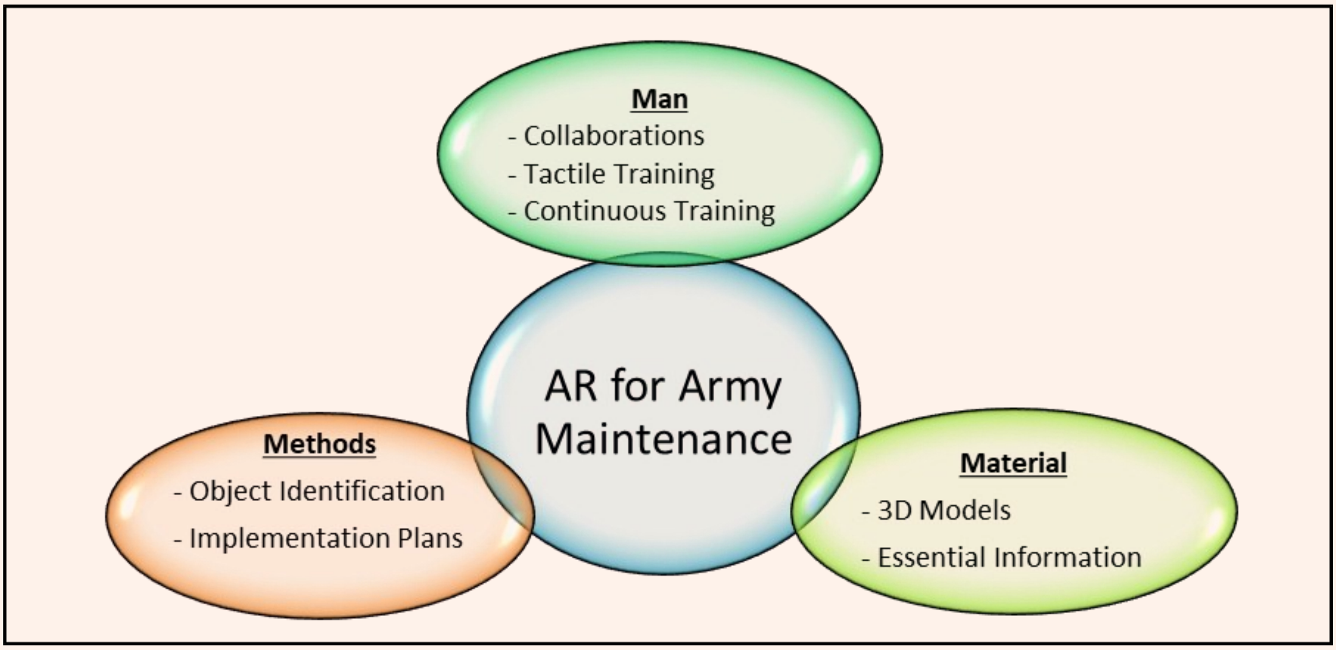

Figure 6: Considerations for Augmented Reality.

preventive maintenance scenario for a vehicle, the overlays may include information such as highlighting components that require replacement, areas to inspect for signs of damage or wear and tear, or the location, volume and grade of lubricant to be filled. As the technician completes each task, the associated marker disappears. This way, only outstanding tasks remain highlighted and the AR software can alert the technician to complete them before closing the job. By displaying the necessary information on the screen, errors such as filling with the wrong grade of lubricant or missing visual inspection areas can be avoided.

MAKING IT WORK

So how do we make AR work for us? The following are considerations in the areas of 'Man', 'Methods' and 'Material' that can enable this (see *Figure 6*).

Collaborations with Educational Institutes

Currently, AR is keenly pursued by commercial companies as well as educational institutes. Thus, AR efforts should ride on what is already available and collaborations can help to speed up the adoption journey. For example, since 2013, the Institute of Technical Education (ITE) has been using a range of scalable VR and AR solutions that enables the school to effectively deploy learning scenarios across a wide range of VR and AR systems—from large immersive rooms to mobile devices.[39] Such solutions should be studied for potential collaboration and use.

Ensure Adequate Tactile Training

Rather than listening to a lecture or watching a demonstration with limited interaction, AR training allows trainees to learn by performing an actual task. Through a repetition of actions, trainees can develop their skills progressively. Thus, it is important to ensure that trainees have adequate tactile training. An example is the P-8 maintenance training facility in Jacksonville, Florida where prospective maintenance crew members undertake vigorous training methods from the publication to physical interaction. A spokesman says, "The reason we mix with the hardware virtual trainers is because the book says 'pull this part out' but it's not that easy, so we give the technicians that experience to remove the parts and install and to give them the opportunity to use tools."[40]

Continuous Training

Currently, Nanyang Polytechnic's (NYP) School of Interactive & Digital Media (SIDM) has a Diploma in Interaction Design which covers AR.[41] As the effectiveness of AR technology lies in its ability to provide useful and contextual knowledge, it is important to keep the databases of 3D models, overlays, and procedural instructions up to date with relevant knowledge or improve the user experience based on feedback received. As the adoption of AR technology becomes more widespread, senior technicians and engineers within the SAF should attend courses to understand the principles of AR, effectively design AR overlays, and guide the software development effort to suit the needs of our organisation.

