UNIVERSITY OF OXFORD

CENTRE *for* DOCTORAL TRAINING *in* CYBER SECURITY

CDT Technical Paper

03/16

Dynamic Re-Planning For Cyber-Physical Situational Awareness

Michal Piskozub

Dynamic Re-Planning For Cyber-Physical Situational Awareness

Mini-Project Report

Michal Piskozub

Wolfson College
University of Oxford

Abstract

Modern warfare increasingly depends on interconnected computers where cyber security plays an essential role. Events from the battlefield are reported to decision-makers verbally, in a textual format, but rarely graphically.
In this project we conduct a feasibility study of a real-time 3D simulation system that visually communicates cyber-physical data to obtain situational awareness. We identify whether such a system is plausible for the real-time planning of simulated battle scenarios, and how such a tool may help real-time decision-making. As part of this feasibility study, we investigate whether the addition of "presence" often described in VR literature helps or detracts value from such a simulation system. We hypothesise that experiencing the situation in virtual reality is beneficial for decision-makers' reaction time and quality of their decisions.
Our simulation is built using a popular game engine Unreal Engine 4. It is then evaluated in a study involving four cybersecurity experts. The results indicate that the simulation is successful in the situational awareness aspect. Most users rate the regular monitor version higher than its virtual reality counterpart, stressing that while the immersion in VR is better, it is not as good in terms of controls, image quality, decision-making and comfort.

Acknowledgements

I would like to extend my sincere gratitude to my supervisors, Prof. Sadie Creese and Dr. Jassim Happa, for the guidance and support throughout the project.

Contents

Chapter 1

Introduction

In the modern warfare, situational awareness is key. In the past commanding officers used the lay of the land to position themselves in the most suitable location, from where the biggest part of the battlefield could be seen. Presently it is more compartmentalised. Decision-makers are usually in remote locations far from the fight. They may be in the base in the same country where the conflict is happening or in the operational headquarters in their home countries. While this disposition gives them the advantage of minimising risk of being injured on the battlefield, it also restricts their ability to assess the situation based on which the future orders are made. Battle-related information is reported to them verbally or occasionally by sending an image or video feed when the situation is too complex to be described by words in the limited time. That information can contain whereabouts and status of the assets belonging to both sides. The former relates to the nature of the environment in which they are operating, e.g. if the battlefield is surrounded by mountains, the placement of tanks in regions of higher altitude gives a more controlling position. The latter comprises of ammunition levels of ground and airborne troops, health of the soldiers, fuel levels of the mechanical assets, and the amount and types of operational weapons. In addition to this, battle-related information includes data from sensors used by both sides of the fight, such as: Wi-Fi range, which represents presence of wireless networks coverage including the Internet; mobile coverage; radio waves that represent communication between soldiers; night vision; thermal imaging; or hyperspectral imaging (which detects what objects are made of by using a spectrum of infrared wavelengths).

The weak link in the decision-making process is the way in which information is presented. Reporting with words is limited in its ability to convey the message quickly. Therefore, in this project we conduct a feasibility study to identify whether a real-time view of the battlefield, respective assets, and visual representation of sensor data make for quicker assessment of the situation. We hypothesise it is possible to build a system that fuses together cyber data with the real world for situational awareness and decision-making capabilities.

Chapter 2

Related Work

While there are numerous titles about using battle simulations for training of soldiers, there is a small amount of them that are concerned with decision-making of people in charge of all troops.
In a publication by Champney et al. [1], training tasks are performed in two modes: augmented reality (AR) and, what the authors refer to as, augmented virtuality (AV) which is equivalent to virtual reality (VR) "augmented by select real elements". In other words, these are two methods that belong to two opposing parts of the virtuality continuum ("between the real world and a completely virtual world"), where in the case of the former the majority of elements are from the real world and only some of them are virtual and the latter is dominated by virtual elements with a few that belong to the real world. The tasks involved Call For Fire (CFF), where the permission to attack the target is requested, and Close Air Support (CAS), where the target is attacked by an aircraft, procedures. Tasks were performed in two modes: AR and AV. AR contained a see-through display, a backpack, and a simulated binocular tool. It was fully mobile and capable of being used outdoor. AV was similar in shape to regular VR headsets with see-through display to accommodate binocular and compass tools. Contrary to AR, AV was an indoor system. To assess the system in both modes, the authors conducted a study with subject matter experts (SME) comprised of five U.S. Marines for AR mode and three participants with Reserves training for AV mode, all of whom had prior experience in CFF/CAS domains. The study resulted in AV scoring higher than AR. However, the results could be affected by the fact that each group of people were presented with only one mode of operation, as well as by the varying quality of implementation of two versions of the system.
Another example of a military simulation for training purposes is [5]. It concentrates on what should be changed in simulation based training (SBT) for infantry soldiers, to make it more effective compared to traditional training. The author with other researchers collected data from the Warrior Leader Course monthly, a total of ten times. Soldiers were using a virtual training program Virtual Battle Spaces 3 (VBS3) that was built using a game engine

ARMA3, which also powers a popular game franchise ARMA. The paper concludes that when considering a next-generation virtual training system, user interfaces should be standardised. Based on the study results there is potential for the successor of VBS3 to be more effective and more widely used.

In addition to the publications mentioned previously, there are papers that concentrate only on the design of the simulation aspect. An example of that is [4], where the researchers aim to build a universal visualisation tool for warfare simulation that facilitates decision-making. That is achieved by creating a collaborative visualisation environment that is based on the CAVE framework. The system is built for a curved seven-channel display with high field-of-view. It is controlled by a desktop computer with the support of tablets to provide domain-specific data. The authors considered using popular game engines to implement their system in, such as: OpenSceneGraph (OSG), Ogre3D, and Delta3D that are open-source; or Vega and Unity3D. They decided to choose Unity3D due to its extensibility and compatibility. The system features a modular design, where each module is responsible for a different function. Data processing module parses data from its raw format to one understood by the environment and passes it to other modules that requested that data. Weapon system visualization module manages the data from data processing module that should be saved, and is responsible for loading the 3D assets and effects in the visualisation. Terrain and environment visualization module loads the land surface data from a database of geographically acurate coordinates and creates an ocean that surrounds the visualised island. Animation module plays the simulation at the rate corresponding to smooth perceived motion. It is used in two modes: real-time visualization and after-action review. The default update rate should oscillate around 60 frames per second. However, when it is not possible to achieve it the system will interpolate the playback by adding frames in-between. Multi-channel module is responsible for managing each of the channels in the seven-channel configuration. UI module enables user interaction with the simulation by graphical controls. Graph plot module is able to show specific data on portable devices.

