AUGGMED: developing multiplayer serious games technology to enhance first responder training

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AUGGMED: DEVELOPING MULTIPLAYER SERIOUS GAMES TECHNOLOGY TO ENHANCE FIRST RESPONDER TRAINING

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ABSTRACT

Many serious games are designed for single player access only. However, the benefits of the immersive nature of serious games and virtual reality may be enhanced when teams who usually train together can also do so within a virtual environment. The purpose of this article is to outline the architecture of the AUGGMED serious game and discuss the technical challenges faced when creating a multiplayer counter terrorism training serious game utilising virtual reality, touch screen interfaces and a realistic crowd simulation. AUGGMED is designed using an agile modular approach utilising user centred design principles, with each technical developer owning a set of tools which are continuously integrated, piloted, and improved throughout the development cycle. Constant piloting with first responders enables iterative improvements, which meet end user training requirements. Building a multiplayer training game specialised in providing realistic simulation of real situations, and enabling users to interface with the simulation through virtual reality identifies a large set of technical challenges. The article identifies a number of the challenges faced while developing AUGGMED and the solutions used to overcome them, including barriers and logistical/technical difficulties to integrating multiple existing (Exodus crowd simulation) and new (virtual reality) technologies into a single serious game for training first responders.

INTRODUCTION

With the ever-changing security threat landscape, the rapid advance of technology, and the need for more advanced and realistic forms of training, modern organisations are looking for novel, state of the art solutions to prepare for terrorist and organised crime threats. Alongside traditional physical dangers posed by terrorists and extremists, a new threat has emerged in recent years: cyber-attacks. As the line between on - and off-line crime blurs, targeted attacks such as denial of service and ransomware, which can be designed to extort money and information (Veerasamy, Grobler and Von Solms, 2007; Broadhurst et al., 2014), can also be used to cripple critical infrastructure (Miller and Rowe, 2012). Cyber-attacks delivered in conjunction with traditional physical attacks aim to maximise impact and hamper response efforts (Leyden, 2008) Thus any training platform targeting the response to such threats should take into account the cyber-element from a high-level training point-of-view.

Traditionally, training for mitigating against these threats may include a combination of desk-based, table-top and live exercise scenarios requiring the investment of significant resources (financial and human), time and effort (Allen, 1992) as well as lacking replicability and standardisation. These traditional forms of training also often require trainees to be co-located increasing the financial and logistical costs. Finding methods of training which can reduce the resource requirements, geographic limitations, and investment for both small and large scale training scenarios would enable trainees to develop skills and experience, which could be used in a far greater number of situations. The AUGGMED project aims to alleviate these considerations through the development of a serious game which encompasses elements of augmented and virtual reality, but can also be played on standard desktop and mobile devices as required. Furthermore, AUGGMED aims to provide a solution which incorporates multiplayer access enabling remote teams to train together even when they are geographically spread. In order to develop such a solution, additional architectural considerations must be factored in to the design which can keep track of the movements and actions of each player as well as how this affects others experiencing the simulation in the same exercise.

A serious game is defined as 'any piece of software that merges a non-entertaining purpose (serious) with a video game structure (game)' (Djaouti, Alvarez and Jessel, 2011). Serious games have been found to have impacts on the player which can be affective and motivational, facilitate behaviour change, enhance knowledge acquisition and understanding, improve motor skills, have perceptual and cognitive benefits, physiological benefits, and improves social and other soft skills (Connolly et al., 2012). Concerning AUGGMED, serious games have already been shown to improve triage accuracy (Knight et al, 2010) [an intended pilot scenario] whilst the military already have a long history in the use of simulation and serious games (Smith, 2010) which may provide cross-overs into aspects of counterterrorism training.

This paper will introduce the goals and aims of the AUGGMED project, the underlying envisioned architecture and implementation methodology, the challenges faced during the initial phases of development, the solutions to those challenges and the remaining considerations for forthcoming piloting scenarios.

1. THE VISION FOR AUGGMED

The AUGGMED (Multi-agent counter terrorist training in mixed reality environments with an automated serious game scenario generator) project is designed to enable law enforcement agencies (LEAs), paramedics, firefighters and other first responders to train simultaneously in a single virtual environment. The environment represents real world locations populated with realistic, civilian agents who react and respond to events, other trainees and threats. Using modern games and server technology the AUGGMED platform enables users to train from any physical location, allowing multiple organisations to collaborate on training without the requirement of co-locating the trainees.

The project has completed one of three pilots which will be carried out throughout development in twelve month intervals. These have already proven to give both trainers and trainees opportunities and capabilities which would not be possible in real world exercises.

The AUGGMED platform, as shown in Figure 1, provides a single system in which both trainers and trainees can operate in the same environment. The trainees access the platform through a range of devices (mobile, tablet, desktop PC, laptop, virtual reality headsets and haptic vests) while the trainers controlling the overall definition and progression of the scenario also have access to live analytics for feedback and evaluation. The AUGGMED project itself centres on three main scenarios, an airport terror attack and fire scenario, an underground station hot bag and explosion scenario and a combined cyber/terror attack on a busy port. These are realised through technological components including the Unity games engine, communications layer and simulation layer.

