Virtual Reality CBRN Defence

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ABSTRACT

Over the past decade, training in virtual reality for military and disaster preparedness has been increasingly recognized as an important adjunct to traditional modalities of real-life drills. However, there are only a few existing solutions that provide immersive virtual reality training and improve learning through an increased amount of presence. In this paper, we present a novel and flexible Virtual Reality (VR) training system for military and first responders that enables realistic multi-user training in large environments. We show how the requirements of peer stakeholders for disaster relief with an explicit focus on CBRN disaster preparedness transfer to the concept, current implementation and future features of our system. The development and integration of multiple technologies allows a wide variety of interaction and collaboration within our immersive system. In addition, we demonstrate the training capabilities of our proposed system with a multi-user training scenario, simulating a CBRN crisis. Results from our technical and user evaluation with 13 experts in CBRN response from the Austrian Armed Forces (National Defence Academy & Competence Center NBC Defence) indicate strong applicability and user acceptance. Over 80% of the participants agreed "much" or "very much" that the presented system can be used to support training for CBRN-crisis preparedness.

1.0 INTRODUCTION

Effective training is a cornerstone of disaster preparedness. Quality, consistency and frequency of training are shown to impact self-perceived disaster readiness of first responder units. However, barriers such as time, cost and safety limit the extent to which large groups of responders can be brought up to established standards, particularly related to integrated disaster team response skills and experience. This is particularly evident during events involving large-scale mobilization of population-based healthcare and public health resources, where skills learned through training impact directly the actual response. The advent of technologically-based approaches through Virtual Reality (VR) environments holds significant promise in its ability to bridge the gaps of other established training formats.

The training of professionals to face emergencies requires the mastery of several skills and abilities that need practice. However, facing real emergencies should be avoided during the initial stages of training. Instead, training should be provided under guidance and in a controlled setting that mimic real-life situations as closely as possible. VR integrates real-time computer graphics, body-tracking devices, visual displays and other sensory inputs to immerse individuals in computer-generated virtual environments (VEs). VR creates an illusion in the user of being physically inside the virtual world, and this sense of presence can have positive effects on task performance, enabling the learning situation to be experienced as a real context, which in turn promotes experiential learning. Indeed, VR enables individuals to learn by doing, through first-person experiences. Virtual Reality provides a tool for developing instruction along constructivist lines and an environment in which learners can actively pursue their knowledge needs. Another important characteristic to highlight is the possibility of self-learning and over-learning provided by these tools, since trainees can repeat the situation as many times as they want. Such activity is in part guided by the trainee, which promotes the development of operational and formal thinking by facilitating the exploration of different possibilities. This kind of training method can be readily adapted to the trainee's pace, timetable and needs. In addition, these tools enable the difficulty of the problems to be solved to be graded, thus facilitating learning by bringing subjects progressively closer to the solution.

Over the past decade, VR-based training in crisis preparedness has been increasingly recognized as an important adjunct to traditional modalities of real-life drills. Multiple studies, i.e. [1]–[4] have highlighted VR applications in disaster training. Many government agencies have adopted until now VR-based training. However, existing solutions mostly offer desktop-based VR training that lacks visual 3D immersion and navigation by natural walking. Both factors reduce the sense of presence. Furthermore, natural walking is essential to simulate stress and physical excitement, which is of particular interest to create a realistic training for on-site squad leaders and rescue teams. There are only a few existing solutions that provide immersive VR training through stereoscopic 3D scene viewing and body motion analysis, e.g. [5], [6]. However, these systems are solely designed for military training, they are very expensive (more than $100.000) and require extensive technical knowledge for system setup. These factors heavily diminish their applicability for crisis training of first responder agencies since they require a flexible immersive VR system to enable multi-user, interdisciplinary team training at different command levels in various training scenarios.

As the first step towards a flexible multi-user VR training system, we performed a thorough analysis of the state of the art of existing VR training systems [7], [8]. Furthermore, we analysed the requirements of two peer stakeholders with a focus on CBRN crisis and disaster preparedness.

Subsequently, from these analyses we have drawn conclusions if - and to which extent - current technologies satisfy the essential stakeholder requirements. Furthermore, we have integrated suitable technologies in our system and - where no suitable technologies were available - developed novel approaches. We assessed our system in a user-study with 13 users, the results of which we present in this paper. Finally, we outline future research steps.

To summarize, the paper presents the following contributions:

- Summary of a requirement analysis for CBRN defence VR-training
- Presentation of the concept for multi-user training system based on stakeholder requirements
- Implementation of a demonstrator VR system
- Results from the evaluation of our system in a user-study.

2.0 RELATED WORK

Employing VR technology to train first responders and relief units is an ongoing research topic for about two decades [9] and has led to the development of several academic, military and commercially available systems. The aim of the following state of the art analysis is to describe internationally available VR training systems, either providing training for military, first responders or civil purposes. To be able to evaluate the applicability of existing systems for providing interdisciplinary training of disaster relief units, we focus on analyzing virtual reality systems that are capable of multi-user training.

Thus, we did not study systems that only provide single user training, systems to train negotiation & language skills (i.e. *Bilateral Negotiation Trainer - BiLAT*), or systems that enhance live exercises in outdoor environment (i.e. *Augmented Reality Software* by ARA - Applied Research Associates). Furthermore, we did not study in detail systems that solely exist as prototypes. However, as some of them show significant potential for future disaster preparedness training, we briefly summarize interesting projects. *Immersive Video Intelligence Network (IVIN)* [10] is a tool offering 360° building walkthroughs that are visualized on a mobile device's display. The buildings' interior is produced from photos and is supposed to enhance the indoor situational awareness of first responder units. It does not provide an immersive setup, natural walking for navigation nor training functionality. *Sportevac* [11] is a desktop-based virtual training scenario simulating the challenges of a stadium evacuation with thousands of avatars, and the *Virtual Terrorism Response Academy* [12] is a desktop-based and non-immersive VR environment that aids trainees practicing various terrorism threats such as chemical hazards. The system *Enhanced Dynamic Geo-Social Environment (EDGE)* [13] is a VR platform with the major goal of enhancing first responders' communications and coordination while also making training more efficient and cost-effective. EDGE provides the creation of a dynamic, scalable and customizable training environment and supports multi-user training in a desktop-based, non-immersive virtual environment using a high-quality game engine for rendering, a standard screen for visualization and keyboard and mouse for navigation.

In the following, we outline the results of our state of the art analysis of available multi-user VR training systems. We categorized the systems into applications that either 1) provide pre-defined scenario(s) to train multiple users, or 2) allow the creation of various, self-defined scenarios that can be subsequently used for multi-user training. For pre-defined scenario systems, we provide an overview as they demonstrate well the potential of VR training. However, we will not go into all details of each approach as the pre-defined scenario systems lack out-of-the-box functionalities to create self-defined training scenarios with arbitrary devices, i.e. by providing open and accessible hard- and software interfaces. Thus, we describe in detail multi-scenario training systems as they might act as technological base to create immersive multi-user VR training systems for disaster preparedness.

2.1 Single Scenario Training for Multiple Users

A large number of simulators using VR technology exists to train military personnel for specific air, land and naval operations. Especially training of aircraft personnel has a long history, resulting in more than 1600 military aircraft simulators up to date that are in service worldwide [14]. The most compelling simulation is provided by Full Flight Simulators (FFS), such as the *Navy MH-60 Romeo* or the *Eurofighter Aircrew Synthetic Training Aids (ASTA)* that comprises a Full Mission Simulator (FMS) and a Cockpit Trainer/Interactive Pilot Station - Enhanced (CT/IPS-E). In addition to simulators for aircraft on-board training, a number of simulators exists to train Unmanned Aircraft Systems (UASs), i.e. the *Predator Mission Aircrew Training System* (PMATS) or the *MQ-8 Fire Scout Unmanned Helicopter*. Since these systems are not of our primary interest for disaster preparedness training, we do not present more details.

For military operations at land, VR simulators exists to train gun handling, shooting as well as tank operations. The *Simulated Weapon Environment Testbed (SWeET)* [15] targets at small arm weapon design and testing. It uses five 2D screens to project a 300° view of indoor or outdoor scenarios with customized weather conditions, locations and times of day. At each screen, up to four users can perform the exercise. The *Small Arms Trainer with 180 Degree Visuals (180SAT)* [16] aims at training of marksmanship skills, situational awareness and reaction times to increase the effectiveness of trainee usage of weapons in realistic threat scenarios. The system comprises large 2D projection walls and screens that are configured for individual and two-person team training. To train handling and operation of tanks, various systems exists, i.e. the *Leopard Gunnery Skills Trainers (LGST)* [17]. It is a self-contained, standalone system to train Leopard 2A4 crew commanders, gunners and loaders. Therefore, it provides at least six desktop-based workstations and one Driver Station Simulator (DSS) to enable multi-user tactical training at platoon level. The DSS simulates the tank interior with actual hardware and allows the driver to take part in the tactical training.