Identifying Objects to Overlay Information

Object identification is an important area of development to allow the AR software to collect information about the physical world through various mediums. Current technology is largely marker-based, which require special markers such as geolocation tags, Quick Response (QR) codes or Near-Field Communication (NFC) tags to indicate and help the AR software identify the objects of interest. These require special preparation on the objects of interest, such as tagging specific components with QR labels or NFC tags. Advances in image recognition, mobile computing power and improvements in camera technology may shift AR towards a marker-less future, where objects can be identified via computer vision. This allows the AR concept to be fully scalable across the entire fleet of equipment and eliminate tagging problems.

IMPLEMENTATION PLAN

We need to remember that AR is just a tool, and not use technology for the sake of it. Therefore, there needs to be a complete implementation plan in the adoption of AR with clear objectives and timelines. It is necessary to include lesson plans, accompanying theory lessons, assessments and to ensure that trainers are adequately trained in AR. An example of how AR will fit into maintenance training is shown through an example of an 'Engine Maintenance Module'. Trainees will each be issued with a personal tablet installed with the SAF Learning Management System (LMS) and AR software and carry out self-directed learning (SDL) on a training vehicle. Four topics in a typical module are shown:

Introduction to Engine System

In this topic, trainees will learn about the basic operations of the engine system and the functional relationship with other vehicular systems. With the engine assembly in view, the AR software will identify the components and sub-systems via markers. Each sub-system, such as the engine block, starter motor, and timing belt, will have associated icons displayed where trainees can select and explore videos and animations showing their functions. Animations depicting the flow of mechanical power from the engine to the transmission, drivetrain, and wheels will help trainees visualise and understand the basic operating principles of the vehicle.

Inspection Checklist

Technicians use inspection checklists to conduct serviceability checks on a vehicle. Through AR software, each of the tasks on the checklist will be displayed on the AR device with an accompanying annotation to describe the inspection required, such as engine fluid level checks (see *Figure 7*).[42] Subjective evaluations, such as checking for leaks along hoses and connectors can be difficult for inexperienced trainees. In such cases,

Figure 7: AR software highlighting the locations for engine fluid level checks.[43]

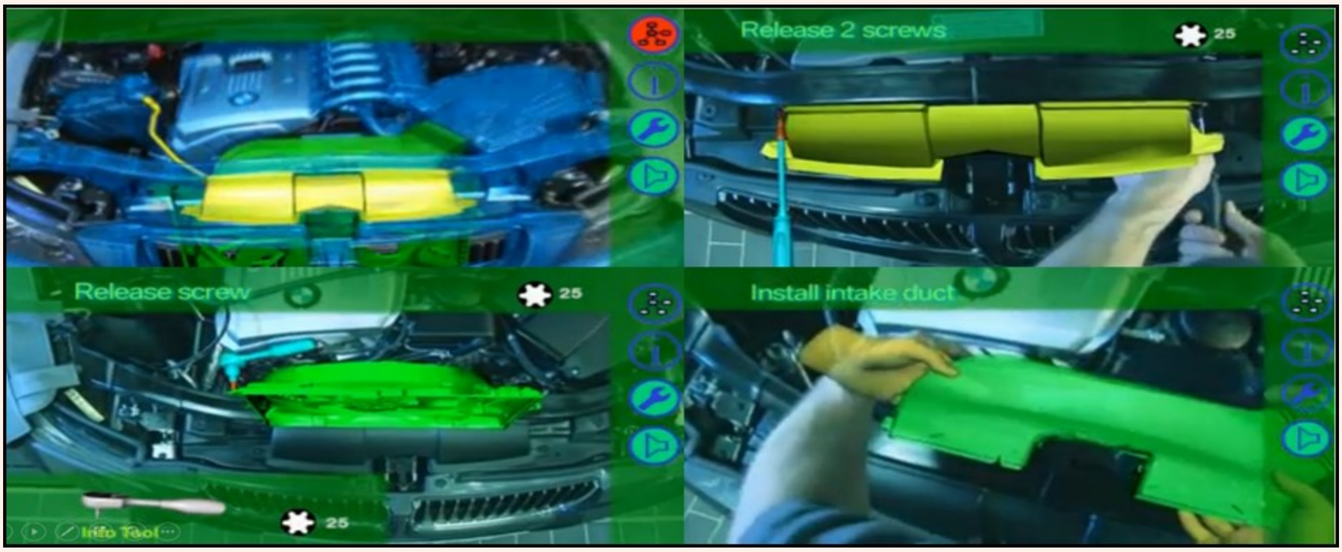

Figure 8: AR software highlighting the steps to remove/install components.[44]

overlays can be displayed to show the differences between negligible and normal dampness versus a leakage which requires action.

