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3D Interaction within a Multi-User Distributed Untethered Virtual Reality Training Simulation

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Mitwirkung: Projektass. Dipl.-Ing. Dr. Annette Mossel

Wien, 19. September 2017

Rafael Perndorfer | Hannes Kaufmann

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DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieur

in

Medical Informatics

by

Rafael Perndorfer, BSc
Registration Number 01025707

to the Faculty of Informatics

at the TU Wien

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Vienna, 19th September, 2017

Rafael Perndorfer

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Erklärung zur Verfassung der Arbeit

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Wien, 19. September 2017

Rafael Perndorfer

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Kurzfassung

Katastrophen passieren weltweit, an manchen Orten öfter als an anderen. Das Vermeiden dieser steht an erster Stelle, ist jedoch eine Katastrophe unumgänglich oder außerhalb des menschlichen Einwirkungsbereichs, müssen gute Vorbereitung getroffen werden, um eine gute Versorgung zu gewährleisten. Nicht nur materielle und bauliche Maßnahmen müssen getroffen werden, sondern auch personelle Vorbereitungen. Ein großer Schadensfall verlangt von allen Beteiligten sehr viel ab. Gerade Führungskräfte müssen in einem kurzen Zeitfenster wichtige Entscheidungen treffen, die den Erfolg der Katastrophenbewältigung nachhaltig beeinflussen. Um in einem Ernstfall effizient reagieren und entscheiden zu können, benötigt es eine dementsprechend gute Ausbildung. Da an manchen Orten Großschadensereignisse und Katastrophen nicht so häufig vorkommen, können nur wenige Führungskräfte auf einen Erfahrungsschatz zurückgreifen. Um diese Defizite bezüglich Erfahrung auszugleichen, müssen groß angelegte Übungen organisiert werden. Die Durchführung von Großübungen ist mit großen Kosten verbunden, diese benötigt personelle und materielle Ressourcen der Einsatzkräfte, örtliche Umsetzungsmöglichkeiten und Figuranten. Auch die Kooperation mit der lokalen Bevölkerung und staatlichen Organisationen müssen berücksichtigt werden. Um eine kostengünstige Alternative zu den realen Übungsszenarien zu schaffen, wurde 2015 das FFG Projekt "VROnSiteïns Leben gerufen. Im Zuge dieses Projekts wurde mit dem aktuellen Stand der Technik eine mobile, generische, immersive Trainingsplattform für Einsatzkräfte (Feuerwehren, Rettungsorganisationen, Polizei) in der virtuellen Realität entwickelt. Das Hauptaugenmerk lag dabei auf die ersteintreffenden Führungskräfte im Schadensgebiet.
Im Zuge dieser Arbeit wurde das bestehende Projekt um ein 3D Interaktionssystem erweitert und für den Mehrbenutzerbetrieb in ein verteiltes System umstrukturiert. Dabei dienen mobile Head-Mounted Displays zur Visualisierung und Gamepads bzw. Omni-Directionale Treadmills als Interaktions- und Navigations-Eingabegeräte. Sinn dieser Erweiterung ist es, dass Üben des vollständigen Kommando-Zyklus (Regelkreis der Führung) für die Trainingsteilnehmer zu ermöglichen. Um eine hohe Qualität zu erreichen und den Nutzen dieses Systems zu maximieren, werden Feuerwehren und Rettungsorganisationen in den Entwicklungsprozess miteinbezogen und eine User Study Evaluierung durchgeführt.

Abstract

Catastrophes happen worldwide, in some areas more often than in others. The first priority is to circumvent these catastrophes. When a catastrophe is not preventable or out of human influence, preparations need to be made. Not only are materials reserves and structural measures required, but also the personnel in the disaster relief management needs to be prepared. The squad leaders, in particular, have to be prepared, to make the right decisions, which influence the outcome of the relief operation tremendously. Therefore, the squad leaders need to be either experienced or are well trained. However, to effectively train squad leader, simulation exercises need to be executed to compensate the experience gap. To arrange large simulation exercises, many relief units, a lot of materials, a suitable location, and role play actors are required. Additionally, the government and the local communities must endorse ambitious simulations. In order to create an alternative to real simulation exercises, the FFG funded project, "VROnSite" was started in the year 2015. The aim of this project was to develop and evaluate the first fully mobile, generic, multi-user immersive virtual reality platform to train squad leaders of first responder units, such as fire brigades, paramedics, police forces and other disaster relief units. The goal of this master thesis was to extend the VROnSite project by developing a distributed 3D interaction system to allow for immersive training of multiple first responders, supervised by a trainer, within a virtual reality environment. For the visualization part of the scenario, mobile head-mounted displays are used. To navigate through and interact within the virtual reality, gamepads and omnidirectional treadmills are used. To make the system able to perform the training simulation with multiple users, a distributed layer had to be integrated. The main intention of the system is to train squad leaders upon arrival at the disaster site. To enable simulation and training of the entire command cycle, distributed 3D interactions are going to be developed, including 3D selection and manipulation tasks employed by the participants within the immersive simulation, and 3D manipulation tasks by the trainer, using desktop input. The innovative modules will be tested with actual stakeholders, such as fire brigade and paramedic training centers.

Contents

CHAPTER 1

Introduction

In an event of an emergency or a disaster, multiple emergency response agencies are required to work together to corporately solve the complex problem and minimize the subsequent damage. To achieve this common goal, proper training in command, communication, coordination, and control is needed. Since in some areas disasters happen less frequently than in other regions, some commanding officers and other personnel lack the aformentioned skill set. Without highly skilled emergency responders and well-trained crews, it is a hard task to manage such extraordinary situations. Training and simulation must balance the difference. Training in real environments is very expensive, both in resources and personnel because a scenario must be created, actors hired and a lot of staff is needed, which is mostly subtracted from normal operations. Even then, each participant can only be deployed in one position, such that only one specific task can be trained at a time. Furthermore, it might be that a participant occupies a different task in an actual emergency, which makes it necessary to repeat the training. Therefore, the training should be repeated with a position rotation of the staff (which is hardly possible). Additionally, in real disaster relief missions, stress handling and preparedness for the unforeseeable play a key factor for success. Secondary, there is almost no room for mentoring emerging squad leaders for educational purposes, in such unpredictable and new situations. These reasons make it apparent, that proper training is of utmost significance.

To mitigate this problem, a simulation in a virtual environment offers valuable advantages. Thereby, the simulation can be adaptable, repetitive, customizable and as realistic as traditional approaches like real-life simulation games.

Although such a system would offer tremendous benefit in the education of on-site squad leaders compared to traditional approaches, no fully immersive, multi-user capable system exists to date.

1.1 The VROnSite Project

In 2015 the Interactive Media Systems Group (IMS) at the Institute of Software Technology and Interactive Systems, Technische Universität Wien performed research to analyze the state-of-the-art of virtual reality training system for crisis, disasters and catastrophes preparedness. It concluded, that no currently available system covers all demands for the needs of a virtual reality training program. Therefore, the decision was made to investigate new methods and create a new virtual reality platform, which offers fully immersive, untethered, multi-user virtual training simulations to account for the specific requirements of on-site squad leaders. This thesis is embedded into the recently finished FFG Bridge research project "VROnSite" (850703) [MFS$^+$17]. This thesis is aimed to improve the 3D interaction possibilities inside the immersive simulation and extend it to a flexible distributed system, which supports multiple users in different roles (operators, trainees), while maintaining high performance experience [MPGK15b, MSGK12, MPGK15a].

1.2 Expected Results

The aim of this thesis is to develop and implement algorithms for distributed 3D interactions to allow immersive training of multiple first responders within a virtual reality environment. Based on the current development state of the VROnSite prototype - comprising a single user training environment using a mobile head-mounted display (HMD) as well as different types of 3D navigational input (gamepad, omnidirectional treadmill (ODT)) - a distribution layer needs to be integrated to allow multi-user training. In the existing VROnSite prototype, the command chain covers only the initial mission, the initial assessment of the situation, and the first plan step. This work aims to enable simulation and training of the entire command cycle. Figure 1.1 describes this plan-do-check-act (PDCA) cycle, whereupon the gray circles (check and act) will be implemented within this work. The first step in the command check is the overall mission or task. After the arrival of the first officer, the situation gets initially evaluated, followed seamlessly over by the PDCA cycle, starting with the planning phase. The personnel under command execute the planned actions. Followed up by a check of the officer, if the executed actions were properly executed. At the end of the cycle, the new situation is assessed, and hence a new basis is set. Subsequently, the cycle starts over again, until the situation is relieved. Additionally, distributed 3D interactions are going to be developed within this thesis, including 3D selection and manipulation tasks. This 3D interaction can be carried out simultaneously by multiple participants within the immersive simulation, plus 3D manipulation tasks can be performed by the trainers abstract input of desktop devices (keyboard, mouse). Due to the planned 3D interaction possibilities, the experience and effectiveness of the trainees, in the context of the skill set, which is needed to successfully relief an emergency situation, can be enhanced. To ensure these improvements, the future real-world stakeholder will be included in the development process. This means, that tests with actual squad leaders from fire brigades and paramedic units will be conducted to perform research and development in an iterative design cycle.

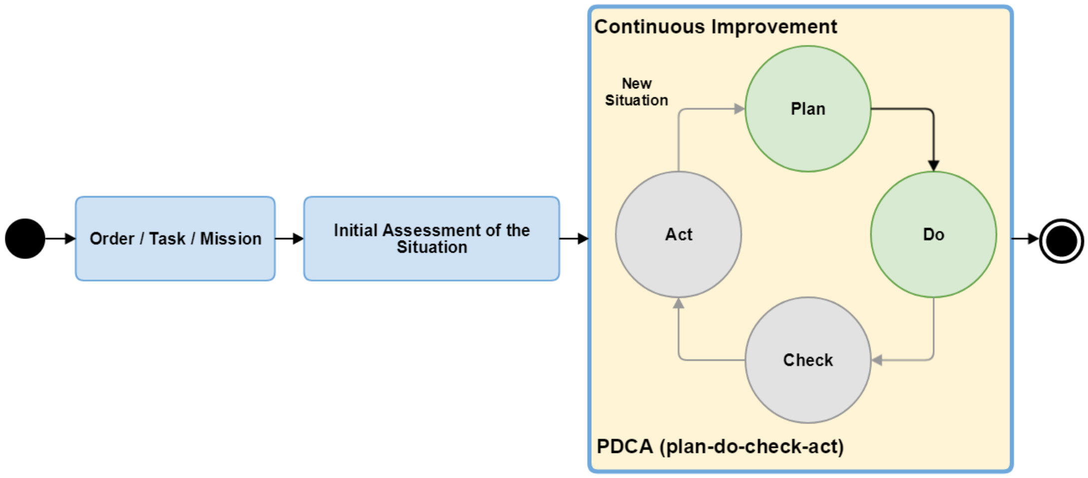


Figure 1.1: The plan-do-check-act cycle

In Figure 1.2, final result of this thesis is depicted. Two firefighters and one operator can be seen during the simulation training. *Trainee #1* and *#2* are using a mobile HMD device which is connected to a router and a headset (optional and not visible in the figure). *Trainee #1* uses an ODT to move inside the simulation and *trainee #2* uses a regular gamepad (this can be varied, depending on what hardware is available). Meanwhile, the operator is able to overview the training from a bird's-eye perspective using the monitor. The operator is also connected to the trainees via the router and can see the same scene as the trainees in real time. Additionally, the operator can interact, with mouse and keyboard, inside the scene and acts appropriately as the trainees give commands.

1.3 Structure of the Work

After the introduction, Chapter 2 describes the fundamentals of disaster relief management in general and some specific characteristic of the Austrian system. On the technical side, fully immersive systems and 3D interaction techniques are explained.

An overview of the state-of-the-art is given in Chapter 3. Besides the current techniques and devices for virtual environments, some of the already existent virtual reality (VR) based training systems are presented.

In Chapter 4, the methodology of this work is explained. Moreover, the transition of the current state-of-the-art from Chapter 3 to the implementation is illustrated in context of requirements, architecture, distributed system and interaction concepts.

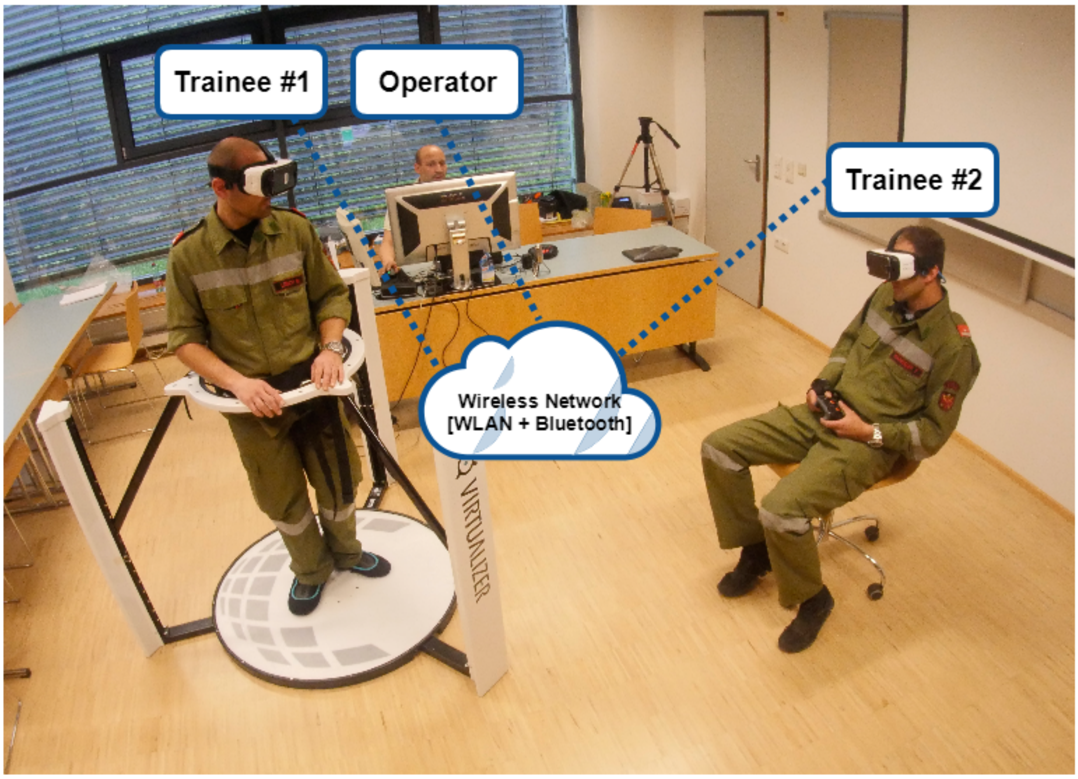


Figure 1.2: Firefighter within the simulation

Chapter 5 shows, how the theoretical concepts were implemented and how the PDCA cycle was finally closed through the final resulted application prototype. Furthermore, it is shown how the details on the implementation changed from iteration to iteration, through the feedback of the stakeholders.

The nature of this user study, as well as the participants will be discussed in Chapter 6, along with experimental results.

Finally, Chapter 7 recapitulates this work and the contribution of this work is summarized.

CHAPTER 2

Fundamentals

The United Nations Office for Disaster Risk Reduction (UNISDR) [UNI09] defines a disaster as follows:

> "A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources." - [UNI09]

In this chapter, two topics are examined with the purpose to provide a better understanding of some techniques used in the later chapters. In the first three sections, the basics behind disaster relief management and the corresponding conventional training for first responders are illustrated. The last two sections address *fully immersive systems*, basic principles of interaction in 3D environments are and how a user can interact in such a virtual environment. These paradigms have the intention to give the reader an overview, of what is important when disasters occur, how an effective training for the first responder in action should look like and what the basics and possibilities of a training system in virtual environments are.

2.1 Emergency Management

Emergency management is the organization and management of resources and responsibilities to create a framework within a community, with the goal to avoid and reduce vulnerabilities to human-caused and natural disasters [UNI09, oEM07].

The vision of emergency management is to make a community able to protect and withstand an otherwise overwhelming catastrophic event. In many countries, the emergency management is a decentralized structure and customized in the area of the community. For example, in areas likely to flood, there are more precautions in context of a flooding catastrophe, just as there is more technical equipment available for car crashes near busy highways. Decentralized means, that a vast number of agencies, nongovernmental organizations, and private sector entities are often involved. The legislation of a country often just defines a frame of what should be done approximately. Therefore, the actual implantation of the precautions are mostly up to the local communities. The federal government however, still plays an important role when a community requests assistance. From the variation of the focus driven management, it follows, that the number of involved actors vary to a high extend in context of the severity of the event [Lin12].

It can be summarized, that the mission of emergency management is to protect communities by coordinating and integrating all necessary services to build, sustain, and improve the capability to mitigate against, prepare for, respond to, and recover from threatened or already occurred human-caused and natural disasters.

To achieve this intent and to ensure an effective cooperation, the communities must agree on a uniform basic condition. For this, the Federal Emergency Management Agency [oEM07] describes eight principles (see Section 2.1.1).

2.1.1 Principles

Emergency management must be:

1. Comprehensive – the emergency managers and communities need to take all hazards, all phases, all stakeholders and all impacts relevant to disasters into account.
2. Progressive – well proven and tested approaches should be used, and the newest research in this field should be built on top of it.
3. Risk-driven – to ensure that the emergency managers invest in the right place, hazard identification, risk analysis, and impact analysis should be taken into account in assigning priorities and resources.
4. Integrated – the united effort among all levels of the government and involved organizations should be ensured by the emergency managers and all elements of a community.
5. Collaborative – encourage trust, emergency managers and communities should maintain their relationships, organizations, advocate a team atmosphere, build consensus, and facilitate communication.
6. Coordinated – emergency managers and all organizations within the community acclimatize their activity for a common purpose.
7. Flexible – in the ongoing challenge of a disaster, the emergency managers need to react fast, and use creative and innovative approaches with the ideal resources.
8. Professional – emergency managers orientate themselves on science and use the state-of-the-art approach in the fields of education, training, experience, ethical practice and continuous improvement.

2.1.2 Phases

Disaster management is usually split into four phases: (1) mitigation, (2) preparedness, (3) response, and (4) recovery [Lin12]. Well executed, losses caused by disasters can not only be reduced by post-disaster relief and recovery, but also by pre-disaster mitigation and preparedness.

(1) Mitigation

The purpose of the mitigation phase is to reduce the loss of life and property by lessening the impact of the eventually occurring disasters. Typical tasks of mitigation are organizing resources, identifying the characteristics and potential consequences of hazards, and insurance. This means, that all possible disasters must be identified and the related risk calculated. Mitigation activities are often long-term tasks and have a sustained effect. Sometimes the need for mitigation actions is a result of the recovery stage after a huge disaster [Lin12, HZ16]. Some examples are:

- Zoning rules that restrict construction in flood-dangered areas
- Flood mapping to identify the effected areas, relocate homes, build dams, and fund insurances
- Defining evacuation plans for people in case of a forest fire (evacuation plans)
- Rebuild houses with more resistant materials (earthquakes, etc.)

(2) Preparedness

In this phase, preparation should be made by developing a preparedness plan in strategic, operational, and tactical tiers. This includes early warning systems, training of the community, and emergency services for disaster risks and responses. The distinction of preparedness related to mitigation is the focus on enhancing the capacity to respond to an incident by preparation. This ensures, that personnel and organization are capable of responding to a wide range of potential incidents. This also includes disasters that are not considered in the mitigation phase at first [Lin12] [HZ16]. Some examples in this context are:

- Proper training and planning
- Provide enough resources, such as food, water, and medication stockpiles
- Ongoing intelligence and surveillance activities to identify potential threats
- Exercising to assure the effectiveness of the planned efforts and the use of after-action reports to improve emergency response units and let the community gain operating experience

(3) Response

The response phase takes place, when the disaster has already occurred. In this case, immediate actions are needed to save lives, protect property and the environment, and to meet basic human needs. Here, the plans from the preparedness phase get into action, including:

- Evacuate the effected persons (search and rescue)
- Provide shelter for victims, if needed
- Deploy qualified response teams
- Provide and distribute the stockpiled resources
- Establish an incident command operation structure (staff work)

The first relief units on scene are most likely the regular emergency service units, until special trained commanding officers arrive. This period is crucial for the success of the operation, since in these moments the first responders must switch from individual aid to disaster aid. This means they must not help individual persons (except in some cases, such as heavy bleeding or almost drowning). Instead, they need to assess the big picture of the scene and follow it up with corresponding actions. The first step is to report the an overview of the big picture to the operator. The next step for medical personnel is to define areas, where the effected people should go and where they get their relief (ideally, already planned in the mitigation and preparedness phase). This step is no linear process, but more likely a cycle, as seen in Figure 1.1. This command cycle repeats multiple times, until the disaster is relieved. To effectively bridge the gap until the command officers arrive, the first responder needs special first responder disaster management training. To get a better understanding of the training, which is important for later requirements in Chapter 4, training gets presented in Section 2.3.

(4) Recovery

After the disaster is relieved, the regular essential services (e.g. emergency services, public safety, and schools) need to be restored, and the caused damages by the disaster need to be repaired. While the recovery phase is still going on, it flawlessly transits to the mitigation phase.

2.2 Tactical Approach on Disasters

A significant challenge in the relief of disasters is to transit from day-to-day responsibilities of emergency services proceedings to optimum response within the disaster relief proceedings, regarding mobility and preparedness. Is the disaster bigger than the regular emergency service can handle, additional resources and units are required. Therefore, it is the task of the emergency organizations to build up reserves, which are used when needed. To define which resources should be alerted, a staged alarm plan should be preassigned in peaceful times (mitigation and recovery phase). When the first units arrive on site, a disparity of power consists, meaning that more problems or victims in need of treatment are on the scene, compared to the amount of emergency units. This disparity of power should be as short as possible in favor of the aggrieved parties.

2.2.1 Roles of First Responders

The solving-process of the aforementioned problem is divided into four phases, (1) self-organization, (2) rescue phase, (3) relief phase, and (4) transport- and supply phase [Han14].

In (1) self-organization phase, the call-taker takes the emergency calls. The call-taker then tries to get the big picture of the situation. Often this is not easy, since the caller might be very nervous or is far away from the disaster. As result, the first responder sometimes does not exactly know the nature of the situation. The first minutes are almost always chaos, and the best trained first responder or the one with the most experience gets the temporary lead of the mission.
Upon arriving on the scene, the initial responsibilities of the leader can be divided into three broad tasks that occur almost simultaneously: surveying the scene, identifying the available and required resources, and establishing initial incident command and communications. These tasks start with the gathering of information about the event, acting on that information, and conveying it through a qualified situation report to others within the chain of command. Checklists must be used, to ensure that every critical information gets obtained. One thing that every first responder should keep in mind, is, that their priority is to ensure their own safety and the safety of other responders.

While surveying the scene, the main goal should be to determine what actions and equipment are needed to mitigate risk and maximize the efficient delivery of care. During this process, important decisions must be made, such as the establishment of a safe place to locate themselves and their equipment. Additionally, reports from bystanders, the communications center, and responders already on the scene must be taken into account, as they often contain critical information. The decisions must be made as soon as possible since resources, such as additional ambulances, fire trucks, major emergency vehicles, security forces, and much more, are eventually required to provide proper relief of the disaster. The first responding firefighters' point of view is to be focused on the technical part of the disaster management. On the medical point of view, the first arriving medical responders will often likely have to face a mass-causality scene with patients with all manner of injuries or illnesses. Once everybody ensured the safety of all involved parties, the next priories are to set up a rapidly triage patients-setting treatment. Triage criteria vary from system to system as many countries implemented different variations. The patients get classified into categories based on a brief subjective interview and physical examination, including vital signs. Some patients will need immediate care, while others can wait for their treatment. This will help to maximize the effectiveness of the limited available resources [PS11].

In (2) rescue phase, and (3) relief phase the location of the treatment room gets defined and a triage gets established. After that, the most critical victims get treated. On the technical part, the main concern is on dangerous substances and the extinguishing of fires.

The transition to the (4) transport- and supply phase is a diffuse. In this phase, victims are transferred to hospitals, and the last remaining properties are saved.

2.3 Training of First Responders

Disaster training is key to manage and relief disasters. It is meant to enhance the first responders' capabilities for responding to emergencies or disasters before an event. Not only first responders need to be trained, but also public officials and the community at large need to be prepared. The purpose of the combined training of every involved party is to allow the local policy-makers and emergency operation responders better and faster accomplishment in emergency operation planning and responding to emergencies or disasters. Specifically, training provides the opportunity to review emergency operation procedures and their subsequent application in a nonthreatening environment and compensate the limited opportunities to gain experience in actual disaster response. On the side of the public officials and community, training will help them to be aware of the strengths and weaknesses of their capabilities as well as their role in operational support. After the training, the effectiveness of the training and the organizational approaches can be evaluated through a variety of discussion and operation based exercises. Additionally, the exercises can provide a platform for the awareness of the community's emergency operation plans. It is important at this moment to create measurable goals and objectives to allow the possibility of comparison and to be able to properly utilize valuable feedback. Therefore, it can be very precious for a whole community to execute proper training and assessing the retention of previous training initiatives in safe environments [PS11].

