TOWARDS AN IMMERSIVE VIRTUAL REALITY TRAINING SYSTEM FOR CBRN DISASTER PREPAREDNESS

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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 that implies improved learning through an increased amount of presence. In this paper, we present a thorough analysis of the state of the art of virtual reality training systems and outline the requirements of two peer stakeholders for disaster relief with an explicit focus on CBRN disaster preparedness. We compare both analyses to specify if - and to which extent - existing virtual reality training solutions meet the stakeholder requirements. Based on the comparison, we present an outlook on existing and upcoming virtual reality components that have the potential to fulfil the stakeholders' requirements of a flexible multi-user immersive virtual reality training system.

Keywords: Virtual and Augmented Reality, First Responder, CBRN Disaster Preparedness, Scenario and Decision Simulation

1. INTRODUCTION & MOTIVATION

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. 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 disaster preparedness has been increasingly recognized as an important adjunct to traditional modalities of real-life drills. Multiple studies, i.e. (Freeman et al. 2001; Wilkerson et al. 2008; Vincent et al. 2008; Farra et al. 2013) 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 decline 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 (IntelligentDecisions 2015; Motion-Reality 2015). 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 disaster 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 such as flexible VR training system, we performed a thorough analysis of the state of the art of existing VR training systems. Furthermore, we analyzed the requirements of two peer stakeholders with a focus on chemical, biological, radiological and nuclear (CBRN) disaster preparedness. Subsequently, we compared both analyses to be able to formulate necessary future steps to develop a VR system meeting the essential stakeholder requirements. To summarized, the paper presents the following two contributions:

1. A comprehensive state of the art analysis that outlines the capabilities of existing VR systems for multi-user training.
2. A requirement analysis of two peer stakeholder - the Austrian Federal Ministry of Defense and Sports (BMLVS) and the Red Cross Innsbruck, Austria - with a focus on CBRN training tasks. Three uses cases are developed that describe training scenarios that would be highly beneficial to be trained with a VR system.

2. STATE OF THE ART ANALYSIS

Employing VR technology to train first responders and relief units is an ongoing research topic for about one decade (Stansfield et al. 1999) 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)* (Ivin3D 2011) is a tool offering 360° building walkthroughs that are visualized on a mobile device's display. The building's' 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* (University-Of-Southern-Mississippi 2015) is a desktop-based virtual training scenario simulating the challenges of a stadium evacuation with thousands of avatars, and the *Virtual Terrorism Response Academy* (Dartmouth-College 2015) 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)* (U.S.-Army 2015a) 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 (Farfard 2013). 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 a 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)* (U.S.-Army 2015b) 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)* (Ameldefense 2015) 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)* (Rheinmetall-Defense 2015b). 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* (Marin 2015) 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 (Szenaris 2015) (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* (Bohemia-Interactive 2015) 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.

Figure 1: Multi-user training with Virtual Battle Space (Bohemia-Interactive 2015)

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 (see Figure 1). It is used by a number of armed forces worldwide, including the U.S. Army, U.S. Marine Corps, UK Ministry of Defense, 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* (E-semble 2015) 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)* (ETC-Simulation 2015) 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. One example of the 3D simulation is given in Figure 2. 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.

Figure 2: Decontamination simulation with ADMS (ETC-Simulation 2015)

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)* (Rheinmetall-Defense 2015a), 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)* (IntelligentDecisions 2015) 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. The DSTS suite is depicted in Figure 3. 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 VSMM allows each dismounted soldier to stand, crouch, jump and lay during the exercise. Movement and thus navigation is done by button controls at the weapon.

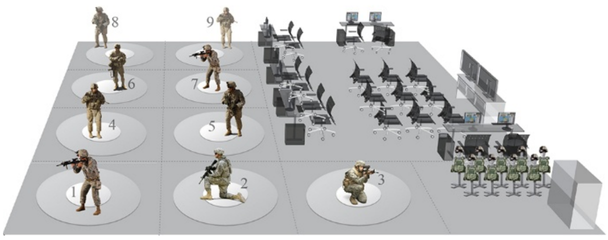

Figure 3:Setup of one DSTS suit (IntelligentDecisions 2015)

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* (Crytek 2015), 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* (The-Verge 2015), 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 (Motion-Reality 2015) 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, as shown in Figure 4. 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 (see the red lights in Figure 4), 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.

Figure 4:Natural walking in immersive VR with VirtSim (Motion-Reality 2015)

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 maneuvers of participants as well as team and squad maneuvers. It provides playback of all actions and shots from every angle, and from each participant's perspective.

3. REQUIREMENT ANALYSIS

A requirement analysis was conducted by two peer stakeholders for disaster relief, the *Austrian Federal Ministry of Defense and Sports (BMLVS)* and the *Ambulance Team of the Red Cross Innsbruck, Austria*. Within this analysis, the interests and requirements of both stakeholders' CBRN defense 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.