Each workstation is equipped with multiple 2D screens, headset and microphone for communication as well as mouse and keyboard for interaction.

Besides training in the aforementioned environments, also systems for exercising naval operations exist, i.e. the *Visual Bridge Simulator* [18] that is used to train all warfare branch officers, except aircrew, for the entire range of watch keeping, ship-handling and navigation at different command levels. Another example is the VR Team Trainer [19] (also named *Cooperative Computer Based Training* by the German Armed Forces) that aims at exercising control, operation and usage of complex systems such as M3 amphibious vehicles. Therefore, the trainees' task is to couple together amphibious vehicles, boats and floating bridge elements in a waterway to form ferries or bridges. Before simulation start, the trainer can configure scenario parameters such as current speed, visibility and wind velocity. The hardware setup comprises a desktop-based VR system, consisting of three to four user workstations, a gesture recognition workstation, a trainer workstation, a shared view workstation and a vehicle simulator. The user workstations are equipped with 2D screens, headset, microphone, keyboard and joystick, the gesture recognition workstation provides a keyboard and a data glove to capture hand gestures. The vehicle simulator offers a 360° projection combined with force feedback for realistic vehicle simulation.

The presented systems cover a wide range of training scenarios and outline the application of VR systems for real-world training tasks at different command levels. However, they share the limitation not providing out of the box accessible hard- and software interfaces to extend the systems for disaster preparedness training.

2.2 Multiple Scenario Training for Multiple Users

To create multiple scenarios for training of multiple users, there has been active development by industry, both offering VR training systems for military as well as civil usage. The amount of immersion provided by the VR training systems range from non-immersive desktop-based to fully immersive environments.

2.2.1. Non-Immersive VR Systems

The software framework Virtual Battle Space 3 [20] offers training of unit tactics, techniques and procedures in decisive actions for soldiers. Its open software platform enables 3rd party products to extend the simulation environment and functionality. To create self-defined training scenarios, it offers several built-in applications, including mission editors, an after-action review module, a development suite, a 3D content creation module including a model library and a modeling tool. The mission editor module comprises an offline editor to create scenarios at air, land and sea, to prepare terrain, objects, avatars, vehicles, weather (i.e. weather, sun, and time of day). The real-time mission editor enables the trainer to influence the scenario during training. With the help of the after action review module, post-training analysis can be conducted with the ability to visually fast-forward or rewind to events. Amongst others, it tracks statistics on casualties, engagement time and rounds fired and provides trainers and trainees to view the scenario from different perspectives including 3D, 2D, and from any trainee's perspective. The real-time 3D simulation is based on the game engine Real Virtuality 3 combined with NVIDIA PhysX. The network module is optimized for a large number of trainees (> 100) and enables to interconnect several Virtual Battle Space servers together or connect with other military simulations.

Out of the box, Virtual Battle Space supports standard workstations for each user with 2D monitors, keyboard and mouse as well as headset and microphone, resulting in a non-immersive desktop-based VR setup. It is used by a number of armed forces worldwide, including the U.S. Army, U.S. Marine Corps, UK Ministry of Defence, German Armed Forces and NATO. Due to the open software framework, it is furthermore used as base technology for a number of training tools, i.e. *Unmanned Aircraft System Training (UAS-TS)* for tactic drone LUNA (eurosimtec GmbH for German Armed Forces) and the *Leopard Gunnery Skills Trainers*.

The system XVR - Virtual Reality Training Software for Safety and Security [21] aims at training and exercising of emergency response professionals. It offers education, training and assessment of incident commanders of operational level up to strategic level, i.e. for members of relief units from emergency services, industry and critical infrastructure. By default, it offers single or multi-user training in a networked environment based on standard computer hardware, using a workstation, 2D screen, keyboard, mouse and joystick. Its software framework offers an editor for rich 3D content creation. The editor allows the configuration of region, incident or disaster scene as well as the determination of indecent type, scale and location. Further incident parameters - i.e. number of rescue vehicles, personal on call - can be customized, forcing the trainees to take into account logistic aspects such as call-up and transport times. During simulation, the trainee uses the joystick to navigate around the environment (walk, drive, fly) to assess risks and dangers of an incident. The trainer can give live feedback and can respond to a trainee's decision by activating events in the virtual scenario. XVR provides the creation of specific assessment scenarios to create predictable and repeatable training environments for an unbiased assessment. The system is used by a number of companies, organizations and state agencies, including ExxonMobil/Netherlands, BASF/Germany, Mont Blanc Tunnel/France&Italy, London Fire Brigade/UK and Austrian State Fire Brigade School.

The Advanced Disaster Management Simulator (ADMS) [22] offers training for incident command and disaster management teams at all command levels. It provides a large number of modeled 3D environments to train in scenarios that simulate building collapses, plane crashs, crowd riots, or nuclear, biological and chemical hazards. The built-in scenario editor allows the configuration of generic, semi-specific or specific 3D environments, incident sites (type, scale and location) and incident specific parameters such as vehicle positions, time of day, precipitation, wind, visibility, condition of casualties, terrain, and traffic as well as bystander behavior.

For performance evaluation, ADMS provides an observation and scoring system and an after action reviewer that records the exercise. In playback mode, training staffers can start, stop, pause and fast-forward the exercise and look at the incident from any point of view. ADMS comes as a modular, expandable disaster simulation platform using proprietary hardware and software (operating system). Thus, specific workstations are required and must be individually purchased. For visualization, projection walls or standard screens are used while interaction is performed with several physical input devices, such as keyboard, joystick or driving wheel. Amongst others, the system is used by the New York City Office of Emergency Management and Netherlands Institute for Safety (NIFV).

2.2.2. Semi to Full Immersive VR Systems

Compared to the systems presented in Section 2.2.1, we will outline in the following systems that provides training in semi to fully immersive virtual environments. The *Advanced Network Trainer (ANTares)* [23] , a system developed for the German Armed Forces, is a land, air, naval weapon system simulator for tactical training operations. Its system's most prominent feature is the modular cubicle hardware concept. It allows to couple multiple, individually equipped simulation cubes to create a networked environment for tactical mission rehearsal of complex operations or scenarios. The open architecture provides the integration of different systems to form a complex networked mission scenario. The cubes can be arranged as plug-and-play components in a customer-defined configuration. The hardware for visualization and interaction of each cube can be individually customized, ranging from off the shelf visualization and interaction devices (i.e. 2D screens, head mounted displays (HMD), keyboard, mouse, joystick, force feedback devices) to fully equipped maneuver stations with actual hardware. Internally, ANTares uses Virtual Battle Space (version 2.0) for 3D scenario creation, training simulation and debriefing.

The immersive VR system *Dismounted Soldier Training System (DSTS)* [5] offers training of dismounted soldiers of infantry platoons. One DSTS hardware suite comprises nine fully wearable and immersive VR setups (Virtual Soldier Manned Module - VSMM) for dismounted soldier training, five workstations for multifunction soldier training, one staff control station and an after action review space. Each VSMM consists of a helmet with attached HMD, headset, microphone and an *Intersense InertiaCube 2+* for 3D orientation estimation of the head. For processing, rendering and networking, a notebook is attached to the soldier's vest that also accommodates another *InertiaCube 2+* for torso tracking. Additionally, a gun is provided, equipped with buttons for navigation and an *Intersense InertiaCube 3* for 3D orientation tracking of the weapon. The VSMMallows each dismounted soldier to stand, crouch, jump and lay during the exercise. Movement and thus navigation is done by button controls at the weapon.

At the software side, a content editor allows the creation of self-defined training scenarios incorporating semi-automated forces and the live participants. Scenario related parameters, such as movement of ground vehicles, aircraft, dismounted infantry, day time and weather effects can be configured. Built upon the commercially available *CryEngine* [24], the systems offers high quality 3D rendering with physics support. The system was developed by Intelligent Decisions for the U.S. Army and is available since 2012. According to the U.S. army, 102 test sites were planned in 2012 to be equipped with DSTS, costing $500.000 for one suite. In 2014, Intelligent Decisions, announced the system *Medical Simulation* [25], a training environment for first responders. According to the provided specifications, the hardware setup is similar to DSTS, extended by biosensors to track gaze, blood pressure and heart rate. However, no information are giving regarding system availability or costs.

VirtSim [6] offers multi-user, fully immersive training for law enforcement situations as well as military tactic training at a squad command level. Therefore, it employs optical outside-in tracking (Vicon) to estimate the position and orientation of user's head, weapon and full body motion. This allows users to navigate in VR by real walking in larger sized physical spaces (20x20m). However, a plethora of Vicon tracking cameras is required to cover that volume making the system hard to setup and highly expensive. Off the shelf HMDs are used for stereoscopic 3D scene viewing that are connected to a user-carried notebook that performs processing, rendering and networking.