Upon completion, utilising the platform would enable organisations to significantly reduce the resource requirements of training for large scale events, such as terrorist attacks and organised crime threats (Allen, 1997). Alongside this it would enable trainers to tailor training specifically to the trainee's requirements using a set of trainer tools. These enable the trainer to customise variables such as time, location, population, demographics, trainee capabilities and threat objectives.

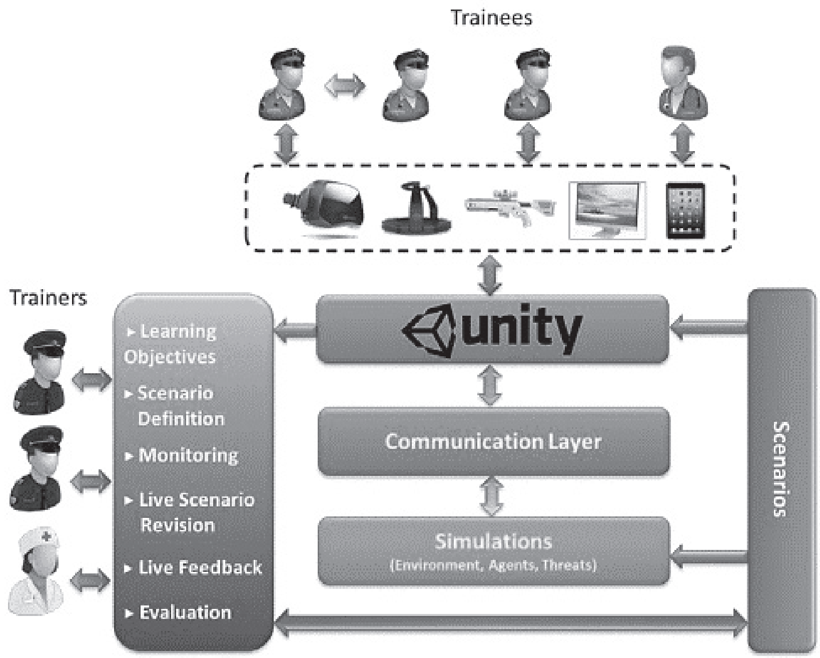

FIGURE 1: AUGGMED PLATFORM

The system incorporates realistic fire and explosion simulations which enable trainees to experience complex life threatening situations, which would not be possible in real world training environment using Exodus. These simulations assess and calculate the impact of these events on both civilians and trainees, realistically replicating the outcomes of smoke inhalation and injuries through negative effects on the trainee avatars.

The AUGGMED platform can be utilised on touch screen devices, standard PC's and in virtual reality, allowing end users to train using the most appropriate input method for their requirement. Each input method is designed to enable trainees to be able to meet their training requirements depending on the context of the scenario they are using.

Using virtual reality enables trainees to build upon both their technical and decision making skills as well as developing their emotional resilience to stressful and often psychologically difficult events (Wiederhold and Wiederhold, 2008). The capability to develop the emotional resilience of first responders is a unique aspect to virtual reality training when compared to standard training methods. Alongside this the system will feature a full immersion mode utilising a virtual reality treadmill, gun controller and haptic feedback vest capable of simulating heat, gunshots and touch. These systems will combine to provide a fully immersive training experience for trainees, further enhancing their training experience and better enabling them to reach their learning objectives.

1.1 AUGGMED ARCHITECTURE OVERVIEW

The AUGGMED platform is comprised of a set of core systems, the platform itself utilises the Unity® Games Engine to handle the base game algorithms responsible for rendering, physics simulation, sound, and networking. The trainer tools are built on top of this, which will enable trainers and trainees to customise, observe, record, analyse and assess any training scenario and trainees on an individual basis. Civilian intelligence, fire and explosive simulations are processed and handled by the Exodus platform, a civilian population simulation program designed for large scale evacuation models.

The architecture of AUGGMED consists of a number of individual components, each responsible for a specific aspect of the platform. Figure 2 displays the individual components contained within the AUGGMED system that interact and integrate with one another.

This section introduces each of the components within the AUGGMED system, discusses the motivations for their inclusion while presenting their roles and functionalities in the context of what the AUGGMED platform is aiming to achieve. This section lays the groundwork for the review of the technical challenges faced when developing the system shown in Sections 2 and 3.