To identify VR-relevant training parameters, the skill catalog for CBRN defense of the Austrian Armed Forces was used as base. Some selected skills are listed below for the subareas CBRN recce, decontamination, search and rescue, water purification as well as aircraft rescue and CBRN explosive ordnance disposal:

- CBRN collective protection
- Advisory services
- CBRN warning and alert
- CBRN observation
- CBRN exploration
- CBRN warfare agent examination
- Partly decontamination
- Full decontamination
- Finally decontamination
- Water testing
- Water purification
- Urban search and rescue
- Deflecting fire protection
- Aircraft rescue

All of the skills were subsequently analyzed with the following parameters:

- Training form
- Infrastructure
- Time resources
- Material resources
- Human resources
- Cost

In a second step, the identified skills were bundled (*skill bundles*) to find possible combinations for the purposes of dependencies with an influence matrix for the further analysis. So with the first step the relevant skills were identified and the second step was to reduce to some skill bundles. At least three skill bundles with a high potential to be trained in VR were identified:

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

It has to be noted for skill bundle 3, that special CBRN defense platoons in duty exist on military airfields. Their main task is aircraft rescue after a crash while CBRN defense is an additional tasks with lower priority. Beyond the above mentioned skills for CBRN defense, the skills for decontamination and firefighting have been included into the analysis. The skills for CBRN collective protection, water purification as well as specific explosive ordnance disposal were identified as not relevant for VR training.

Based on the identified skill bundles, three use cases have been derived that are described in detail in the following subsections. All three uses cases outline training scenarios that would be highly beneficial to be trained with a VR system.

3.1. Scenario: *CBRN Defense 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 defense 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, as shown in Figure 5.

Figure 5: Armored CBRN recce vehicle and dismounted soldiers

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 defense 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 team, 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-storey high building has a cellar and shows different damages caused by an earthquake. Examples are given in Figure 6. It shows a typical earthquake scenario with totally damaged buildings as well as medium and light damaged ones.

Figure 6: Austrian Forces Disaster Relief Unit (AFDRU) on an earthquake site, Turkey

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 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 Defense*

This scenario aims at training of some specific CBRN-defense 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. Derivatives

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

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

The specific derivatives were categorized as:

- Specific Movements
- Specific Manipulations

For the scenario *CBRN Defense 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 derivatives were identified. One example is given in Figure 7 in which the identified derivatives for the activity “Operate CBRN observation post” are outlined.

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**
movement	going
	running
	sitting in vehicle
	lay on the ground
	bend down, lay down
specific movement	**dismount**
Customization of Scenario Content & Parameters	virtual persons
	hazard - chemical agent
	hazard - nuclear explosion

Figure 7: Derivatives for activity “Operate CBRN observation post”

To specify these derivatives, 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 Defense recce scenario consists of seven activities. For each of activity the content was formulated and analyzed with regard to its applicability in a VR training application.

4. TOWARDS AN IMMERSIVE VR SETUP

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

4.1. Virtual Reality Objectives

The training environment should be 1) fully immersive to exploit the advantages of learning in VR, 2) it should provide 3D object interaction (selection and manipulation), 3) natural walking for navigation and to realistically simulate stress and exhaustion, and 4) it and should be multi-user capable to allow for collaborative training.

4.2. Hardware Objectives

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

4.3. 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.

4.4. Discussion & Conclusion

The summarized peer stakeholder requirements are not met entirely by any existing system. While DSTS offers fully immersed multi-user training, it does not provide natural walking and 3D object interaction. VirtSim offers full immersion combined with real walking, but does not provide the unbound creation of new training scenarios. Furthermore, both DSTS and VirtSim are too expensive for many disaster relief units to be implemented as an everyday training system. The software framework of both Virtual Battle Space and XVR are promising, as they provide rich 3D scenario generation, parameter customization, high quality rendering and an after action review module. Both work with standard hardware, making the system capable to be extended with off the shelf VR hardware. This is particular true for Virtual Battle Space as it provides an open platform architecture. Although the Advanced Disaster Management Simulator offers a rich scenario editor for disaster training, its proprietary hardware making the system incapable for 3rd party extensions.

To conclude, a novel hard- and software VR system must be developed that should built-upon existing solutions. It is subject to future work to evaluate if either Virtual Battle Space or XVR should be employed as core software technology. Both need to be heavily extended to communicate with the required immersive VR hardware. The recently as free-to-use released game engine *Unreal* should be also considered at future developments, as provides high quality rendering and physics support. Commercially available and upcoming VR hardware, in particular *Samsung Gear VR* for fully immersive stereoscopic scene viewing, *Virtuix Omni* or *Cyberith Virtualizer* to provide natural walking, and *Microsoft Kinect* as structured light sensor for natural 3D object interaction have the potential to form the hardware base that meet the outlined stakeholder requirements.

5. CONCLUSION

In this paper, we outlined the current state of the art in immersive VR training systems for military and civil usage and described the requirements of two peer stakeholders with a focus on CBRN disaster preparedness. Both analyses form the two main contributions of the paper. Subsequently, we evaluated the two analyses to specify if - and to which extent - existing solutions meet the stakeholder requirements.

We came to the conclusion that no available systems can satisfy all demands and that no existing solution focuses on CBRN preparedness training in immersive VR. Thus, we formulated an outlook on upcoming VR components that have the potential to fulfil the stakeholders' requirements of a flexible, multi-user immersive VR training system.

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