The *VirtSim* content editor provides a range of reconfigurable environments. For law enforcement, pre-defined scenarios exists for training of individuals in weapon discipline, making deadly force decisions, covering danger areas, team clearing techniques, use of cover and concealment, and communications among team members. Military scenarios comprises training of individuals in direct action, counter-terrorism and react to contact. An after action review module records trainees' body motions, shots, the individual manoeuvres of participants as well as team and squad manoeuvres. It provides playback of all actions and shots from every angle, and from each participant's perspective.

3.0 REQUIREMENTS

A requirement analysis was conducted by two peer stakeholders for disaster relief, the *Austrian Federal Ministry of Defence and Sports (BMLVS)* and the *Ambulance Team of the Red Cross Innsbruck*, *Austria*. Within this analysis, the interests and requirements of both stakeholders' CBRN defence elements were firstly identified. Next, scenarios were developed and described to derive demands to a VR training system. Within the scenarios, the stakeholders furthermore focused on specifying the involved command levels, the target groups and the required training content. For the full requirement analyses, please refer to [7], [8]. We briefly summarize the results in the following paragraphs and subsections.

To identify VR-relevant training parameters, the skill catalog for CBRN defence of the Austrian Armed Forces was used as base. Relevant skills were identified and subsequently reduced to skill bundles. At least three skill bundles with a high potential to be trained in VR were identified:

1. CBRN-defence recce
2. Urban search and rescue
3. Skills for aircraft rescue

Based on the identified skill bundles, three use cases have been derived that are described in more detail in the following subsections. All three uses cases outline training scenarios that would be highly beneficial to be trained with a VR system. The focus is placed on the first scenario, which has been implemented in the current version of the system.

3.1 Scenario: CBRN Defence Recce

For this scenario, a virtual area of approximately 30x30km with a 24km airspace is required for the training of motorized and stationary elements.

The virtual environment should comprise a rural area containing some villages and infrastructure like bridges, power lines, railways or streets. This scenario aims at training of a CBRN defence recce platoon consisting of three specific vehicles and 28 staff members in different functions, such as platoon leader, squad leader, signal, driver, etc. Thus, at least 28 persons are directly involved in the virtual environment, requiring a multi-user collaborative VR system. The major mission tasks are:

- Observing
- Detection
- Decontamination

For the virtual simulation, it is necessary to customize the simulated hazard materials - i.e. chemical agents or radiological materials in various physical states - the weather conditions and time of day. Furthermore, it is required to move within the map, either within the entire map by controlling the virtual vehicles or by natural walking within a smaller physical volume (20x20m) for dismounted CBRN operations.

Furthermore, the virtual buildings can be entered and it is possible to communicate with the virtual bystanders in the simulated environment. For dismounted operations, the CBRN squad staff must be able to wear their actual defence protection suites, some additional equipment and radio sets. Amongst other, there are the following benefits employing a VR simulation to train this scenario:

- The scenario can be used for squad, group and platoon training/education as well as for single user training/education.
- The process of decision making can be trained as often as required for leaders of all levels.
- It is possible to visualize different areas, seasons and precipitation upon request. Furthermore, necessary tools and instruments can be virtually simulated.

In a real-world environment, providing all of the required infrastructure, participants and equipment for the intended training scenario is a cost and time extensive process, especially since there is a large amount of resources necessary. Furthermore, only a very small amount of hazardous material can be used for training since environmental contamination has to be avoided. Thus, using VR implies a tremendous potential to save costs and time, train the full range of hazardous material and provide training on a regular schedule.

3.2 Scenario: Search and Rescue

For this scenario, the virtual environment consists of an urban area, containing at least four to five buildings. Each two to four-story high building has a cellar and shows different damages caused by an earthquake. It shows a typical earthquake scenario with totally damaged buildings as well as medium and light damaged ones.

This scenario is targeted for training of the search and rescue elements of a search and rescue platoon. At least 45 soldiers are involved in the simulation at different command levels. So members of each command level have to cover specific topics to collaboratively solve the major mission tasks:

- Exploration
- Searching
- Rescue of persons
- Clearing

For scenario creation, building structures (door entries, properties of staircases), obstacles and affected persons (amount, various injury patterns) should be straightforwardly to generate and customized. Furthermore, parameters such as weather and time of day should be adaptable. Compared to training in a real environment, there are the following benefits employing a VR simulation to train this scenario:

- Training and education of decision makers of all levels of a search and rescue platoon can be performed with this simulated scenario.
- It is possible to simulate medium earthquakes as well as large damages of the building structures.
- Various hazards can be simulated as well as number of casualties and the grade of injuries.

Upon decision making of a specific thread are rescue operations, a lot of different equipment is subsequently required and used on site such as generators, devices for drilling, crushing and cutting. However, we found no benefit to incorporate the training of their handling into the VR simulation due the following reasons. Firstly, a lot of quick ways to provide real-world training of these tools exist. Secondly, haptic and tactile clues as well as force feedback are important to train their correct handling. At the current state of the art of VR input technology, it is very hard or still impossible to mimic these tactile sensations in a realistic manner. Thus, we excluded equipment handling from this VR training scenario. To summarize, this scenario aims specifically at decision makers of all command levels and does not target (dismounted) personnel of a squad unit.

3.3 Scenario: Aircraft Rescue and CBRN Defence

This scenario aims at training of some specific CBRN-defence elements on military airfields. In case of an airplane crash, their priority is to rescue the pilots. This implies specific requirements to which these rescue units have to obey, such as arriving on the disaster site within 90 seconds and start firefighting within 2 minutes after the crash. Furthermore, the relief unit staff have to know all relevant parameters and specific handles of all aircraft types that are currently in use in Austria. A large number of different on-site hazards are possible such as explosives of ammunition, fuel and safety devices like ejection seats. All the safety devices depending on the various types of aircrafts must be known and correctly handled in case of an emergency to avoid false releases. Thus, the soldiers must be extensively trained to know by heart all necessary procedures. Therefore, drill training is often used.

This training scenario is not developed for decision making but for training of standardized procedures depending on the different airplane types. Thus, the virtual environment provides the trainees a training facility to improve their experience and handling on the basis of unlimited repetitions. Additionally, the virtual training scenario allows training in a virtual simulation of the different real airfields. Hence, trainees do not need to visit the various aircrafts in their real home bases, resulting in a reduction of time and costs.

3.4 Derived Requirements

In accordance to the developed scenarios there are some general and specific requirements derived. The general requirements were categorized as:

- Movement (virtual and physical)
- Manipulation of objects (virtual and physical)
- Communication
- Customization of Scenario Content & Parameters

The specific derivatives were categorized as:

- Specific Movements
- Specific Manipulations

For the scenario *CBRN Defence Recce* some of the necessary activities are listed below:

- Operate CBRN observation post
- Develop a weather report
- CBRN exploration

For each activity of all three scenarios the derived requirements were identified. One example is given in Table 1, which illustrates the identified derivatives for the scenario CBRN Defence Recce.

Table 1: Derived requirements of CBRN Defence Recce, showing in colour already implemented requirements and in grey functionalities planned for a future prototype.

Communication	Team communication (speech, signs)
	Team communication (radio)
	Communication to commander via radio
	Instruction to virtual person
Manipulation	Transportation of equipment
	Transportation of weapons
	Map consulting
Specific manipulation	**Reading measurement results**
	Use of binoculars
	Use of height level protractor
	Use of compass
	Filling in forms
	Writing of markers
	Sampling contamination on a flat surface
	Fixating marker (putting a stick in the ground)
	Skimming and Soaking up liquids
	Digging (up) ground material
	Packaging sample
Movement	Going
	Running
	Sitting in vehicle
	Lay on the ground
	Bend down, lay down
Specific movement	**Mount/dismount vehicle**
Customization of Scenario Content & Parameters	Hazard - chemical agent
	Positions (entry point and events)
	Weather (wind and visibility)
	Virtual persons
	Hazard - nuclear explosion

To specify these derived requirements, it was necessary to identify and describe the generic processes of each of the three scenarios. For instance, the search and rescue scenario consists of seven generic steps and the CBRN Defence recce scenario consists of seven activities. For each of the activities the content was formulated and analysed with regard to its applicability in a VR training application.

3.5 Technical Requirements

Based on the analysis of the stakeholders' requirements, the demands on a VR training system can be derived and summarized as follows.

3.5.1 Virtual Reality Objectives

The training environment should 1) be fully immersive to exploit the advantages of learning in VR, 2) provide 3D object interaction (selection and manipulation) with CBRN equipment and other mission relevant objects, 3) allow natural walking (and crawling) for navigation and to realistically simulate stress and exhaustion, 4) not limit the virtual movement range by physical space and 5) and be multi-user capable to allow for collaborative training.

3.5.2 Hardware Objectives

The immersive VR hardware setup should be 1) fully wearable, 2) quick to setup, 3) consisting strictly of off the shelf hardware components and 4) requiring a small amount of hardware to lower price and system complexity.

3.5.3 Software Objectives

The software framework should provide 1) creation of new 3D training scenarios, 2) level and terrain editor, 3) customization of scenario parameters before and during the training, 3) high quality 3D rendering with physics support and 4) after action reviewing for trainee evaluation.