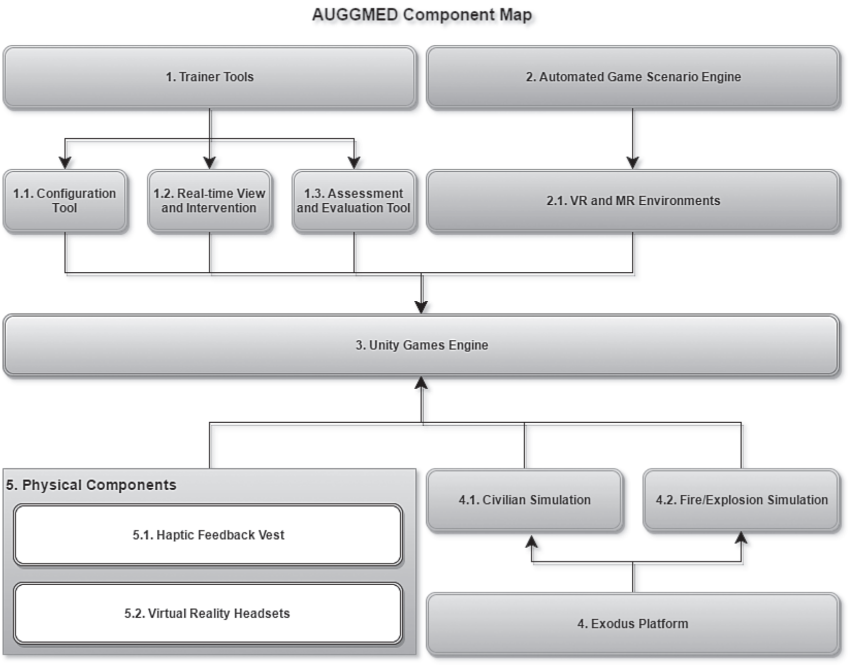

FIGURE 2: COMPONENT VIEW OF AUGGMED

1.2 THE TRAINER TOOLS

To be able to control the simulation and provide benefits to the trainer as well as the trainees, AUGGMED features a 'trainer tools' interface and associated functionalities which give each trainer fine-grained control over how the scenario evolves. The trainer tools consist of three individual components, each of which is designed to enable trainers to maximise their capabilities whilst using the platform. The trainer tools have been designed based on Microsoft's design layout for Windows 10 devices . This ensures interaction with the trainer tools is consistent with the operating system and retains a specific theme on both desktop personal computers and touch screen devices (such as the Microsoft Surface). The trainer tools themselves are then divided into three further components: the configuration tool, real-time view and intervention interface, and the assessment and evaluation tool.

1.2.1 Configuration Tool

The configuration tool enables trainers to generate unique and customised training scenarios by changing setup variables such as time, location, population, potential cyber-attacks, trainee roles and capabilities, and the severity of the threat they face. This is achieved by creating a custom scenario which can be saved and re-used at a later date. Each scenario can contain a set of roles, each role uses an inventory system to determine the capabilities of the trainees who are performing that role. The interface for setting up such a scenario is displayed in Figure 3, while the character selection interface is shown in Figure 4.

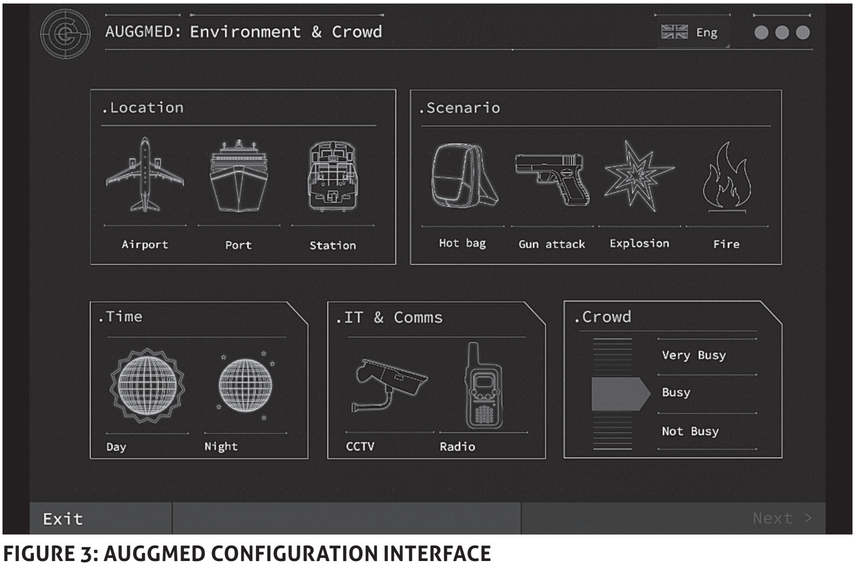

FIGURE 3: AUGGMED CONFIGURATION INTERFACE

Trainers can build a list of template inventories allowing them to quickly change the items available depending on the requirements of the training scenario. An individual trainee can carry up to five items depending on the type of objects they require. A role has one primary item slot, used for large items such as rifles, extinguishers or fire axes; one secondary slot for small items such as pistols, triage tags or a torch; and three utility slots for carrying utility items such as explosive devices, bomb disposal kits, or gas masks.

FIGURE 4: AUGGMED CHARACTER CONFIGURATION

1.2.2 Real-time View and Intervention

The real-time view and intervention tool enables trainers to observe trainees from a number of perspectives and intervene when necessary. Trainers can observe the entire simulation from a bird's eye perspective and watch an individual or group of trainees, simultaneously through the zoom controls. They can also set the camera into a "follow" state which automatically tracks and focuses in on the movements of the selected trainee.