Besides small community exercises, the Austrian Red Cross arranges a nationwide simulation exercise biannually. To this national exercise, every federal state sends some disaster relief units (including paramedics, firefighters, water rescue, police forces, military forces, etc.) in order to get all of their units to the same level. Specifically, this difference of the localities gives a great challenge to all attending units, but this, in particular, is what is needed when a great scaled disaster occurs [Kre17]. Figure 2.1 shows a moment of the Austrian national exercise "Would 2017" where the relief units are working on a train accident. At first sight, it looks very chaotic, but in fact, it is well organized. At the front, the firefighters try to free the persons out of the vehicles and in the background the paramedics have their own defined areas for treating the victims in tents and transporting the insured to the hospital with their emergency vehicles. As one might guess, a wrong decision in the beginning, i.e. by not having the big picture in mind, can have fatal consequences for the entire operation. For example, the first arriving units can block the road or access to the vehicles which makes it almost impossible for the following units to get proper access to the area of accident with almost no way to clear the blockade afterwards. This highlights the need for proper training. Additionally, it should be mentioned that the executing units do not know at the beginning of the exercise, about the extent of disaster they will face.

In their work "Balancing pre-disaster preparedness and post-disaster relief" Fei He and Jun Zhuang [HZ16] tried to find the optimal policy on balancing pre-disaster preparedness and post-disaster relief for local, state and federal government or business units, that are facing potential disasters. They concluded, that the ability to provide help in disasters, increases with the increase in preparedness. The need for more relief always increases with the size of the catastrophe. While training and preparing the units leads to an increase in cost, it will finally reduce the cost of the relief when the disaster occurs.

Figure 2.1: Austrian emergency services simulating a train accident at the national exercise "Would 2017" [Kre17]

2.4 Mobile Fully Immersive Virtual Reality Systems

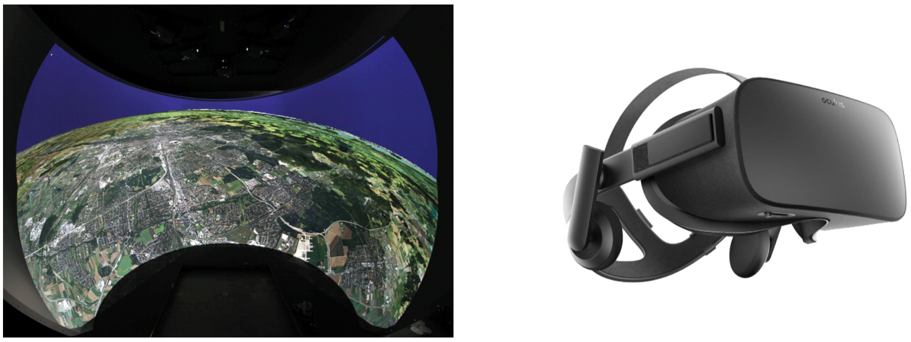
To create and utilize a (mobile) fully immersive VR-system, a communication between the users and the system must be established. This means, that the system must provide a human-computer interface to allow the users to communicate their commands, requests, intents, and goals to the system. Multiple steps need to be taken in order to make this interface beneficial. First the users must translate their intended goals into actions. The next step for the system is to interpret this physical actions into an electronic form. In the last step, the system deciphers the electronic actions into signals which the system can handle, based on the current state of the system. In most cases, the system then gives some form of feedback back to the users. To communicate the feedback to the users, the system needs to translate the information into a digital display representation, and a proper device needs to translate it again back to the user in form of a perceivable and meaningful representation [BKLP04].

2.4.1 Visual Display Devices

Many possible visual display solutions can be used to represent 3D user interfaces (UIs) [BKLP04]. Including the following few visual display device types:

- **Monitors** are often used for 3D applications, like modeling, scientific visualization, and computer games. To achieve full 3D views with a monitor, additional hardware is required. Including a stereo-capable graphics card (if not already integrated) and stereo glasses. Monitors provide a non-immersive VR system.
- **Surround-screen displays** consists of three or more large projection-based display screens. Sometimes the user is surrounded completely. To avoid unwanted shadows, the display screens typically get projected from the backside, or convex projectors are used. Surround-screen displays constitute non- to semi-immersive VR systems.
- **Hemispherical displays** are also projection-based devices that make use of special optics to display images in an 180- by 180-degree field of view (FOV). Special software is used to distort the image to an extend before the projection, this has the result, that the image is shown correctly on the curved screen (see Figure 2.2a). Hemispherical displays provide a non- to semi-immersive experience.
- **Head-mounted displays (HMDs)** enable fully immersive VR environments. The main goal of HMDs is to place the images directly in front of the users' eyes, often with some lenses or mirrors in between the device and the eyes. The biggest advantage of this devices is their mobility. With HMDs the users can move freely and when in a wireless setup, this freedom is extended even more. Another advantage of HMDs is the complete physical, visual immersion in the form of a 360-degree view because the users see the virtual world in dependence of their head position and orientation (see Figure 2.2b).

- **Virtual retinal displays** apply the idea of projecting the images directly onto the users' retina. This approach also comes with a high FOV and the same mobility like HMDs. However, a major problem of the virtual retinal displays is the lack of eye tracking. By moving the eyes in some specific direction, the user might lose all parts of the image (see Figure 2.2c).



(a) Hemispherical screen [Mps15] (b) Oculus Rift HMD [Ocu17]

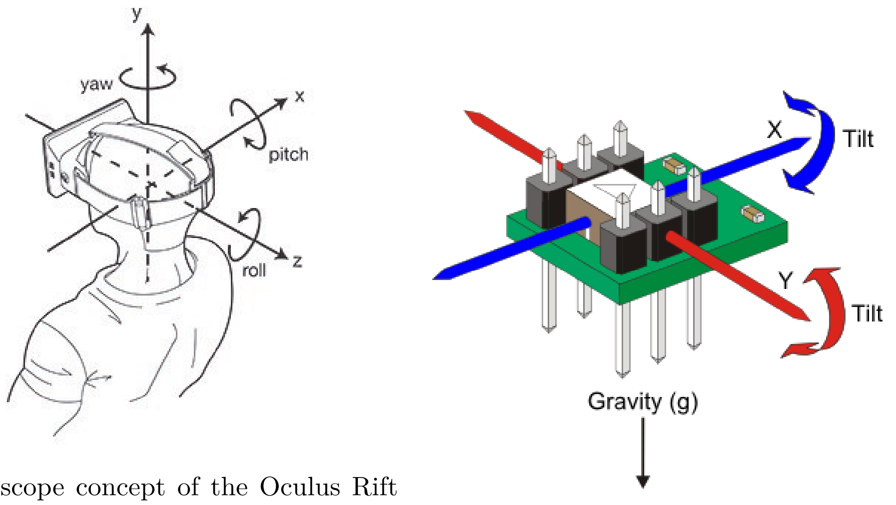
(c) Virtual Retinal Display [CNE13]

Figure 2.2: Three different kinds of visual display devices

2.4.2 Tracking Systems

When the users should be semi to fully immersed in the virtual reality, it is important to track the users' action in 3D space. Only this way can the system react to the user's action and produce an appropriate response. Tracking allows the user free egocentric scene viewing. For example, when a user turns the head, the view, which gets shown by the system, must change according to the altered angle. Another example is, when a user tries to grab an object in the virtual space, the system must know when the user is in reach of the desired object to get a hold on.

In this thesis, the most important type of tracking is *inertial tracking*. Inertial tracking is used in mobile HMD devices [ELM15]. Uses of inertial measurement devices, like angular-rate gyroscopes and linear accelerometers (see Figure 2.3a and 2.3b). These devices determine the angular velocity and linear acceleration. As these sensors are integrated into the HMDs (for the 3 degrees of freedom (DOF)), the system knows how the user is oriented in space. Advantages of this technology are, that it is inexpensive and can provide high update rates as well as low latency. The downside is a loss of accuracy due to a drift over time. Another way to track users is *optical tracking*. Most optical tracking systems consist of a infrared light source and a infrared detector (camera). The infrared light source periodically illuminates the surroundings and the reflections get detected by the camera. This allows the system to calculate the 2D feature positions with high precision. When using multiple cameras, it is possible to detect 3D positions by combining the 2 DOF to calculate 3 DOF or even 6 DOF. The basic principle of an optical tracking system is shown in Figure 2.4. While optical tracking provides full 6 DOF position & orientation, and mitigates drift, it has not included in this thesis to reduce cons and setup complexity [BKLP04].



(a) Gyroscope concept of the Oculus Rift HMD [Ocu17]

(b) Concept of an accelerometer [Eng17]

Figure 2.3: Concepts of the inertial tracking principles

2.4.3 Input Devices

To translate the users' goals into actions and subsequently into something that the system can interpret, input devices are required. There is no device, which can be used for every sort of input, but rather many devices with different characteristics, depending on its purpose. One essential characteristic, especially in this work, is the DOF that an input device allows. Another characteristic is the frequency of data, which the device generates. For example, a button only generates boolean values (true or false), i.e. pressed or not pressed. The abstract input of a gamepads analog stick additionally generate the angle, in which the stick is pulled to. As mentioned in the previous section, some device (e.g. HMDs) have integrated sensors which deliver input. In this case, the users does not have to use their hands to generate input. A way to characterize input devices is the intended use of them. Some devices are better at some tasks than other ones [BKLP04].

Most of the desktop input devices for 3D UIs were initially designed, for the 2D desktop application. The most known desktop-based input devices are mouse & keyboard. Other often used input devices, especially for gaming and simulations, are joysticks and gamepads. Input devices which offer 6 DOF, allow the user to truly interact in 3D space. This includes navigation through 3D environments, 3D model manipulation, and the ability to pan, zoom, and rotate at the same time [BKLP04].

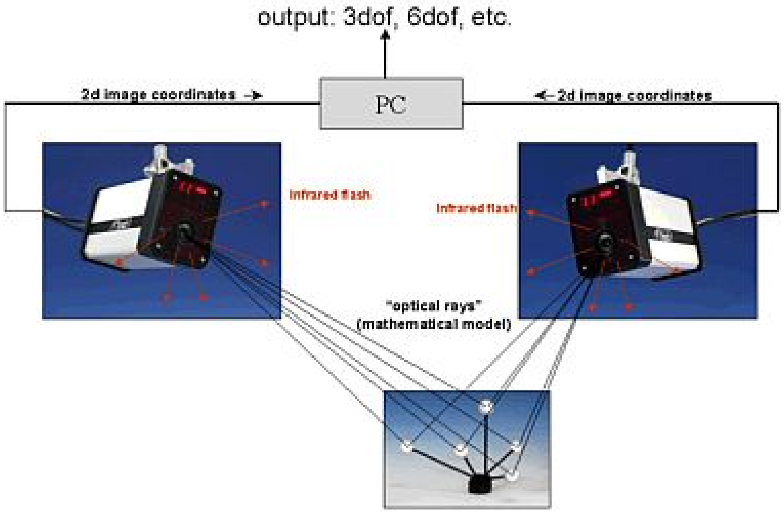


Figure 2.4: Concept of an optical tracking system [fRuM01]

2.5 3D Interaction in Virtual Reality

Navigation, object selection, and manipulation are the most fundamental tasks in the physical world. This is applies also on the virtual environment. The higher the quality of the interaction techniques, the higher the immersion in VR. Without the possibility to interact with the virtual world, many tasks would not be possible to execute. The goal of the interaction techniques is to deduce real world human interaction and implement a appropriate technique in VR. So, it should be possible for the user to interact in the virtual world, as he would interact in the physical world. For example: when users want to pick something up, they most probably will reach out for the desired object in the real world. The same real world action, which is needed to pick up the object, should be required in the virtual world as well [Sal12]. Therefore, the effectiveness of 3D manipulation techniques is constrained by the task itself. Even if the technique is intuitive and works well with one assignment, it could be useless in a different one. To fulfill this task, it often requires special hardware (e.g. gloves, tracking systems, gamepads, etc). For this task, there are prototypes, dev kits, and market ready solutions available, some of them are presented in the State-of-the-Art Chapter 3.

3D interaction tasks are important to allow full immersion of the user in the virtual environment. Existing techniques, their dependencies as well as how they work, will be briefly explained in the upcoming Sections 2.5.1 to 2.5.2. It does not necessarily lead to the desired results to design and evaluate interaction techniques for manipulation tasks in general. Instead, the design, analysis, and deployment of interaction techniques need to be customized on the details of a single tasks.

Manipulation tasks can be characterized by a multitude of variables [BKLP04], such as application goals, object sizes, object shapes, the distance from objects to the user, characteristics of the physical environment (e.g., weather, daytime, temperature), and even the physical and psychological state of the user can be a factor. As mentioned earlier, it is not profitable to just combine all theses characteristics in one unified technique, and it is more desirable to use a balanced subset. There are two possible approaches in existence: using a *canonical* set of manipulation tasks or using *application-specific* manipulation tasks.

Canonical Manipulation Tasks

Virtual 3D manipulation challenges are to some extent deductions of general target acquisition and positioning movements, that are performed in the same way as in the real world. 3D manipulation challenges can be divided into a few number of basic tasks. With these basic tasks, any task in the 3D environment can be derived. Each task is dependent on many variables that significantly affect its procedure. These variables define the task parameters, which include multiple variations of the same task. An example for this would be tasks of taking objects, which are in different distances of the user. One possible result of this division and its parameters are presented in the following three tasks:

- **Selection** Is to acquire or identify a specific object in a mix of many other objects. In the real world, this task is comparable to pick the desired object with a hand.

  Parameters are the distance and direction to the target, target size, density of objects around the target, number of targets to be selected, and target occlusion [BKLP04].

- **Positioning** Is to move a selected object in a virtual environment, the objects 3D position must be changed. In the real world, this would be to move an object from a starting point to a target point.

  Parameters are distance and direction to the initial position, distance and direction to the target position, translation distance, and required precision of positioning [BKLP04].

- **Rotation** Is to change the orientation of a selected object. Here the real world counterpart is to rotate an object from its starting rotation to a target rotation.

  Parameters are distance to target, initial orientation, final orientation, amount of rotation, and required precision of rotation [BKLP04].

Application-Specific Manipulation Tasks

The canonical manipulation task approach simplifies the task to its smallest component and creates the variation of it for different tasks. Sometimes this is not possible and will fail to constitute some application specific tasks. Examples of such tasks are to manipulate the position of a medical probe relative to virtual 3D models of internal organs in a VR medical training application or to move a control stick of a virtual airplane in a flight simulator without a hardware replica of the control stick [BKLP04]. To implement such tasks, it does not make much sense to generalize them, because it is critical to translate the real world as realistic as possible into the virtual world. How to design this specific tasks, can be found in the literature of this applications.

2.5.1 Interaction Techniques

The characteristic of input devices and visual display devices (supported depth cues, refresh rate, resolution, etc.) are significantly affecting the way 3D interaction techniques are going to be implemented. Therefore, the properties of input devices and the design of effective 3D interaction techniques are very important. Sometimes some trade-offs need to be taken into account, due to hardware limitations or constraints of the human body [BKLP04].

The most fundamental classes in 3D interaction are the *interacting by pointing* techniques. These techniques allow the user to easily select and manipulate (translate, rotate, etc.) object by simply pointing at them.

Ray-Casting

Ray-Casting [BH97] is a grabbing technique in which a ray gets cast from a specific source point (e.g., virtual hand, mouse cursor, etc.) into the virtual environment. If the ray interferes with an "object of interest," a hit gets returned. Now the user can manipulate this object. The pointing direction of the ray is estimated from the attached object (vector $\vec{p}$) and the 3D position of the virtual hand **h**. The calculation to define the virtual objects, which can be selected by the ray, is defined in the following equation:

$$p(\alpha) = h + \alpha\vec{p} \tag{2.1}$$

where $0 < \alpha < +\infty$ [BKLP04].

If more than one object is interfering with the ray or an object is occluded by another object that is selectable, the implementation of the interaction technique should traverse all possible object candidates for the selection. The simplest possible solution is to take the object, which is hit first by the ray. Another possibility is to implement a layer system, in which each layer has a priority or ignore state. This might be handy, when dealing with a lot of selectable objects.

2.5.2 Navigation

For a fully immersive experience, navigation is as important and fundamental as the navigation is in the physical environment. The main aspect of navigation is to move from the current location to a new target location or in the desired direction [BKLP04]. This process is call *traveling*. The process of traveling in the physical environment is a rather automated process, when the person decides to move, the brain induces every needed muscle to perform the task. In the virtual world, this is not that easy, but contemplated to make it as intuitive. It depends heavily on the chosen form of traveling. Going by vehicle, flying and walking, all have different interfaces to use and need to be translated into the virtual environment.

There are three different reasons [BKLP04] for an user to travel though the environment:

- **Exploration** is, when the user does not have a specific goal where to go. Therefore, the user just navigates through the environment to explore and gain knowledge about the world. Typically, this kind of traveling is used at first, where the users want to get their bearings.
- **Search** is the task of the user to find something in particular or to travel to a specific target location. Whether the user knows where to go or not, does not matter in this case.
- **Maneuvering** is a task of precise movement in a rather small area. For example, one wants to interact with an object, which is in front of the user, but not close enough for executing the interaction. In this case, the user must navigate a few small steps in the direction of the object.

Physical Locomotion Techniques

The physical locomotion techniques approximate the natural locomotion of the physical world. The obvious technique is walking. To translate natural *walking* into the virtual environment, the users need to be tracked by sensors. From this, it follows that there will be still some boundaries, limited by the range of the sensors in the monitored area. To overcome this problem, devices for *walking in place* were developed. Some of this devices will be shown in Chapter 3.

Steering Techniques

An alternative to physical locomotion is steering. With steering, the users can either specify the absolute direction in which they want to travel or to move in a relative direction. An example and most common steering technique is *gaze-directed steering* [SD12]. This technique allows the users to move into the direction $\vec{g}$ in which they are looking. The gaze will most probably be taken from a head tracker or HMD. The gaze vector is then taken, normalized and translated along the world coordinate system. Optionally, the vector can be multiplied by a velocity factor ψ. To initialize the movement, the users need to take some action, and this could be a joystick or some input from a gamepad. Therefore, the users' position s should be updated between the start and stop actions as the following expression in [BKLP04] illustrates:

$$s_{new} = s + \psi \frac{\vec{g}}{||\vec{g}||} \tag{2.2}$$

Viewpoint Orientation Techniques

In virtual environments, especially with the usage of HMDs not only traveling (*xyz* coordinates movement) is important, but also the change of the position of the viewpoint. The task of changing the viewpoint orientation (heading, pitch, and roll) plays a great role, among others, in *head-tracking*. The best way to take the viewpoint orientation is to take it from the users' head tracker or HMD [BKLP04].

CHAPTER 3

State-of-the-Art

This state-of-the-art chapter provides an overview of existing VR-based training systems and exemplifies some existing 3D interaction frameworks for immersive virtual reality systems.

3.1 3D Interaction for Immersive Virtual Reality

The next few sections contain some of the existing interaction possibilities in VR. Beginning with state-of-the-art 3D game engines, VR-frameworks and an overview of HMDs, which allow the user to look around in the virtual environment, to the ODTs, which enables the navigation by physical movement through the virtual world.

3.1.1 3D Engines

When implementing a virtual or augmented reality (VR, AR) application, the requirements on both, software and hardware, are rather high, especially when it is a distributed application. For the purpose, not to implement a 3D engine from scratch for every new application, there exist some engines. Two state-of-the-art engines are the Unreal Engine 4 (UE4) [Epi17] and Unity 5 [Uni17]. The engines use advanced techniques, both for realistic visual and physical effects, such as lightning, physics, and realistic character visualization, just to mention a few. Both engines are free to use for personal usages and have a large asset store. The greatest advantages in comparison to many other engines is the possibility to deploy applications on multiple different platforms (e.g. desktop, mobile, web, game consoles, etc.). This is very important for the implementation of a distributed system when desktop and mobile devices are used simultaneously. Another important feature, is the support of VR devices, like HMDs and VR specific (e.g. ODT) and generic (e.g. gamepads) input devices, supplemented by both engines out of the box. For the implementation of the ongoing research project "VROnSite" [MFS$^+$17] the Unity

5 engine was used. Therefore, Unity 5 will be used for its further implementation in this thesis.

3.1.2 Frameworks

VARU is a rapid prototyping framework for tangible space applications. Its focus is to provide extensibility, flexibility, and scalability. VARU combines three spaces, such as VR, AR and ubiquitous computing (UC), into one, called tangible space. The user can interact either with the virtual, physical or mixed environment. This opens the possibility to explore different types of collaboration across the different spaces. Extensibility means, that new features can be added to the framework through custom extensions. The flexibility refers to the possibility to adapt different application scenario, through XML configuration. VARU scales from the support of one user to the ability to handle multiple users in one or multiple spaces [IAKK08].

The Augmented Reality Framework for Distributed Collaboration (ARTiFICe) is a lightweight framework and provides a platform for multiple users. It is based on an off-the-shelf engine and builds the application layer of a VR/AR framework. The key features contain a graphical user interface and scene management for rapid prototyping of VR applications, an adaptable interaction and distribution framework for collaborative applications, and support for versatile VR setups on different operating systems and platforms [MSGK12].

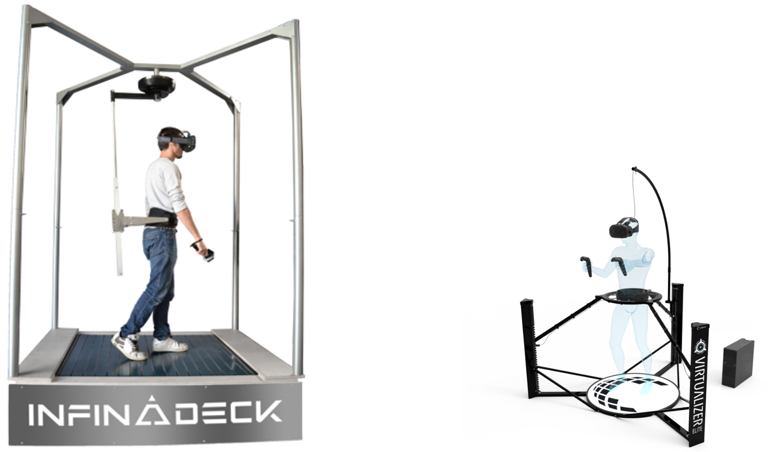
PrimroseVR is a web development framework for building virtual reality web-applications. It focuses on a rather small subset than on maxing out all the VR possibilities. It allows fast prototyping and experimenting with a provided VR editing form. This happens inside of a virtual world, in which the user stands and freely moves around and can interact with the objects directly. In this way, users can quickly find out, which interaction designs fit them best. In the future, interaction types, that tend to become best-practice, will be added to the basic building blocks of PrimroseVR. Examples, in which it has been used, are 3D chat rooms, billiards games, live-programming environments, and even music sequencers [Pri17].

3.1.3 Head-Mounted Displays

HMDs are devices, in which one or two displays (monocular HMD or binocular HMD) and lenses are integrated. They are worn like glasses or are part of a helmet. The application range of HMDs are versatile, which include gaming, aviation, engineering, medicine, training, and simulation. The later is, at this moment, a key application for HMDs and VR in general. It allows a trainee to train and exercise tasks and missions, which must otherwise be trained in situations, that are either expensive or too dangerous to easy replicate them in the real world. Training applications like driving, welding, spray painting, flight and vehicle simulation, medical procedure training and combat are excellent examples, which can be realized in VR. There are two different HMDs. On the one hand, are the ones, that only can display computer-generated imagery (CGI), sometimes also referred as a virtual image. This type is mostly used for VR and, therefore, will be in focus in this thesis. On the other hand, these are HMDs which allow laying the CGI view upon a real-world view. This is used for augmented reality (AR). Another essential function besides the displaying of CGI is, to track the position and orientation of the user's head. This allows the user to explore the virtual world the same way as people explore the real world, by turning the head. This technology helps to user to truly immerse in the virtual world. Some currently available state-of-the-art devices are amongst others the HTC Vive [HTC17], the Oculus Rift [Ocu17], Playstation VR [Pla17], Gear VR [Sam17] and Google Daydream [Goo17]. Despite the usefulness of HMDs, there is the downside of motion sickness, which is currently under heavy research. Motion sickness (or cybersickness) can occur while being inside the virtual world. One way to prevent motion sickness is by actually walking in reality, due to space limitations it is sometimes not possible. One alternative way is the usage of an ODT, which will be presented in the next section (3.1.4) [HS14].

3.1.4 Omni-directional Treadmills

To bypass the limitation of space to move in the virtual world, ODTs were developed. ODTs are mechanical devices, just like a regular treadmill in a fitness center, but except for being able to perform the locomotive motion in any direction, which allows the freedom of movement in 360 degrees. Therefore, the user can explore many virtual worlds by physically performing walking or running without leaving the spot or running into physical obstacles. There are two approaches of ODTs, active and passive systems. In the active approach, the user walks on a flat floor while the system tries to nullify the users' position by moving the ground underneath the user. In the passive approach, the user is fixed in one position and moves by sliding her feet on a low-friction surface (more like pseudo-treadmills that requires sliding more than actual stepping). State-of-the-art devices (Figure 3.1) are the Infinadeck (see Figure 3.1a) [Inf17], which uses the active approach, as well as the Cyberith Virtualizer (see Figure 3.1b) [CH14] and Virtuix Omni (see Figure 3.1c), [Vir17] which are using the passive one. While the Infinadeck provides a higher immersive experience, the two passive approaches are more affordable, even for home users. The addition of HMDs makes the user even more immerse into the virtual world. Because it allows the user to explore the virtual world, like one would explore the physical world. Some advantages over regular hand-based movement techniques (e.g. mouse, keyboard, joystick) are, that the user has its hands free for other interaction tasks and when including the users' legs, a whole-body experience emerges. A current missing point of ODT is haptic feedback when running against obstacles, like walls or furniture.