4.0 SYSTEM DESIGN

We designed our system to fulfil the requirements described in the previous section. Figure 1 provides an overview of the overall system architecture. Horizontally we split the illustration in client (I) and server (II) modules. Vertically, starting from the top it illustrates the input devices (III), plugin-layer (IV), application-layer (V) and output devices (VI). Besides the different modules and sub-systems themselves also their integration stage is illustrated. Parts framed and written in turquoise are already implemented at demonstrator level, while entirely grey blocks show modules planned for future integration and implementation. Modules on the client-side are replicated with each additional user.

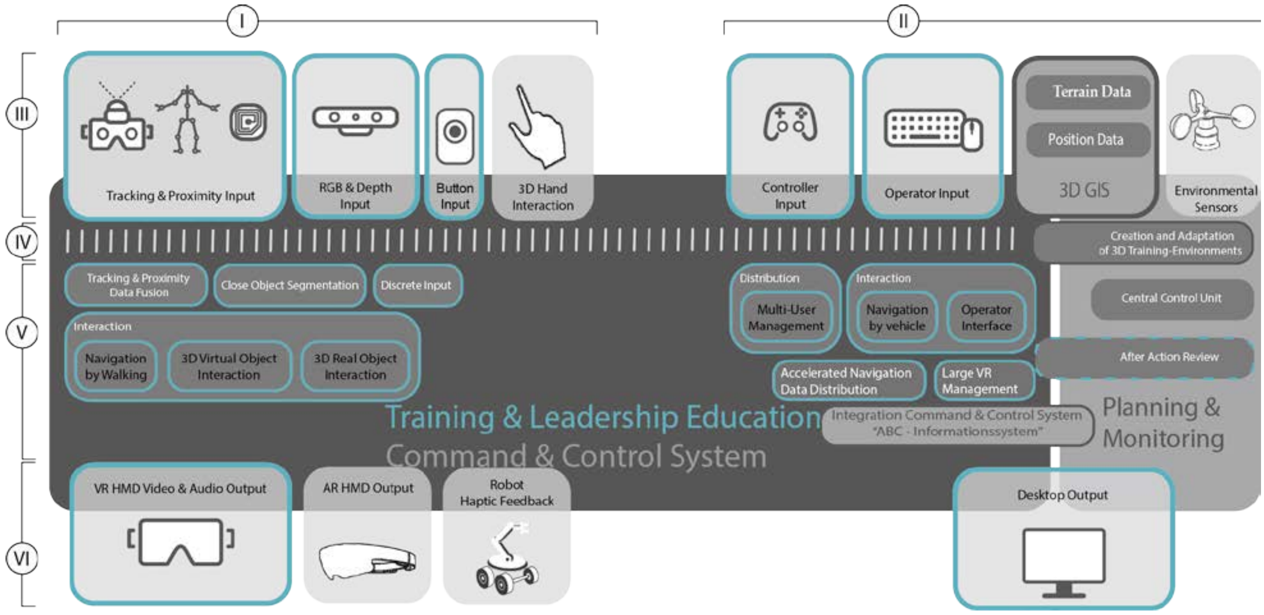

Figure 1: Schematic visualization of all modules and components of the VR client (I) as well as the server side (II) within our VR system. Input data (III) is forwarded through the plugin layer (IV) to the application layer (V), containing all application logic. After processing all data the visual, audio and haptic output is produced (VI).

4.1 Client

In the current demonstrator training at squad level is possible with up to four client VR setups, while the plan is to increase the number of users to a group in the next step while the final goal is training at platoon level.

For each client in the current demonstrator the input layer provides position and orientation data from the Inertial Measurement Unit (IMU) of an HMD with an attached camera for inside-out marker tracking as well as from a motion capture suit. The plugin-layer integrates the devices with the Immersive Deck, which in turn fuses the tracking data. These technologies provide the basis for an immersive and interactive user experience of the environment.

In addition, the plugin-layer integrates an RFID reader, which supplies information about the proximity of RFID-tagged objects. Furthermore, a button on the chest of the user provides options for discrete input. Finally, each user is equipped with an RGB-D sensor, which provides a colour and depth image stream for reconstruction of real objects in the VE. The system visualizes real objects, which are within two meters of the camera, so an individual user can see his/her entire own body and close objects/users. In order to track equipment items we equipped them with RFID-tags and the users with an RFID-reader on the dominant lower-arm. Once a user grabs such an object, the RFID-reader discovers the tag and the application layer updates the state of the object to be attached to a certain user's hand. In combination with tracking data from the motion capture suit, the system can determine the position of the object in world space to within an accuracy of about 25cm. In the multi-user environment other users can then see a corresponding virtual object rendered at the interacting user's hand position. In addition, we apply the rotation of the user's hand to the object so it is rotated in the approximately correct way and observers in a multi-user scenario can more easily interpret the action. The drawback of this approach is that virtual items have to be predefined beforehand, resulting in a decrease of flexibility compared to the RGB-D sensor based approach.

Furthermore, the multi-user management distributes the users' head poses and motion capture data, which is visualized by means of avatars. Therefore, not only can users visually follow the actions of others, but also they can communicate non-verbally by gestures, with a great benefit for collaborative scenarios.

Finally, in the current demonstrator we render video and audio output on a VR HMD.

In the next step the prototype will also provide integration of an AR HMD and gesture interaction targeting requirements of a command and control system. Furthermore, a mobile robot platform will be integrated for haptic feedback to increase realism and immersion of the simulation.

4.2 Server

The server part of the application layer contains a number of modules and interfaces providing functionalities to generate and manage the training simulation. Central element is the user-management and distribution service which is responsible for the multi-user collaboration. All positions and movements are synced with the server and sent to other users by using a multicast connection. Every client renders the movements of all participants and offers the possibility to trace their gestures and communicate visually. Furthermore, the usage of the gamepad eliminates the physical space restriction by offering a way to move around within the complete large-scale VE by a virtual vehicle without leaving their physical real world location. An accelerated navigation mechanism is used to distribute the translation data fast enough to accomplish a fluent simulation, which is critical for fast movements. Furthermore, the server provides multiple after action review (AAR) functionalities, to analyse, monitor and supervise the training process. The mentioned VE is managed and controlled by the server with a basic control UI, to give an operator the ability to maintain all actions and execute control different tasks.

Our concept also plans integration of various subsystems, mainly 3D GIS, “ABC-Informationssystem” and a separate planning and monitoring module. The latter will integrate with existing AAR methods and in addition allow creation and adaptation of training environments. Terrain data from a 3D GIS system will be integrated in the planning module, while real-time position data will be used in the future command and control system. Furthermore, integration with the "ABC-Informationssystem" will provide realistic data of CBRN contamination. Finally, integration of environmental sensors will allow realistic updates and predictions of contamination spreads and other environmental effects.

5.0 IMPLEMENTATION

The implementation of our current demonstrator system integrates a number of hard- and software components.

5.1 Hardware

The computational platform on the client side of our system (shown in Figure 2) is a mobile VR backpack PC, the Schenker XMG Walker with an Intel Core i7-6700HQ, a NVIDIA GeForce GTX 1070 8GB GDDR5 and 32GB of RAM running Windows 10. Furthermore, we use an Oculus Rift CV1 fully immersive HMD for visualization and audio output. Our system utilizes the IMU of the HMD together with a marker tracking solution running on monochrome images from an IDS uEye IDS camera uEye UI-3251LE (please refer to [26] for details on the tracking system). For the RGB-D sensor required in AV we are employing an Intel Realsense SR300 with a depth resolution of 640x480 pixel at 60fps and a RGB resolution of up to 1920x1080 pixel at 30fps. Both imaging devices attach to the HMD by a 3D-printed custom-designed clamp. Furthermore, the Perception Neuron motion capture system records users' arm and leg movements. In addition, the UHF-RFID reader Sparkfun M6E Nano provides input on proximity of tags.