Removal of Engine Components

AR software will display the procedural animations relating to the maintenance tasks required for an engine assembly. This may include adjustment of valve clearance, replacement of oil filter, or removal and installation of engine block. AR software can highlight the various connections and mounting points with actions such as remove, dismantle or disconnect, and virtually demonstrate the steps required via animations (see *Figure 8*).[45] Practical sessions can be carried out using the AR software, and can be monitored by the instructor via the LMS. Trainees can pick up a screwdriver to remove screws, manipulate objects within the real space and the AR software can monitor the completion of tasks.

Troubleshooting Engine Faults

Trainees will undergo an AR-guided troubleshooting task and learn to diagnose and rectify common faults. For example, to help trainees learn about the diagnosis and rectification of air lock, animations and 3D overlays can be displayed to show the various causes, such as dirty filter, fuel tank and water separator choke, and how it affects engine functions. The locations and components to check, as well as a step-by-step guide to the troubleshooting process, can be displayed as an overlay when viewing an actual engine through the AR device.[46]

3D MODELS OF COMPONENTS

It may become necessary for equipment manufacturers in future acquisition projects to provide 3D drawings and models of their equipment and related components. The AR software will draw upon a database of such models for object identification and as overlays to aid the user in visualising the component structure. The models are also necessary for creating procedural animations, such as inspection, removal or installation of components. Ancillary information such as mounting points, fasteners and tools required must also be included to provide comprehensive and timely details for technicians to carry out the task.

TRANSLATING INFORMATION FROM PAPER INTO AR SPACE

Through AR, traditional formats of displaying information in documents such as maintenance manuals will be transformed from complex data sets and broken down into smaller segments suitable for displaying on a display of limited screen size. Instead of displaying information on the 2D space of paper, it will now be transformed into a manipulable 3D space with AR. The concept of displaying contextual information in AR will draw intricate links between different data sets. For example, when viewing a vehicular sub-system such as the engine assembly, it may draw upon information from the maintenance manual to display work instructions, external connections to electronic control units from wiring diagrams, or utilisation characteristics from on-board monitoring systems. As trainees move closer to examine a particular component, such as the starter motor, the AR software may display part number and dimensions from the parts catalogue, and stock availability information from Warehouse Management Systems (WMS).

Various developments in Man-Machine Interface (MMI) can potentially turn AR into a seamless and convenient technological aid to human activities.

Ergonomics of Devices

The ergonomics of AR devices will play a huge role in the eventual adoption of technology. Initial prototypes were bulky and limited by computational and electrical power constraints of the platform.[47] This poses practical constraints, especially in the field of maintenance, where the technician hands must be kept free to carry out his work. With modern advances in mobile computing and increased power density in batteries, emerging wearable technologies such as head -mounted displays, smart glasses and smart contact lenses will drive the adoption of AR technology in maintenance and production industries.[48] Various developments in Man-Machine Interface (MMI) can potentially turn AR into a seamless and convenient technological aid to human activities. Apple is actively developing MMIs for their products, such as speech recognition technology Siri, which allows users to communicate with their iDevice via voice instead of touch, and filed a recent patent for 3D depth sequencing using one or more cameras, which can be used to track hand gestures.[49]

DISPLAYING ESSENTIAL INFORMATION

Finally, it is possible to overwhelm users by displaying large amounts of information. It is therefore crucial, to carefully analyse the information before presenting it to the users in order to ensure that the amount of information conveyed is sufficient for their intended purpose. This prevents the distraction of the user and maximises the outcome of the application's use.[50] Contextualising the information displayed is necessary to prevent overcrowding the screen and overloading the operator with too much information. This can be achieved by sensing the size of the object in view and the quantity of markers in view.[51]

CONCLUSION

With the advent of AR and its increased uses for enhancing training, it is indeed a technology that can benefit the SAF's training community. Now that technological barriers of AR are decreasing, it is timely that we study how we can use the technology to enable us to enhance training while overcoming our manpower and land constraints. Thus, with the considerations that we have put forth, we think that it is an ideal technology to be implemented for Army maintenance training.

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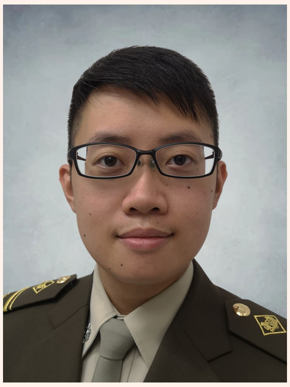

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