Trainers can also switch to "player perspective" allowing them to experience exactly what an individual trainee sees and hears during the exercise. When a scenario begins, a trainer uses this tool to deploy individual trainees and threats to any selected location in the environment. Similarly, if a trainee is shot and killed they can be re-deployed by a trainer, if it is required, to achieve the learning objectives of the scenario. Trainers also select if a fire will be included in the scenario and where in the environment it will begin. At anytime during a simulation the trainer can initiate a pre-selected cyber-attack, these include loss of CCTV and/or radio communication interference.

In addition to trainers, observers are also able to use some of the functionality of this tool to monitor the progress of trainees, however they do not have access to the intervention aspects such as deployment, fire initialisation or cyber threat controls.

1.2.3 Assessment and Evaluation Tool

The assessment and evaluation tool collects and analyses statistical data about the performance of individuals and groups of trainees. It then collates and outputs this data as a report for trainers and in a visual format immediately after a scenario has concluded. It records metadata for the entire scenario, allowing trainers to replay the scenario and re-observe trainee behaviour, actions and decisions as if it were a live scenario.

The data collected includes statistical information regarding player actions such as bullets shot, enemies hit, civilians hit, and visual data such as movement heat maps. Trainers will be able to use this data to support them during debriefing sessions and as inputs into future training scenarios. Trainees' will have access to a subset of the data relating to their own personal performance at the conclusion of an exercise.

Due to the multiplayer element of AUGGMED, an interesting use case for the statistical tracking data is the possibility to compare team and individual performances. Furthermore, it is not always clear what might represent a successful individual performance as many members of SWAT or counterterrorism teams may play more of a tactical role, which may not translate well into 'good statistics'.

1.3 AUTOMATED GAME SCENARIO ENGINE

The Automated Game Scenario Engine manages the location, environmental factors and interact-able objects. This engine ensures that the scenarios developed are non-deterministic and that even if a trainee re-enters the game at the same location with the same general theme (e.g., terrorist attack) the area in which the attack begins, the reactions of the civilians, and the extent to which smoke or exit routes can cause problems can all be modified. Monitoring of how the scenario is initialised can then be combined with player behaviour to identify where training efforts may need to be focused.

1.3.1 VR and MR Environments

The Virtual Reality (VR) and Mixed Reality (MR) environments within the AUGGMED platform dictate the virtual geometry, environmental behaviour and available fire locations. Each location has a number of preselected locations for a fire to begin as well as varying the size and types of fire available for trainers to use. Each location is unique and provides opportunities for first responders to train in an environment which represents a real world location.

1.3.2 AUGGMED Scenarios

A part of the automated game scenario engine is the individual scenarios which are simulated within the AUGGMED platform. There are multiple scenarios per location including terror attack, hot bag, explosion and fire. Each type of scenario changes the capabilities of the trainees and allows for additional elements to be set up before a scenario begins, for instance choosing the location of a fire or placing suspicious items into the scenario.

1.4 UNITY GAMES ENGINE

Unity® is a multi-platform games engine enabling developers to rapidly develop and deploy software on a multitude of platforms simultaneously. Games engines are software frameworks which facilitate the creation and development of games by providing a base set of functionalities and capabilities, such as rendering, audio and physics calculations (Unity Technologies, 2016).

The Unity engine acts as the core of the AUGGMED project, handling a large set of the backend features and requirements of the system. As well