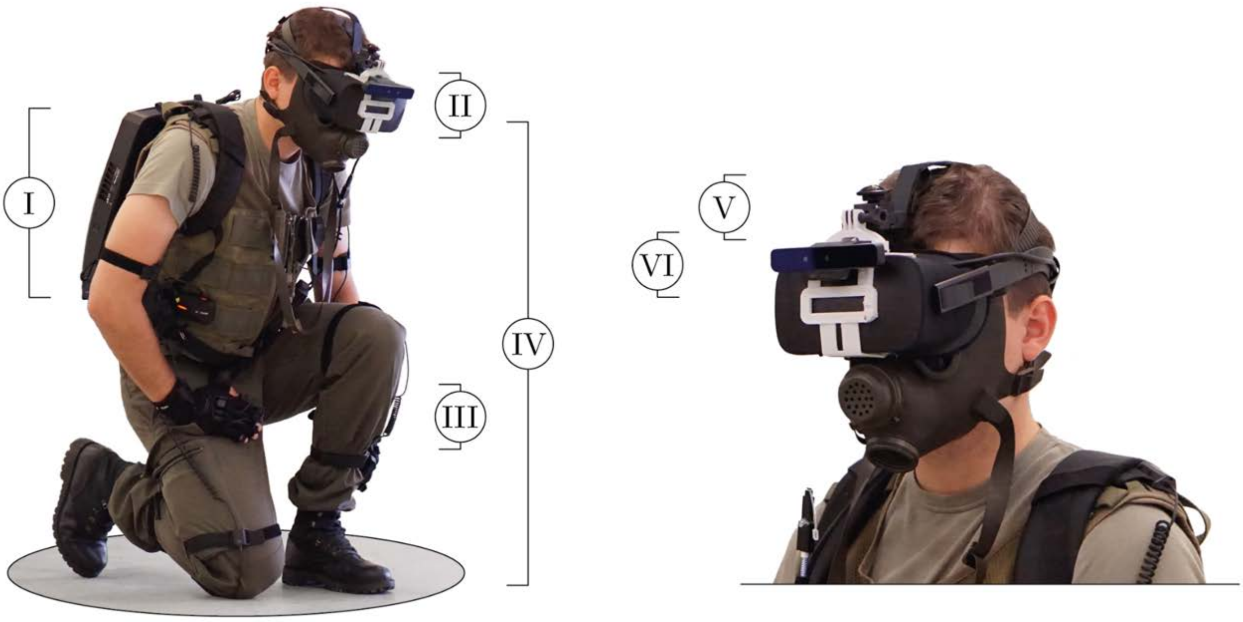

Figure 2: User wearing the setup with: I VR Backpack, II HMD, III RFID-reader, IV MoCap suit, V/VI tracking/RGB-D camera.

Finally, we use a push button and contact block of the RAFIX 30 FS + system wired to a NodeMCU development board. Fixed to the chest of the user in a customized 3D-printed enclosure (as seen in Figure 7) button presses bring up and select menu items in VR. In our current prototype all input devices are connected via USB cables to the backpack PC. The clients connect wirelessly to the server through Wi-Fi operating in the 5 GHz band. Therefore, each client-setup is independent and mobile within the Wi-Fi range.

The server runs on a PC with an Intel i7-7700 processor, 8GB RAM and an NVIDIA Geforce GTX 1060 graphics card. Due to the desktop setup the computational load is less demanding on the server side. Besides traditional mouse and keyboard input a Microsoft XBOX One controller is connected to the server for use in vehicle navigation.

5.2 Software

5.2.1 Framework

The software builds upon an updated version of the Immersive Deck framework as first described in [26] running Unity3D 2017.2.0f3 game engine [27]. Immersive Deck provides several functionalities enhancing development of a multi-user VR application. The basic configuration is a client-server setup, where multiple VR-clients connect to one desktop-server.

5.2.2 Application Scenarios

Our demonstrator implements a CBRN defence Recce based on the requirements summarized in subsection 3.1 and in close collaboration with specialists of the AAF. For this scenario, we created a virtual environment of 10x10km with a 2500m airspace, which is not yet the size that we plan for the final system. It is modelled after a real rural area located in northern Austria. The area includes a village with residential, administrative, commercial and industrial buildings (see Figure 3) and infrastructure like streets and is suited for training a motorized squad, although the focus of this work is interaction and collaboration in a dismounted CBRN operation in an area of approximately 15x15m. The major mission tasks in this scenario are observation and detection.

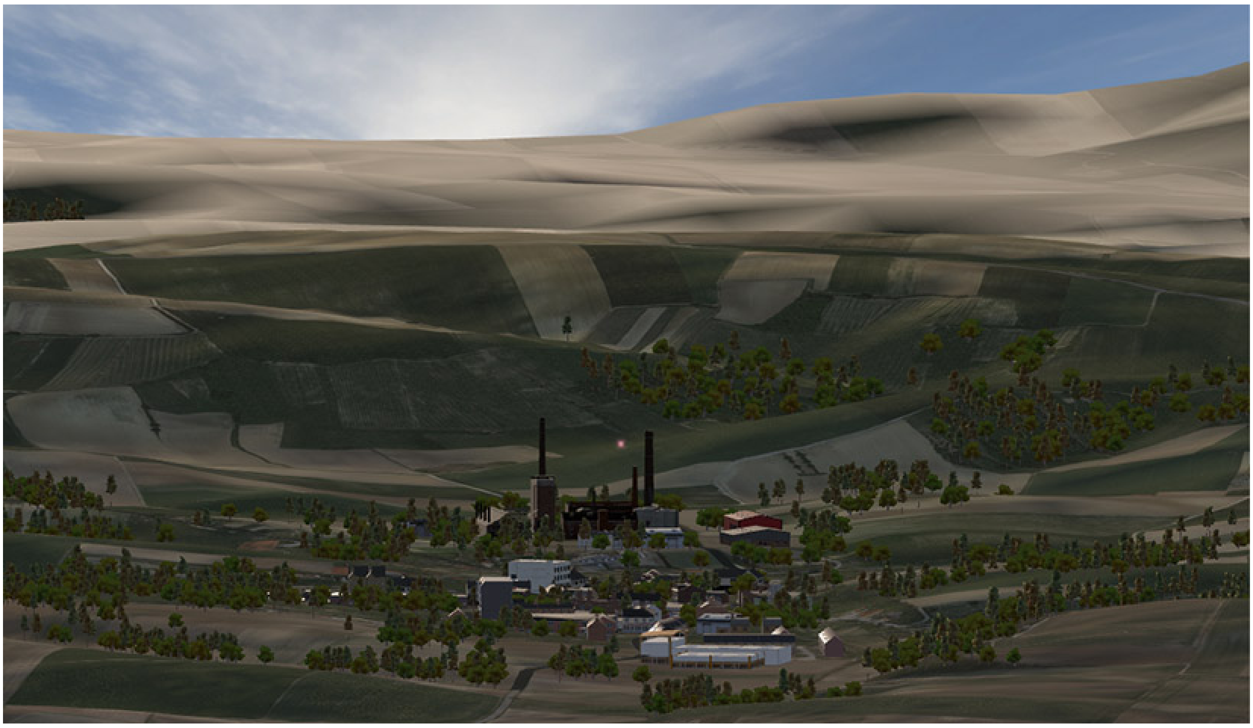

Figure 3: Screenshot of the training environment, showing a village modelled after a real environment.

An operator can configure the scenario regarding the simulated hazard materials - i.e. chemical agents in various physical states - the weather conditions and time of day. Users are able to move within the entire area by natural walking and a virtual vehicle (Pinzgauer 710FM), which can bridge larger distances.

Figure 4: Vehicle (Pinzgauer 710FM) for navigation within the training environment (left). Avatar of a soldier operating the ECAM (right).

The CBRN squad staff can wear their actual defence protection suites and additional equipment and radio sets, if required. For the observation task we implemented a binocular (zoom) feature, as-well-as a compass and height angle protractor. The development of virtual contamination scales enhances the detection task. While most devices themselves are integrated via our MR approach, displaying data flexibly and consistent with the VR simulation would be a challenge. Thus custom HUD elements show the information in a similar fashion as on the display of the device. Figure 4 shows a CBRN specialist holding an Enhanced Chemical Agent Monitor (ECAM) in our application.

5.2.3 Operator Interface

The operator interface provides a central UI to control various server functionalities and modules as illustrated in Figure 5. We separated the main window visually into six regions, where every part has its own functionalities. Some include interactive elements and others are only capable of monitoring the scene while the rest offers additional information about the training simulation, e.g. the minimap (III) or the timer (VI). The visual appearance combines several grey shades and a turquoise highlight colour. Therefore, the focus stays on the important elements and points out their actions. The UI for the operator has to offer multiple functions that are stated in the section 3 on the requirements. The main viewport uses the largest amount of space (I). It offers the possibility to supervise the sequence within the three dimensional scene. The operator chooses a camera view on the right side (II), which is expanded afterwards into the main window. We implemented four different perspectives to choose from, which include a free moving camera controlled by mouse and keyboard input, one that is attached to the virtual vehicle, though it is able to look around freely, one for every individual with its first-person perspective and a stationary one that users can place inside the VE. Four cameras of the last type are available to be positioned and the operator can switch between them with the numbered buttons at the bottom of the scene view (I). All virtual cameras, except those of the participants, are controlled with mouse and keyboard input. The user is able to drag the view in every direction and move the position with the WASD-keys, which results in an easy to use and adaptable point of view over the entire scene. The fluent switch between these aspects offer an instructor many options, to configure his monitoring interface as suitably as possible. Another part of the graphical interface is a minimap (III) (see Figure 5), which is located inside the main view. Figure 6 illustrates the details of this component that shows a map of the terrain from above. Users are able to adjust zoom or extend it to the complete main window with buttons located on the left (I). Besides illustrating the position of the vehicle (III) the predefined area of incidents is marked with a dotted texture (II) and the contaminated region is coloured in turquoise (V). All elements are arranged accordingly around the current active camera (IV). Various interactive elements give an operator the ability to manipulate and interact with a training sequence (see Figure 5 (IV)). Starting from the left upper corner, the first button toggles the visibility of the minimap, while the second one is responsible for the symbols within the map, as for example the vehicle. The event and the contamination buttons toggle the visualizations of the event/contamination areas in the minimap as well as in the 3D scene. In addition, the operator can reduce the user's range of sight, by turning on a particle based rain visualization. Furthermore, a translation switch activates the ability to move the selected camera with the keyboard. Additionally, the operator can unlock a predefined series of explosions, which can be released with the explosion button. Finally, the last button enables a debug window (see Figure 5 (V)), which provides information and error messages concerning the state of the simulation.