(a) The Infinadeck treadmill (b) The Virtualizer treadmill

(c) The Virtuix treadmill

Figure 3.1: The state-of-the-art omnidirectional treadmills devices.

3.2 Virtual Reality Based Training Systems

The company Szenaris GmbH developed a PC-based Virtual Reality simulation system for cooperative training, called "VR Team Trainer". The main idea behind the VR Team Trainer was to develop a system, in which the personnel can train the control, operation, and use of complex systems like special vehicles, tanks, etc. The system serves many uses, like the interaction between the users in the virtual world, and transmission of hand signals per data gloves and a tracking system. The system also has a wide variety of user input possibility. It reaches from standard joysticks to heavily customized instrument panels of a tank. While the personnel is training, the trainer can monitor the exercise and record the exercise for debriefing, to increase the learning curve. The VR Team Trainer is in development since 2012 and is mainly used by the German armed forces [Sze12].

Another military application is the Advanced Network Trainer (ANTares) from Rheinmetall. It is designed for joint and combined training with networked and interoperable simulators in land-, air- and sea-based fields. It is intended to be realistic and to provide a high-intensity virtual combat training environment within a single training scenario. The hardware concept consists of many modular cubics (Figure 3.2), which allow building a highly flexible combat training environment. It is easy to install those simulators in another location and form complex networked mission scenarios. Therefore, it is possible to move them to an on-site training mission. The personnel can use the different scenarios for main battle tanks, transport helicopters, crew-coordination training, etc. The hardware used are 2D screens, HMDs, default PC input devices and even fully equipped maneuver stations with the actual hardware [Def13].

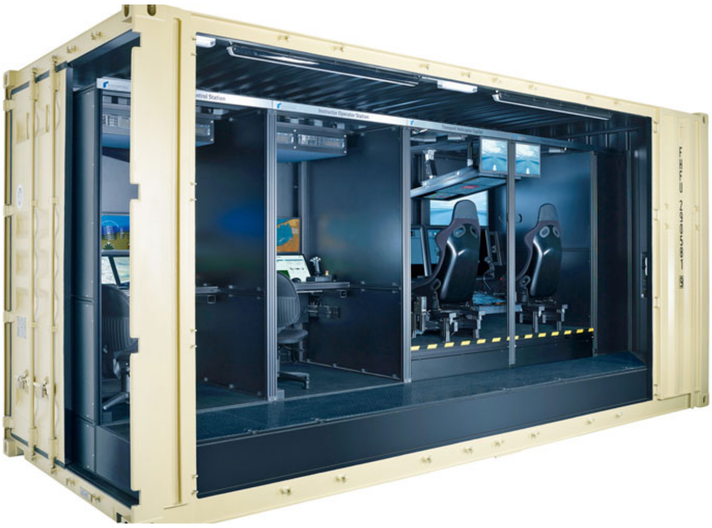


Figure 3.2: Antares modular training container

VIRTSIM is a virtual reality team training application for multiple officers in law enforcement and military. It was first developed for military use during the Iraq and Afghanistan wars. VIRTSIM has a large number of pre-made scenarios and also has the ability for the training facility to create their virtual worlds and customize their training scenarios with the usage of a built-in editor. The used hardware consists of an integrated system including full-body sensor kits, HMDs, instrumented replica weapons, intelligent cameras, man-wearable computers, muscle stimulation equipment and infrastructure including rack servers [Rea09].

XVR Training Software for Safety and Security from XVR-Simulation is a platform for training, exercising and educating emergency response professionals of operational level up to the strategic level. The platform is divided into two parts. The first part is the instructor, which can build an indecent scenario and has full control over the simulation at all times. The instructor can give instant feedback and challenge the simulation participant. The created challenges can be, to answer questions, or the instructor can activate events which the participants need to manage. The second part is the participant of the simulation. Each participant can have a different role such as being a firefighter or an ambulance crew member as seen in figure 3.3a and figure 3.3b. Naturally, each participant has to fulfill different tasks and will most likely have to work together to overcome the incident in the simulation. To navigate through the virtual environment, a joystick is used. Along the specified hardware requirements, no further restrictions are given [Sim15].

(a) XVR firefighting training

(b) XVR paramedic training

Figure 3.3: XVR Training screen captures

ETC Simulation has developed a wide variety of simulation modules. One of the modules is the Advanced Disaster Management Simulator (ADMS). The focus of this module is to train, command and manage teams at all levels in a disaster incident, including emergency managers, public safety officials, incident commanders, crew leaders, first responders, and offices of emergency management. It is already used worldwide by many agencies and companies. ADMS offers realistic 3D training environments, that can be generic, semi-specific or specific. To develop, adapt and customize the scenarios the module has a built-in content creator. The software is a desktop based VR system with 2D screens or large projections. Many different custom tools are used as input devices, from unspecific joysticks over driving wheels to augmented fire extinguishers [Sim92].

High Voltage Switching is a virtual reality compatible application in which the simulation participant has the opportunity to operate the otherwise dangerous procedure of switching a 22KV switch in a virtual environment (Figure 3.4). It should help the participant to familiarize themselves with the equipment and its safety considerations. This application has no team module, but instead, the focus was held on the 3D interaction part. It uses an Oculus Rift Virtual Reality headset, and Razor Hydra motion controls to increase the immersive experience of the participant. The task, which have to be fulfilled, should include the same physical movement actions and the same workflows as the participant would need to do on a real 22KV switch. This should increase the knowledge of how to do the task, make the participant familiar with the equipment and raise the awareness of incorrect and unsafe switching procedures [Sen16].

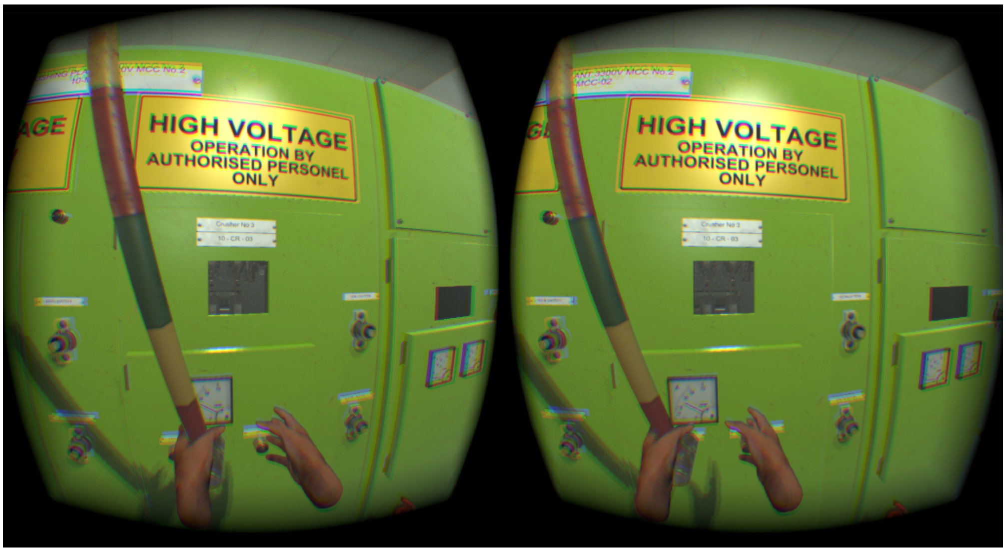


Figure 3.4: Stereoscopic view of the High Voltage Switching training

CHAPTER 4

Methodology

In this chapter, the analysis of the requirements and associated tools, concepts and the structure of the implemented application are presented. Furthermore, the applied methods and the composition of different techniques are explained. Details of the implementation are shown in Chapter 5.

The methodological approach to reach the expected results starts with a requirements analysis and the definition of the scope. To get applicable requirements, literature research about the current executed procedures of disaster relief management in Chapter 2, the current state-of-the-art in Chapter 3 and the future stakeholder are taken into account to define the requirements. For the involvement of the stakeholder, usability engineering techniques are used. To implement a system based on these requirements, an architecture design of the application and its distributed system must be created. To perform the implementation of the planned interactions, concepts of these interaction techniques must be acquired and elaborated on. Due to the interaction possibilities in distributed systems, potential conflicts must be identified and eradicated. The last part of this chapter examines the usage of a 3D engine for visualization and possible hardware devices for navigation and interaction. Combinations of the hardware for an optimal user interaction experience, along with the pros and cons of these hardware configurations are, can be found at the end of this chapter.

4.1 Requirements Analysis

Requirements analysis is a key part of the software engineering process. The consequential requirements of the analysis determine the needs and conditions of the resulting project. Multiple factors of different stakeholders need to be taken into account to minimize potential conflict of interest. The analysis includes checks for necessity (if the requirements are needed), consistency (the requirement must not be in conflict with one another), completeness (nothing is missing), and feasibility (the requirement is possible to implement regarding budget, schedule availability) [PEM03].
To acquire all requirements completely is not a trivial task, but is crucial for the success or failure of the project [KS98]. The requirements can be divided into three categories: functional requirements, non-functional requirements, and domain requirements [Gre10]. To stay on top of things, the requirements should be documented and preferably rounded-up with some graphical describing languages, like the unified modeling language (UML).

4.1.1 Scope

The scope determines the size and effort for the project. At that point, the goals of the project are as important as the non-goals, to be able to define the boundaries of the project. Requirements are always a trade-off between functionality and the given resources. The following listing describes the requirements, which are in conflict with each other:

- Complete implementation of the requirements
- The precise understanding of the user requirements and their connection
- The specification on how the requirements are getting implemented in the design of a project
- The completion in all the details of the requirements for the usage of the given time and resources

In most cases, only a fraction of the requirements with a certain quality can be implemented. Because of the intention that a user study with actual stakeholders is going to be taken. It this work it is essential to get the implemented requirements to a stable and usable state. Criteria, such as performance, usability, and faultlessness of the application, play a key role [Gre10].

4.1.2 Stakeholder

All involved persons, who have an interest in the project or gain a benefit from it are stakeholders. Hence, the stakeholders have the biggest influence on what the requirements are and what are not. Usually, a software project has more than one stakeholder with different interests [Gre10]. The stakeholders for the software application, resulting from this work, are all kinds of emergency services, especially firefighters and paramedics. The following listing gives an overview of the actual and possible future stakeholders:

- Firefighters
- Paramedics and other medical services
- Police forces
- Military
- Training and educational facilities of the above
- Staff work
- Government
- Local communities in general

4.1.3 Functional Requirements

Functional requirements define the functions or services, which should be provided by the system. For example, how the application should act to various user inputs [Gre10].

In real training, many tasks are going on, and many factors are playing a role to perform the training as realistic as possible. Therefore, it can be expected that this applies to the virtual training as well. Requirements must be defined to cover all the essential aspects of the software engineering process:

- Hardware design adaptable and operating system (OS) independent (mobile, desktop)
- Affordable for smaller organization
- Multi-user distributed platform
- Freedom of movement for exploration (rotation, translation)
- Voice chat for giving commands
- Complete command cycle
- Untethered hardware
- Recordable training sessions

4.1.4 Non-Functional Requirements

Non-functional requirements describe the quality characteristics of the system rather than how the system acts. For example, how easy the system can be used regarding usability or how secure the system should be [Gre10].

Non-functional requirements for the application of this work:

- Ease of use, especially for the users that are unfamiliar with VR.
- Performance, less frames per second (FPS) leads to more cybersickness [LCC$^+$13].
- Maintainability, the maintenance expense should not raise the number of assets.
- Extensibility, it should be able to extend the application with new scenarios and feature to increase the overall applicability for more stakeholder.
- Scalability, the number of clients and assets should not be limited by the system.

4.1.5 Domain Requirements

Domain requirements are functional or non-functional requirements, which are implied by the nature of the field of the application [Gre10]. In this work, two major requirements are to overcome current limitation in squad leader training [MFS$^+$17]:

1. Realism: as already mentioned in Section 1.2 all tasks of the PDCA cycle should be executable. Additionally, aggravating circumstances such as locomotion, time pressure, stress and (physical) exhaustion should be added.
2. Effectiveness: the usage of the application should save costs and time for the stakeholder, while only a minimum of hardware devices and preparation are needed to operate the system.

4.2 Usability Engineering

The application, which is implemented within this work will be used and tested with actual relief units. For this reason, a major focus is on the usability of the application. What usability is and how to ensure a user-friendly experience will be explained in this section. The following suggestions and key points will be utilized throughout the whole implementation process.

Usability engineering is the process of making the user interface of a system more user-friendly [Nie00]. The usability of a system can not be defined by a single property. As early as 1988, Norman made four basic suggestions in [Nor88], for designs:

1. It should be easy for the user to determine, at any given moment, what actions are possible.

2. Things, which the user can interact with and eventually alternative actions should be visible.
3. It should be easy for the user to evaluate in which state the system currently is.
4. The procedure between the following assertions should be obeying natural mappings: intentions and the required actions, actions and the effect, and the information, that is visible and the interpretation of the systems state.

Nelson specified this suggestion into a more certain way [Nie00]:

- **Learnability**: The learning curve of using a system, should be as steep as possible. Users with more knowledge about the system work faster with the system.
- **Efficiency**: Describes how productive the system can be used, after the user has learned how to use it. After a while, the user reaches a point where the efficiency can not increase any more. Sometimes it is useful to require a longer training period to accomplish a higher efficiency.
- **Memorability**: Every user, even when the system is hardly used, should be easily able to remember how the system works, without the need of another training period.
- **Errors**: The fewer errors in the system, the better. It should be hard for the users to produce errors with their interactions. Nonetheless, when they occur, it should be easy for the user to recover from it. Critical errors and errors, which ruin or delete the work of the user, must not occur.
- **Satisfaction**: The users should be subjectively satisfied with the system and have the feeling that the system makes their work easier or even more fun. It should animate the users to use the system more often.

To measure the usability of a system, some test persons are usually needed [Nie00]. Mostly the usability requirements are not defined by the developers, but instead, from future users and stakeholders. The future system should be customized as good as possible to the needs of the users. The users can be seen as experts in their field, and their feedback defines the usability requirements. If the system is going to be used by different groups of users, the test should be preferably executed with all groups. It might be, that diverse groups want to use the system differently. For such cases, a good trade-off needs to be found [Gre10].

4.2.1 User-Centered Design

The term user-centered design (UCD) describes a design process in which future users play the key role in influencing the shape of the system. There are multiple ways to involve the users in the UCD process, but the key part is, that the users are involved in one way or another [AMKP04]. In contrast to classic development processes (e.g. waterfall model) the UCD process follows an iterative way. The international standard 13407 (ISO 9241-210:2010) makes the basis for many UCD methodologies, [fS10] although, the exact methods for each phase are not concretely specified in the standard. In [Gre10] the iterative development process is separated into four consecutive, cyclic phases:

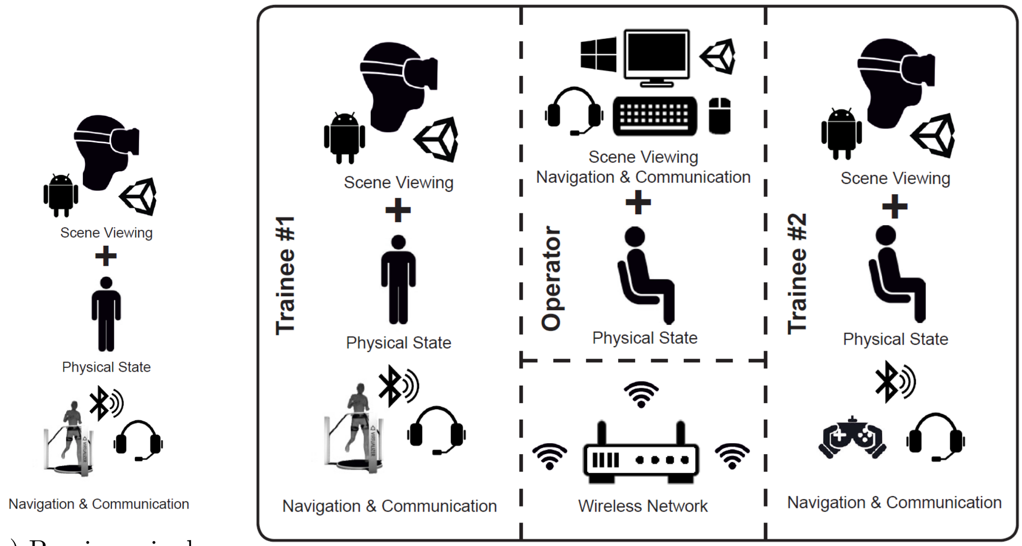
- **Requirements**: The focus of this phase is to get knowledge and understanding of the users' tasks. Subsequently, on this knowledge, requirements are defined (mainly non-functional requirements).
- **Design**: Based on the defined requirements, a design solution needs to be developed. Additional to the input of the users, the knowledge of the developer and the state-of-the-art should have an influence.
- **Prototype**: After the possible design solution is finished, a prototype, based of this design, is implemented. What kind of prototype this is, can be varying from paper-prototypes over to mocked UIs, to finally even full executable systems.
- **Evaluate**: When the prototype is in a testable state, the prototype is evaluated by the developer team and the users. The received feedback can either be used to set the parameter for the next requirements phase or to ensure the qualities or standards of the system.

4.3 System Architecture

> "An architecture is the set of significant decisions about the organization of a software system, the selection of the structural elements and their interfaces by which the system is composed, together with their behavior as specified in the collaborations among those elements, the composition of these structural and behavioral elements into progressively larger subsystems, and the architectural style that guides this organization—these elements and their interfaces, their collaborations, and their composition" - [Kru04]

The application, which was implemented within this thesis, was not started from scratch. Instead, the starting point was the current state of the VROnSite [MFS$^+$17] project. In Figure 4.1a and 4.1b the schematic view of the previous single-user VROnSite system can be seen in comparison to the new multi-user, distributed VROnSite system.

In this thesis, VROnSite was among other features extended by a multi-user and interaction system. Figure 4.2 illustrates the system architecture of the newly developed



(a) Previous single-user VROnSite

(b) Distributed multi-user VROnSite

Figure 4.1: Comparison of the (previous) single-user and (new) multi-user VROnSite systems

VROnSite application. It shows the application with its base modules. The first major part of the implementation within this work was to develop a distributed system to make it possible to run the VROnSite application on multiple clients in the same environment. The second major part was to develop a 3D object interaction system to allow the clients in the distributed system to interact with each other and the virtual environment. VROnSite is an application implemented on top of the Unity Engine with the integration of the ARTIFiCe [MSGK12] interaction framework. Unity can run on many different platforms. In this thesis, the focus is on the android and windows operation system. The application can run in two modes. The first one is the VR mode, which can be run on mobile devices and computers. Naturally, this mode requires a HMD. The input for the application can be from multiple devices. The expected input source for the application is very generic and not limited by the type of device, as long as the input device is compatible with the computer or mobile device, on which VROnSite is running. The same applies to the sound output and microphone devices. To utilize input devices currently not supported by mobile devices, a plugin between the mobile and input device is required. As exemplified in Figure 4.2, this could be a Cyberith Virtualizer. The second one is the desktop mode, in which the visual output of the application is on a 2D monitor. Input devices are mouse, keyboard and microphone or headset.
As mentioned earlier, multiple instances can be put together inside a local area network (LAN) to allow a multi-user experience. For this purpose, one instance on a computer must be the host/server. The details of the resulting distributed system will be briefly explained in the next section.

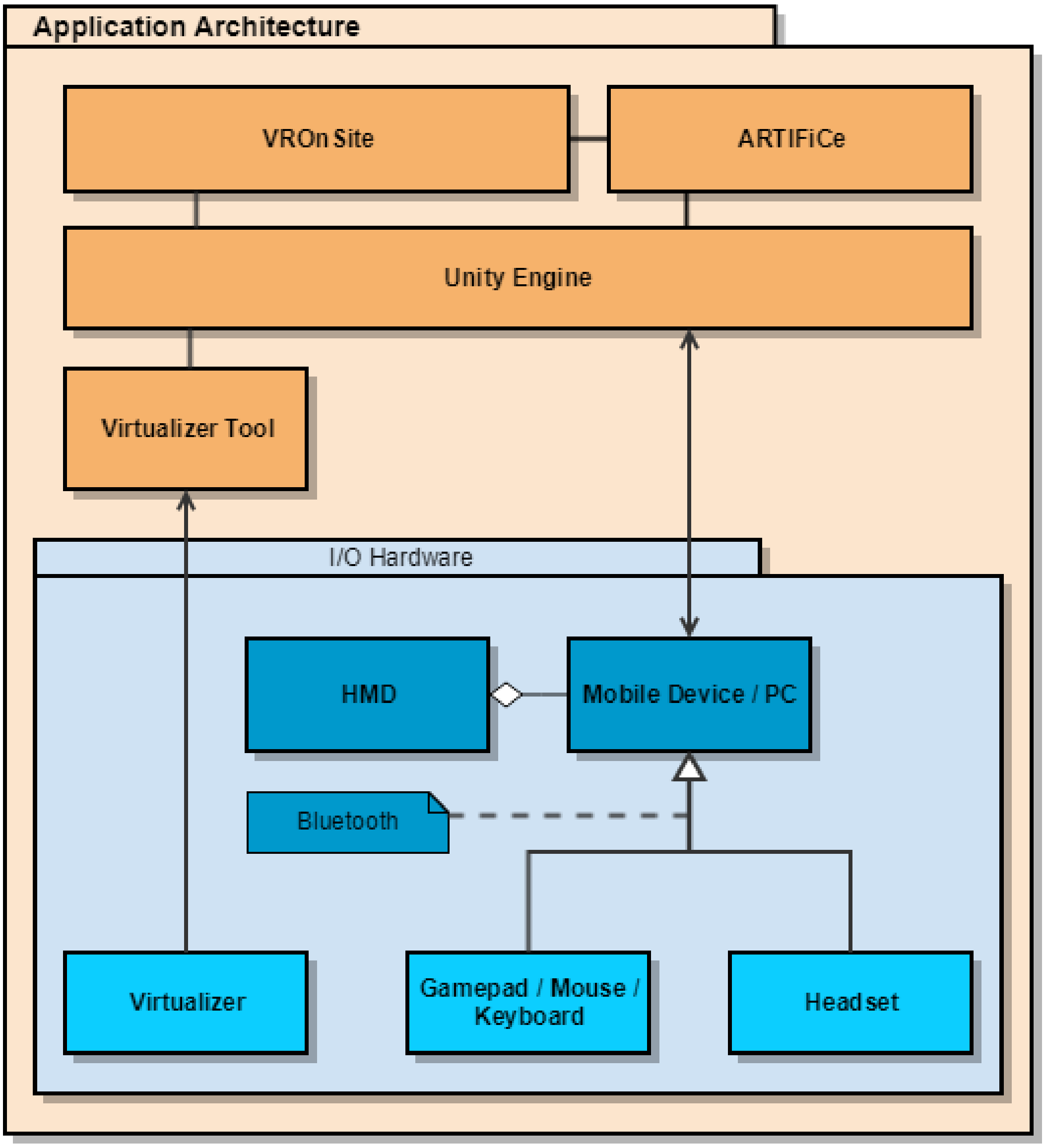


Figure 4.2: System architecture of the new VROnSite system

4.4 Distributed System

A distributed system consists of autonomous components, while it looks like a single system from the users' perspective. For this reason, the components need to communicate and collaborate, can be implemented in different ways. An important characteristic of a distributed system is, to mostly hide how the various components communicate with each other. For example, for the user, it is only important what communication technology is going to be used (e.g. WLAN, Bluetooth), but not how exactly the communication works. Another characteristic is, that it should be easy to extend and scale the system. This matches perfectly with the two mentioned non-functional requirements of *extensibility* and *scalability* in Section 4.1.4. To support devices with different operating systems in a heterogeneous distributed system, a layer needs to be placed right before the application [TS06]. In a 3D interaction application, a 3D engine provides this functionality. In the case of the new VROnSite system, as shown in Figure 4.2, the unity engine serves the purpose of the required layer.

For the development of the new VROnSite system, a distributed system pattern was used, which is shown in Figure 4.3. The system consists of two main components, the server and one to multiple clients. These two components can be connected via (W)LAN. The same application runs on the server and the clients, but on each instance, different code is going to be executed. The server can be dedicated or running as a host, with a client as an operator.