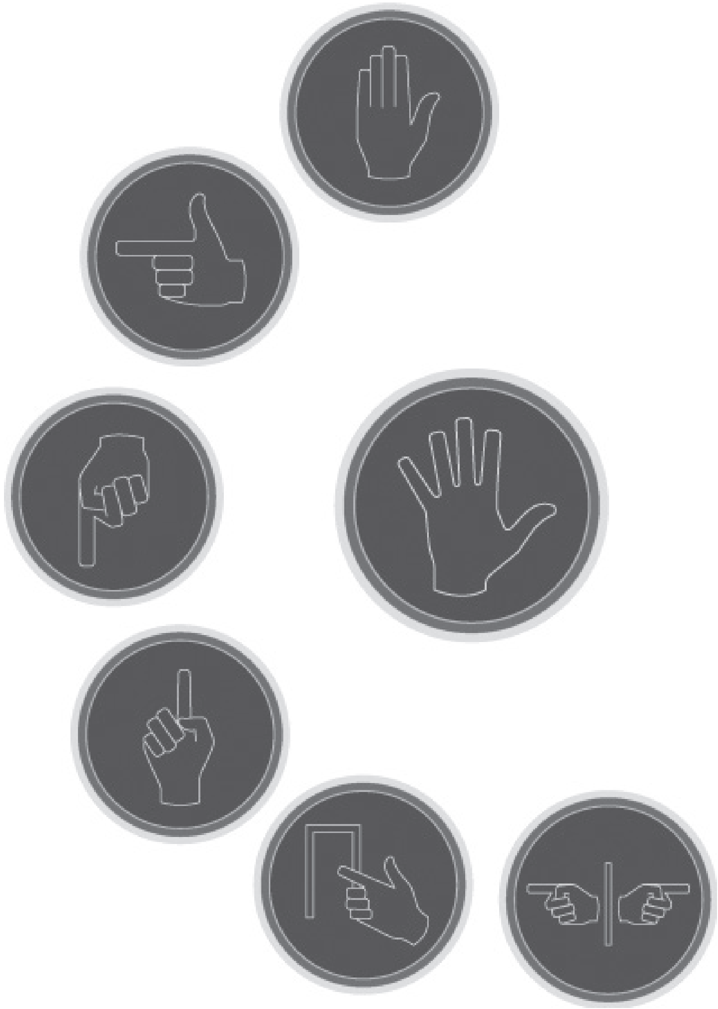

FIGURE 5: CIVILIAN COMMAND ICONS

as managing the rendering, audio and physics it also provides built in networking capabilities which enable AUGGMED to create servers and clients, which connect to these servers. Unity handles the entire visual, audial, interface and communications within the AUGGMED platform, all other components communicate through and/or are realised using the game engine.

As part of the rendering system for AUGGMED, all the main components for the trainees heads up display (HUD) are represented using Unity's built in 2D rendering canvas system. This system, which has been built specifically for developers to create player interfaces, enables the AUGGMED project to create dynamic and intuitive control systems for the trainees to use. An example of this is the player to civilian interaction inputs, a trainee can issue commands such as "Get Down" and "Stop" to civilians inside a training scenario at any time. For standard keyboard inputs this can be achieved through keyboard commands, however when using a touch screen device the player will require touch specific methods of initiating commands to players. Figure 5 displays the touch screen gesture control inputs available to a trainee, the central button represented by an open palm is used to reveal and hide the surrounding controls. These controls then directly map to a single command a trainee can give to civilians, these include: stop, move, get down, get up, evacuate now and get out of the way.

1.5 EXODUS PLATFORM

The Exodus platform is a civilian simulation system which realistically replicates civilian behaviour during an evacuation event. It also simulates behaviour relating to commands from first responders as well as injuries and fatalities due to fire and explosions (Galea, Owen and Lawrence, 1996).

1.5.1 Civilian Simulation

The civilian simulation system is responsible for realistically replicating civilian behaviour during a scenario, based on real world data it replicates civilian movements, reactions and injuries throughout a scenario. The number of civilians in any given scenario can range from tens to high hundreds depending on the requirements of the trainer.

The Exodus platform calculates all civilian information before sending that information to the Unity Engine. The engine then updates all of the relevant information on the server, and all local clients, before sending contextual information back to exodus, such as player movements and actions.

1.5.2 Fire and Explosion Simulation

The Exodus fire and explosion simulations are responsible for calculating and producing data which create realistic representations of these events in the environment provided. In the case of a fire, this includes the build-up of smoke, the effect of inhalation of the smoke on players and civilians, and the spread of fire throughout a given location. The explosion simulation handles information relating to an explosives area of influence, depending on the type and amount of material used. This information is built up using a predictive algorithm which determines the effect of an explosion on an actor including fatalities and injuries.

1.6 PHYSICAL COMPONENTS

The AUGGMED platform relies on a selection of specialised physical components to deliver the fully immersive virtual reality experience. Whilst not required for all users of AUGGMED, these components enable trainee's to experience a significantly more interactive scenario through the use of virtual reality headsets and haptic feedback vests.

1.6.1 Haptic Feedback Vest

The vest provides new methods for providing nonstandard information to a trainee through the use of a number of built in components, which can replicate temperature change and kinetic feedback. The vest will react to the state of the player character in the virtual environment and will convey specific information such as being shot, walking too close to a heat source or a tap on the shoulder. Combined with the virtual headset, this will give the AUGGMED platform an effective way of portraying non-visual or audial information, enabling trainees to make better informed decisions as their experience ever more closely resembles the real world environment.

1.6.2 Virtual Reality Headsets

The virtual reality headsets which interface with AUGGMED will provide trainees with an immersive method of engaging with the platform. Modern headsets not only display the environment in 3D, they allow 360 degrees of rotation and can track real world movements.

With the recent release of commercial virtual reality headsets they have become far more affordable and reliable. Both the HTC Vive[1] and Oculus Rift[2] provide accurate head-tracking and high quality visual fidelity. Users training using virtual reality will require state-of-the-art computers with powerful rendering technology when compared to standard desktop and touch screen computer.

Virtual Reality users will also be able to use other specialised input devices for their training including replica gun controllers and virtual reality treadmills, such as the Virtuix Omni.[3] These combined with the haptic feedback vest being developed have the potential to maximise the levels of interaction and immersion. Higher levels of immersion have been found to improve learning of geospatial tasks, including search operations and environmental awareness (Pausch, Proffitt, and Williams, 1997).