To augment military simulation and training games, Griffith et al. [3] examine puppeteering techniques of humans in the simulation. They use motion capture to project face expressions and body movements of users to their virtual counterparts, for which they use a game engine Unreal Engine 4 (UE4).

Simulations for decision-making are not only limited to the military field. In [2] the authors show the design and implementation of a simulation of a rugby player to demonstrate decision-making on the field. They captured movement of professional rugby players and embedded it in a virtual representation of a stadium. Users can impersonate a player and make decisions about their future moves, which is reflected on the screen. The researchers considered using VR to give better immersion and sense of presence. However, they deemed the idea as too sophisticated for the situation in which it will be used. Instead, Microsoft Kinect sensor was chosen to provide motion capture.

Chapter 3

Methodology & Design

In the project we pose two research questions. The former is concerned with the method of engagement of decision-makers. It aims to evaluate whether graphical way of presenting information from a battle is the most effective and leads to quality decisions quicker. The latter examines two modes of interaction: a version of the system shown on a computer monitor, and a version of the system viewed in virtual reality using a dedicated head-mounted display (HMD).

In order to answer the research questions we designed a simulation of a battlefield. It comprises of a scene where a battle can potentially take place. It is set on a desert where an abandoned village is surrounded by large dunes. On one side of the village there are our soldiers, tanks, fighter jets and helicopters - all painted in shades of green. Enemy troops and assets, which are yellow, are scattered throughout the remaining sides. Hostile soldiers can be hiding in any of the abandoned buildings including an old factory, a farm house, or a church. The simulation consists of visuals, anchored to buildings, representing cyber data from the following sensors: Wi-Fi, radio, and mobile. The purpose of the visuals is to hint what activities could be taking place in respective locations, e.g. buildings encompassed by sensor signals are more probable of sheltering enemy soldiers. Cyber data visuals are represented by different shapes (cones, spheres, cylinders, and cubes) that approximate the coverage of their signal. To tell them apart, distinct colours and materials are used: light blue translucent material represents Wi-Fi signal, green semi-transparent material with high refraction rate represents radio signal, and dark red translucent material represents mobile signal. They were selected to be compliant with users who are colour blind.
In addition to a free-roam camera, our simulation features cameras attached to every active asset - a soldier or a tank. We argue that this could increase situational awareness greatly, while disclosing enemy's location and actions.

We assume that our simulation is the result of a mapping system (such as [6] where terrain is scanned to a 3D model using drones) that has to be previously chosen if the system were to be deployed in a real world scenario.

Chapter 4

Implementation

To implement our design, we considered two most popular game engines: Unity3D and Unreal Engine 4 (UE4). Unity3D excels at cross-platform compatibility and ability to program using C# language. Unreal Engine 4 is easier to set up for virtual reality and all of its features are free. We found it important for the engine to offer workflow belonging to a higher level of abstraction. This would enable us to create a complex three-dimensional simulation in the project's short time frame. We decided to use Unreal Engine 4 due to its excellent visual scripting language referred to as Blueprints. In situations when Blueprints would be too high-level, UE4 also offers regular programming capabilities using C++ language.

The simulation uses 3D models (from a free 3D models website [7]), which can be seen in Figure 4.3, that are divided into the following categories: buildings, soldiers, airborne vehicles, and land vehicles. Buildings comprise of an old house, a factory, a church, and a farm house. Airborne vehicles are represented by helicopter and fighter jet models. Land vehicles comprise of a tank model with added suspension (Figure 4.2) and physics that simulate the engine and the gearbox.
Every tank and soldier can be possessed, which means that it can be controlled by a user. It also changes the view to a third-person camera that is placed directly behind an asset we have possessed (Figure 4.3). When possessed a tank can be driven by a user, which in a real world scenario can correspond to decision-makers controlling the tank themselves instead of giving an order. It is an additional feature that is supposed to test whether the sense of presence given by the simulation results in better decisions when the decision-maker is performing an action while seeing the environment and interactions in it. The same applies to soldiers who can be controlled when possessed. Controls allow for them to spring or jump. Moreover, their movement is simulated to resemble a real battle scenario by being able to order them to run to specific points on the map (Figure 4.4).

The simulation can be experienced on either a monitor or a virtual reality headset. Those two versions do not differ in terms of capabilities. This means

Figure 4.1: Free-roam camera view at the beginning of the simulation.

that every action that can be performed in the monitor version can also be performed in the VR version. Oculus Rift (DK2) was used to test the VR version. Due to known issues with the low resolution of the headset's display as well as chromatic aberration and screen-door effect, reading text on the device is hard to achieve. To overcome this we experimented with conutermeasures such as supersampling, which is a form of anti-aliasing. This resulted in clearer text, but at a cost of increased performance requirement. In practice, on a PC with GeForce GTX 980 graphics card it only managed to compute 30 frames per second, which is a lot below the recommended 75 frames per second (maximum on a DK2). Therefore, because of hardware limitations (of both GPU and VR headset) we decided that the simulation will not have any textual elements. Current implementation is capable of being rendered at the rate of 100 frames per second at 4K resolution on the mentioned GeForce GTX 980 graphics card. In VR version it rendered 75 frames per second.