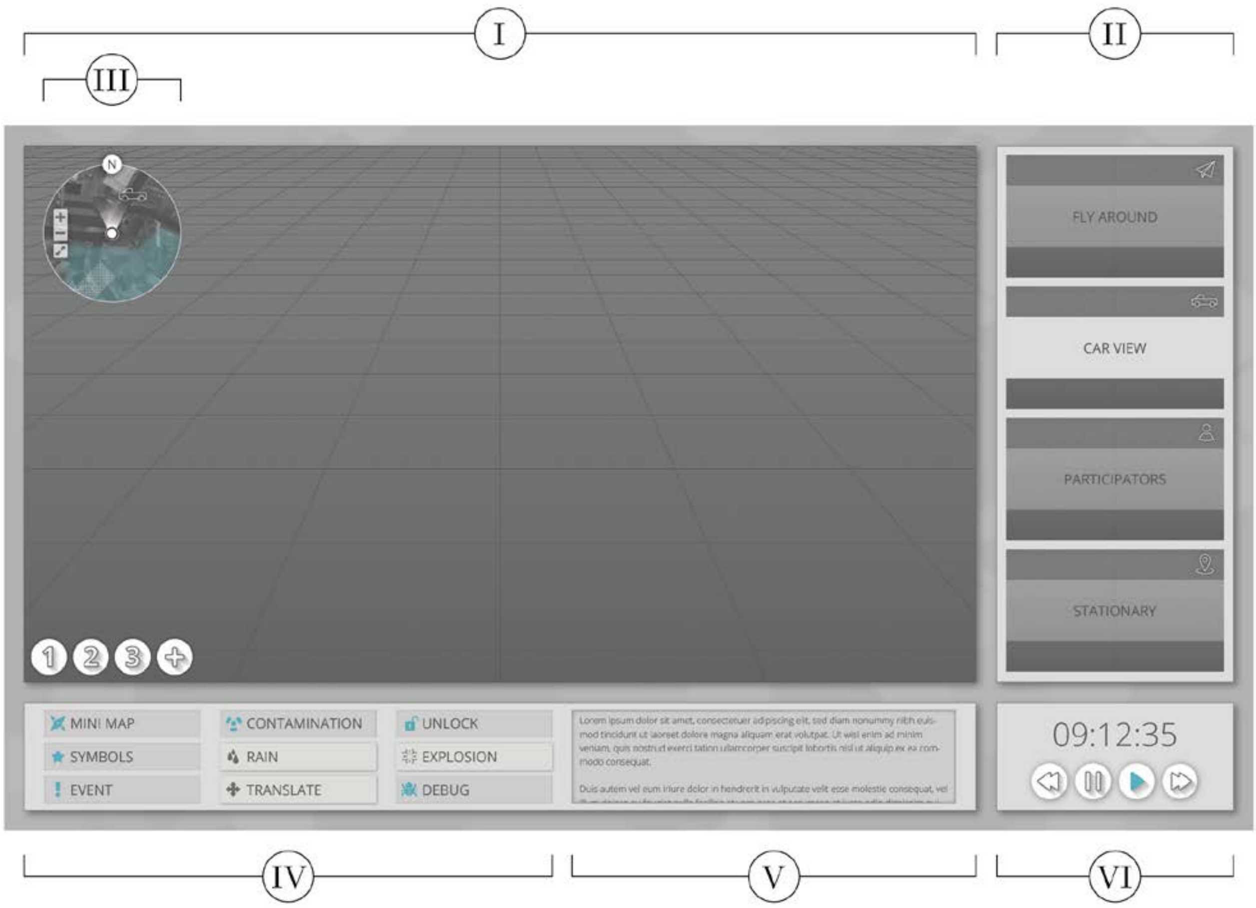

Figure 5: The operator UI with different functional regions including the main scene view (I), four different camera perspective settings (II), a minimap (III), function keys (IV), a debug output window (V) and a time control and recording panel (VI)

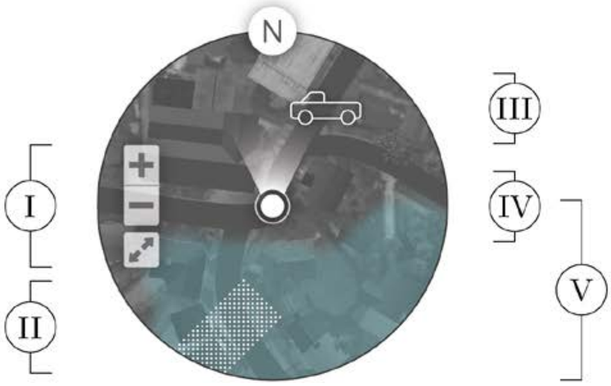

Figure 6: The minimap including zoom tools (I), the location of the incidents (II), the virtual vehicle (III), the position and rotation of the current selected camera aspect (IV) and the region of contamination (V).

Finally, a time control and recording panel (VI) provides capabilities for AAR. It allows timing of the simulation and recording of videos from training sessions. All described functionalities offer various capabilities to monitor training sequences and trigger events within the simulation. In this highly adaptable interface, operators can utilize those features that suit best for their needs.

5.2.4 Large Virtual World Generation

To provide realism in the simulation, an area with approximately ten by ten kilometers in Northeastern Austria was selected to be transferred into our VE. We use satellite images from Google Maps [28] in our demonstrator. The images have a total resolution of 10240 to 10240 pixel. Each pixel represents one square meter in reality and before importing them into Unity3D, the image is divided into 25 tiles with dimensions of 2048 to 2048 pixels, as this is the maximum the engine can handle on terrains. To give the terrain its height profile, we used a digital ground model from data.gv.at [29] with a grid of ten by ten meters, which is converted with QGIS [30] into a 16bit greyscale raw image. The raster images stores surface elevation data, which is converted by Unity3D into terrain meshes. The imported heightmap does have a lower pixel density and therefore steps occur on the terrain. A smoothing tool removes them and the plugin TerrainStitcher [31] merges all tiles into one big mesh without gaps. The Unity3D plugins Gaia [32] and EasyRoads3D [33], add world elements such as trees, houses, grass, and streets.

5.2.5 Multi-User Interaction

The server manages connections to multiple clients and allows customization of the clients' avatars through a customized GUI. Properties like player height can be calibrated in this GUI. Besides distribution of avatars' and objects' poses the server controls the ownership of objects equipped with RFID-tags. Once an RFID-reader detects a tag, the corresponding client sends a call to the server, which in turn attaches the object to the user's hand and notifies all clients to do the same. Similar to its avatar the client assumes control of the object and the movement originating in the client's motion capture suit is synchronized over the server to all clients. In this way multiple users can train together as shown in Figure 7. We built our current system for a squad of max. four people, however it could be extended to more, limited mainly by aspects like network bandwidth and server performance.

5.2.6 Augmented Virtuality

We integrated the Intel Realsense SR300 by accessing the Software Development Kit (SDK) 2016 R3 from Intel [34] from the plugin layer in our system. The SDK offers functions to start streaming frames, extracting pixel values and many more. The plugin opens a stream and provides RGB and depth data as color (1280x720) respectively monochrome (640x480) image data. We transform both into a Unity3D texture and use a mesh with 14400 vertices as basic geometry. To texture the mesh properly the RGB and depth images are aligned, filtered and the vertex positions of the meshes set according to depths in a strongly optimized process. Through the texture's alpha value we continually fade out pixel, that are too far for near range augmented virtuality or too close to the sensor's minimum operation distance.

6.0 EVALUATION

We conducted a user study with early versions of the system with 13 participants, from the National Defence Academy and Competence Center NBC Defence of the Austrian armed forces. Figure 7 shows four users in our VR training system at the Competence Center NBC Defence.

The emphasis in this evaluation was placed on navigation, interaction with virtual equipment, collaborative training with multiple users, training environment, trainer evaluation and education in CBRN defence. In addition, we collected data on interaction with real objects in a mixed reality setting.