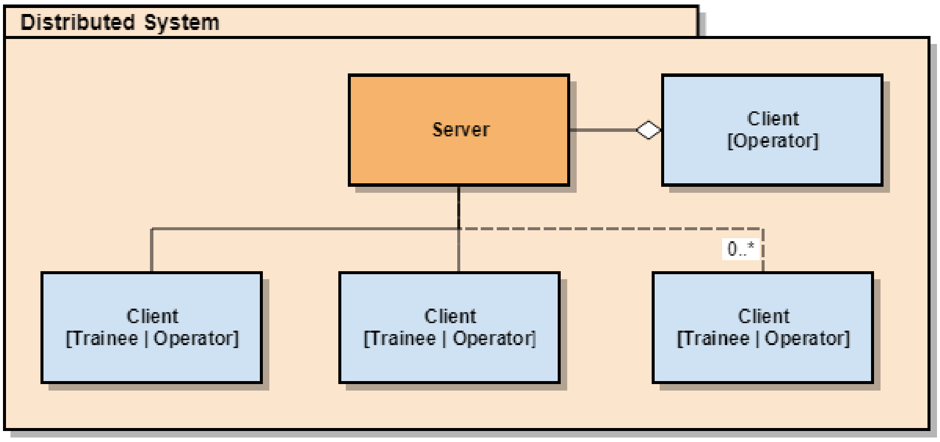


Figure 4.3: Basic class diagram of the distributed system

Only variables, which are important for all clients, are transferred to the server and then further to every client. For example, the position of the character, or when a client is interacting with the scene, must be synchronized with the server and all clients. An example for something, that should not be forwarded to the clients, is, when a client sets a marker with a note, just for itself.

The client supports multiple platforms (e.g. windows, android, etc.) to run on. Because of a loose coupling between the client itself and its functionality, it does not matter what kind of client is used. Therefore, the client can be a trainee or operator and it is easily possible to extend this in the future with additional roles (e.g. spectator, radio operator). In Figure 4.4 this inheritance is visualized.

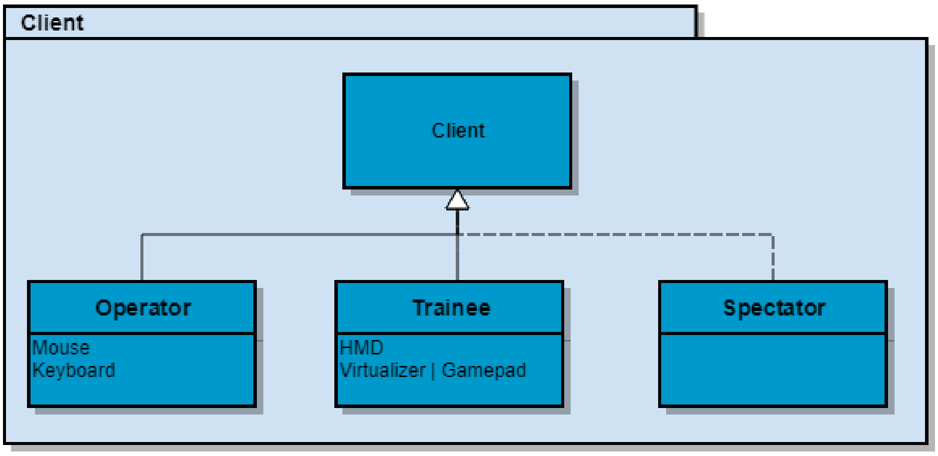


Figure 4.4: Basic class diagram of the client and its inheriting subclasses

The server manages multiple clients and multiple objects in one scene. Each client can interact with every interactable object. Therefore, some precaution must be taken into account to prevent possible conflicts. When multiple clients try to interact with the same object, a lock mechanism is used to inhibit possible problems. The sequence diagram in Figure 4.5 illustrates a lock strategy. The first actor ($client_n$) interacts with an interactable object. This object then gets locked to this actor on the server side. If another actor ($client_{n+1}$) tries to interact with the same object while the object is locked, the second client ($client_{n+1}$) will get informed, that this is not possible. After the object is released again, every other client is capable of interacting with it.

This section gave an abstract overview on how the distributed system works fundamentally. How the system was exactly implemented and how all of the distributed components function together (server, trainee-client, operator-client, ARTiFICE, virtualizer tool, etc.) will be briefly explained in Chapter 5.

4.5 Freedom of Movement

For navigation and orientation, the user must have some degrees of freedom DOF. The two roles (trainee, operator) for the clients need different DOF implementations. Because the role of the trainee is bound to an avatar, it underlies the gravitational influence. However, the role of the operator does not have any boundaries, except the limit of the virtual environment. Therefore, the operator has 6 DOF regarding navigation. Owing to

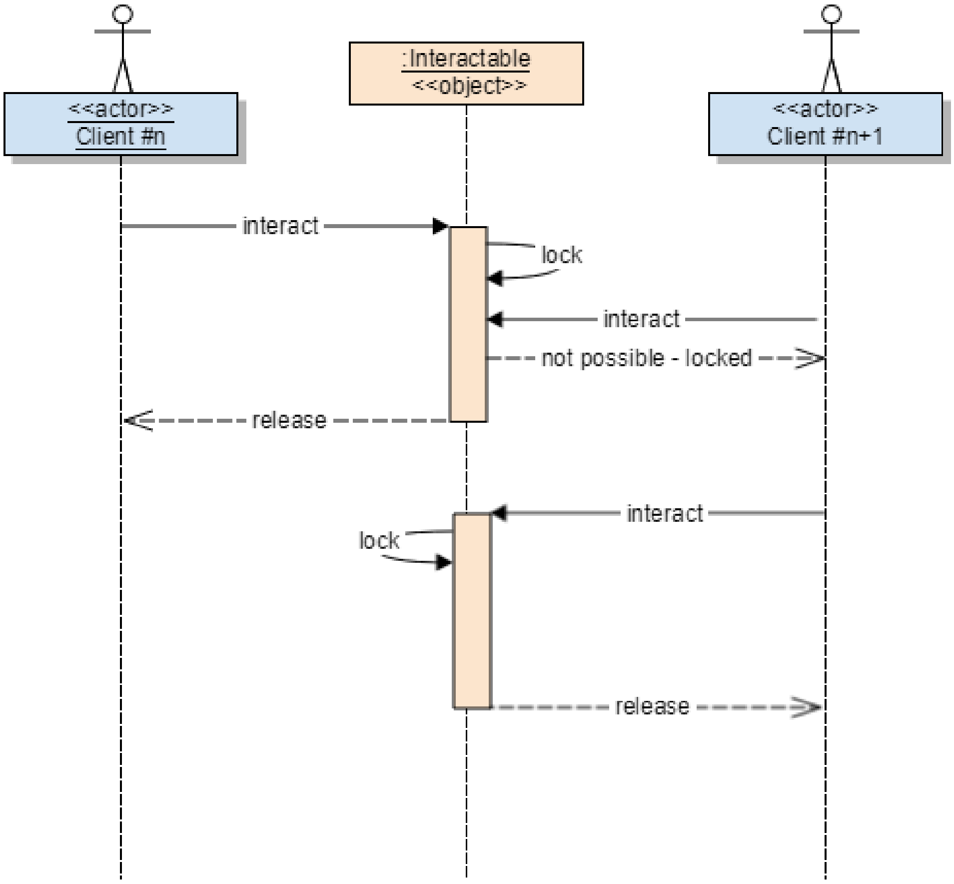


Figure 4.5: Sequence diagram: multiple clients try to interact with the same interactable object simultaneously

usage of HMDs by the trainee, *head-tracking* is enabled. *Head-tracking* is essential for VR applications, due to its 3 DOF, the real world movements of the users head can be mapped to the camera ration in the virtual world [PPMP15]. To circumvent the problem of too little physical space for navigation, the *head-tracking* is not a good choice, as opposed to other input devices. Teleporting would be a possible solution, but it brakes the immersion and takes stress factors, like physical exhaustion from the training. To navigate seamlessly through the virtual environment, gamepads or ODTs can be used. With the usage of these devices, the head and body can still be rotated independently from the rest of the body. Figure 4.6 shows all the possible movements of the trainee character. The head can yaw (blue), roll (green), and pitch (red). The avatar as a whole can rotation wise yaw (blue) and translation wise go forward/back (green), right/left (red) and up/down (blue, terrain and gravity depended).

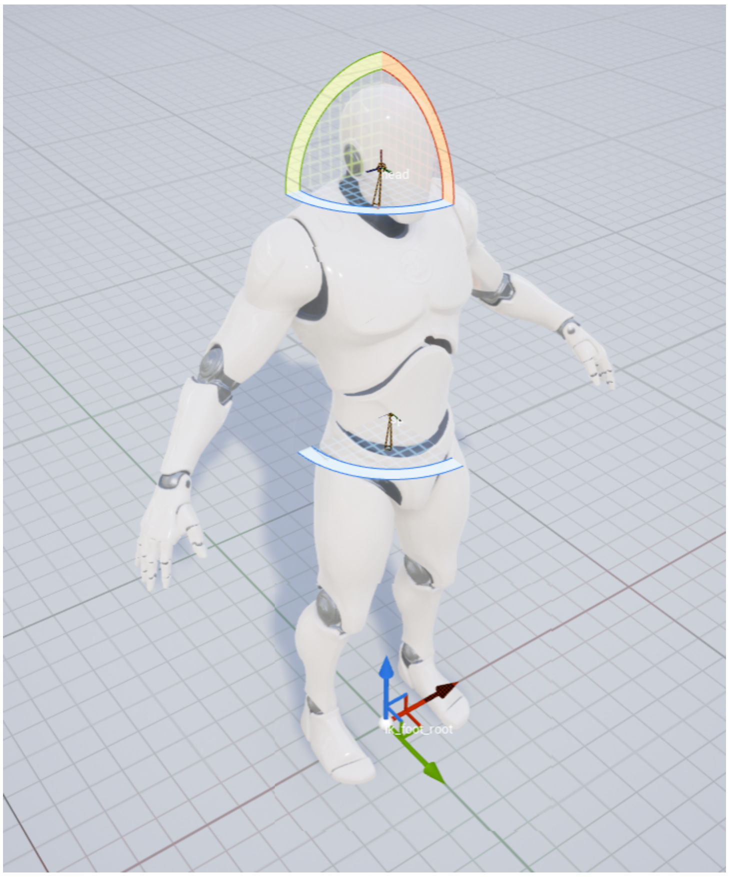


Figure 4.6: Freedom of movement of the trainee avatar

4.6 3D Object Interaction

Due to the different roles and various input devices, two different raycast approaches (see Section 2.5.1) must be implemented. Which furthermore need to be distributed to provide a consistent experience for all connected users (→ ARTiFICe interaction distribution). In the previous section, the different DOF of the trainee and operator were mentioned. The operator is virtually a completely free moving camera and is controlled by mouse and keyboard. At this moment, the keyboard is used for the movement and the mouse for rotation and interacting with the cursor. As the operator moves through the scenario, the angle to the scene is changing frequently. For the operator, the raycast is not directly casted by the camera. Instead, the raycast starts at the mouse cursor and has an unlimited length until it hits a collider, which is usually the ground floor of the scene. Figure 4.7 visualizes the ray (red diagonal line) of the operator. The camera symbolizes the viewpoint of the operator and the ray is cast from the tip of the mouse cursor. In this case the cylinder gets selected by the ray.

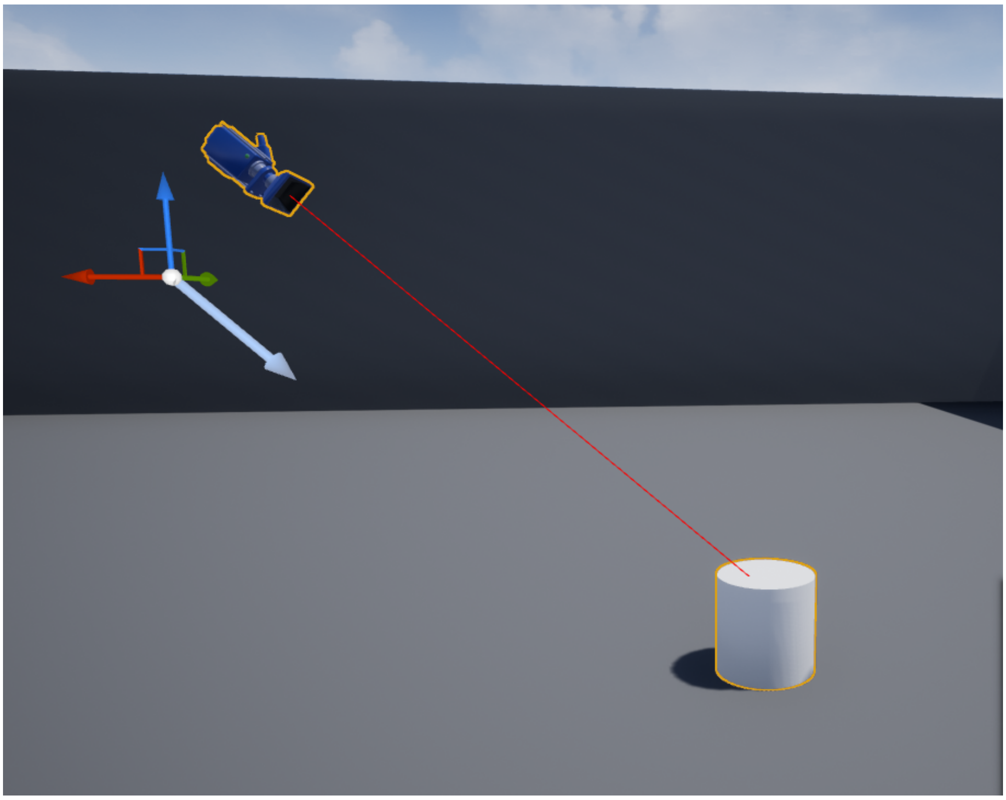


Figure 4.7: Operator raycast

The raycast approach for the trainee differs here immensely. For trainees, the raycast starts from the center of the camera/head of the character, and only casts a ray with a predefined length. Only if the ray interferes with an object, which can be interacted with, a hit is returned. As shown in Figure 4.8, the ray (red horizontal line) is casted and ends after some length without hitting any objects of interest.

4.7 Visualization, Navigation, Interaction and Communication

To realize the training scenarios for the relief units in VR, some tool for visualization is needed. For the purpose of navigation, interaction, and communication, some appropriate hardware is required. For these needs, the following sections will subsequently satisfy the demands.

4.7.1 Unity 3D Engine

The Unity 3D engine [Uni17] has been used for visualization in this work. A major advantage of this engine is the easy possibility to deploy applications on multiple different

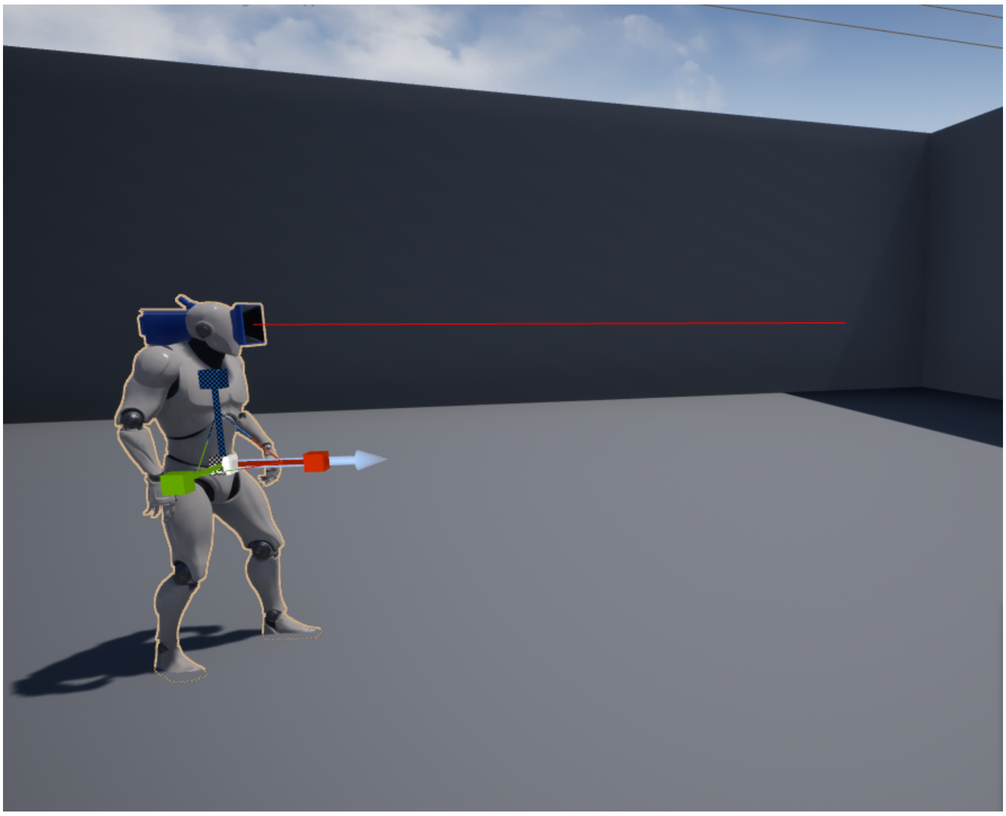


Figure 4.8: Trainee raycast

platforms. Currently, more than 25 platforms are supported (e.g. desktop, mobile, web, game consoles, VR, AR, etc.). Furthermore, the engine is hardware independent and can be freely configured for all sorts of input devices. It includes 3D design tools, instant play mode for rapid editing and iteration, a powerful animation system, and has artificial intelligence (AI) pathfinding support to navigate non-player characters (NPCs) through the virtual environment. Unity takes advantage of the latest graphics processing unit (GPU) and hardware improvements, and stays close to the low-level graphics application programming interface (API), while supporting multiple platforms. To boost the developing process even further, off-the-shelf content is provided in an asset store (paid and free).

4.7.2 Comparison of Input/Output Devices

To be as hardware independent as possible, the navigation algorithms should only have the need for generic, cross-device, input values (e.g. vector for translation, button pressed/released). Therefore, the client listens for an input value, where it does not matter if it comes from an analog stick of a gamepad, key event of a keyboard or the input signal of an ODT. This provides the possibility to use future hardware and other

Head Mounted Displays		
Device	**Pros**	**Cons**
Mobile Device HMD (e.g. Gear VR, Google daydream)	Standalone	Low processing capabilities
	Low costs	Low graphics capabilities
	Input functionality	No tracking
		Navigation device needed
Tethered HMD (e.g. Oculus Rift, HTC Vive)	High graphics capabilities	High-end computer required
	High processing capabilities	High costs
	Tracking included	Tracking limited by physical space

Table 4.1: Comparison of head mounted displays

currently available hardware, which is not taken into account within the implementation of this work.

How the user can interact with the virtual environment is highly dependent on the used hardware. Different hardware types offer a different set of possibilities. Some of these will be compared in the following tables. Table 4.1 compares the differences between a HMD, which uses a mobile phone as processing unit, and a HMD, that needs a computer to do the processing (video input signal). Table 4.2 compares the pros and cons of input devices. There are many different approaches for user interaction in VR. After this comparison and the literature research in Section 2.5, it can be said, that there is no perfect solution for every task.

Possible combinations that fulfill the mentioned requirements to be used for the VROnSite application in combination with a HMD are: gamepad only and ODT only. The cost factor plays a big role at this moment, especially for smaller training facilities and organizations. Table 4.3 compares two different sound settings. The key role for the sound setup is the location. If it is the case, that many participants are training in one room, an omnidirectional microphone would be the preferable option. If the participants are separated into different rooms or locations, headsets definitively are the desirable option.

Input Devices		
Device	**Pros**	**Cons**
Gamepad	Easy to use	Less realistic
	Low Costs	Less intuitive in VR
	Often many input possibilities	
Gloves (e.g. Manus VR)	Very intuitive interaction	High level degree of the interaction implementation required
		High Costs
Tracking system	Maps physical world movement of the user 1:1 into the virtual	High Costs
	Limbs free for other tasks	Limited by the size of the physical tracking area
		Teleportation for navigation needed
Visual Hand Tracking (e.g. Leap motion)	Hands free → intuitive interaction	High level degree of the interaction implementation required
	No sensors on the body	
Omnidirectional treadmill (e.g. Cyberith Virtualizer)	Unlimited movement (only boundaries of the virtual scene)	Familiarization with the device needed
	Simulates stress factors (exhaustion)	High costs
	Almost real walking experience	

Table 4.2: Comparison of input devices

Sound Devices		
Device	**Pros**	**Cons**
Generic headset	Tethered or non-tethered	Microphone indifference when in a room with noise or multiple participants
	Low costs	
	Bone conductor possibility	
	Distinction of who is talking	
	Push to talk, for imitating the radio	
Omnidirectional microphone	Works well, when all participants are in the same room	Noise; needs to be in the center of the room; only when all participants are in one room
		Hard to identify and trace back the sound source

Table 4.3: Comparison of sound devices

CHAPTER 5

Implementation

In this chapter, the implementation of the new modules for distribution & 3D interaction of the VROnSite system are described. Beginning with an abstract overview of the system, what is the procedure of the system, how the system is structured and why performance does matter. To test the application with the actual stakeholders, scenarios had to be designed and constructed. The starting point is the previous developed VROnSite project with the usage of the acquired knowledge from the involved stakeholders. Due to the different point of views of the operator and trainee, different perspectives were created. As already mentioned in the introduction, the aim of this work is to complete the PDCA cycle. This was achieved by an interaction system, both for the operator and trainee. To fulfill the requirements of the navigation and interaction for the stakeholders as good as possible, the stakeholders get involved in a UCD process. This process will be repeated for two iterations and the differences between the iterations will be presented. Because of slightly different demands of the firefighters and paramedics, multiple scenarios were implemented.

To implement the application, following tools and frameworks were used:

- Unity Engine 5.5.2f1
- Microsoft Visual Studio Enterprise 2015 Version 14.0.25431.01 Update 3
- Virtualizer Bluetooth Integration for GearVR
- ARTiFICe - Augmented Reality Framework for Distributed Collaboration

5.1 Overview

In this section, an overview of the implemented system is given. With the usage of UML diagrams, the implementation details are illustrated. At first, the step-by-step procedures of the application are explained. Including the initial start up, organizing the session, starting the virtual training, and completing it. It is outlined, how the clients and server are getting managed by a lobby implementation. The dependencies and inheritances of the most important classes are described and visualized by class diagrams. At last, some aspects of performance factors are mentioned.

5.1.1 Execution Sequence

Initially the system starts at a common point, for whatever device or for whatever purpose the application is going to be used. Therefore, at the start it does not matter if the application is executed on a mobile device or desktop PC and however it will be used as a server, host or client. The whole sequence is visualized in an activity diagram shown in Figure 5.1.

At first, the *menu lobby scene* is loaded. Right before the scene is shown to the user, a check is performed on whether a HMD device is detected or not and if the appropriate setting is set, to use the perhaps detected HMD.

Usage of a HMD

When a HMD is going to be used, the desktop UI is disabled, and the VR menu environment is enabled. Then the application automatically goes into the client mode and actively searches for a LAN server.

Without the usage of a HMD

Without a HMD the desktop UI is enabled and the VR menu environment is disabled. Subsequently, the main menu UI shows up and the user can choose, if the application should continue with the host or client mode. Alternatively, the application can be quit. When the host mode is selected, the server starts and a local client is started, which instantly connects to the local server. Meanwhile, a *network discovery broadcast* is initiated in a separate thread, which gives possible clients in the network information about the server. At the same time, these three distinct tasks are visualized for the user in the *lobby menu UI*. More information about the lobby will be explained in Section 5.1.2. Does the user choose to join, a client is started, and if a server is found, the client tries to connect to this server.