Controls are divided into three categories: free-roam, soldier, and tank. The VR version has the same controls as the monitor version, with the addition of camera's direction being tied to the head movement. In free-roam mode, camera's look-around function is controlled by a mouse, with E and Q keys to move camera up or down respectively. In soldier mode, the camera is also operated by a mouse. The scroll moves it closer to and further from the

Figure 4.2: Simulation with visuals shown - representing Wi-Fi (blue) and radio (green).

character. The soldier is controlled with WSAD keys to move and the space bar to jump. In tank mode, the camera is operated in the same manner as in the soldier mode. The tank can drive forward by pressing W and reverse by pressing S. Turning is achieved with A and D keys, which initially move only one track and with time start moving the second track in the opposite direction to increase the turn speed and decrease space required to perform the maneuver. Visualisation of sensor data, belonging to cyber domain mentioned in the Methodology & Design chapter, can be toggled by pressing the V key. Toggle behaviour takes advantage of our ability to easily see change, which results in spotting more sensor signals in less time. This is especially applicable to the bird's-eye view of the battlefield, shown in Figure 4.5.

Possessing tanks and soldiers helps with better situational awareness and increases the details seen from different perspectives. A combination of Shift and 1 to 9 keys allows to control and view from behind of respective soldiers. To possess a tank in the simulation users can press keys from 1 to 8. First four are tanks belonging to our troops and the latter four are enemy tanks. Gaining view from enemy assets may not be possible to achieve in the real world scenario. We assume that such technology exists, e.g. by using drones transmitting a scanned 3D model of the environment from different angles.

Figure 4.3: Third-person view of an enemy tank overlooking the battlefield.

Figure 4.4: View of soldiers running to a target point from a possessed soldier.

Figure 4.5: Drone view of the battlefield with sensor data visuals.

Figure 4.6: Adjusting camera distance to achieve first-person view.

Chapter 5

Evaluation & Discussion

The simulation was evaluated in a small study with four participants. The purpose of it was to identify whether presenting battle information in a real-time graphical format is beneficial for decision-makers, and secondly to compare the way of experiencing it - on a VR headset or a monitor. Due to the small number of participants we cannot be confident whether their views represent views of a wider population or more importantly views of military personnel.

The study began with signing the consent form, after which a participant was presented with the introduction questionnaire. It consisted of demographic questions, which would later help us with understanding their choices and contribute to our speculations. The full form is shown in Appendix A. We aimed to recruit participants who had a background in cyber security. This would limit the probablity of their not being familiar with the topic to impact the result of the study. We were motivated by the similar assumption when we added the question about playing video games. People who are familiar with them, are used to the controls we implemented in the study.
After completing the introduction questionnaire, participants were asked to wear the Oculus Rift (DK2) headset were the simulation was run. The first task was to adjust the headset so that the lenses are centered with the eyes. The simulation uses no sound, hence the was no need to wear headphones, which enabled participants to hear sounds from the real world. The next task was to get to know the controls. This included moving the camera, switching the camera by possessing soldiers and tanks, and controlling them. When participants knew how to navigate the environment, the simulation was played where soldiers moved from one location to the other. It was then explained to the participants what the simulation means and which problems it tries to solve, so that they have this in mind when performing future tasks. Next, participants could use the free-roam camera to get the situational awareness, possess a tank to see its position (including enemy tanks) and drive it, possess a soldier to give an order for the others to move to the specified location, and use different cameras to view the visuals representing cyber data. After

participants had completed those tasks, they were presented with the same simulation on a monitor. Due to them knowing the controls and the simulation, there was no need to explain it again. However, we were happy to remind them of any keys and controls when they needed help. When they finished with the monitor version, we proceeded to the last stage of the study - the interview questionnaire (see: Appendix A). We asked them about their impressions after which they were asked to rate their experience for each mode in terms of: immersion, image quality, decision-making, controls, comfort; as well as the overall rating. We next inquired about the aspects they feel work well and the ones that do not. Lastly, we asked whether they thought there may be value in developing the project further.

We will now present the results from every of the four participants, all of whom were male in the age range between 18 and 29, treating each of them as a case study. At the end the average results will be shown, which will help picture the general opinions of two versions of the simulation. Their ratings are shown in radar charts that present different factors in a graphical format.

The first participant had a background in social aspects of cyber security. He used virtual reality before on an annual basis for games and architectural visualisations. He belonged to the IT and information services sector, in which he has spent 0 to 5 years. He was also familiar with video games, was not colour blind, and did not need correction for his eyesight. He rated the VR version at 9 justifying that it was very immersive and realistic. However, he mentioned that he felt slightly dizzy afterwards, hence he did not rate it at 10. The other ratings in five remaining categories are presented in Figure 5.1. Notcing objects in virtual reality was easier. Visuals were very clear. Steering and navigating the world with the free-roam camera and third-person cameras were the aspects he thought had worked well. The monitor version was not as immersive and the visuals of sensor data were harder to see. Therefore, the rating of it was 3. Its advantages were the key controls, because he could see them, which was not possible in the VR version. However, it was harder to see the bigger picture using the monitor version. In terms of developing this project further, he thought it had been a really good experience and he would like to see more.

The second participant had a background in both technical and social aspects of cyber security. He has never used virtual reality before and he never or rarely plays video games. He has been involved in academia for the range of 5 to 10 years. He was colour blind and did not wear glasses or contact lenses to correct for eyesight. His rating of the VR version was 6 (Figure 5.2), which he thought was better than he had expected, but was not much different than the monitor version. Navigating the world with current camera system was good, as well as the ability to see things from different positions. Visuals helped a lot with the situational awareness and the colours were clearly distinguishable. Being nauseous was the negative aspect. Sound could make the experience better. The keys were harder to find in the VR version. He rated the monitor