6.1 Demography

Thirteen participants were involved in the experiment (12 male, 1 female), with an age between 19 and 51 years (μ =34, σ =12). All participants are experts in the field of CBRN defence from the National Defence Academy and the Competence Center NBC Defence of the Austrian armed forces. All but two occupy leading positions and all are associated with training and education activities. Only a small number of experts with this kind of qualification exists on a national as well as an international level and volunteers are therefore very hard to find. Seven participants reported previous experience with VR. All participants considered themselves to be average or moderately fit.

6.2 Methodology

We evaluated early versions of the system at two separate occasions approximately half-a-year apart with six respectively seven participants. We used feedback of the first round to improve certain aspects of the demonstrator for the second. After filling in a short pre-questionnaire, the users could explore the open world and system features freely in groups of two to four people and in their own time. During the test, the experimenters encouraged the participants to try out functionalities or procedures. During one of the occasions six of the participants were asked to also use the operator interface of the system.

After the tests, we asked the participants for their opinion on a number of aspects of the system and the application. We used questionnaires with a five point Likert scale and some open questions.

6.3 Results

The presentation of results in this paper mainly focusses on questions regarding navigation, interaction with virtual equipment, collaborative training with multiple users, training environment, trainer evaluation and education in CBRN defence. The results of interaction with real objects in a mixed reality setting are not discussed here, because it would be beyond the scope of this publication.

Figure 7: Users during multi-user CBRN recce training, wearing protective masks and VR equipment.

6.3.1 Evaluation of the Trainee Perspective

Our system provides two modes of navigation within the virtual environment. The first is navigation in a virtual vehicle, which one of the users can control by gamepad. The second is navigation by walking. We have evaluated both modes separately according to difficulty, speed and users' preference.

Navigation with the gamepad was rated simple or very simple by most users ($\mu = 4.18, \sigma = 0.75$). Most of the users had already at least some experience in the use of gamepads ($\mu = 3.39, \sigma = 1.26$). However, no correlation between prior experience and ease of use in our VR simulation could be established. The speed of navigation with the gamepad and virtual vehicle was rated little above average ($\mu = 3.18, \sigma = 1.25$). This might be attributed to the fact, that we set the maximum speed of the virtual vehicle to about half of the real vehicle's approximately 100km/h in order to avoid cyber-sickness. However, improvements of synchronization of vehicle movement in the current version of the demonstrator should allow for higher speeds. Finally, about half the users at least somewhat liked the navigation method ($\mu = 3.71, \sigma = 0.95$), again no correlation could be found to prior experience. From the users' written answers and comments we know that control of the virtual vehicle with the gamepad can be challenging in certain situations. Current and future optimizations will target vehicle physics to avoid frustrating situations.

Ten of the participants rated navigation by walking - supported through our wide-area tracking system - as easy or very easy ($\mu = 3.77, \sigma = 0.93$). The speed of navigation was rated above average

($\mu = 3.39, \sigma = 1.33$), although with significant deviations among the users. Overall, the navigation method was liked or liked very much by most users ($\mu = 3.64, \sigma = 1.12$).

We evaluated a number of virtual equipment options (compass, height protractor, binoculars, enhanced chemical agent monitor) during the second evaluation-round with six participants. Interaction with the menu itself was rated mostly positive ($\mu = 3.67, \sigma = 1.21$, respectively $\mu = 4.0, \sigma = 1.0$ when only considering participants with normal vision). However, inaccuracies in tracking, especially in border-regions of the tracking area, made it more difficult for some users to select menu items by coordinated button presses and head-rotations, which might account for the large variance of the responses. Interaction with the compass was considered easy or very easy by all participants ($\mu = 4.33, \sigma = 0.52$). Difficulty of using the height protractor was answered similarly well ($\mu = 4.4, \sigma = 0.89$). Handling of the binoculars has been rated slightly more difficult ($\mu = 3.5, \sigma = 1.64$, respectively $\mu = 4.0, \sigma = 1.22$ when only considering participants with normal vision). Especially feedback of one participant suggests different placement of the visualization. This is also true for visualization of readings of the enhanced chemical agent monitor, which especially while wearing a protection mask resulted in bad visibility at the users' periphery and only average ratings for ease of use ($\mu = 3.0, \sigma = 1.23$).

Please refer to Figure 8 for an illustration of some of these results.

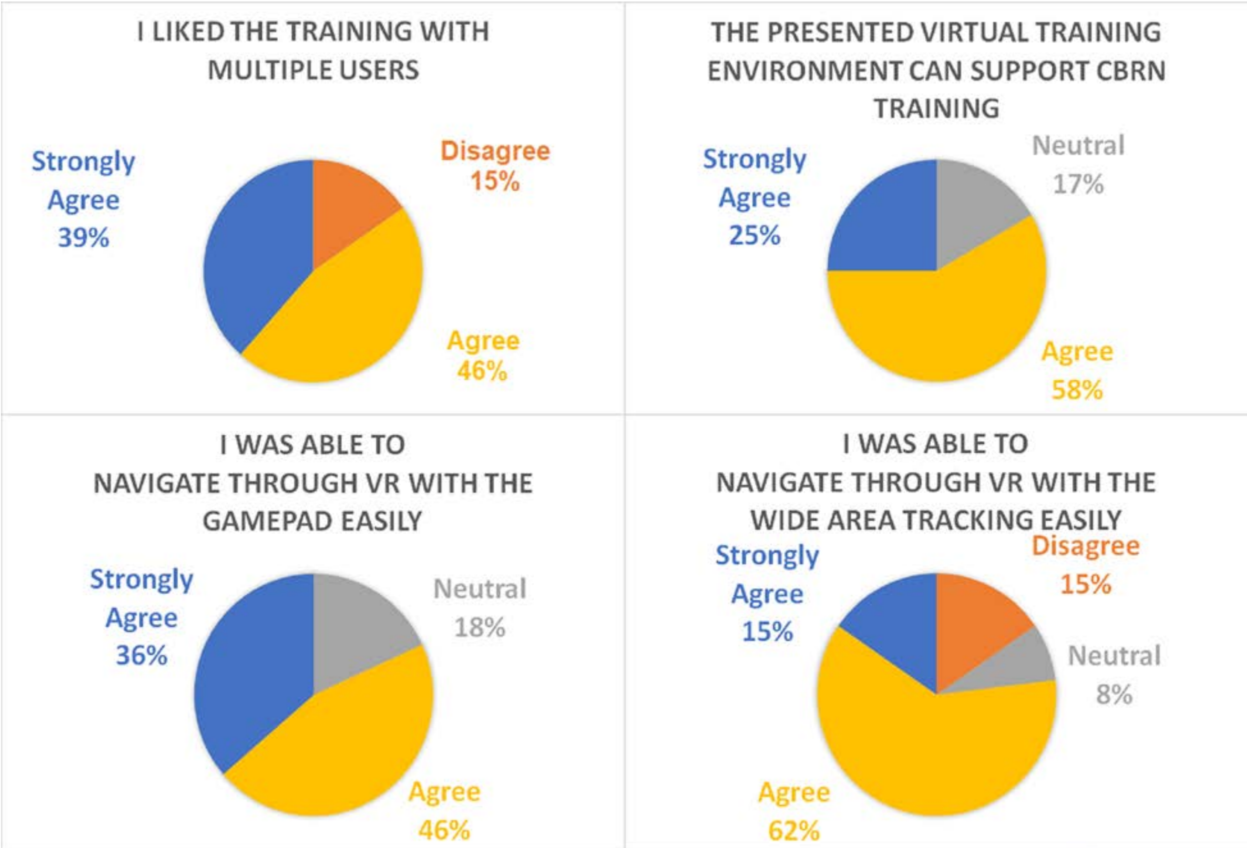

Figure 8: Results from the questionnaires regarding VR CBRN training.

We asked a number of questions regarding the quality of the virtual training environment and usability of the VR equipment. Most of the users felt a strong immersion into the virtual world ($\mu = 3.85, \sigma = 0.8$). Even more, our expert users agreed that the virtual training environment presented in the demonstrator can support CBRN training ($\mu = 4.08, \sigma = 0.67$). Participants in average rated the suitability of the simulation' s visual quality as good for an observation task ($\mu = 3.92, \sigma = 0.86$) and sufficient to good for a detection task ($\mu = 3.62, \sigma = 0.96$). The results regarding the visual quality of various objects and elements of the simulation was rated similarly for the terrain ($\mu = 3.92, \sigma = 0.86$), the vegetation ($\mu = 3.62, \sigma = 0.87$), buildings ($\mu = 3.85, \sigma = 0.80$), roads and pathways ($\mu = 3.5, \sigma = 1.0$) and events ($\mu = 3.67, \sigma = 0.78$). Only the avatar just received an average rating of ($\mu = 2.92, \sigma = 1.38$).

The participants agreed very much on the importance of being able to train with multiple users ($\mu = 4.92, \sigma = 0.28$) in the application scenario. In general, users liked training with others in the system ($\mu = 4.08, \sigma = 1.04$). They were able to communicate with their partners ($\mu = 3.42, \sigma = 1.24$) and could also follow the actions of their training partners ($\mu = 3.83, \sigma = 0.58$).