Start of the training

When all connected clients are ready, the application continues and starts the training after a short fade-out of the view. Currently when using a HMD, only the *trainee mode* is

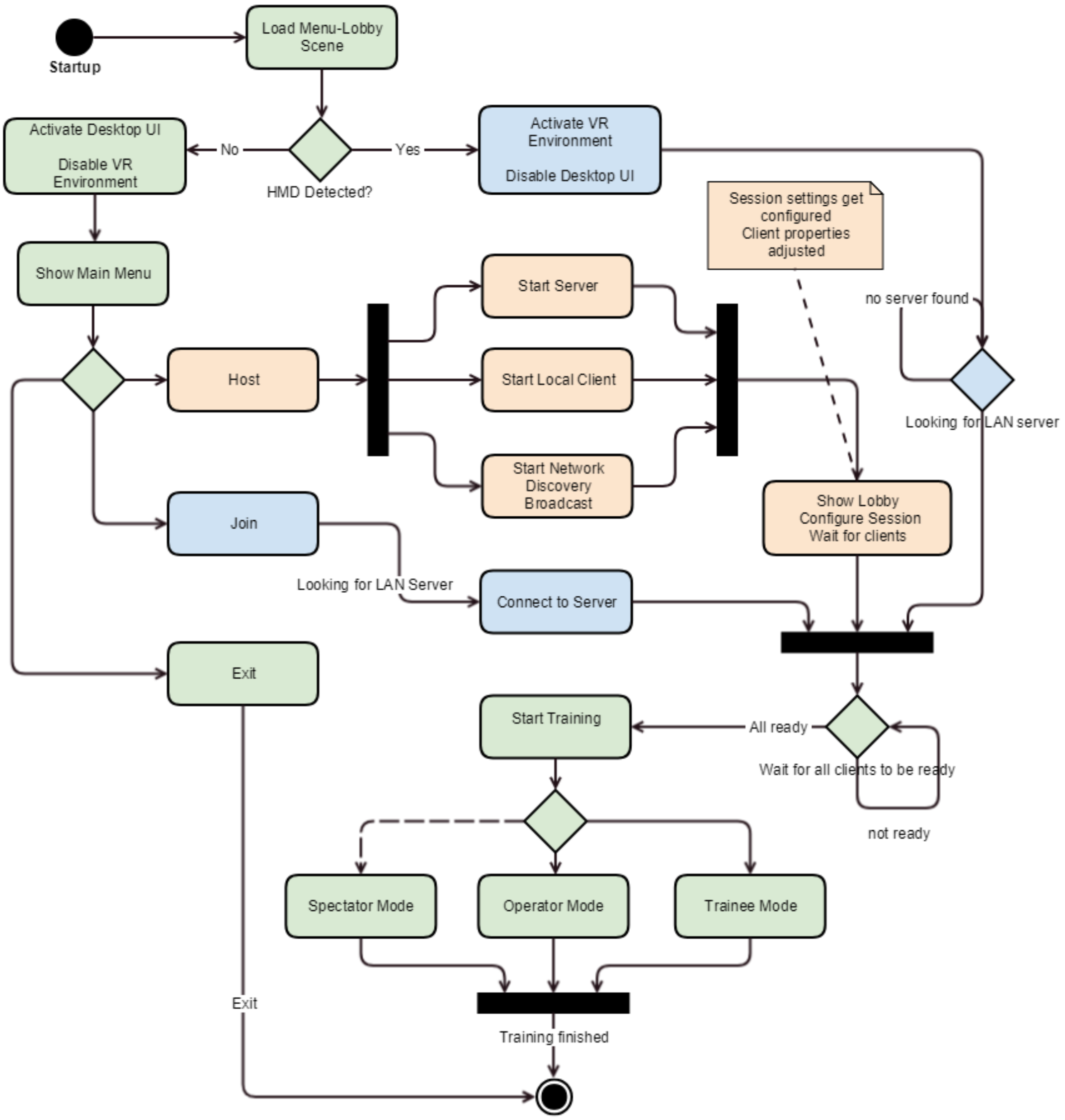
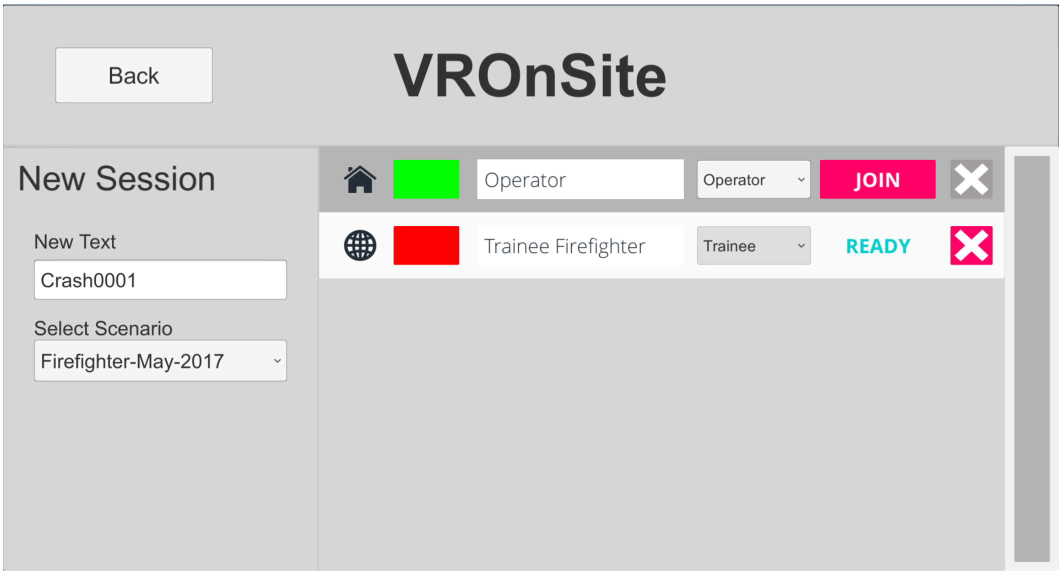


Figure 5.1: Activity diagram of the distributed VROnSite system

available. Without a HMD it only works in the *operator mode*. But, it was implemented and planned, that the system can be extended by additional modes in the future (e.g. spectator mode with and without HMDs). How the different modes work and how the virtual environments look like will be briefly explained in the upcoming sections of this chapter.

5.1.2 Lobby Manager

The lobby manager handles all clients on all devices in the distributed system. On the server side, a *network discovery broadcast* sends information packets about the server on a particular port. While on the client side a *network discovery receiver* is looking for these server packets. When a client receives a packet from the server, the client connects to the server. Is the client running on a mobile device, the role is automatically set to the trainee. A user on a desktop PC can choose between the trainee and operator role. In the meantime, the client on the server side can configure the session. The session name and the name of the clients can be changed, in order to make it easier to identify the distinct clients in training. The most important option is probably the selection of the scenario. At this moment, the user can select one scenario out of a predefined list. All of these settings are saved in the local storage of the respective device (session on the server; name of the client on the (mobile) device) and will be loaded again on the next startup. To start the training session, all clients must change their state to *ready*. Figure 5.2 represents the UI of the lobby.



New Session

New Text
Crash0001

Select Scenario
Firefighter-May-2017

Operator
Operator

Trainee Firefighter
Trainee

Figure 5.2: Lobby menu

5.1.3 Class Structures

In Chapter 4, the basics of the systems architecture and the distributed were described. Now, in this section the detailed class diagrams of the important parts of the system are presented. As in most cases of the distributed VROnSite application, the class structure is heavily depended on the role of the client. How the interaction works in the view of the trainee or operator is shown in Section 5.3.

Trainee

The trainee class diagram, as seen in Figure 5.3, can be divided into three packages.

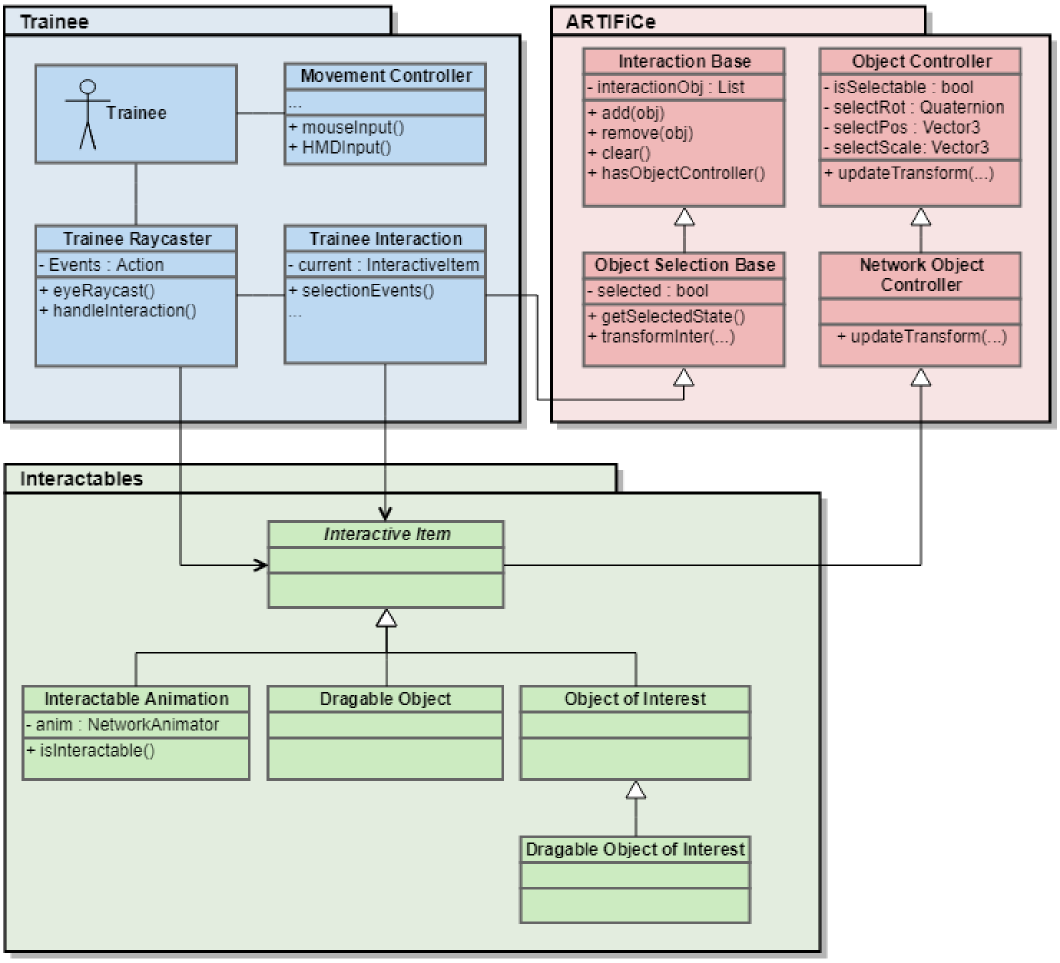


Figure 5.3: Abstract overview of the trainee interaction classes

(1) The first package is the base class of the trainee itself (blue). The *trainee* class represents all the client-server communications and other helper classes (e.g. input processing). The navigation of the trainee through the virtual environment is handled by the *movement controller*. On the head of the trainee avatar a camera is placed. From this camera the ray for the interaction is cast. If the ray collides with an object that is interactable, the users will get a notification on their displays. To define what sort of interaction can be performed, the second package "interactables" was implemented.

(2) In the "interactables" package (green) the inheritance structure of the interactable items are defined. All interactable items inherit from the abstract *interactive item* class. Interactables of the *interactable animation* class trigger an animation when interacted

with (e.g. close/open doors). *Dragable object* can be moved by the trainee. If and how long *Object of interests* are seen by the trainee, will be saved in a file. *Dragable objects of interest* is a combination of *dragable object* and *object of interests*. Thus far, when and how to interact was mentioned. But how the interactables are managed in the distributed system with multiple users is still open. For this purpose, the ARTIFiCe framework was integrated.

(3) The ARTIFiCe package (red) manages the objects in the scene and provides an *interaction/object selection base* for the trainee. The *network object controller* communicates with the server when the user interacts with an object. As long as this happens, this particular object is locked for all other users as shown in Figure 4.5. The intersection between all this packages and classes provides the *trainee interaction* class. This class inherits from the ARTIFiCe interaction classes and performs the interaction on the *interactive items*. The information about on what interactive item the interaction gets executed is provided from the *trainee raycaster* class.

Operator

The operator interaction system is much simpler than that of the trainee (see Figure 5.4), because the interactions of the operator do not interfere with another clients. The operator class has its movement controller to navigate through the virtual environment. The operator can spawn new objects into the scene. This is why the *spawn manager* was implemented. It gets a predefined list of *spawnables* at the startup of the system, which can be spawned by the operator via mouse and raycast. Additionally, the *marker manager* class is used to create a marker in the scene, which constitutes as notes. These *marker objects* consist of a manually inputted text by the operator and a position where they were placed.

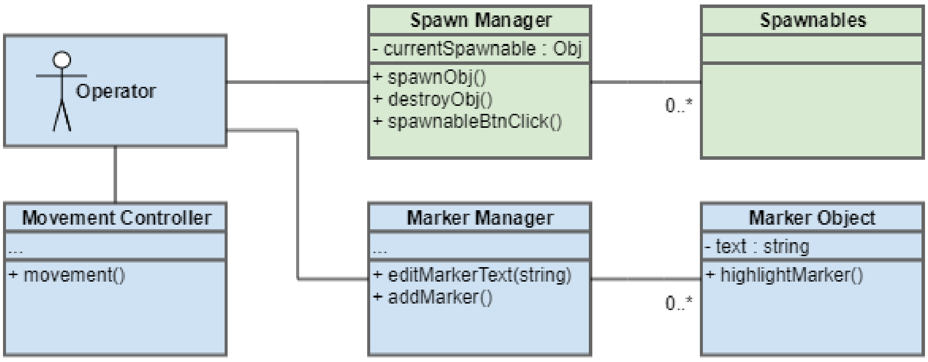


Figure 5.4: Operator interaction class diagram

5.1.4 Performance

The performance (FPS) of VR applications plays a key role for immersion, and thus presence inside the virtual environment and reduces the occurring of cybersickness [LCC$^+$13]. To keep the FPS high on a mobile device, the used objects need to have a low level of detail (LOD) or at least the possibility to reduce the LOD at runtime when the performance is about to diminish. However, a high LOD is desirable for realistic depiction of the virtual scenarios. For this reason, definitions were made to reduce the LOD of the objects when the user is further away.

5.2 Perspectives

Due to their role, the two implemented clients have a different perspective of the scenario they are in. The operator should have a good overview of the whole scenario. In contrast to the operator, the trainee is bound to a ground locked character avatar and has just the view of a virtual person. Figure 5.5 and Figure 5.6 show the different perspectives of the same situation of a scenario.

5.2.1 Trainee

Figure 5.5 shows the perspective of the trainee. Here the trainee can see the scene as he would in a real world disaster. In the background the trainee sees the firetrucks in which they were arriving and beside that are some bystanders. Directly in front is a red car with a woman inside. In this case, the woman is unable to open the door, which she also says verbal to the trainee. To tense the situation, smoke is coming from the engine and oil is leaking from the car. The trainee is then halted to take action. One possibility for the trainee is to check if the door is intractable. If not, the trainee must command his (virtual) units to free the woman.

5.2.2 Operator

Figure 5.6 shows the same situation as Figure 5.5. As mentioned in Section 4.5, the operator has 6 DOF and can decide by himself from which point of view the scene is observed the best. In Figure 5.6, the operator can see the trainee while standing in front of the red car. This view has the advantage that the operator can directly watch how the trainee acts in stressful situations and if the right or meaningful commands are given.

5.3 Interaction

The implementation of 3D interaction functionality plays a key role in this work. In the previous VROnSite project, only the plan and do of the PDCA cycle were included, as shown in Figure 1.1. To complete the PDCA cycle, an interaction system was implemented. This interaction system allows the trainees to interact by themselves with the object in the scene and allows to delegate complex tasks to the operator, who has much more

Figure 5.5: Trainees point of view, as they are experiencing the scenario

possibilities to execute them due to the input devices (keyboard and mouse) and the birds-eye overview. After the operator executes the commands of the trainee, the trainee can check if the given commands were realized correctly. Consequently, the trainee can then act accordingly. With the addition of the interaction system, the PDCA cycle can finally be closed (see Figure 5.7).

The navigation and movement system for the trainees and operators is implemented as described in Section 4.5. In the following section, the changes, which were made throughout each of the two iterations of the interaction system, are illustrated.

5.3.1 Trainee

The next few paragraphs compare the changes of the trainee interactions between the first and second iteration:

First Iteration

The initial implementation of the interacting system was was done as rapid prototype, focusin on functionality and not yet on usability and easy of understanding. The sequence of pictures in Figure 5.8 shows how the trainee can drag a person out of a car by interaction. If the trainee gets close enough to an interactable object and looks at it (raycast), a small red dot becomes visible in the center of the field of view (see Figure 5.8a). By pressing a particular button (independent from the device) the person locks onto the trainee, although no feedback is given for this. This enables the trainee to drag the person. Figure 5.8b shows the person being dragged out of the car. This is possible by

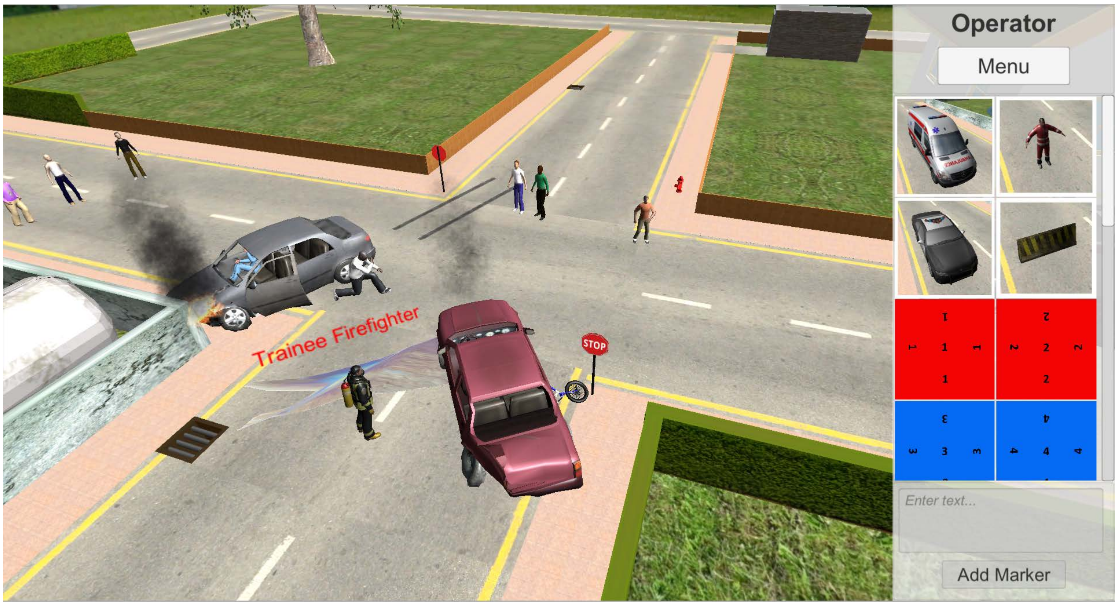


Figure 5.6: Operator point of view of the scenario

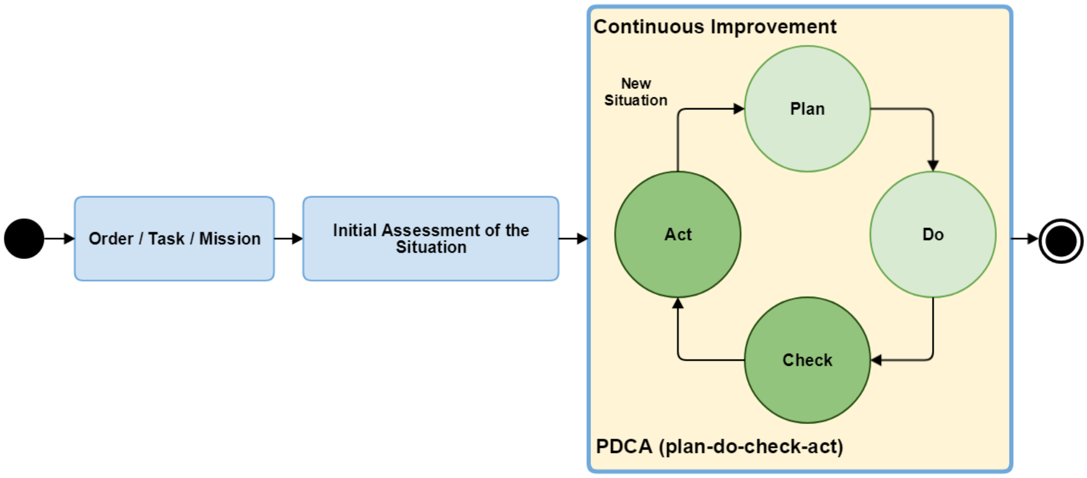


Figure 5.7: Complete PDCA cycle

moving in some direction which allows movement. In Figure 5.8c the person is released by pressing the same button (as initial) again. In Figure 5.8d the person was released and the trainee moves on. When the trainee looks away from the person and is not in range of another interactable object, the red dot disappears again.

(a) The trainee initiates the drag interaction on the person in the car

(b) Person in the car is dragged by the trainee

(c) The trainee releases the dragged person outside

(d) The interacting process with the person from the car is finished

Figure 5.8: First interaction iteration of the trainee with a person in a car

Second Iteration

After the feedback of the first tests for the user study, the mechanism of how the interaction works slightly changed. The major criticism was the lack of feedback while performing the interaction. Many test trainees were often not sure, if the interaction worked. The changes mostly affect the feedback side of the interaction, which can be seen in Figure 5.9. Now if the trainee gets close enough to the interactable person, a light red radial is shown additionally to the red point (see Figure 5.9a). In order to interact now, the trainee has to hold the interaction button (see Figure 5.9b). While the button is held down, the light red radial is filled red. When the radial is completely filled red, the interaction action is triggered (see Figure 5.9c). Now the trainee can drag the person the same way as it was in the first iteration. The filled radial stays full, no matter where the trainee looks, until the interaction button is pressed again. When the button is pressed, the person is released, and the radial becomes light red again (see Figure 5.9d). This indicates to the trainee, that the current interaction has been finished and a new interaction is possible again.

(a) The trainee initiates the drag interaction on the person in the car

(b) The user needs to hold the input button till the circle is filled, in order to successfully start the drag interaction

(c) Person in the car gets dragged by the trainee

(d) The interacting-process with the person from the car is finished

Figure 5.9: Second interaction iteration of the trainee with a person in a car

5.3.2 Operator

The next paragraphs present the implementation of the operator interactions which were added in the first and second iteration. At this moment, Figure 5.10 gives an overview of all final use cases of the operator.

First Iteration

Figure 5.11 shows the view of the operator with all of the corresponding UI elements.

(1) The view of the operator on the scene, where the operator can observe all the things which are going on in the scenario. The operator can move in 6 DOF through the scene. The keyboard is used to move, and the mouse is used to rotate the view.

(2) Shows what role the operator has (e.g. dispatcher, call-taker, spectator, etc.) and a menu button, which opens the game menu of the application. In the menu, the application can be exited, transfer all clients to the lobby menu again and of course resume the

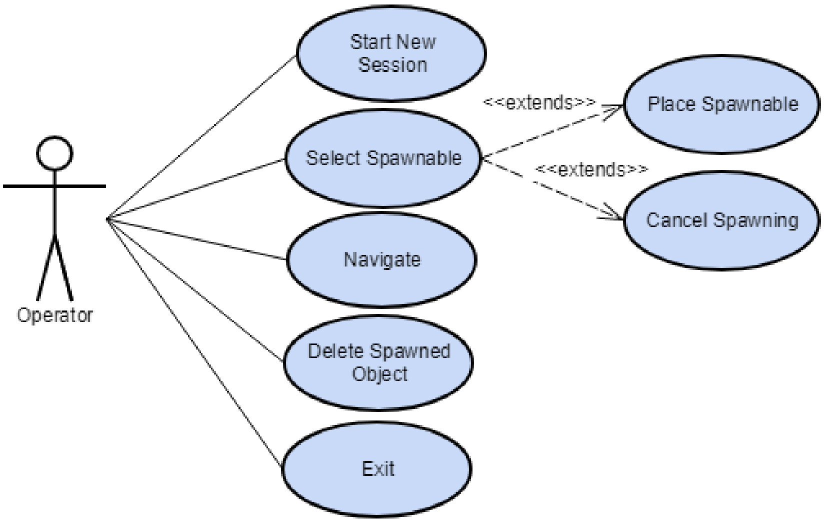


Figure 5.10: The complete use case diagram of the operator

initial view again. When the trainee gives a command, the command has to be somehow executed. To do so, the operator has the appropriate tools for it.

(3) Shows the available objects, which can be placed or respectively spawned dynamically inside the scenario. These objects are predefined, but there are no limitations on the models of the objects. Many placeholders are used in the current state of the application. To spawn an object in the scenario, the operator has to select the desired object with a left mouse button click. Then the operator can use the mouse cursor to freely spawn the object at the favored position by another left mouse button click. While moving the object with the cursor, the object can be rotated by using the mouse wheel. Then the object rotates with a 45-degree factor. To cancel the ongoing placement, the right mouse button can be pressed.

(4) Sometimes the operator may want to document things, which were or were not done by the trainee. To document things, the operator has to double-click the left mouse button on a location on which a marker should be placed. When the operator double-clicks, the text field in (4) gets into focus and the operator can put in some text. By pressing enter or hitting the "add marker" button, the text gets confirmed.

Second Iteration

In the first iteration, some raycast code malfunctions were introduced. Sometimes the raycast was occluded by some other objects, which led to a misplacement of objects. In the second iteration, the raycast layer was optimized and the handling of the object spawning was made much smoother. After that, no more raycast occlusions were observed by the operators. A many requested feature by the operators was to be able to remove

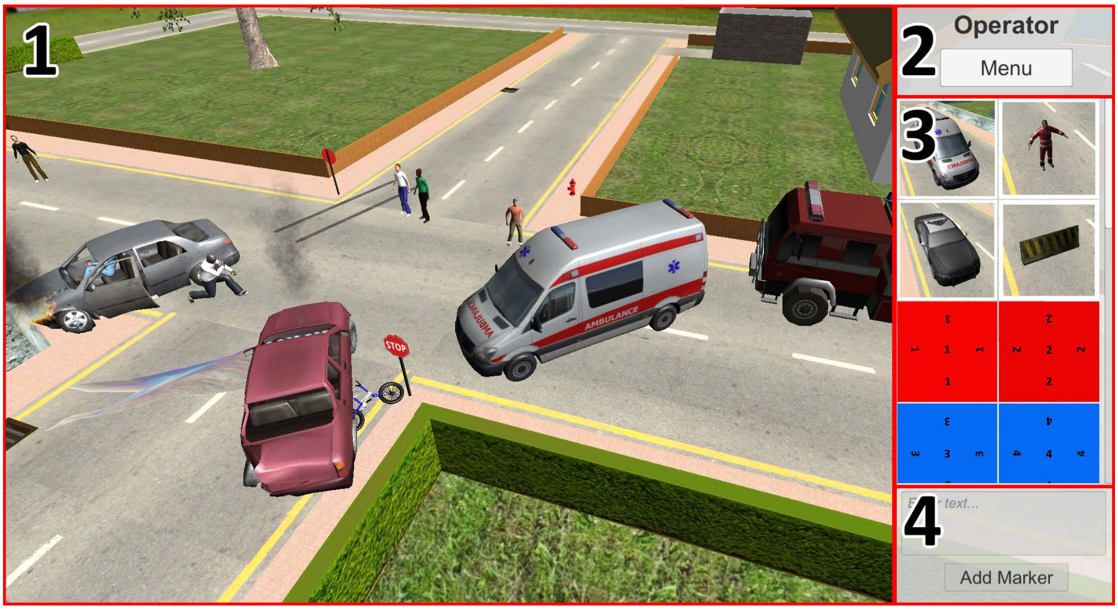


Figure 5.11: Operator interaction overview, partitioned in its individual components

spawned objects. This was implemented in addition to the raycasting function. Now the operator can remove already placed objects with a middle mouse click on the desired object. Another addition in the operator interaction sort of things was the better visibility of the documented text in the markers. To read the text of the old ones, the operator had to move over the marker to see text in the right below text field. The new markers also show the text above them while the mouse is over the marker object.