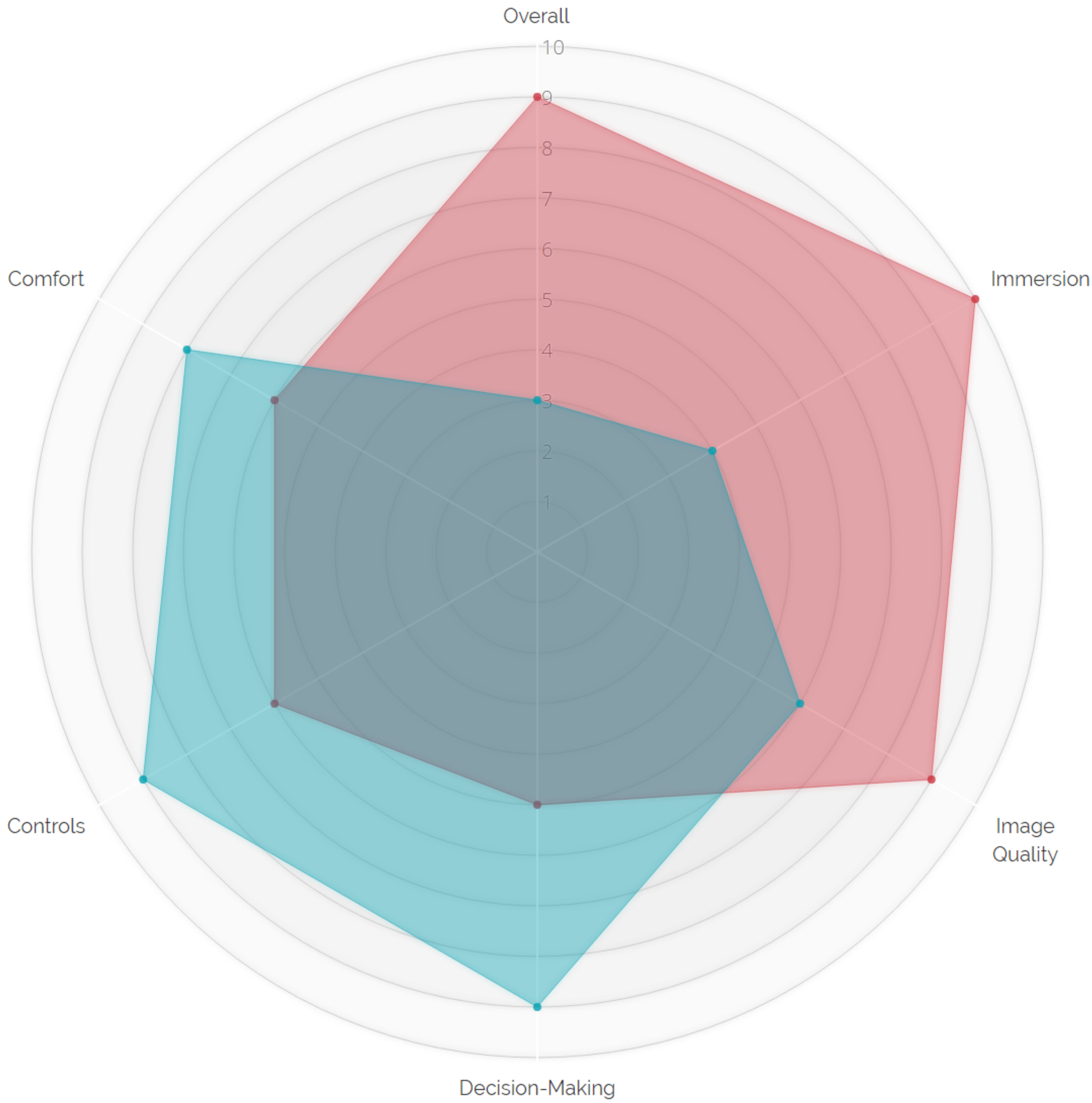

Figure 5.1: Radar chart with ratings from the first participant (VR in red, monitor in blue).

version at 9, argumenting that he was more familiar with the setting and the controls. The resolution and colours were better. Mouse movement was more natural and you could see the visuals from far. However, it was less immersive than VR. He felt that it should be developed further with better VR hardware and implementation. The ability to enter buildings would contribute greatly to situational awareness.