The overall ratings for statements above regarding collaboration and avatar dropped mainly due to calibration issues with some of the inertial motion capture suits (users complained in the free comments about twisted or disappearing avatars). This explains also the outliers regarding the first multi-user questions illustrated in Figure 8. Considering only users where the calibration worked properly, the values are better by around a half point.

Finally, we asked our last seven participants if the VR equipment was comfortable and easy to wear, which was much agreed on ($\mu = 4.14, \sigma = 0.69$), while comfort and ease of use degraded significantly, when combined with CBRN protection equipment ($\mu = 2.75, \sigma = 1.26$).

In the end, eleven of the participants agreed “much” or “very much” that the presented system can be used to support training for CBRN-crisis preparedness. One user considered it “very interesting as complementary training".

6.3.1 Evaluation of the Trainer Perspective

During the user-study we gave six of the participants the chance to use to use the system from the operator side through the monitoring and controlling interface described in subsection 5.3.2. This subsection presents results from the post-questionnaire. The participants found it very easy to observe the simulation and retrace the participants movements and the whole training sequence ($\mu = 4.5, \sigma = 0.76$). The functionality to interfere and trigger incidents within the simulation received even better feedback ($\mu = 4.67, \sigma = 0.47$).

These two statements point out that our developed control interface offers a good way to supervise and monitor all procedures. Furthermore, users found the handling of the interface appealing in general ($\mu = 4.33$, $\sigma = 0.47$).

A number of statements regarding the usability of the operator interface were presented to the users. The complexity of the UI was rated very low with a mean value of $\mu = 1.5$ and a standard deviation of $\sigma = 0.50$. Usage of the interface on the other side was rated very simple ($\mu = 4.33$, $\sigma = 0.75$). Five out of the six participants agreed that no technical experienced personnel would be necessary for assistance during a training sequence. Consequently, we could conclude that almost all of them are confident with using the system by themselves as all functionalities and actions are properly mapped onto the UI for an intuitive operation. This is also supported by agreement to the next statement about good integration of the different functionalities in the interface ($\mu = 4.67$, $\sigma = 0.47$).

All participants agreed much or very much ($\mu = 4.50$, $\sigma = 0.50$) that also other people would learn using the interface quickly and most of them are sure that they handled the GUI correctly ($\mu = 4.33$, $\sigma = 0.47$) without having to learn a lot of things.

All participants agreed “much” or “very much” that the operator interface can support training in CBRN defence ($\mu = 4.67$, $\sigma = 0.47$). Furthermore, we asked the participants to rate and rank the three features

“Monitoring of training sequences”, “Ability to switch camera perspectives” and “Ability to position incidents”. Although the three aspects received the same average rating of 4.67 “Monitoring of training sequences” and “Ability to position incidents” each was ranked first by half of the users.

Participants declared their positive and negative experiences with the operator interface in an open questions section. Multiple statements in the open questions deal with a debriefing, to be more precise, capture camera outputs for analysing all occurrences and actions during the simulation. These features of an AAR are already implemented in the current version of the demonstrator, while the request for contaminations moving downwind will be implemented in the future prototype.

6.4 Discussion

From the results we can see that the proposed multi-user VR system is highly relevant for the use-case. Participants found it relatively easy to navigate within the training environment by gamepad and natural walking. However, we observed relatively large variations in perceived interaction speed and preference for both navigation methods. One reason for this might lie in the differences how participants were coping with imperfections in tracking quality, a property that is continually improving in current and future implementations.

Difficulty of using the various virtual equipment items was rated between average and very simple. Especially using a cursor and running scale for compass and height protractor in the implemented form therefore appears to be a good solution in the proposed context. Others were easy to improve by small adaptations of the UI items following user input, such as the readings of the enhanced chemical agent monitor. Some features, such as the menu item selection itself, will be improved through updated versions of the tracking system, as stated above.

The quality of the virtual training environment and different virtual objects was largely rated as well suited for the various tasks. Nevertheless, there is room for improvement in the visual quality of certain elements such as roads and vegetation. However, there is always a trade-off between performance and visual quality. Additionally, tracking as-well-as other back-ground tasks of our VR-system limit the available resources further. Especially in combination with the vast virtual environment we had to reduce geometric detail and texture resolution in several cases to achieve frame rates suitable for VR. Future system configurations with more CPU- and GPU-performance, however, could alleviate these restrictions.

Furthermore, the level of detail is usually limited, when using freely available aerial images that can be used to texture terrain. The same is true for freely or cheaply available 3D models. Therefore, visual quality is also a cost factor, even more so with the time- and cost-effort when modelling customized content.

Multi-user training and collaboration is a corner stone of the proposed application area, which was confirmed by the experts in our questionnaires. Feedback regarding these aspects was largely positive, despite some technical issues. Fast, reliable and secure distribution of data, especially between many users, is challenging and will be a critical aspect on group and platoon level.

Two participants of our user-study had corrected vision, but could not wear their glasses with the HMD. Therefore, in certain situations of the training they had problems with the visual perception of the environment, e.g. properly seeing their training partners’ actions. In the future, corrective lenses incorporated in the HMD could provide an improvement for users with vision aid. Unfortunately, currently not many HMD manufacturers offer this feature. Nevertheless, collaboration in a multi-user scenario was possible and very much appreciated by the users. Furthermore, our novel system makes it possible to follow other user's interactions with equipment items.

The equipment necessary for the VR system alone was considered comfortable to wear, while the combination with CBRN equipment was rated significantly less comfortable. We did not ask the participants for their opinion on the CBRN equipment alone in the questionnaires, but from discussions following the study, we conclude that discomfort largely results from the protection mask itself rather than the combination.

The results from the evaluation of the operator interface show very encouraging results. The design of the interface hides unnecessary complexities from the operator and exposes only relevant core-functionalities. Responses of our expert users rated the interface easy to use and easy to learn. In the long term, the fact that most participants would consider technical assistance during operation unnecessary is very important for cost-efficient operation. Although we have not evaluated the AAR capabilities of the operator interface yet, we are very optimistic regarding future user-studies, since they follow the same design paradigms as the rest of the interface and incorporate a lot of feedback from our expert users.

7.0 CONCLUSION & FUTURE WORK

We have presented how we transferred requirements of CBRN training into the implementation of a demonstrator providing an immersive multi-user VR training environment. Besides the requirements, we showed a visionary design concept and described in detail how we implemented parts of this concept into a working demonstrator. The demonstrator provides a large number of features including navigation, interaction with virtual and real equipment, collaborative training with multiple users, wide-area training environment, trainer evaluation and education in CBRN defence.

Furthermore, we implemented one of three scenarios offering training possibilities in a CBRN defence recce, which would require massive effort when simulated in reality. Multiple experts from the AAF evaluated an early demonstrator and qualitative and quantitative results show a high acceptance and potential of the system. Most of the system's features showed to be easy to use and more than adequate for the purpose. Due to the early stage of the demonstrator during evaluation, smaller technical issues reduced usability of some aspects, but overall feedback was very positive, suggesting that the system can be used to support training for CBRN-crisis preparedness.

In future work we plan to extend the current demonstrator to a more powerful prototype including all features presented in the system design. This includes extensions towards MR, with integration of an AR HMD and gesture interaction targeting requirements of a command and control system. Furthermore, a mobile robot platform will be integrated for haptic feedback to increase realism and immersion of the simulation. In addition, we plan on the integration of various subsystems, mainly 3D GIS, “ABC-Informationssystem” and a separate planning and monitoring module. The latter will integrate with existing AAR methods and additionally allows creation and adaptation of training environments. The final system will be able to generate a broad range of scenarios and configurations, providing the means of also simulating training situations, which are too expensive or dangerous to create in the real world. Furthermore, integration with the “ABC-Informationssystem” will provide realistic data of CBRN contamination. Finally, integration of environmental sensors will allow realistic updates and predictions of contamination spreads and other environmental effects. Future prototypes will emphasize multi-user training with group and platoon size at a higher technical readiness level, benefitting also from new and improved technologies (e.g. motion capture suits, tracking etc.). We plan to continue the project with Austrian and international partners and funds from Austria's FORTE defence research program and more long term with funding from the European Defence Agency.

8.0 ACKNOWLEDGEMENTS

We thank Jürgen Schlechter, Klaus Kothgasser, Olivier Foissy and Friedrich Binder for the contribution of their expert knowledge in the area of CBRN defence training and their support during tests of our system.

Moreover, we extend our thanks to Annette Mossel for her valuable analysis regarding the requirements of VR CBRN defence training, which are summarized in the first sections of this paper and published in full length in [7] and [8]. Furthermore, we want to thank Thomas Wechdorn and Bernhard Rainer for their valuable contribution in the development of the system. This work was funded in large parts by the Ministry of Defence and led by the National Defence Academy, together with the project partner TU Wien. We gratefully acknowledge the support of NVIDIA Corporation with the donation of a GeForce GTX 1080 Ti used for this research.

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