5.4 Scenarios

Previous to this thesis, multiple scenarios were developed for the VROnSite project [MFS$^+$17], in an iterative design process and in close collaboration with squad leaders of fire brigades and paramedics. The results of this process were early prototype scenarios which enabled the tasks plan and do. Small fires and traffic accidents with injured people as well as animated bystanders were simulated, just to name a few. Because of the positive feedback from the squad leaders about these scenarios, the new scenarios for this thesis were build up upon the previous ones. Due to the usage of a mobile platform, the content of the scenarios still has to be optimized for performance. This may lead to an unappealing impression for some user, especially for those who are used to high-end graphics. To match the requirements of a multi-user environment and a complete command cycle, some additions need to be made. How this was achieved will be presented in the next sections.

5.4.1 Concept

Many new implementations start with a sketch-drawn concept. After the decision had been made to implement a traffic accident, circumstances of how the accident could have happened were sketched. The final drawing of the concept, done by the industry partner of the VROnSite project, is shown in Figure 5.12. In the figure, a street junction with sidewalks can be seen. The two rectangles symbolize the crashed cars. The left car is leaking oil, which is flowing in the direction of a sewer entrance. The person who is sitting inside that car cannot exit, because the door is jammed. The engine of the car on the right-hand side is on fire and the driver has already exited the car and sits at the side of the car. One person is still in the burning car and lost consciousness. On the top-left sidewalk a power transformer can be seen with a wounded person beside it. The square on the top-right should represent some danger source, like a gas tank. The person in the south symbolizes a group of bystanders.

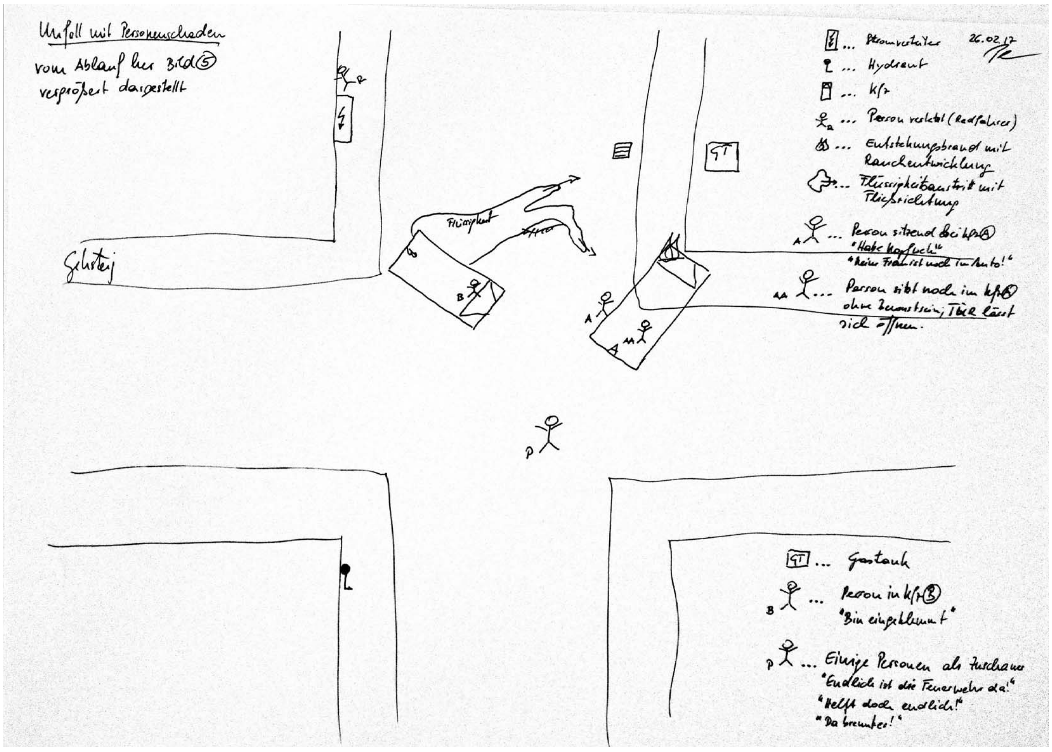


Figure 5.12: Concept of the scenario

5.4.2 Warm up

Since not every participant will already have experience with VR in general, nor this application in particular, some form of pre-training is required. For this purpose, a

"Warm up" scenario was created. In this simple scenario, the trainee and operator can practice navigation, movement, giving commands and interaction. To practice the latter, some movable persons and a car with interactable doors were inserted. Figure 5.13 shows an angular view of the warm up scenario. Every person can be moved and the trainees can open a car door. Meanwhile, the operator can interact with the environment as it will be explained in Section 5.3.2.

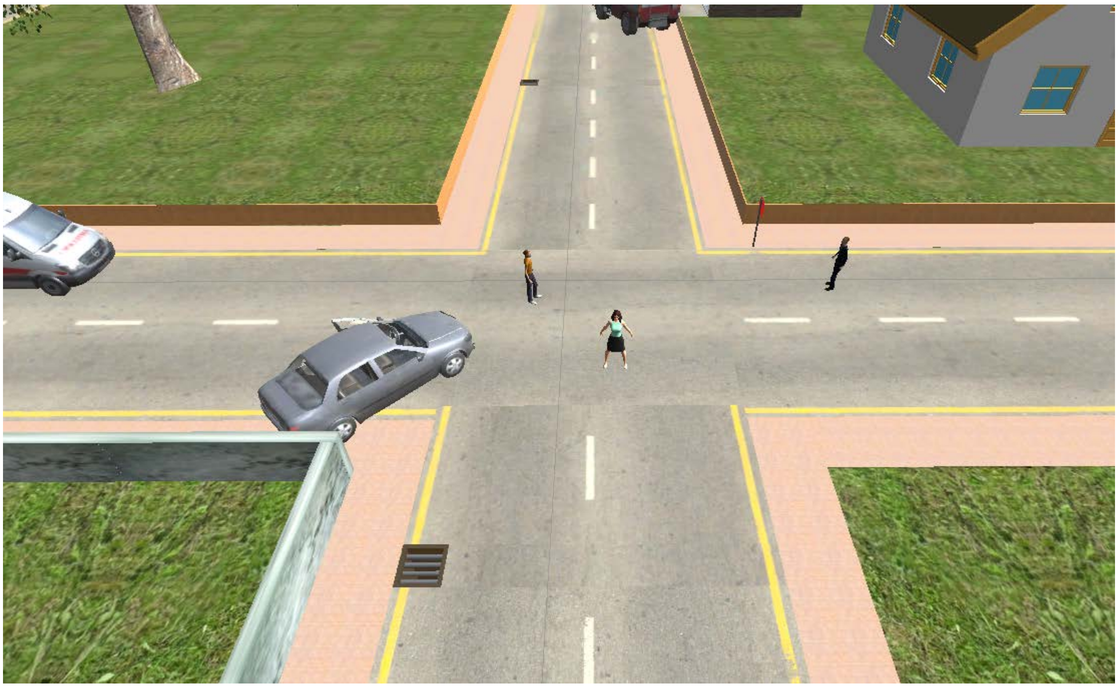


Figure 5.13: View at the Warm up scenario

5.4.3 Firefighter

The primary focus of first the first arriving firefighter squads is to secure the danger zone, rescue human beings as well as animals and prevent further damage to properties. In this scenario, two fire trucks arrive at the scene with one squad leader each, one of them is the officer-in-charge. Virtually every squad leader has a whole team sitting in their fire truck. In real scenarios, the squad leader always exits the vehicle first and investigates the disastrous scene. Meanwhile, the team stays inside the vehicle, until they get the appropriate command to dismount. The virtual scenario follows the same procedure. In Figure 5.14, the two fire trucks on the right-hand side indicate the spawning points of the squad leaders. In the middle of the street junction the two crashed cars are visible. The skid marks show how the accident may have happened. Additionally, a bike was inserted underneath of red car. This bike belongs to the person, who is in the right bottom corner of the screenshot. This person is not visible from the starting point of the squad leaders. Therefore, it is important that they explore the whole scene.

Figure 5.14: View at the firefighter scenario

In this scenario, many objects of interest are included, which the squad leader has to identify and decide how to handle them. The first thing the squad leaders encounter is most probably a bystander who asks them, if the ambulance service is already alarmed. To request the right amount of ambulance cars, the trainees need to spot every potential patient. While they are looking for injured people, they will encounter a burning car with an unconscious person inside and where the fire is dangerously near to a gas tank. There is also a second car with a smoking engine and with a person inside which is locked but responsive. After the first sweep through the site, the officer-in-charge has to give a qualified on-site report to the operator. The squad leaders need to communicate with each other and the operator, in order to distribute their teams effectively for the required tasks. The given commands to their teams will then be executed by the operator and will also be visible for both squad leaders. For example, the command for the firefighting operations gets called for two members of their team. Then two abstract illustrated team members and the associated equipment will be appearing at the fire. The squad leaders themselves can do the rescue of the persons. The door of the gray car, with the unconscious person inside, can be opened and the person can be dragged out of it.

5.4.4 Paramedics

The paramedic scenario comprises same accident as the firefighter one in Section 5.4.3. The main difference is how the paramedics approach such a situation. At first, the task to investigate the scene and give a qualified response to the operator stays the same. In comparison to the firefighters, the paramedics are only a two person team where one of them is the officer-in-charge with often only one vehicle arriving at a time. Therefore they have no team in the background and must manage the scene in the first few minutes on their own. Paramedics often do not have proper protective equipment for heat. Thus, the burning fire got removed and was replaced by smoke. Otherwise they need to stay away from the scene and wait for the firefighters. The focus of the paramedics should be to treat as many patients as fast and qualified as possible. To do so, they must know how many patients are on the scene. The more patients there are, the more measures need to be made. For this purpose, more patient were included for the paramedic scenario. To treat the patients, they need to be transferred to a safe area outside of the danger zone. To provide this extra needed place, a parking lot was added to the scenario as seen in Figure 5.15. Although the space, which is actually going to be used, is in the hands of the officer-in-charge.

Figure 5.15: View at the paramedic scenario

CHAPTER 6

User Study

With the VROnSite team, multiple user studies were conducted by testing real-world stakeholders. For this thesis, the aim of the user studies were to observe squad leaders of relief units while they are inside the simulation, how they act and proceed to relief disastrous situation in the virtual environment. The main goal is to evaluate and research the usability, diverse navigation input devices, immersive perception, decision-making, command execution and the effectiveness of the whole system for the education of squad leaders.

In comparison to the user study in [MFS+17], in this study the observations focus is on 1) how the participants interact with the virtual environment, 2) how they make use of the multi-user system, and 3) how they give their commands. Once the training had started, it was intervened as little as possible. If a participant asked questions about the live training, the questions were noted down, but not answered right away. Only if the participant got completely stuck, the observation team intervened and helped the participant.

In this chapter, the three setups of the different roles and their hardware, of which they consist, are listed. Subsequently, the participants of the user study, what kind of relief units they are in and what role they take part in the study, are presented. The next sections explain the procedure of the study and what questionnaires had to be filled by the participants after each step. At last, the results of the questionnaire are presented, and after that, the outcome is discussed and interpreted.

6.1 Setup

For the user study, three different roles were allocated to the participants, (1) the operator, (2) the officer-in-charge, and (3) the squad leader.

(1) The operator works on a desktop PC or laptop, in this user study a laptop was used in a combination with a regular monitor. As input devices, a keyboard and mouse were used. The VROnSite application was running on the Windows 7 OS.

(2) The setup of the officer-in-charge or trainee #1 was coupled with *setup 1*. The device used in *setup 1* was a mobile HMD, featured a Samsung S7 smartphone, that was combined with the 3 DOF orientation tracking GearVR device. The OS of Samsung S7 was Android 7, on which the VROnSite application was running. The input navigation device was an ODT Cyberith Virtualizer. The Virtualizer was connected via USB to the laptop of the operator and then paired via Bluetooth with the smartphone. When using an ODT, the simulation of physical exhaustion adds aggregative to the experience. For sound in- and output, a Trekz Titanium headset was used, that was also paired via Bluetooth.

(3) The setup of the squad leader or trainee #2 was coupled with *setup 2*. Similar to the *setup 1*, a mobile HMD, featured a Samsung S6 smartphone that was combined with the 3 DOF orientation tracking GearVR device. The OS of the Samsung S6 was Android 7, on which the VROnSite application was running on. For navigation, an ordinary gamepad (SteelSeries Stratus XL) was used. For sound in- and output a Trekz Titanium earphones was used. The gamepad and the earphones were both paired via Bluetooth with the Samsung S6.

Overview of the every setup is summarized in the following listing:

1. Operator (*operator setup*)
    - Windows 7
    - PC Keyboard Mouse
2. Trainee #1 (*setup 1*)
    - Android 7
    - HMD: Gear VR Samsung S7
    - Controller: Virtualizer
    - Bluetooth earphones: Trekz Titanium
3. Trainee #2 (*setup 2*)
    - Android 7
    - HMD: Gear VR Samsung S6
    - Controller: Gamepad Steelseries Stratus XL
    - Bluetooth earphones: Trekz Titanium

6.2 Participants

Two major distinct groups were taking part in the user study. The first group are firefighters and the second are paramedics. In the following two section the characteristics of these groups are described.

6.2.1 Firefighters

For the firefighter scenario, 42 male firefighters took part in the user study. Half of them (21) were using *setup 1* and the other half *setup 2*. The ages of the participants range from 19 to 58 years. The ages of the *setup 1* users were between 19 and 52 year (mean μ = 32.9, standard deviation $\sigma = 8.677$) and the ages of *setup 2* users ranged between 28 and 58 years ($\mu = 41.14$, $\sigma = 8.150$). 17 of the *setup 1* users already have experience in leading squads and are working as an educator. The users of *setup 2* are 20 participants squad leaders, and 18 are educators. Figure 6.1 shows firefighters during the live training. After the training, 27 firefighters took the opportunity to be the operator for the next session (*operator setup*).

Figure 6.1: Firefighters of Feuerwehrschule Telfs/Tirol during live training

6.2.2 Paramedics

Despite the main focus of the user study on the firefighters, the VROnSite team also tested with paramedics. For the paramedic scenario, eight paramedics (one female) were involved in the study. However, due to the small amount of participants (small sample size), the evaluation of the paramedic scenario has little statistical significance. Nevertheless, the subjective feedback of the paramedics was valuable and gave an impression on what is important in the training of paramedics. The realism of the character models, including animations, injuries, and behavior were very important for them. In Figure 6.2, paramedics of the Johanniter Unfallhilfe (Innsbruck, Tirol) can be seen in training during the user study.

Figure 6.2: Paramedics of the Johanniter Unfallhilfe during live training

6.3 Procedure

On every iteration of the user study, a group of two (*setup 1* and *setup 2*) did the procedure together. Additionally, the operators were taking part, which consists of a member of the observation team and optional with one or two trainees of the previous iteration. The study procedure was divided into five mandatory and two optional stages: (1) introduction, (2) pre-questionnaire, (3) test scenario, (4) training scenario, (5) post-questionnaire, (6) operator position, and (7) operator questionnaire. The overview of the procedure, in the form of a flow-chart, is illustrated in Figure 6.3.

(1) Before the actual training scenario began, some preceding tasks had to be done. Starting with an introduction of the upcoming scenario and what the goal of the user study is. To get the participants into the right mood of the mission, a short intro video was shown.

(2) The introduction was following up with a pre-questionnaire about how many exercises the participants take part in a year and if they are in a leadership position at the moment. Furthermore, their current well-being and whether they already have some experience with virtual reality and with its devices is prompted. After finishing the questionnaire, the participants needed to decide among themselves, who will take the lead as the officer-in-charge within the training. The pre-questionnaire can be found in Appendix A.

(3) To avoid problems with the devices used in training, the participants were familiarized with the devices they will use (*setup 1* with the HMD and the Virtualizer, *setup 2* with the HMD and gamepad). Extra time was used especially for the Virtualizer, because this device was new to most participants. After familiarizing with the hardware, wearing no HMD, a test scenario (see Section 5.4.2) was started. Therefore, every participant had the chance to practice the navigation and interaction in the virtual environment before the actual scenario was started.

(4) Whenever the two trainee participants and the operator were in position and ready, the actual training scenario was started. Which scenario was selected, was depending on the kind of relief unit. For the firefighter, the firefighter scenario was selected and vice versa for the paramedics. Meanwhile, observations of the training were made about the duration of the training, comfort with the hardware device setup, general conspicuousness, user-commentaries and what commands they give to the operator and fellow trainee.

(5) When the training was finished, the participants had to complete the post-questionnaire. This questionnaire was again about their well-being after the training (e.g., motion-sickness, vertigo, etc.). Continued with questions about the navigation challenges through the virtual environment, 3D interactions, training with multiple users, and the built-up virtual environment in general. In between, the participants had the possibility to write down subjective feedback in free text fields. Moreover, the participants were advised to make lists of some features in order of their importance. Additionally, space for free text was given for making remarks on (possible) future improvements. In Appendix B, this questionnaire can be found.

(6) After the post-questionnaire, the participants got the offer to decide if they want to take part in the next session as the role of the operator. This part was optional; therefore, not every participant took the opportunity to do so.

(7) If a participant took the possibility to act as the operator in the next iteration, another questionnaire had to be filled by the participants. This operator questionnaire was about the opinion of the participants on the operator view. How useful the view/role is (e.g. for the training of squad leaders), and whether the operator view positively impacts the training or not. The operator questionnaire can be seen in Appendix C.

6.4 Questionnaires

As mentioned in the previous section, three questionnaires were used, the pre-questionnaire before the training, the trainer questionnaire after the training, and the operator ques-

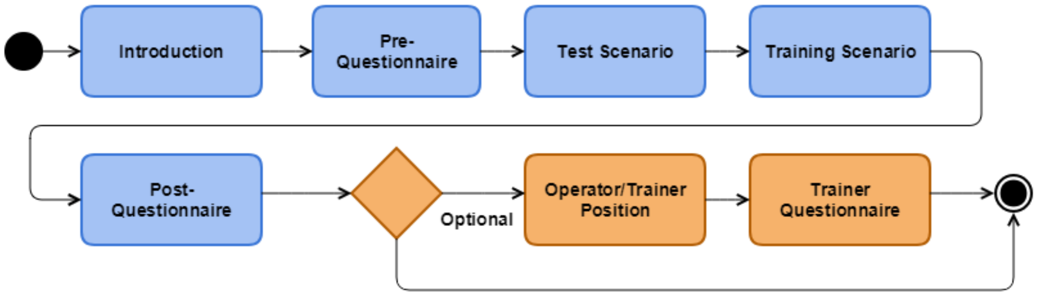


Figure 6.3: User study procedure

tionnaire after the participation in the operator position. Unless stated otherwise, the answers are evaluated by using the 5-point Likert scale [Lik32].

The **pre-questionnaire** (see Appendix A) starts with a short survey about how often the participant takes part in first-responder training exercises, how many exercises the participant prepares for others, and how many exercises for the participant are prepared. The answers range from none (1), one to three (2), four to seven (3), and more than seven (4). Asides of the experience of real exercises, the experience of the participant with VR and its devices was asked. The answer possibilities were none (1), not much (2), moderate (3), much (4), and very much (5). Additionally, the fitness of the participant was asked, as in the immersive tendency questionnaire (ITQ) [WS98]. The last questions in the pre-questionnaire were about cybersickness symptoms of simulator sickness questionnaire (SSQ). Eight questions from the SSQ were used, general discomfort, fatigue, headache, sweating, nausea, blurred vision, vertigo, and confusion. The SSQ had to be answered by the participants with none (1), slight (2), moderate (3), or severe (4) [SKELBGL93].

These same eight questions from the SSQ were repeated after the training, in the **trainer questionnaire** (see Appendix B). The main survey of the trainer questionnaire and the **operator questionnaire** (see Appendix C) consist partly of the presence questionnaire (PQ), ITQ [WS98] and mainly of the following measures.

- *Perceived satisfaction of input and perceived scene quality*: not at all (1), not much (2), moderate (3), much (4), very much (5).
- *Perceived spatial understanding*: strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), strongly agree (5).
- *Perceived system usability* is measured with the system usability scale (SUS): strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), strongly agree (5) [B$^+$96].
- *Perceived task load* is measured with the NASA task load index (TLX): very low (1), low (2), average (3), high (4), very high (5) [HS88].

6.5 Experimental Results - Scenario 1 Firefighters

In this section, the results of the user study are presented. At first, the prompted experiences of the participants in their firefighting training duty are presented. Subsequently followed by presenting the evaluation of the training and operator questionnaires.

The evaluation has three independent variables *setups* (*setup 1* and *setup 2*), *leader* (has experience as a squad leader within the fire brigade), and *education leader* (is active as an educator within the fire brigade). The allocation of the participants to these values was presented in the participants Section 6.2.1. Most variables of the questionnaires are dependent and the results of the SUS and TLX were each pooled to one variable. For pooling, the arithmetic mean A was used:

$$A = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{a_1 + a_2 + \cdots + a_n}{n} \tag{6.1}$$

The following three analyses were conducted:

1. Descriptive statistics of the dependent variables for each questionnaire, without grouping the independent variables.
2. Independent t-test for each independent variables to test of significance (confidence interval 95 % $\alpha < 0.05$). Because of the unbalanced distribution within the sample of the independent variables, leader (37 yes, 5 no) and education leader (35 yes, 7 no), bootstrapping was additionally conducted.
3. Cohen's d was calculated to evaluate the effect size.

6.5.1 Pre-Questionnaire

Table 6.1 shows an annual overview of how many exercises are prepared for the participants, how many exercises they are preparing for another member of the fire brigade, and how many exercises they take part.

Per year	Exercises prepared for the participant	Participant prepared exercises for other	Exercises participated
None	3	2	1
1 - 3	0	6	14
4 - 6	30	15	13
7 +	9	19	14
	42	42	42

Table 6.1: Experiences of the participant in preparing and taking part in training exercises

The fitness of all participant is balanced with $\mu = 3.38$ ($\sigma = 0.774$). Almost half of the participants (19) had no prior experience with VR to this point. The rest had little experience, which resulted in $\mu = 1.71$ and $\sigma = 0.774$ for all participants.

Independent Variable: *Setup*

Data indicates that for participants with *setup 2* were more training exercises prepared $\mu = 2.14$, $\sigma = 0.655$) than for participants who were using *setup 1* ($\mu = 1.71$, $\sigma = 0.463$). This difference was significant $t(40) = 2.449$, $p < 0.019$.

Only few of the *setup 1* users already used a device like the Virtualizer ($\mu = 1.33$, $\sigma = 0.483$). In comparison, the *setup 2* users had some more experience with a gamepad ($\mu = 2.52$, $\sigma = 1.470$).

6.5.2 Training Questionnaire

The trainings length was in average $\mu =$ 09:37 [min] with a deviation $\sigma =$ 01:55 [min]. The difference between the SSQ questions before and after the training were in average $\mu = 1.12$ ($\sigma = 2.287$).

The arithmetic mean of the navigation TLX variable resulted in $\mu = 2.698$ ($\sigma = 0.483$).The arithmetic mean of the systems interaction usability in SUS was $\mu = 2.873$ ($\sigma = 0.231$). The arithmetic mean value of the multi-user TLX evaluation was $\mu = 2.568$ ($\sigma = 0.509$). The box plot diagrams of these three pooled value evaluation shows Figure 6.4.