The third participant had a background in both technical and social

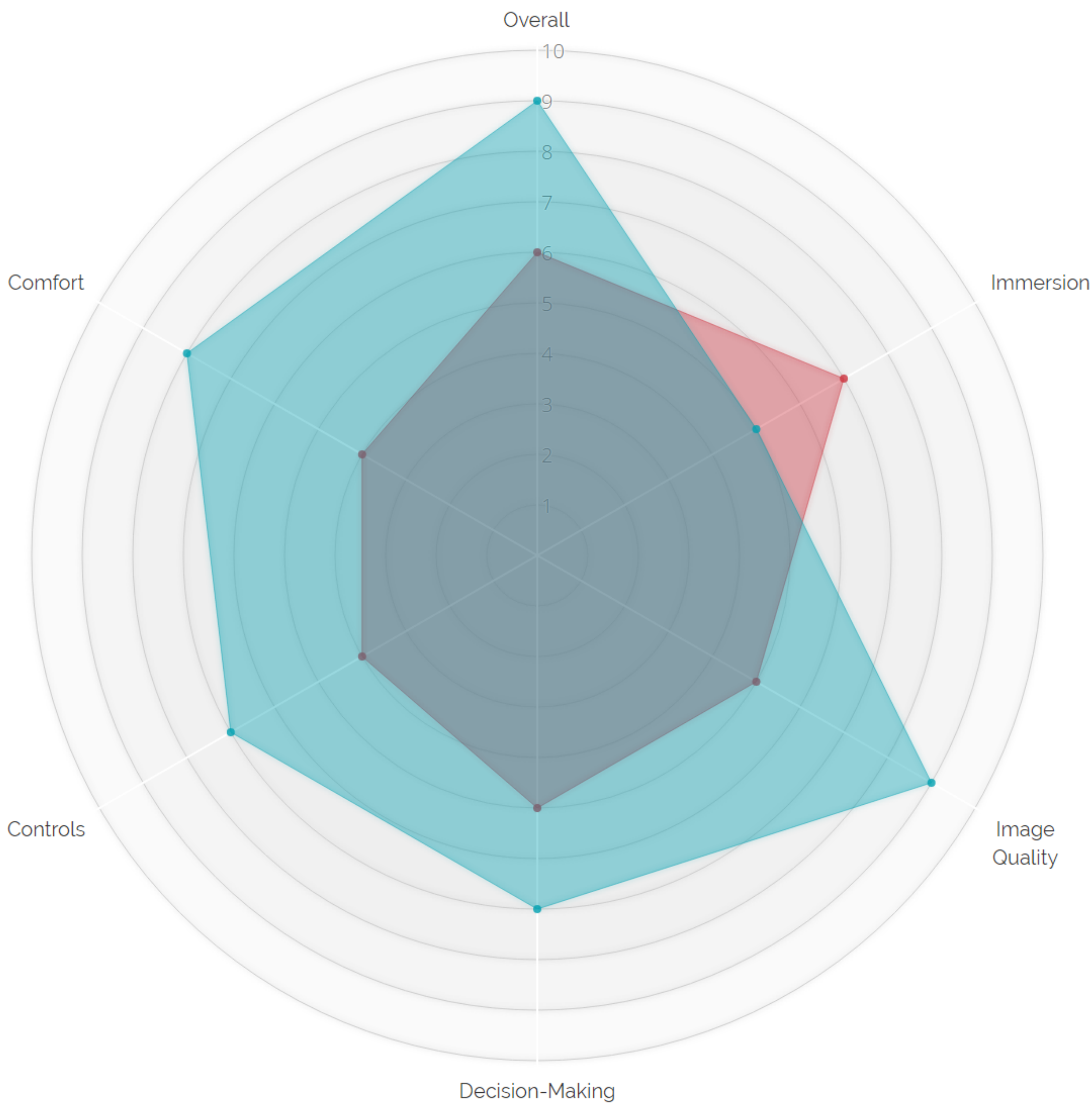

Figure 5.2: Radar chart with ratings from the second participant (VR in red, monitor in blue).

aspects of cyber security. He has never used virtual reality before, but he plays video games once a month or less. He belonged to the sector of academia where he has spent from 0 to 5 years. He is not colour blind and he wears glasses or contact lenses to correct for eyesight. His rating for the VR version was 6 (Figure 5.3), which was more immersive but also made him feel dizzy. You do not have the same agility in the movement, but it was more intuitive to look

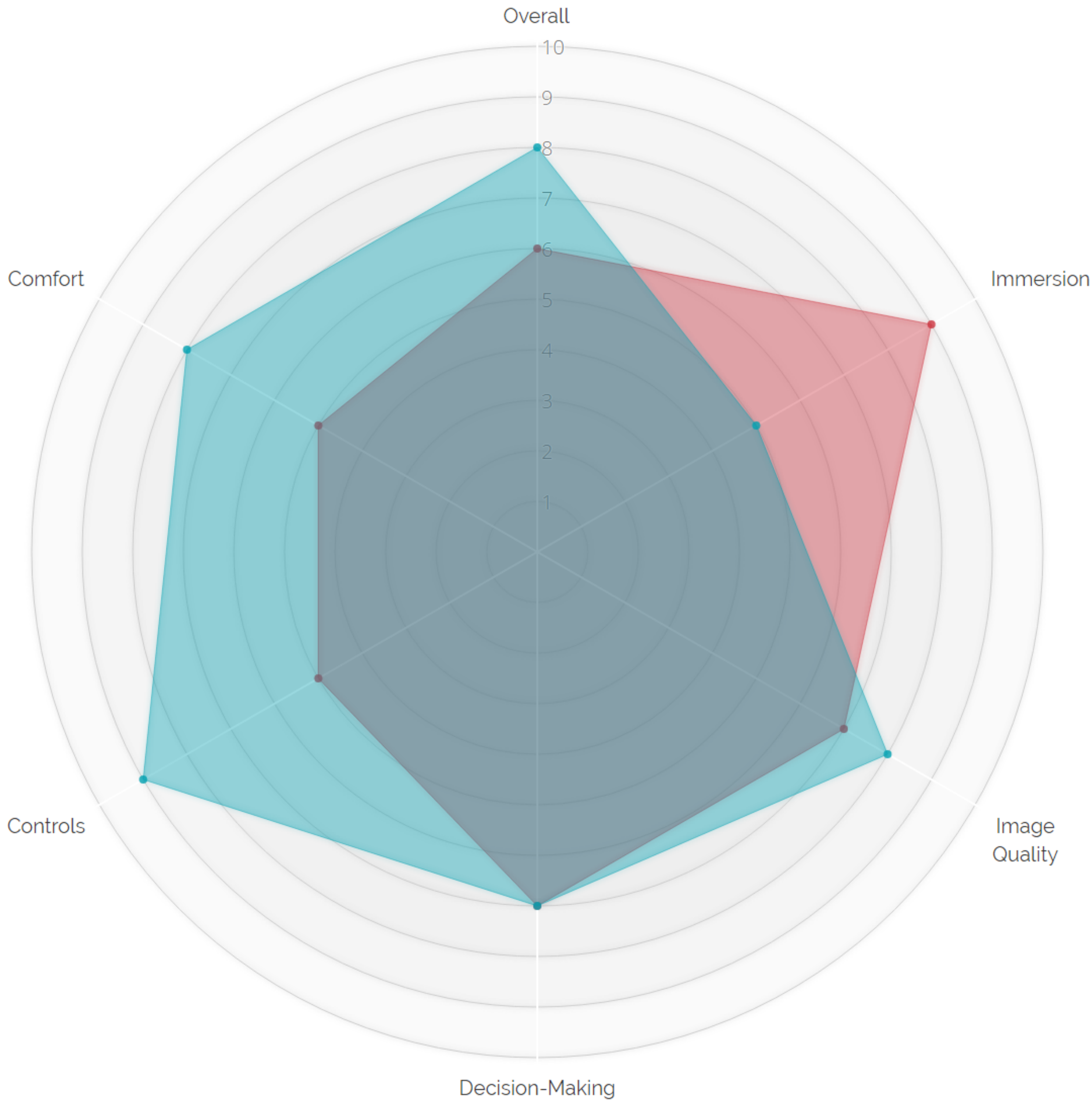

Figure 5.3: Radar chart with ratings from the third participant (VR in red, monitor in blue).