1 https://www.htcvive.com/

2 https://www.oculus.com/

3 http://www.virtuix.com/

2. DEVELOPMENT APPROACH

The AUGGMED project follows an agile user-centred design methodology focused on attaining constant end user input and integrating the results with future developments of the platform.

> *'Agile development excels in exploratory problem domains — extreme, complex, high-change projects — and operates best in a people centered, collaborative, organizational culture.' (Cockburn and Highsmith, 2001).*

Agile's focus on rapid iteration and approaching the development process from the bottom up fits precisely with the aims of the AUGGMED project. Through the identification of non-rigid development targets and milestones the platform can focus on developing the highest priority features and easily react to changing priorities during development.

The design methodology followed by AUGGMED utilises an approach of compartmentalising elements of the platform into independent modules assigned to individual technical partners. These modules encompass a specific technical requirement of the project, such as environments, and ensure a single, accountable point of responsibility exists. Each module owner is responsible for developing, testing and integrating their work into the core project, with the technical lead responsible for overseeing the integration process, ensuring AUGGMED remains stable, responsive and reliable.

2.1 DEVELOPMENT

Development of the individual modules of the AUGGMED platform started once an initial set of end user requirements was gathered. These were collated with the help of LEAs and other blue light services who usually participate in table-top and live exercises. These requirements shaped the core mechanics of the game and helped the developers prioritise features based on their capability to help trainees meet learning objectives. Following the requirements gathering phase of the project, the outputs were consolidated and prioritised based on the resource requirements of each individual feature weighted against the end users own promised requirements.

Using this method deadlines were set out for the systems which were required for the first pilot of the platform. Subsequent features and their deadlines were introduced based on observations, feedback, and more requirements identified during the first pilot. This iterative method of requirements gathering and feature prioritisation has enabled the developers and end users to build the AUGGMED platform to client specifications without significant redundancies in work.

This iterative approach which is at the core of agile software development methodologies ensures the project can continuously adapt to end user requirements and promotes the need to constantly integrate, test and pilot the software. This in turn ensures the AUGGMED serious game is bug free, reliable and robust.

2.2 TESTING

New features and large changes to the core of the AUGGMED platform are developed and worked on in separate independent branches of the project for a maximum of two weeks. Before integration into the main branch at completion of the feature the entire branch must be rigorously tested for errors, processing and rendering speeds, and network behaviour, as well as code and project continuity.

Upon passing the testing process the feature is merged into the core project and re-tested to ensure no merge conflicts interfered with the process of merging the two versions of the platform. Failing either of these tests requires the technical developer to address the issues found and restart the testing and merging process.

Following this method of internal testing, both before and after integration takes place, ensures any potential problems can be identified and addressed as early as possible in the development process.

2.3 INTEGRATION

Integration of every module of the AUGGMED platform is handled using GIT version control software[4] and third party merge conflict management tools[5]. The principal technical developer in charge of a specific module is responsible for carrying out the merge, resolving any conflicts arising during the process and testing the full integration. Every module, task and subtask being developed in a development cycle is discussed during bi-weekly development meetings to ensure all technical developers are aware of coming changes; this reduces the chances of significant merge conflicts and duplicate work being carried out.

The integration of the separate modules is overseen by the lead technical developer, who handles any significant feature merges or conflicts. This certifies continuity of the merged content and ensures the lead technical developer understands the purpose, implementation and behaviour of each module.

2.4 PILOTING

Piloting is a critical aspect of the AUGGMED development process, it is not only responsible for acquiring a refined set of user requirements, it also serves as a method of disseminating the progress of the project and stress testing the capabilities of the platform.

The critical nature of the piloting process in regard to future development of the platform creates a definitive set of deadlines and milestones which must be adhered to throughout the project. It also ensures the development of the platform is grounded through end user inputs, testing and feedback.

Each pilot is designed to test the entirety of the core AUGGMED serious game alongside a specific input method. The purpose of the first pilot was to test the mouse and keyboard control system for both the

[4] https://git-scm.com/

[5] https://sourcegear.com/diffmerge/

trainers and trainees alongside the core functionalities required for all training scenarios. These core functionalities include network stability, system reliability, agent behaviour, hardware load and avatar interaction capabilities.

The second pilot will once again stress test these core functionalities alongside the mouse/keyboard control method. In addition to these features, the second pilot is also required to test the virtual reality capabilities of the system. This includes an assessment of the ability of end users to adopt virtual reality as an input method - which is likely to be alien to most users - and compare its effectiveness against standard inputs.

The third pilot will introduce the mixed reality implementation of the AUGGMED platform with users training simultaneously within the same space using standard PC's, virtual reality and augmented reality. This final pilot will validate the use of multiple novel control systems and technologies, which have yet to be used within modern serious game systems.