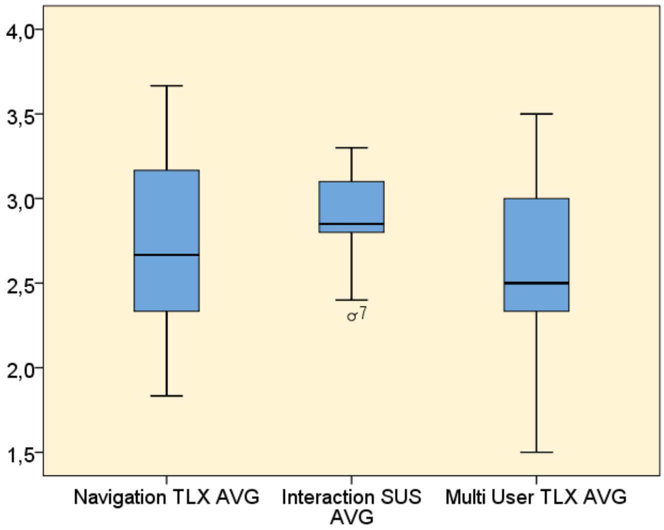


Figure 6.4: Box plot of the pooled values of the navigation TLX, usability SUS, and interaction TLX

The results for the question "How much does this virtual training supports the education of squad leaders?" was at $\mu = 4.15$ ($\sigma = 0.760$). The following listing shows the results of components of "How effective the training simulation is for squad leaders" without an independent variable. The corresponding box plot can be viewed in Figure 6.5.

- Free look with the HMD: $\mu = 4.64$ ($\sigma = 0.430$).
- Free navigation through the virtual environment: $\mu = 4.67(\sigma = 0.472)$.
- 3D interaction with virtual objects: $\mu = 4.52$ ($\sigma = 0.671$).
- Virtual sound $\mu = 4.19$: ($\sigma = 0.917$).
- Multi-user system $\mu = 4.45$: ($\sigma = 0.739$).
- Visual execution of the given commands: $\mu = 4.81$ ($\sigma = 0.505$).
- Realism of the 3D illustration (graphics, animations, sound effects): $\mu = 4.45$ ($\sigma = 0.803$).

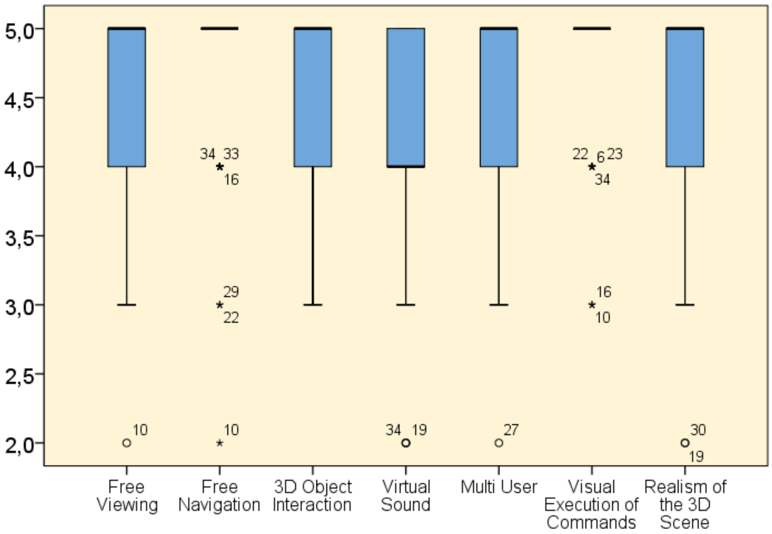
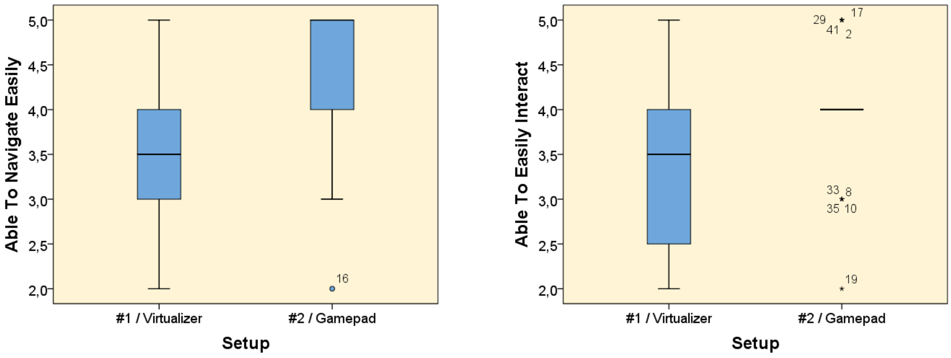


Figure 6.5: Box plot of the effectiveness of the virtual reality training

Independent Variable: *Setup*

Users of *setup 2* experienced navigation easier ($\mu = 4.43$, $\sigma = 0.811$) than users of *setup 1* ($\mu = 3.62$ $\sigma = 0.805$). This difference was significant $t(40) = 3.248$, $p < 0.002$. It did represent a large-sized effect $d = 1.002$. Figure 6.6a shows the resulting box plot diagram. Users of *setup 2* also found it easier to interact with the virtual environment ($\mu = 3.90$, $\sigma = 0.768$) than users of *setup 1* ($\mu = 3.24$, $\sigma = 1.091$). This difference was significant $t(40) = 2.289$, $p < 0.027$. It did represent a medium-sized effect $d = 0.707$. Figure 6.6b shows the resulting box plot diagram.



(a) Able to navigate easily

(b) Able to interact easily

Figure 6.6: Results of being able to easily navigate and interact (*setup*)

A tendency has shown that for users of *setup 2* the ability to interact more quickly was slightly greater ($\mu = 3.95$, $\sigma = 0.865$) than to users of *setup 1* ($\mu = 3.52$, $\sigma = 0.680$). This difference was nearly significant $t(40) = 1.360$, $p > 0.082$ and did represent a medium-sized effect $d = 0.551$. The joy of training together enjoyed users of *setup 1* slightly more ($\mu = 4.71$, $\sigma = 0.463$) than users of *setup 2* ($\mu = 4.33$, $\sigma = 0.856$). This difference was almost significant $t(40) = -1.793$, $p > 0.080$. It did represent a negative medium-sized effect $d = -0.553$.

For the other variables no significance was found ($p > 0.05$). The effect size was small for the following variables: able to quickly navigate (small-effect size $d = 0.420$), joy of using the navigation device (small-effect size $d = 0.402$), how demanding the navigation through the virtual environment is (TLX arithmetic mean, negative small-effect size $d = -0.394$), joy of interacting with the device (small-effect size $d = 0.425$), the systems interaction usability in SUS (arithmetic mean) (negative small-effect size $d = -0.316$), able to visually collaborate well (negative very small-effect size $d = -0.130$), able to train commands collaboration well (negative very small-effect size $d = -0.168$), how demanding the multi-user exercising is (TLX arithmetic mean, negative small-effect size $d = -0.459$), amount of immersion (negative very small-effect size $d = -0.135$), able to quickly get an overview (very small-effect size $d = 0.158$), able to quickly identify causalities (small-effect size $d = 0.262$), the training supports the education of squad leaders (no effect size $d = 0.000$), free look with the HMD (negative small-effect size $d = -0.216$), free navigation through the virtual environment (negative small-effect size $d = -0.277$), 3D interaction with virtual objects (very small-effect size $d = 0.141$), virtual sound (very small-effect size $d = 0.103$), multi-user system (negative small-effect size $d = -0.4575$), visual representation of the given commands (negative small-effect size $d = -0.379$), realism of the 3D illustration (very small-effect size $d = 0.177$), the usefulness and usability of the whole training concept SUS (arithmetic mean, negative very small-effect size $d = -0.242$), and how demanding the system is (TLX arithmetic mean, negative very small-effect size $d = -0.178$).

Independent Variable: ***Leader***

Leaders found the component "Free viewing with the HMD" less important ($\mu = 4.59$, $\sigma = 0.686$) than non-leaders ($\mu = 5.00$, $\sigma = 0.000$). This difference was significant $t(36)$ = -3.597, $p < 0.001$. The Bootstrap result, at a mean difference of 0.405, was also significant $p < 0.015$, based on 996 samples. It did represent a negative medium-sized effect d = -0.623. Leaders found the component "Free navigation through the environment" less important ($\mu = 4.62$, $\sigma = 0.721$) than non-leaders ($\mu = 5.00$, $\sigma = 0.000$). This difference was significant $t(36)$ = -3.193, $p < 0.003$. The Bootstrap result, at a mean difference of 0.378, was also significant $p < 0.024$, based on 996 samples. It did represent a negative medium-sized effect d = -0.553. Leaders found the component "Virtual sound" more important ($\mu = 4.32$, $\sigma = 0.852$) than non-leaders ($\mu = 3.20$, $\sigma = 0.837$). This difference was significant $t(40) = 2.776$, $p < 0.008$. The Bootstrap result, at a mean difference of 1.124, was also significant $p < 0.009$, based on 996 samples. It did represent a large-sized effect $d = 1.323$. Leaders found the component visual representation of the given commands less important ($\mu = 4.78$, $\sigma = 0.534$) than non-leaders ($\mu = 5.00$, $\sigma = 0.000$). This difference was significant $t(36)$ = -2.462, $p > 0.019$. The Bootstrap result, at a mean difference of 0.216, was nearly significant $p = 0.061$, based on 996 samples. It did represent a negative medium-sized effect d = -0.427. Leaders had less joy of navigating with their device ($\mu = 4.06$, $\sigma = 0.860$) than non-leaders ($\mu = 4.60$, $\sigma = 0.548$). This difference was not significant $t(39)$ = -1.369, $p > 0.179$. It did represent a negative small-sized effect d = -0.118. The amount of immersion that leaders experienced, was less ($\mu = 3.86$, $\sigma = 1.084$) than non-leaders ($\mu = 4.40$, $\sigma = 0.548$). This difference was not significant $t(39)$ = -1.141, $p > 0.261$. It did represent a negative medium-sized effect d = -0.513. The results of the systems usefulness and usability of the whole training concept in SUS (arithmetic mean) was for leaders slightly greater ($\mu = 2.876$, $\sigma = 0.227$) than for non-leaders ($\mu = 2.853$, $\sigma = 0.293$). This difference was not significant $t(40)$ = -1.077, $p > 0.288$. It did represent a negative medium-sized effect d = -0.746. The training length (sec) of leaders was less ($\mu = 565.252$, $\sigma = 109.052$) than for non-leaders ($\mu = 650.433$, $\sigma = 91.088$). This difference was not significant $t(36)$ = -1.497, $p > 0.143$. It did represent a negative medium-sized effect d = -0.791.

For the other variables no significants was found ($p > 0.05$). The effect size was small for the following variables: able to navigate easily (negative small-effect size d = -0.221), able to quickly navigate (negative very small-effect size d = -0.047), how demanding the navigation through the virtual environment is (TLX arithmetic mean, very small-effect size $d = 0.149$), able to interact easily (negative small-effect size d = -0.260), able to interact quickly (negative small-effect size d = -0.371), joy of interacting with the device (negative very small-effect size d = -0.118), the systems interaction usability in SUS (arithmetic mean, very small-effect size $d = 0.096$), able to visually collaborate well (small-effect size $d = 0.340$), able to train commands collaboration well (negative small-effect size d = -0.300), joy to train together (negative very small-effect size d = -0.121), how demanding the multi-user exercising is (TLX arithmetic mean, very small-effect size $d = 0.002$), able to quickly get an overview (small-effect size $d = 0.221$), able to quickly identify causalities (small-effect size d = 0.302), the training supports the education of squad leaders (negative very small-effect size d = -0.085), 3D interaction with virtual objects (small-effect size d = 0.207), multi-user system (small-effect size d = 0.386), visual representation of the given commands (negative small-effect size d = -0.427), realism of the 3D illustration (small-effect size d = 0.355), and how demanding the system is TLX (arithmetic mean, very small-effect size d = 0.159).

Independent Variable: *Education Leader*

Education leaders found it easier to navigate through the virtual environment ($\mu = 4.11$, $\sigma = 0.867$) than non-education leaders ($\mu = 3.57$, $\sigma = 0.976$). This difference was not significant $t(39) = 1.470$, $p > 0.149$. It did represent a medium-sized effect $d = 0.614$. Education leaders had less difficulties to quickly get an overview of the scene ($\mu = 4.06$, $\sigma = 0.873$) than non-education leaders ($\mu = 3.57$, $\sigma = 0.976$). This difference was not significant $t(39) = 1.305$, $p > 0.487$. It did represent a medium-sized effect $d = 0.546$.

For the other variables no significants was found ($p > 0.05$). The effect size was small for the following variables: able to quickly navigate (small-effect size d = 0.415), joy of using the navigation device (small-effect size d = 0.378), how demanding the navigation through the virtual environment is (TLX arithmetic mean, negative small-effect size d = -0.396), able to interact easily (no effect size d = 0.000), able to interact quickly (very small-effect size d = 0.035), joy of interacting with the device (small-effect size d = 0.443), the systems interaction usability in SUS (arithmetic mean, negative small-effect size d = -0.361), able to visually collaborate well (small-effect size d = 0.392), able to train commands collaboration well (small-effect size d = 0.373), joy to train together (very small-effect size d = 0.160), how demanding the multi-user exercising is (TLX arithmetic mean, very small-effect size d = 0.046), amount of immersion (small-effect size d = 0.244), able to quickly identify causalities (very small-effect size d = 0.094), the training supports the education of squad leaders (no effect size d = 0.000), free look with the HMD (negative very small-effect size d = -0.129), free navigation through the virtual environment (negative very small-effect size d = -0.082), 3D interaction with virtual objects (very small-effect size d = 0.169), virtual sound (negative very small-effect size d = -0.123), multi-user system (very small-effect size d = 0.038), visual representation of the given commands (small-effect size d = 0.224), realism of the 3D illustration (very small-effect size d = 0.035), the usefulness and usability of the whole training concept SUS (arithmetic mean, very small-effect size d = 0.100), and how demanding the system is TLX (arithmetic mean, small-effect size d = 0.204).

6.5.3 Operator Questionnaire

The results of the operator questionnaire without an independent variable shows Figure 6.7, Figure 6.8, and the following listing.

- Able to easily observe the training: $\mu = 4.48$ ($\sigma = 0.700$).

- Able to easily observe the training of multiple users: $\mu = 4.37$ ($\sigma = 0.688$).
- Able to easily manipulate the training: $\mu = 4.56$ ($\sigma = 0.577$).
- Joy to operate the operator view: $\mu = 4.59$ ($\sigma = 0.636$).
- The systems interaction usability for the operator view in SUS (arithmetic mean) $\mu = 2.974$ ($\sigma = 0.223$).
- The operator view supports education of squad leaders: $\mu = 4.33$ ($\sigma = 0.679$).
- Observe the training in real time: $\mu = 4.50$ ($\sigma = 0.510$).
- Mark important targets: $\mu = 4.62$ ($\sigma = 0.496$).
- Change the perspective of the view: $\mu = 4.23$ ($\sigma = 0.908$).
- Place objects depending of commands of the trainees: $\mu = 4.69$ ($\sigma = 0.471$).
- Place textual bookmarks in the scene: $\mu = 4.12$ ($\sigma = 1.033$).

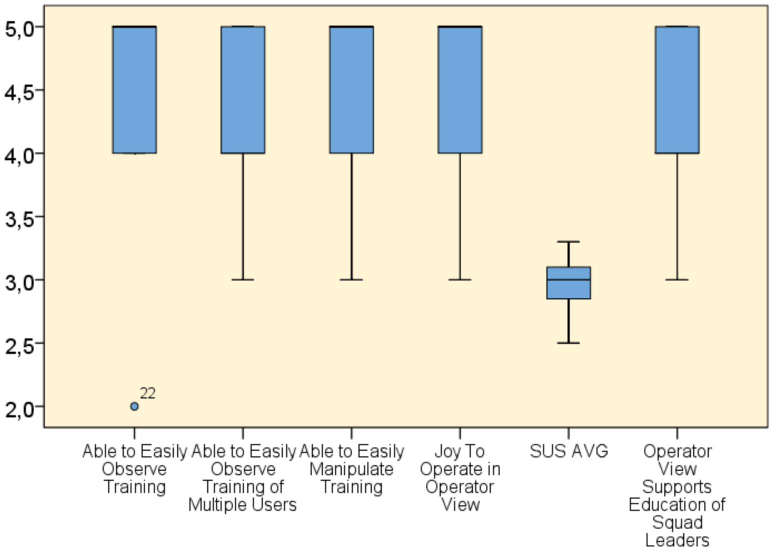


Figure 6.7: Box plot of the operator view results

Independent Variable: *Setup*

In terms of *setups*, the results of the systems usability in SUS (arithmetic mean) was for *setup 1* users greater (μ = 3.063, σ = 0.171) than for *setup 2* users (μ = 2.846, σ = 0.234). This difference was significant $t(25)$ = -2.792, $p < 0.010$. It did represent a negative large-sized effect d = -1.093.

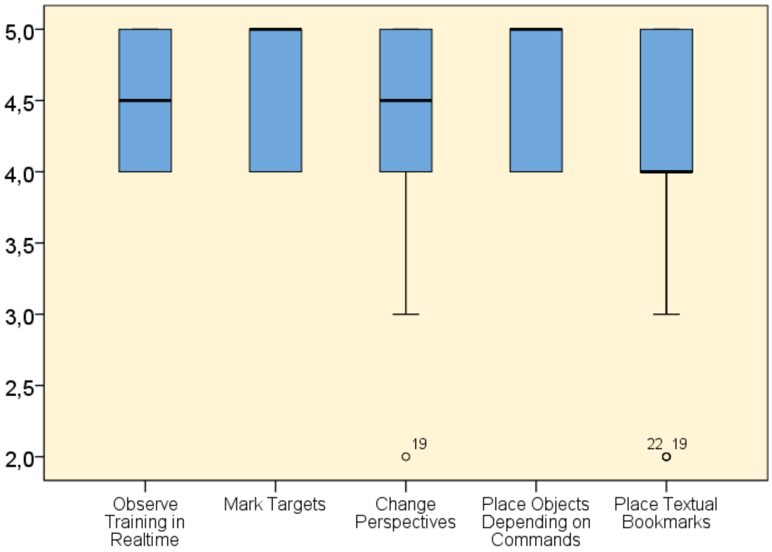


Figure 6.8: Box plot of the operators interaction details

For the other variables no significants was found ($p > 0.05$). The effect size was small for the following variables: able to easily observe the training (small-effect size $d = 0.373$), able to easily observe the training of multiple users (small-effect size $d = 0.203$), able to easily manipulate the training (negative small-effect size $d =$ -0.293), joy to operate the operator view (negative small-effect size $d =$ -0.376), the operator view supports education of squad leaders (negative small-effect size $d =$ -0.365), observe the training in real time (negative very small-effect size $d =$ -0.152), mark important targets (small-effect size $d = 0.391$), change the perspective of the view (negative small-effect size $d =$ -0.264), place objects depending of commands of the trainees (negative small-effect size $d =$ -0.203), and place textual bookmarks in the scene (negative very small-effect size $d =$ -0.040).

Independent Variable: *Leader*

It was easier for leaders to observe the training of multiple users ($\mu = 4.48$, $\sigma = 0.665$) than for non-leaders ($\mu = 3.75$, $\sigma = 0.5$). This difference was significant $t(25) = 2.075$, $p < 0.048$. The Bootstrap result, at a mean difference of 0.728, was also significant $p < 0.014$, based on 985 samples. It did represent a large-sized effect $d = 1.124$. The results of the systems interaction usability for the operator view in SUS (arithmetic mean) was for leaders greater ($\mu = 3.013$, $\sigma = 0.196$) than for non-leaders ($\mu = 2.750$, $\sigma = 0.265$). This difference was significant $t(25) = 2.362$, $p < 0.026$. It did represent a very large-sized effect $d = 1.280$. For leaders it was more important to be able to observe the training in real time ($\mu = 4.59$, $\sigma = 0.503$) than for non-leaders $\mu = 4.00$, $\sigma = 0.000$). This difference was significant $t(21) = 5.508$, $p = 0.000$. The Bootstrap result, at a mean difference of 0.591, was also significant $p < 0.003$, based on 985 samples. It did represent a very large-sized effect $d = 1.255$. The results have shown, that for leaders, the operator view supports the education of squad leaders more ($\mu = 4.39$, $\sigma = 0.722$) than for non-leaders ($\mu = 4.00$, $\sigma = 0.000$). This difference was not significant $t(25) = 1.066$, $p > 0.297$. It did represent a medium-sized effect $d = 0.577$. For leaders it was easier to manipulate the training in the operator view ($\mu = 4.61$, $\sigma = 0.499$) than for non-leaders ($\mu = 4.25$, $\sigma = 0.957$). This difference was not significant $t(25) = 1.154$, $p > 0.259$. It did represent a medium-sized effect $d = 0.625$. Leaders had more joy to operate the operator view ($\mu = 4.65$, $\sigma = 0.573$) than non-leaders ($\mu = 4.25$, $\sigma = 0.957$). This difference was not significant $t(25) = 1.176$, $p > 0.251$. It did represent a medium-sized effect $d = 0.637$.

For the other variables no significants was found ($p > 0.05$). The effect size was small for the following variables: able to easily observe the training (negative very small-effect size d = -0.031), mark important targets (negative small-effect size d = -0.316), change the perspective of the view (small-effect size $d = 0.296$), place objects depending of commands of the trainees (negative very small-effect size d = -0.142), and place textual bookmarks in the scene (very small-effect size d = -0.130).

Independent Variable: ***Education Leader***

For education leaders it was easier to manipulate the training in the operator view ($\mu = 4.64$, $\sigma = 0.490$) than for non-education leaders ($\mu = 3.50$, $\sigma = 0.707$). This difference was significant $t(25) = 3.100$, $p < 0.005$. The Bootstrap result, at a mean difference of 1.140, was also significant $p < 0.001$, based on 865 samples. It did represent a very large-sized effect $d = 2.278$. Education leaders had more joy to operate the operator view ($\mu = 4.64$, $\sigma = 0.569$) than non-education leaders ($\mu = 4.00$, $\sigma = 1.414$). This difference was not significant $t(25) = 1.394$, $p > 0.176$. It did represent a large-sized effect $d = 1.024$. For education leaders it was easier to observe the training of multiple users in the operator view ($\mu = 4.40$, $\sigma = 0.645$) than for non-education leaders ($\mu = 4.00$, $\sigma = 1.414$). This difference was not significant $t(25) = 0.786$, $p > 0.439$. It did represent a medium-sized effect $d = 0.577$.

For the other variables no significants was found ($p > 0.05$). The effect size was small for the following variables: able to easily observe the training (negative very small-effect size d = -0.028), the systems interaction usability for the operator view in SUS (arithmetic mean, (small-effect size $d = 0.114$), and the operator view supports education of squad leaders (negative small-effect size d = -0.261).

6.6 Discussion

> “I found the handling of the system fantastic, surely improvable, but great for training that especially could be utilized in the winter season. This training system should be mandatory for every officer-in-charge and squad leader.”
> - A user study participant

The user study was performed to evaluate the effectiveness of the system for educating and training squad leaders of relief units. An additional task was to identify the most and least important factors and components of the training system. At last it was evaluated if there are differences between the usage of different devices, the experience level of the trainee, and if the trainee is also an educational leader.

The overall fitness level of the participants was balanced and most of them had no or very little prior experiences with VR technologies. For users of *setup 2*, significant more exercises are prepared. This could be, because the *setup 2* users were on average eight years older than the *setup 1* users. Therefore, these users are probably more experienced and take more often leading roles in training exercises. Only a few *setup 1* users had experience with ODTs before, while slightly more *setup 2* users had experience with gamepads. Some users commented, that at the beginning it takes some time to familiarize with the devices, but after some practicing they could feel improvements.

6.6.1 Training

Overall, the navigation TLX, interaction SUS, and multi-user TLX evaluation resulted in average ratings (see Figure 6.4). Therefore, the usage of the system is fair, but at the same time has some room for improvements. All in all the following variables were found particular important: free look with the HMD, free navigation through the virtual environment, 3D interaction with virtual objects, virtual sound, multi-user system, visual execution of the given commands, and realism of the 3D illustration. Especially, the visual execution of the given commands received an extraordinarily high value. This is backed up by many subjective statements of the participants, who said that through this feature the PDCA cycle can be finally closed. Participants, who were taking part in the first user study of the VROnSite project, mentioned this is the most sophisticated and valuable addition to the system.

For users with *setup 2* it was significant easier to navigate and (quickly) interact in the virtual environment than for users with *setup 1*. Maybe because of the aforementioned experiences, users of *setup 2* already had with gamepads. No significance was found, if one setup is (physically) more demanding or is quicker to navigate than the other. The reason for this is probably the high fitness level of all participants. Nevertheless, users of both setups enjoyed the training. No significance and no effect was found for the influence of setup type to train on-site squad leaders. One participant pointed out, that the ODT does not adequately transmission his movement force into the virtual world.

Between the independent variable of leader and non-leader, some significant differences were found, but theses results should be viewed with caution, because of the small sample size of non-leaders. Free viewing with the HMD and free navigation through the environment were for leaders not as important as for non-leaders. The virtual sound was for leaders significantly more important than for non-leaders. Additionally, it had a large effect, probably because some leaders had problems with the implemented communication system. They commented that they would prefer a system that approximate the a radio-like system. The visual representation of the given commands were valued more by leaders than to non-leaders. Leaders are more used to utilize the PDCA cycle for working on-site. The visual representation of the given commands is a key part to allow the on-site squad leaders to *check* if the given commands were performed as they *planned* and then they can *act* accordingly.

Educational leaders found it easier to navigate, but this result was found not significant but had a medium effect. Educational leaders had less difficulties to obtain an overview of the scene than non-educational leaders. Educational leaders are used to get an overview of unclear training scenarios in real training exercises. This probably also affects their ability to easier get an overview in VR simulations.