around. You get a greater sense of presence and you could make a decision faster. Visualisation of sensor data is better than textual data. However, the keyboard keys were not visible and hard to find. He rated the monitor version at 8, justifying that he was used to mouse, keyboard and monitor setting. However, with VR he felt like he was part of the situation presented in the simulation, whereas on the monitor he only saw the situation, but did not feel

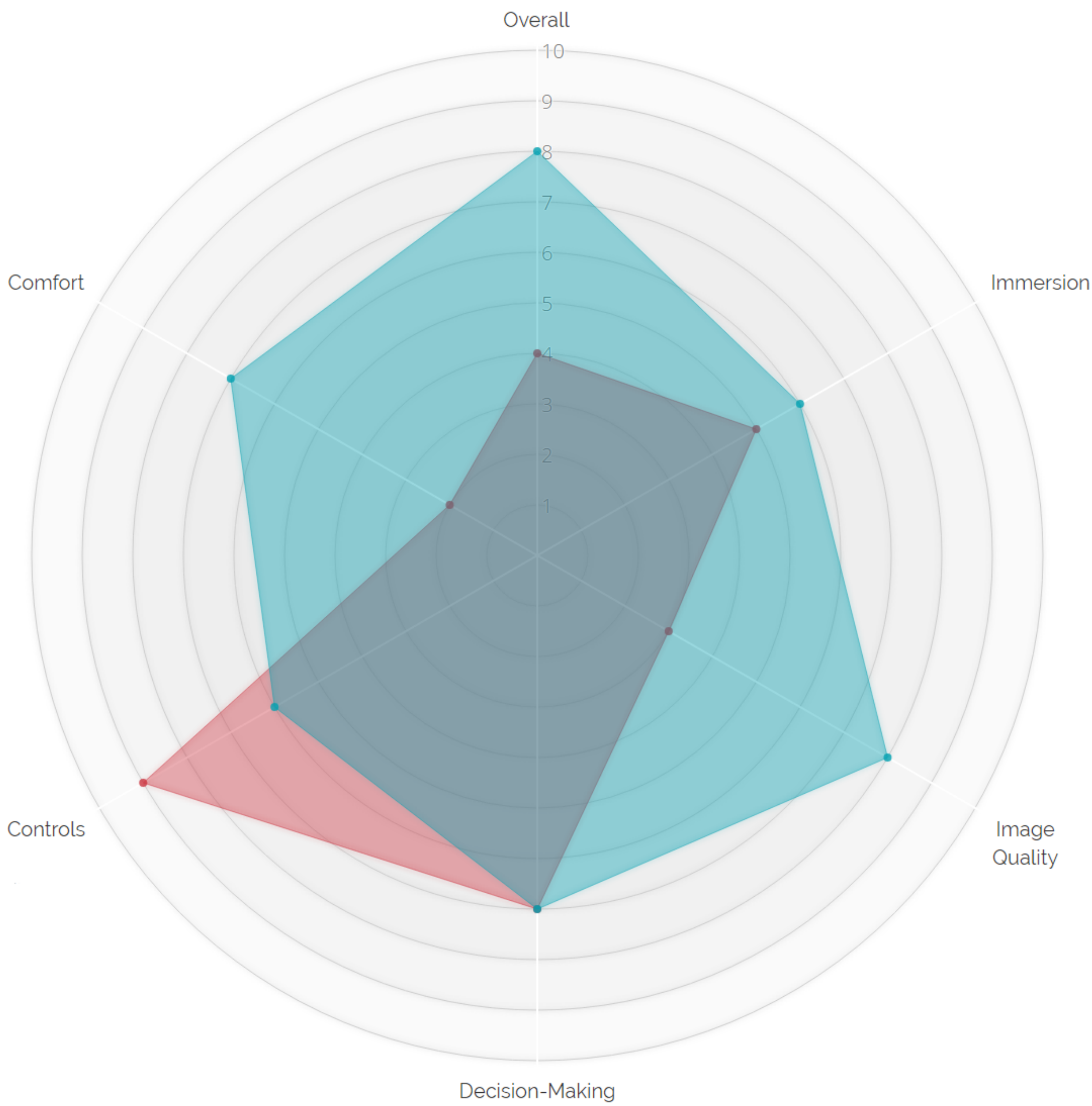

Figure 5.4: Radar chart with ratings from the fourth participant (VR in red, monitor in blue).

like he participated in it. He thought there would be value in developing the project further. VR would would be beneficial in a multi-user setting.

The last participant had prior expierience in technical aspects of cyber security. While he plays video games once a week or less, he has never used virtual reality before. He was currently affiliated with business, consulting and management sector for the last 0 to 5 years. He was not colour blind and