3. TECHNICAL CHALLENGES

Thus far, the AUGGMED platform has overcome a number of significant technical challenges throughout its development, leading up to, and beyond the first pilot. These challenges both guided and defined the outcome of the platform including its simulation capabilities, concurrent users and customisability.

3.1 MULTIPLAYER NETWORK SYNCHRONISATION

A key challenge faced by the project was the amount of network capacity required for each client and by the server hosting a scenario.

A scenario could have 200 to 800 civilian agents at any one time. Exodus would simulate the origin and targets of each agent, and send an update to the Unity games engine every 10th of a second. This update contained positional information for every agent. Within the games engine each agent's movement delta was calculated between the last and next position and a vector, with both direction and magnitude, and could therefore be used to interpolate agent positions. This information would be used to simulate movement of the agents on the server and would be relayed to all clients.

Given the number of civilian agents, the amount of information sent between the server and individual clients has to be optimised at every opportunity, for this reason all orientation specific information was omitted from the synchronisation process of artificial intelligence agents, and would instead be inferred by calculating the vector between the origin and the target of an individual agent. Whilst rotational data is insignificant for an individual agent, it becomes a considerable task to send the rotational data of hundreds of agents multiple times per second.

A player's position, look rotation, and body rotation, data was synchronised alongside agent data. Rotational data was included in the synchronisation process for players to ensure identical player behaviour was replicated between all clients. Whilst this meant more information was synchronised for a player compared to an agent, the small number of concurrent players ensures it is not a significant load for the network system. The total data, required to synchronise players per update is the sum of these variables and whilst insignificant compared to the collective agents data requirements, adds to the total network requirements of AUGGMED. The equation shows how to roughly calculate the total server network load required based on the number of players, while Table 1 shows the amount of data transmitted for each element of position data for each player.

TABLE 1: NETWORK REQUIREMENTS FOR TRANSMITTING PLAYER DATA

Variable	Type	Size	Variable
Player Position	Vector 3	12 (4+4+4)	*p*
Body Rotation	Quaternion	16 (4+4+4+4)	*b*
Look Rotation	Quaternion	16 (4+4+4+4)	*l*
Total Size Per Player	44 Bytes		

$$D \cong \sum_{i=0}^{n} u(p + L + b)$$

As an example, a single server simulating 400 agents with a single client connected would be sending a total of around 26,000 bytes per second based on the standard variables used to control each agent. This is based on a single agent's data containing a single (single-precision floating-point) value for time; two single values for origin position; two single values for target positions; an integer representing the character's stance; and these values being updated three times per second between the server and client. The relationship between these components is shown in Equation (2), while Table 2 shows the requirement for each individual agent.

TABLE 2: AGENT DATA REQUIREMENTS

Variable	Type	Size	Variable
Time	Single	4	
Agent Position	Vector 2	8 (4+4)	
Agent Target	Vector 2	8 (4+4)	
Stance	Integer	2	
Total Size Per Agent	22 Bytes		

$$A = t + o + T + s$$

A standard simulation could contain around five trainees, three red team players, three observers and a second trainer. Assuming a simulation contains four hundred agents being synchronised between users three times per second (u). Equation (3) defines the equation required to calculate the amount of bytes per second needed for an individual user, and Equation (4) shows the final method of calculating the rough bandwidth requirement to send the information to all clients effectively.

$$U \cong \sum_{i=0}^{n} uA$$

To discover the total expected bandwidth requirement of the server, the total number of concurrent users must be calculated, which in the above example is roughly equal to 344,256 bytes per second, or 344.3Kbps.

$$B \cong cU$$

The method for calculating the entire bandwidth required for the server to effectively manage the network traffic of the AUGGMED platform, as shown in Equation (5) was defined by the methods used during the design process of AUGGMEDS network capabilities.

$$B \cong c\left(\sum_{i=0}^{n} u\left(\sum (t, o, T, s)\right)\right) + \mathrm{D}$$

This total bandwidth requirement does not cater for all other messaging systems required to enable player interaction with the system, such as player voice commands.

Due to the amount of information the server is expected to send and receive, developing efficient and minimal methods of updating each client's individual game state was a core challenge the development team would need to overcome.

During the course of the first pilot test of the platform it was discovered that the built in network system UNET[6], which is Unity's standard network API, struggled to handle the level of data and network connections required by the platform. This resulted in an unreliable network with synchronisation problems and inconsistent agent behaviour. As a result of this the developers decided to look for alternative network API's, such as Photon[7], which would be better suited to handle the amount of data and concurrent users required by AUGGMED. Whilst this decision would set back development, the requirement for a stable and scalable network API far outweighed the importance of other features planned in development. This decision meant a re-prioritisation of work and new targets and milestones were defined.

3.2 MULTI-MODAL PLAYER INTERACTIONS

A core aspect of the AUGGMED platform is the capability for users to train using their preferred method, which can enable them to better meet their learning requirements, style and availability. This includes the ability to train using a standard mouse and keyboard setup, using a touchscreen device or utilising virtual reality headsets. These interaction methods require specific considerations when it comes to player input systems, the on-screen heads-up display (HUD) and their methods of interacting with the environment.