It has been shown that participants with more experience (leaders & educational leaders) do not profit as much as participants with less experience (non-leaders & non-educational leaders). The more experienced have a higher imagination of how the training should be and therefore, VR immersion & 3D interaction have less subjective training-effect than for the less experienced. The most often mentioned subjective feedback of the system was the illustrations and realism of the scenario. Initially, they said the currently implemented degree of abstraction is enough, but the whole training would be profiting from more realism and more truthfully designed models. Furthermore, some mentioned that a higher degree on realism would improve the acceptance of a VR training system for more squad leaders and educational institutions.

6.6.2 Operator

As Figure 6.7 and 6.8 shows are the results of the operator evaluation exceptional high rated. This was concluded by the author that all aspects of the operator view are very important and useful for the training of squad leaders. But with low rating for the interaction usability. Therefore, the operator is an useful tool but usability improvements need to be performed. Some participants gave as a subjective feedback that the operator view is easy to operate. Many participants mentioned that it was important to comprehend what is happening in the scenario and be able to easily follow the actions and commands of the trainees within the VR simulation.

The only relevant differences between the users in terms of setups was that participants who used *setup 1* in the training, rated the usability significant higher than the users of *setup 2*. This had also a large-sized effect. The reason for this could be that the users of *setup 1* are more experienced and thus rate the operator view as more useful.

For leaders, it was significant easier to observe the training of multiple users with a large-sized effect than for non-leaders. Leader who where using the operator view valued the usability (SUS) of the system significant larger, with a very large-sized effect than non-leaders. Furthermore, also with a very large-sized effect, it was significant more important for leaders to be able to observe the training in real time. Leaders rated that the operator view supports the education of squad leader and that it was easier to manipulate the training higher than non-leaders. It had a medium-sized effect, but had no significance.

Education leaders found it easier to manipulate the training in the operator view compared to non-educational leaders. This result was significant and had a very large-sized effect. Not significant but with a large-sized effect was that education leaders had more joy to operate the operator view. For education leaders it was not significant easier to observe the training of multiple users in the operator view, it also has a medium-sized effect.

The evaluation of the operator view results, also backed by the qualitative feedback of the participants, that the operator view is a very important part of this training system. Results have shown that the more and the less experienced can equally enhance their subjective training effect with the operator-view. Especially the overview of the whole training from the birds-eye perspective gave them valuable insights, on how other squad leaders manage the scenarios.

CHAPTER 7

Conclusion

This thesis describes the design, implementation, and evaluation of a multi-user virtual reality training system for first responders. It presents the fundamental tasks and principles that squad leaders in case of a disaster have to follow. With the combined knowledge of the important facts in disaster relief management and the current state-of-the-art technologies a novel system was developed. This VR system was evaluated in the course of a user study. Throughout the user-centered design process and evaluation of the user study, a clear & strong tendency was shown from the participants' point of view that the implemented system is beneficial for the education of on-site squad leaders. The results have shown, that non-leaders and non-educational leader profit more from the VR simulation than the already more experienced squad leaders. Furthermore, all participants profit from the functionalities of the operator view. The current level of 3D rendering & visualization of the system is sufficient for most of the stakeholders, but should be improved in the future to add more realism. The participants who were using the Virtualizer as a navigation tool had some difficulties to navigate through the virtual environment. The unfamiliarity of ODTs of the participants could be the reason for this in comparison to the gamepad user. There was no correlation between the used setup and the physically exhausting while using the navigation device. Probably because of the high physical fitness of the firefighters. Nevertheless, both setup groups enjoyed the usage of their navigation device, thus no tendency which hardware is more beneficial for on-site squad leader training can be shown.

Multiple participants, who also took part in previous VROnSite user studies, stated that the innovations provided in parts by this thesis has been significant since the last user study run. The evaluation approves this statement by showing a clear tendency to the success of the multi-user and interaction extensions to improve the effectiveness of the system for squad leader training. Especially the operator view feature was praised as a very useful addition. Furthermore, it was highlighted by some that the PDCA cycle could finally be closed. However, the evaluation showed that there are still improvements

necessary regarding usability, navigation, and interaction. At last, many participants requested a larger variety of different scenarios, in particular scenarios that seldomly occur in the real world.
The following paragraphs show the contribution, limitation, and possible future work.

7.1 Contributions

Virtual reality system for first responder training - To be well prepared in the case of a disaster, the firstly arriving response units need to be trained. For the proper training of first responder squad leaders, large exercised need to be organized. Such exercises need much personnel and material resources. Therefore, the costs of these exercises are high. It is also desirable to allow the squad leaders to participate with different roles. This improves their knowledge of the various tasks different functions have to handle in the occurring scenarios. This helps the squad leaders to get a clearer picture of the full relief process. For this reasons, VR can be used to train frequently, switch the field of duties for the trainee, and at the same time keep the costs low.

Multi-user 3D interaction system - At the beginning of this thesis, the VROnSite training system comprises a single user experience without interaction possibilities with the virtual environment (except navigation/exploration). This gap was close within this thesis. The VROnSite project was extended by a distributed system that allows multiple users in different roles (trainee and operator) to interact with each other. Additionally, in this thesis, the previous implemented ODT movement functionality was also utilized. This increases realism by physically stressing the user when moving through the virtual environment.

Closed plan-do-check-act cycle - Due to the 3D interaction possibilities, a complete implementation of the PDCA cycle can be conducted by trainees. Especially, through the interactions of the operator. When squad leaders give commands in a real-world scenario, the associated group, which is under their command, executes these. Because of the absence of personnel, no commands were executed in the virtual environment. For this problem, the interaction possibilities are the solution. If the trainee gives a command, this specific command can now be executed by the operator.

Flexible untethered mobile interaction input - During the implementation of the system, many different requirements for different stakeholders were considered. This led to the adaptation of the input handling to be as generic as possible. Therefore, it does not matter whether the input comes from a joystick, gamepad, or even an ODT. Furthermore, the setup was kept mobile and untethered to maintain the maximum flexibility and prevent tangled cables when using multiple devices.

7.2 Future Work and Outlook

In the future, the scenarios can be extended with more obstacles, walkable indoor buildings, larger scenes, and other disaster scenarios. The depiction of scenarios and injured person can be visually improved, by making their behavior more appropriate to the situations. The addition of virtual persons who interact with integrated **artificial intelligence (AI)** persons and vehicles would contribute to the creation of more complex and chaotic scenarios.

To relief big disasters, many different organizations (e.g. police, firefighters, paramedics, etc.) need to frictionless collaborate and communicate. Therefore, these organizations need to invest considerable resources into improving cross-organization cooperation. The presented thesis can act as fundamental core to enable cross-organization training, using immersive virtual reality. To represent this inside the virtual world, more different roles should be able to choose in the system. To make the training easier to organize **interdisciplinary trainings**, the distributed system should be extended by allowing the participants to connect via the Internet. This subsequently leads to a more location independent system.

It is often hard to keep the big picture of the scene in the often chaotic situation during disasters. Therefore, **checklists** will be used by the squad leader to ensure their focus on the relevant things. Hence, it makes sense to use the exact system in the form of virtual checklists inside the simulation. This could be in example a head-up display (HUD) or a virtual smart watch.

With the increasing usage of **unmanned aerial vehicles,** (UAV) in emergency situations, the logistic problem, organizations during disaster relief operation can be more counteracted, by dropping supplies via these [Bog16]. This and other similar additions could be added to the simulated training. To raise the level of realism even higher.

When a really large disaster occurs, on-site squad leader are rarely working independently. They often have **staff work** groups in the background, which supply them with essential information of the situation and manage amongst others, shift changes of the units, mobilize reserves, answering press requests, handle communication between relief organizations, etc. The staff work group trains dry runs of their work, without the execution of a relief unit exercise. Like in the real world, in VR a staff work group can be established in the background to back up the trainees in the simulation.

APPENDIX A

User Study Pre-Questionnaire

TeilnehmerIn #: ________

Allgemeine Informationen

1. **Alter:** ___________ (Jahre)

2. **Geschlecht:** [ ] männlich [ ] weiblich

3. **Sind Sie mit einer Führungsaufgabe betraut?** [ ] Ja [ ] Nein

4. **Sind Sie im Rahmen der Ausbildung tätig?** [ ] Ja [ ] Nein

5. **Bitte geben Sie an, wie viele Übungen im Schnitt pro Jahr für Sie vorbereitet werden.**

Keine	1-3	4-7	Mehr als 7

6. **Bitte geben Sie an wie viele Übungen Sie im Schnitt pro Jahr für andere Führungskräfte vorbereiten.**

Keine	1-3	4-7	Mehr als 7

7. **Bitte geben Sie an, an wie vielen Planspielen Sie im Schnitt pro Jahr teilnehmen.**

Keine	1-3	4-7	Mehr als 7

8. **Wie würden Sie Ihren persönlichen Fitness-Level einschätzen?**

Keine Fitness	Geringe Fitness	Durchschnittlich	Moderate Fitness	Starke Fitness
1	2	3	4	5

9. **Haben Sie Vorerfahrung mit Virtual Reality?**

Keine	Gering	Durchschnitt	Moderat	Viel
1	2	3	4	5

10. **Haben Sie Übung / Vorerfahrung in der Benutzung eines Gamepads?**

Keine	Gering	Durchschnitt	Moderat	Viel
1	2	3	4	5

11. **Haben Sie Übung / Vorerfahrung in der Benutzung eines omni-direktionen Laufbands (Virtualizer)?**

Keine	Gering	Durchschnitt	Moderat	Viel
1	2	3	4	5

Prä-Exposition Simulatorkrankheit

Bitte markieren Sie, welche der folgenden Symptome aktuell auf Sie zutrifft. Die gleiche Fragestellung wird Ihnen nach dem Experiment nochmals gestellt.

1.	Allgemeines Unwohlsein	Kein	Gering	Moderat	Stark
2.	Müdigkeit	Keine	Gering	Moderat	Stark
3.	Kopfweh	Kein	Gering	Moderat	Stark
4.	Schwitzen	Kein	Gering	Moderat	Stark
5.	Übelkeit	Kein	Gering	Moderat	Stark
6.	Unscharfes Sehen	Nein	Ja (Gering	Moderat	Stark)
7.	Schwindel	Nein	Ja (Gering	Moderat	Stark)
8.	Verwirrtheit	Nein	Ja (Gering	Moderat	Stark)

APPENDIX B

User Study Training Questionnaire

FRAGEBOGEN TRAINING

TeilnehmerIn #: ________ Setup Typ:_________

Post-Exposition Simulatorkrankheit

Bitte markieren Sie, welche der folgenden Symptome aktuell auf Sie zutreffen.

1.	Allgemeines Unwohlsein	Kein	Gering	Moderat	Stark
2.	Müdigkeit	Keine	Gering	Moderat	Stark
3.	Kopfweh	Kein	Gering	Moderat	Stark
4.	Schwitzen	Kein	Gering	Moderat	Stark
5.	Übelkeit	Kein	Gering	Moderat	Stark
6.	Unscharfes Sehen	Nein	Ja (Gering	Moderat	Stark)
7.	Schwindel	Nein	Ja (Gering	Moderat	Stark)
8.	Verwirrtheit	Nein	Ja (Gering	Moderat	Stark)

Fortbewegung mit Gamepad ODER Virtualizer

1. Bitte geben Sie an, wie sehr Sie dem Argument zustimmen: "Ich war in der Lage, mich EINFACH in der virtuellen Umgebung fortzubewegen".

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

2. Bitte geben Sie an, wie sehr Sie dem Argument zustimmen: "Ich war in der Lage, mich SCHNELL in der virtuellen Umgebung fortzubewegen".

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

3. Bitte geben Sie an, wie sehr Ihnen die Bedienung das Navigationsgerät gefallen hat.

Sehr schlecht	Schlecht	Unentschieden	Gut	Sehr gut
1	2	3	4	5

4. Bitte geben Sie an, in welchem Ausmaß Sie die folgenden Aussagen wahrgenommen haben:

1. Wie mental anspruchsvoll empfanden Sie die Navigationsaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

2. Wie körperlich anspruchsvoll empfanden Sie die Navigationsaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

3. Wie hastig oder eilig empfanden Sie das Tempo der Navigationsaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

4. Wie subjektiv erfolgreich waren Sie damit, sich durch die virtuelle Umgebung zu bewegen?

Sehr schlecht	Schlecht	Unentschieden	Gut	Sehr gut
1	2	3	4	5

5. Wie sehr mussten Sie sich anstrengen, um die Navigationsaufgabe zu bewältigen?

Wenig	Eher wenig	Unentschieden	Eher viel	Viel
1	2	3	4	5

6. Wie unsicher, entmutigt, gestresst oder genervt waren Sie von der Navigationsaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

3D-Interaktion mit der virtuellen Umgebung (zB. Tür öffnen,..)

1. Bitte geben Sie an, wie sehr Sie dem Argument zustimmen: "Ich war in der Lage, EINFACH mit der virtuellen Umgebung zu interagieren".

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

2. Bitte geben Sie an, wie sehr Sie dem Argument zustimmen: "Ich war in der Lage, SCHNELL mit der virtuellen Umgebung zu interagieren".

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

3. Bitte geben Sie an, wie sehr Ihnen die Bedienung zur Interaktion gefallen hat (Kombination aus Blickrichtung und Tastendruck)

Sehr schlecht	Schlecht	Unentschieden	Gut	Sehr gut
1	2	3	4	5

4. Bitte geben Sie an, in wie weit Sie den folgenden Aussagen zustimmen:

1. Ich denke, ich würde das Interaktionskonzept regelmäßig nutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu

1	2	3	4	5

2. Ich habe das Interaktionskonzept als unnötig komplex empfunden.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

3. Ich denke, das Interaktionskonzept war leicht zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

4. Ich denke, ich würde Unterstützung einer technisch versierten Person benötigen, um das Interaktionskonzept zu verwenden.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

5. Ich fand, dass die unterschiedlichen Funktionen (Schauen, Knopfdruck) gut in das Interaktionskonzept integriert waren.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

6. Ich finde, dass es zu viel Inkonsistenzen im Interaktionskonzept gab.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

7. Ich könnte mir vorstellen, dass die meisten Leute schnell lernen würden, wie man das Interaktionskonzept verwendet.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

8. Ich fand das Interaktionskonzept sehr umständlich zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

9. Ich war sicher, das Interaktionskonzept richtig zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

10. Ich musste eine Menge Dinge lernen, bevor ich das

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu

Interaktionskonzept nutzen konnte.

1	2	3	4	5

Bitte beschreiben Sie kurz Ihre Erfahrung mit der Interaktion (was mochten Sie besonders, was sollte verbessert werden, was hat Ihnen gefehlt, ..).

Übung mit mehreren Benutzern

1. **Bitte geben Sie an, in wie weit Sie der Aussage zustimmen: "Ich war in der Lage, die Aktionen meines Trainingspartners VISUELL GUT nachzuvollziehen."**

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

2. **Bitte geben Sie an, in wie weit Sie der Aussage zustimmen: "Ich war in der Lage, die Befehlsgebung EFFEKTIV mit meinem Trainingspartner zu üben."**

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

3. **Bitte geben Sie an, wie sehr Ihnen das Üben mit mehreren Benutzern gefallen hat.**

Sehr schlecht	Schlecht	Unentschieden	Gut	Sehr gut
1	2	3	4	5

Bitte geben Sie an, in welchem Ausmaß Sie die folgenden Aussagen wahrgenommen haben:

1. Wie mental anspruchsvoll empfanden Sie das Üben zu zweit?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

2. Wie körperlich anspruchsvoll empfanden Sie Üben zu zweit?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

3. Wie hastig oder eilig empfanden Sie das Tempo der Übung zu zweit?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

4. Wie subjektiv erfolgreich waren Sie ihre Aufgaben in der Befehlsgebung umzusetzen?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

5. Wie sehr mussten Sie sich anstrengen, um die Übung zu zweit zu bewältigen?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

6. Wie unsicher, entmutigt, gestresst oder genervt waren Sie von der Übung zu zweit?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

Bitte beschreiben Sie kurz Ihre Erfahrung mit der Übung zu zweit (was mochten Sie besonders, was sollte verbessert werden, was hat Ihnen gefehlt, ..).

Gesamte Virtuelle Trainingsumgebung (VR Brille, 3D Umgebung, Navigationgerät, 3D Interaktion)

3. **Bitte geben Sie an, in wie weit Sie der Aussage zustimmen: "Ich hatte das Gefühl, dass ich mich im wahrsten Sinne in der virtuellen Welt befunden habe".**

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

4. **Bitte geben Sie an, in wie weit Sie der Aussage zustimmen: "Ich war in der Lage, mir SCHNELL einen Überblick über das virtuelle Einsatzgebiet zu verschaffen".**

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

5. **Bitte geben Sie an, in wie weit Sie der Aussage zustimmen: "Ich war in der Lage, SCHNELL Gefahrenbereiche / verletzte Personen zu identifizieren".**

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

6. **Bitte geben Sie an, inwieweit mit der vorgestellten virtuellen Trainingsumgebung die Ausbildung von Führungskräften unterstützt werden kann.**

Wenig	Eher wenig	Uentschieden	Eher viel	Viel
1	2	3	4	5

7. **Bitte geben Sie an, wie wichtig Sie die folgenden Komponenten für ein effektives Training von Führungskräften erachten:**
   a. **Freies Umherschauen mit der VR-Brille**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

   b. **Freie Navigation durch die Umgebung**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

   c. **3D Interaktion mit Objekten**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

   d. **Virtuelle Geräuschkulisse**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

   e. **Mehrbenutzerbetrieb**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

   f. **Visuelle Umsetzung der Befehlsgebung**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

   g. **Realismus der 3D Darstellung (Grafik, Animationen, Klang)**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

8. **Bitte priorisieren Sie die Faktoren aus Frage 7 nach Wichtigkeit für ein effektives Training für Führungskräften.**

Priorität	**Faktor (zB. 7d)**
1 (sehr wichtig)	
2	
3	

4	
5	
6	
7 (unwichtig)	

9. Bitte geben Sie an, in wie weit Sie den folgenden Aussagen zustimmen:

1. Ich denke, ich würde dieses Trainingskonzept regelmäßig nutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

2. Ich habe das Trainingskonzept als unnötig komplex empfunden.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

3. Ich denke, das Trainingskonzept war leicht zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

4. Ich denke, ich würde Unterstützung einer technisch versierten Person benötigen, um das Trainingskonzept zu verwenden.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

5. Ich fand, dass die unterschiedlichen Funktionen (Sehen, Hören, Bewegen, Interagieren, Befehlsgebung) gut in das Trainingskonzept integriert waren.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

6. Ich finde, dass es zu viel Inkonsistenzen im Trainingskonzept gab.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

7. Ich könnte mir vorstellen, dass die meisten Leute schnell lernen würden, wie man das Trainingskonzept verwendet.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

8. Ich fand das Trainingskonzept sehr umständlich zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

9. Ich war sicher, das Trainingskonzept richtig zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

10. Ich musste eine Menge Dinge lernen, bevor ich das Trainingskonzept nutzen konnte.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

1. Bitte geben Sie an, in welchem Ausmaß Sie die folgenden Aussagen wahrgenommen haben:

1. Wie mental anspruchsvoll empfanden Sie die Trainingssaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

2. Wie körperlich anspruchsvoll empfanden Sie die Trainingssaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

3. Wie hastig oder eilig empfanden Sie das Tempo der Trainingssaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

4. Wie subjektiv erfolgreich waren Sie bei der Bewältigung der Trainingsaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

5. Wie sehr mussten Sie sich anstrengen, um die Trainingssaufgabe zu bewältigen?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

6. Wie unsicher, entmutigt, gestresst oder genervt waren Sie von der Trainingssaufgabe?

Gering	Eher gering	Unentschieden	Eher hoch	Hoch
1	2	3	4	5

Offene Fragen

Bitte beschreiben Sie kurz Ihre Erfahrung mit der Anwendung (was mochten Sie besonders, was sollte verbessert werden, was hat Ihnen gefehlt, ..).

Welche anderen Trainingsszenarios können Sie sich vorstellen, die mit dem verwendeten Virtual Reality Setup beübt werden könnten.

APPENDIX C

User Study Operator Questionnaire

FRAGEBOGEN TRAINERANSICHT

TeilnehmerIn #: ________ Setup Typ:_________

Funktionalitäten

1. Bitte geben Sie an, wie sehr Sie dem Argument zustimmen: "Ich war in der Lage, EINFACH den Trainingsverlauf während des Trainings nachzuvollziehen".

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

2. Bitte geben Sie an, wie sehr Sie dem Argument zustimmen: "Ich war in der Lage, EINFACH den Trainingsverlauf von unterschiedlichen Teilnehmern nachzuvollziehen".

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

3. Bitte geben Sie an, wie sehr Sie dem Argument zustimmen: "Ich war in der Lage, EINFACH die Trainingsszene zu beeinflussen (Platzierung von Objekten)".

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

4. Bitte geben Sie an, wie sehr Ihnen die Bedienung der Traineransicht gefallen hat.

Sehr schlecht	Schlecht	Unentschieden	Gut	Sehr gut
1	2	3	4	5

5. Bitte geben Sie an, in wie weit Sie den folgenden Aussagen zustimmen:

1. Ich denke, ich würde das Konzept der Traineransicht regelmäßig nutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

2. Ich habe das Konzept der Traineransicht als unnötig komplex empfunden.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

3. Ich denke, das Konzept der Traineransicht war leicht zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

4. Ich denke, ich würde Unterstützung einer technisch versierten Person benötigen, um das Konzept der Traineransicht zu verwenden.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

5. Ich fand, dass die unterschiedlichen Funktionen gut in das Konzept der Traineransicht integriert waren.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

6. Ich finde, dass es zu viel Inkonsistenzen im Konzept der Traineransicht gab.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

7. Ich könnte mir vorstellen, dass die meisten Leute schnell lernen würden, wie man das Konzept der Traineransicht verwendet.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

8. Ich fand das Konzept der Traineransicht sehr umständlich zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

9. Ich war sicher, das Konzept der Traineransicht richtig zu benutzen.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

10. Ich musste eine Menge Dinge lernen, bevor ich das das Konzept der Traineransicht nutzen konnte.

Trifft nicht zu	Trifft eher nicht zu	Unentschieden	Trifft eher zu	Trifft zu
1	2	3	4	5

Ausbildung von Führungskräften

1. **Bitte geben Sie an, inwieweit mit der vorgestellten Traineransicht die Ausbildung von Führungskräften unterstützt werden kann.**

Wenig	Eher wenig	Uentschieden	Eher viel	Viel
1	2	3	4	5

2. **Bitte geben Sie an, wie wichtig Sie die folgenden Komponenten für ein effektives Training von Führungskräften erachten:**
    a. **Verfolgen des Trainings in Echtzeit mit Blick in 3D Szene**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

    b. **Markierung von wichtigen Elementen, die wahrgenommen werden müssen**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

    c. **Möglichkeit zwischen den Perspektiven zu wechseln**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

    d. **Möglichkeit Objekte gemäß Befehlsausgabe in der 3D Szene zu platzieren**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

    e. **Möglichkeit, Kommentare textuell zu bestimmten Zeitpunkten einzugeben**

Unwichtig	Eher unwichtig	Uentschieden	Eher wichtig	Wichtig
1	2	3	4	5

3. **Bitte priorisieren Sie die Faktoren aus Frage 2 nach Wichtigkeit für ein effektives Training für Führungskräften.**

Priorität	**Faktor (zB. 2d)**
1 (sehr wichtig)	
2	
3	
4	
5 (unwichtig)	

Offene Fragen

Bitte beschreiben Sie kurz Ihre Erfahrung mit der Traineransicht (was mochten Sie besonders, was sollte verbessert werden, was hat Ihnen gefehlt, ..).

Welche anderen Funktionalitäten für die Traineransicht können Sie sich vorstellen, die für die Ausbildung von Führungskräften relevant wären.

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Acronyms

AI artificial intelligence. 42, 85

API application programming interface. 42

AR augmented reality. 21–23, 42

CGI computer-generated imagery. 23

DOF degrees of freedom. 14, 15, 38–40, 53, 57, 66

FOV field of view. 12, 13

FPS frames per second. 32, 53

GPU graphics processing unit. 42

HMD head-mounted display. 2, 12–14, 18, 19, 21–23, 25, 35, 39, 43, 48, 49, 66, 69, 73–76, 80, 81

ITQ immersive tendency questionnaire. 70

LAN local area network. 35, 37, 48

LOD level of detail. 53

NPC non-player character. 42

ODT omnidirectional treadmill. 2, 3, 21, 23, 39, 42, 43, 66, 80, 83, 84

OS operating system. 31, 66

PDCA plan-do-check-act. 2, 32, 47, 53, 54, 80, 81, 83, 84

PQ presence questionnaire. 70

SSQ simulator sickness questionnaire. 70, 72

SUS system usability scale. 70–72, 74–80, 82, 108

TLX task load index. 70–72, 74–76, 80, 108

UCD user-centered design. 34, 47

UI user interface. 12, 15, 34, 48, 50, 57

UML unified modeling language. 30, 48

VR virtual reality. 3, 12, 15, 21–23, 32, 35, 39, 41–43, 48, 53, 60, 70, 72, 80, 81, 83–85

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