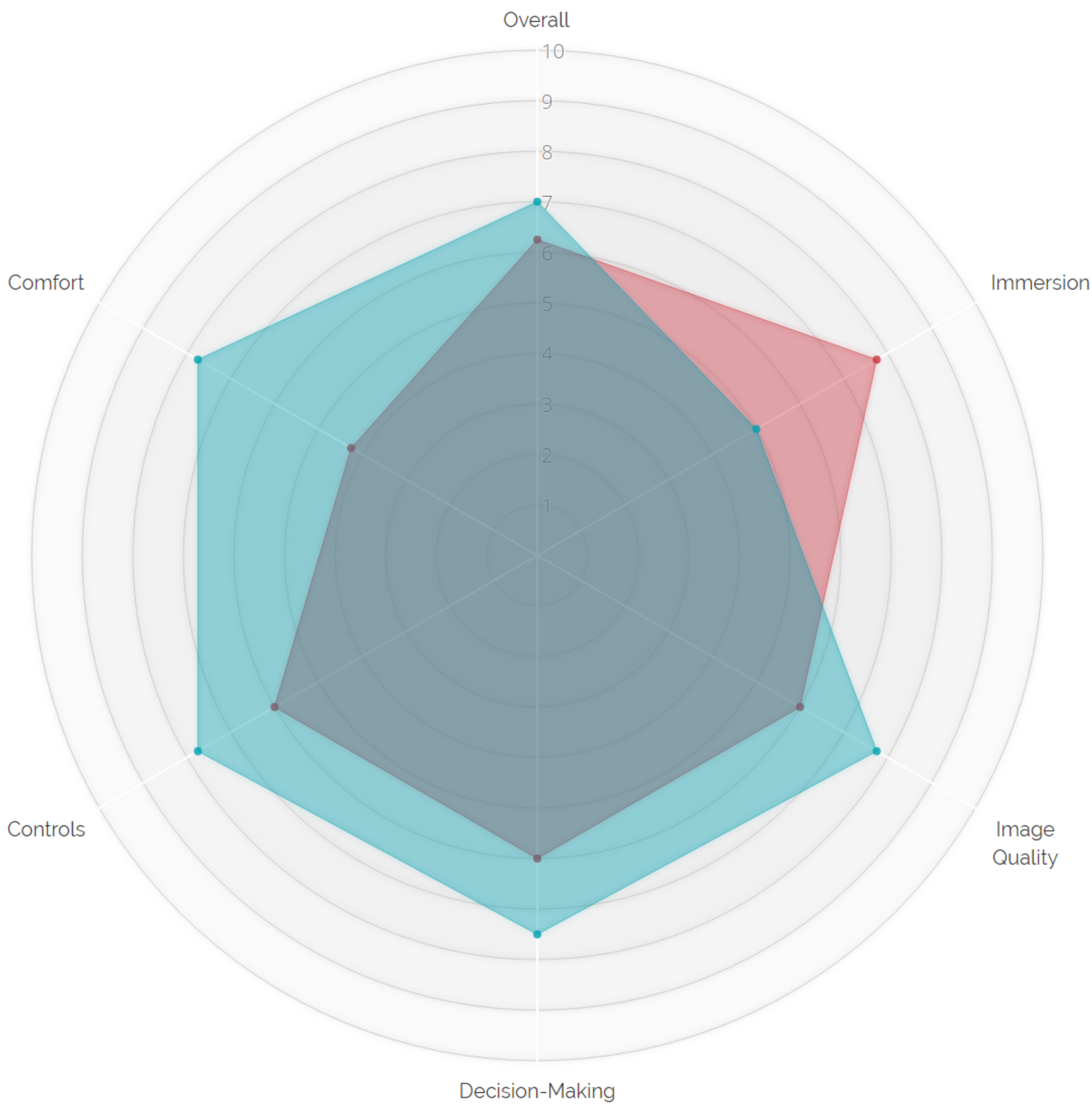

Figure 5.5: Radar chart with the average of ratings from the all participants (VR in red, monitor in blue).

needed to correct for his eyesight. When rating the VR version he admitted he was a bit disappointed and he initially expected more. The rating was 4 (Figure 5.4) explained by not clear vision in the VR headset. He said that he liked the fact that you did not need two inputs (keyboard and mouse) to control movement and looking around (navigation using the head-mounted display was so natural that he did not count that as an input). He also liked the fact that you were not limited by the size of the screen. He had difficulties with fitting the headset and complained about the resolution and visibility, which may have been due to the fact that he needed stronger eyesight correction than lenses provided by Oculus. The monitor version was rated at 8. In comparison it was very clear and more usable. He liked the physics of tanks and the realistic way in which its mechanical aspects were imitated. The sensor data were easy to notice and helped get better situational awareness.

According to the study, we can say that having prior experience with virtual reality positively affected the results of the VR version. On the other hand, we can only speculate, because of such a small number of pariticpants. In our case only one of them had used VR before. This may be the deciding factor for the result of the first participant, which differed quite greatly from the remaining three.

The final result (shown in Figure 5.5) shows that the monitor version outperformed the VR version. It won in four of a total of five categories. The difference was from 1.25 to 1.75 points for Controls, Decision-Making, and Image Quality. The biggest variation was in the Comfort category where the monitor version was better by 3.5 points. The VR version was better on in the Immersion category leading by 2.75 points. Overall the monitor version was judged to be better than VR by 0.75 points.

In could be less confusing for the participants, if the study was conducted in the different order, that is the monitor version first and the VR version second. Currently VR was a new type of experience for most of them. In conjunction with having to learn the key and other controls, it is possible that the balance in terms of learning new things was not ideal.

Showing the monitor version at 4K resolution may have created an unnecessary difference in image quality between two versions. However, this is a fair assumption that the simulation, if employed in the real world, would be run on a state-of-the-art screen.

A common complaint was the lack of dedicated controller for VR, which hindered interaction with objects in the VR version. It could be solved by using a newer VR headset like HTC Vive which comes with two controllers.

Another issue with the VR version was the implementation of camera movement. Users felt dizzy when driving tanks or controlling soldiers, because the motion of the camera (which orbits around the asset) was added on top of the asset's motion. Camera should be fixed to the asset while it is possessed in the VR mode, which would avoid any unnecessary movements. Mouse movement in the VR version should only work on X axis to prevent the user from having to turn around in the real world. Mouse should be used only occasionally, to turn the camera in the simulation, while limiting the movement of the head-mounted display. It should be taken into account that it is not possible to use the monitor version in all environments. When a decision-maker is in bright surroundings, VR with dedicated controllers is the only feasible solution.

Chapter 6

Future Work & Conclusion

The project was deemed worth to be explored further by the participants of the study. In the future version it would be interesting to simulate cyber data and make it available to the assets within the range of a sensor, e.g. network packets could be shown to a soldier that is within a Wi-Fi coverage. It was suggested by one of the participants that adding sound to the simulation may contribute to better situational awareness. The signals from sensors could not only be shown as in the previous proposal. Radio messages between soldiers could be played in the simulation as sound.
The future version could use augmented reality (AR) with virtual components added to the perception of the real world. The whole feed (real world video with added visuals) could then be transmitted to decision-makers who would be able to see it on a monitor or VR headset. Due to the early stages of development of AR technology there are currently no easily available AR headsets. AR could also be used between soldiers to avoid friendly fire.
Different types of VR controllers can be explored. Leap Motion, a device that brings users' hands along with finger movement to the virtual world, could be used in the simulation to be able to draw in the 3D scene. This could be useful in presenting the strategy and targets in a multi-user setting. Controllers like the ones included with HTC Vive can be used to interact with the environment instead of keyboard and mouse, which belong to the standard setting involving a monitor. In the simulation, menus could be anchored to one controller with the other being able to interact with it.