6 https://docs.unity3d.com/Manual/UNetOverview.html

7 https://www.photonengine.com/en-US/Photon

McMahan et al. (2012) have shown that input methods used to interact with a virtual environment can have a significant effect on the performance output of the user. This difference in performance can make it difficult for a trainer to fairly evaluate multiple trainees using different interaction methods while performing the same task. Identifying the strengths and weaknesses of these methods and building upon these is critical in helping trainees' achieve their learning requirements.

Alongside different interactions, players using a selection of devices will require diverse levels of information displayed depending on their capability. An example of this is a touch screen user verses a standard desktop user. Players controlling their avatar using a mouse and keyboard are presented with standard controls attributed to first person shooter (FPS) games as well as an on screen crosshair, whereas a touch screen user needs to see their controls on screen as well as the crosshair.

Table 3 displays the current and planned control systems for each input method, these are based on current best practices and successful serious and standard game controls.

TABLE 3: MULTI-MODAL CONTROLS

Interaction Method	Movement Control	Look Control	Jump/Sprint/ Crouch	Civilian Interactions
Mouse/ Keyboard (Current)	W, A, S, D Keyboard Keys	Mouse Movement	Spacebar, Shift, CTRL	Keyboard Number Keys
Touch Screen (Current)	Radial Joypad Control	Radial Joypad Control	Jump Button, Sprint Toggle, Crouch Toggle	Interaction Buttons
Virtual Reality (Planned)	Controller Joypad	Head Rotation	Controller Buttons: A, Left Joypad Press, B	Radial Selection

These control systems were based on tried and tested methods utilised by standard computer games on personal computers and touch screen devices.

The largest challenge when developing a multimodal serious game is to give all players the same capability, regardless of their device. To overcome this, it was decided to accept the strengths and weaknesses of each interaction method and build upon these to cater them to specific areas of training.

Standard desktop interaction using a mouse and keyboard allows for the most balanced form of training and the most precise control methods (McMahan et al, 2012). Whilst it loses virtual reality's geospatial and emotional benefits; it has lower resource requirements, is more accessible for trainees, and is easier for remote training. This standard form of input provides greater precision capabilities to trainees and is the most accessible of the three interaction methods.

Touch screen device interactions enable even more capabilities for remote training; most touch screen devices are portable enabling for trainees to use AUGGMED on the move and can further reduce the resource cost of training. However these benefits are offset by the loss in precision which a mouse and keyboard can give, and virtual reality's emotional resilience and geospatial capabilities. Training using touch screen devices is the cheapest and most portable of the three interaction methods, enabling remote training capabilities and cost effective training solutions.

Virtual Reality can provide the most immersive experience and is capable of greater emotional resilience training (Wiederhold and Widerhold, 2008) and development of geospatial skills (Pauch, Proffitt and Williams, 1997; Bowman and McMahan, 2007) which are often overlooked in traditional forms of training. However these benefits have greater costs and less portability due to the higher technical requirements of virtual reality and the necessity for more hardware. Virtual reality training delivers the most complete training experience, capable of developing a multitude of skills from situational awareness, geospatial capabilities, tactics, to communication and stress management.

Through the identification of the strengths and weaknesses of each interaction method the AUGGMED platform can ensure greater knowledge transfer through specific devices by targeting the capabilities of each device to better support its strengths. For instance mouse and keyboard users aiming and controls are finely tuned to allow effective and realistic movement within the simulation without the loss of the fine controls associated with using a mouse.

Using this method we identified the best forms of interaction for both trainers and trainees. Whilst it was decided all devices could promote learning for the trainees, the trainers only required the capability to customise, observe and intervene with a scenario accurately and efficiently. With this in mind only mouse and keyboard input was implemented for the trainers.

CONCLUSION

The AUGGMED project identified and overcame a number of technical challenges during the first year of development. These challenges introduced important questions to the development process utilised during the project and the solutions implemented also require reflection.

The challenge of creating a multiplayer serious game which contains tens of players and hundreds of intelligent agents' highlighted limitations of Unity's built in UNET network protocol, and of standard Wi-Fi connections and hardware. The discovery of these problems during development and during the first pilot project highlighted the necessity for constant testing, piloting and refinement during the development process. Utilising the findings of the first pilot, the development process of the platform was changed, with more emphasis on early testing of core systems. Through this process alternative networking API's were identified as potential replacements to UNET which are better suited to AUGGMED's networking requirements.

Similarly the multi-modal input challenges faced by the project reinforced the requirement for informed development planning, research and end user feedback. Through efficient and effective planning during development, the AUGGMED platform built upon the strengths of using multiple input methods to ensure the platform can deliver a complete training experience, regardless of the devices used to achieve the learning requirements.

Leading up to the second pilot of the AUGGMED serious game, learning from these challenges and implementing the changes to the development process has reinforced the ideal that efficient planning and development alongside end users can help overcome significant barriers when developing new technologies.

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