In the project we successfully built a simulation of a battlefield that allowed us to verify whether it helps in decision-making. We also created a virtual reality version to compare it with the standard monitor mode. Both of them were evaluated by a small study involving four participants. The project was an exploratory piece. The main contribution was the fusion of cyber data and physical situational awareness using virtual reality and monitor. With previously mentioned improvements, there is value in continuing the development of the project, which was indicated by the participants of the study. For accurate feedback, assessment could be conducted with military personnel.

References

[1] R. Champney, J. N. Salcedo, S. J. Lackey, S. Serge, and M. Sinagra. Mixed Reality Training of Military Tasks: Comparison of Two Approaches Through Reactions from Subject Matter Experts. *Virtual, Augmented and Mixed Reality: 8th International Conference*, pages 363–374, 2016.

[2] A. Cummins and C. Craig. Design and Implementation of a Low Cost Virtual Rugby Decision Making Interactive. *Augmented Reality, Virtual Reality, and Computer Graphics: Third International Conference*, pages 16–32, 2016.

[3] T. Griffith, T. Dwyer, C. Kinard, J. R. Flynn, and V. Kirazian. Research on the Use of Puppeteering to Improve Realism in Army Simulations and Training Games. *Virtual, Augmented and Mixed Reality: 8th International Conference*, pages 386–396, 2016.

[4] H. Kim, Y. Kang, S. Shin, I. Kim, and S. Han. Collaborative Visualization of a Warfare Simulation Using a Commercial Game Engine. *Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality: 6th International Conference*, pages 390–401, 2014.

[5] D. B. Maxwell. Application of Virtual Environments for Infantry Soldier Skills Training: We are Doing it Wrong. *Virtual, Augmented and Mixed Reality: 8th International Conference*, pages 424–432, 2016.

[6] R. McAlinden, E. Suma, T. Grechkin, and M. Enloe. Procedural Reconstruction of Simulation Terrain Using Drones. *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*, 2015.

[7] TF3DM. 3D Models for free. Retrieved on 2016-09-05 from `http://tf3dm.com/`.

Appendix A

Study Questionnaires

On the following pages we present the introduction questionnaire that participants filled in at the beginning of the study, and the interview questionnaire that asked about their opinions about the simulation in both modes: VR and monitor.

Introduction Questionnaire: *Dynamic Re-planning For Cyber-Physical Situational Awareness*

General Questions

1. What is your age range?
18-29, 30-39, 40-49, 50-59, 60+

2. What is your gender?
Male, Female

3. Where did you spend the majority of your childhood and adolescent years (tick all that apply)?
North Africa
Central Africa
Southern Africa
Asia (Russia)
Asia (Arabian Peninsula)
Asia (Orient)
Europe
North America
South America
Oceania
Multiple continents

4. Do you have a background (work or education) in Cyber Security?
Yes
No

4.1 If yes, which aspect (mainly) of Cyber Security?
Technical aspects – e.g. primarily focused on the implementation side of cyber security
Social aspects – e.g. primarily focused on the social science

5. Do you have a background (work or education) in Computer Graphics or Visualization?
Yes
No

5.1 If yes, which aspect (mainly)?
Computer Graphics technical – e.g. implementation of computer graphics algorithms.
Computer Graphics design – e.g. designing media based on existing tools.
Visualization technical – e.g. worked with visual analytics at a greater capacity than at high school/6th Form College level

6. Have you ever used virtual reality headsets?
Yes
No

6.1 If yes, how often do you use virtual reality?
Every day
Once a week
Once a month
Once a year
Other (please specify)

6.2 If yes, what types of applications did you use (tick all that apply)?
Games
Architectural Visualisations
Media (3D movies or photos)
Educational
Other (please specify)

7. What work sector do you belong to (tick all that apply)?
Academia
Accountancy, banking and finance
Armed forces and emergency services
Business, consulting and management
Charities and voluntary work
Creative arts and culture
Energy and utilities
Engineering and manufacturing
Environment and agriculture
Health and social care
Hospitality, tourism and sport
IT and information services
Law
Marketing, advertising and PR
Media and publishing
Property and construction
Public sector
Recruitment and HR
Retail and sales
Science and pharmaceuticals
Teaching and education
Transport and logistics
Unemployed

8. How many years have you been involved in your work?
0-5 years, 5-10 years, 10-15 years, 15-20 years, 20+ years

9. How important is the use of visualisation for your work (one answer)?
N/A
Not at all
Not very
Somewhat
Very

10. Do you generally prefer static dashboard visualisations or interactive ones to explore data?
Static
Interactive
Don't know

11. How often do you play computer and video games?
Never or rarely, 2-3 times a year or less, Once a month or less, Once a week or less, Almost every day

12. Are you colour-blind?
Yes, No, Don't know

13. Do you wear glasses or contact lenses to correct for eyesight?
Yes, No

Interview Questions

1. Can you describe your experience in the VR version?
Rate from 0-10 in terms of:
- -Immersion
- -Image Quality
- -Decision-Making
- -Controls
- -Comfort
- -Overall

2. Which aspects in the VR version do you feel work well?
Why?

3. Which aspects in the VR version do you feel do not work well?
Why?

4. Can you describe your experience in the monitor version?
Rate from 0-10 in terms of:
- -Immersion
- -Image Quality
- -Decision-Making
- -Controls
- -Comfort
- -Overall

5. Which aspects in the monitor version do you feel work well?
Why?

6. Which aspects in the monitor version do you feel do not work well?
Why?

7. Do you think there would be value in developing this project further?
Why / Why not?