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SOFTWARE ENGINEERING

Augmented Reality in First Aid Training

Author:

Tord Hettervik Frøland

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UNIVERSITY OF BERGEN

Western Norway
University of
Applied Sciences

Abstract

To gain high experiences in handling accidents, live training is necessary. It has to be periodically reoccurring and is important in many organizations, but expensive to set up. One of the most important moments for this training is wounds treatment. Current methods used in live training for treating wounds are limited by the fact that physical replication of such situations is resource demanding. While live training is needed to gain skills from increased experience and concrete cases, the training is usually a trade-off between accuracy and efficiency of set-ups. Augmented Reality(AR) technologies allow blending the physical training environment with digital trauma wound representations. This work presents the design of such a mixed reality application using the Microsoft HoloLens and pressure sensitive sensors, based on repeated observations from live training. The main result is this design solution illustrating the possibilities of AR and sensors, and a prototype showing its main functionalities.

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1 Introduction

There are several environments where workers at an organization need to train trauma and wound treatment, e.g. militaries, oil companies and construction firms. The necessity of this stems from the fact that these are hazardous work environments where accidents are prone to happen, and first aid-trained personnel can play a crucial role in saving lives and mitigating injuries. There are also indications that such training has a preventive effect on the risks taken by workers (Lingard 2002) and may contribute to learning to give right first help in time (Mundell et al. 2013).

Live-training is a type of training that is performed as a simulation of real-life situations using scenery, props, actors, moulage and more (see section 2.3.2 for more details). By minimizing the difference between the training scenarios and possible emergency situations, and supporting high grades of immersion, it is considered one of the most valuable training forms for first aid (Mundell et al. 2013, Lateef 2010). While in health this training can be called "simulation training", this thesis reserved simulation training for cases when computer simulation is used in the training.

There is a large challenge for facilitators in planning a valuable training, setting up realistic environments and reducing differences between sessions. This is needed because they usually need to train in the same manner. They also need to balance resource costs such as personnel hours, equipment and logistical efforts. Additionally, the training field, crucial safety and environmental regulations limit the span of possible scenarios to train. Current simulation and VR technologies promise benefits for defining cheaper, more efficient training environments (P. et al. 2013).

In this MSc thesis, the focus is on live-training for treatment of trauma wounds by using Augmented Reality(AR) technologies. The current training is uncomfortable, less effective and messier than desired, with considerable time spent on preparation and cleanup. The hypothesis is that AR can provide benefits to first aid training.

1.1 Motivation

To organize role plays by using synthetic body parts and other physical equipment is the standard for first aid live-training. Realism is acquired by applying moulage to actors, equipping them with systems that pump blood from fake wounds and having them wear suits with synthetic skin to cut in and fake organs. Advanced patient simulators are widely used, where techniques such as CPR can be tested without danger of harming an actor, as well as potential benefits in skill acquisition (Mabry 2005, Ziv et al. 2000, Heldal I. 2017).

While a wide array of technology has been utilized in physical tools for first aid training, the use of digital vision equipment is limited. By this I mean using computer simulations to see e.g. accident scenery, patients or effects of accidents. There has been a large focus on utilizing digital tools in medical training, such as stationary laporascopic training simulators (Barsom et al. 2016), 3d-visualization tools and Augmented Reality for pre-operative planning (Tang et al. 2018). Application of similar technology in first aid live-training has to my knowledge not been properly explored and could provide the next step in its evolution.

1.2 Practical circumstances

Through my research I got in contact with Ferdighetssenteret at Haukeland University Hospital. This is a medical training facility where they facilitate skill-based and team-based training. They were greatly interested in the possibility of using AR to improve their training methods. Gains in cost, time usage and comfort were desired, read more about this in section 4.10. Through them I have gained domain knowledge and an understanding of the challenges faced in their training. By allowing me to observe a team-based case they do for rig-workers at Equinor I have been able to define their training process for first aid, which you can read about in section 4. Discussing this process and activities possible to be changed or supported by technologies, motivated this thesis.

1.3 Theoretical possibilities

Several studies argue for the benefits of using Augmented Reality technologies in training (Lee 2012, P. et al. 2013). Augmented Reality (AR) and Mixed Reality (MR) technologies could allow for better user experiences and a more dynamic environment by blending the physical training environment with digital representations. MR technologies offer a great possibility to complement the training of today in healthcare (Riva & Wiederhold 2015), e.g. by allowing solutions to objectively assess decision making for nurses when treating wounds (Jorge et al. 2016) and mobile telemedicine (Kobayashi et al. 2018).

1.4 Scope

The main goal of this thesis work is to improve current first aid live-training. I believe exploring the use of Augmented Reality in this area could be a worthy pursuit, thus the following research questions have been defined to accomplish my goal:

- **Q1:** How is current first aid training practiced?
- **Q2:** What can Augmented Reality improve on today's first aid training?
- **Q3:** What are the first steps that AR-based systems need to handle to better support user experiences?

I will be creating a Mixed Reality-prototype to use as the basis of my evaluation. Through insight gained from the development process and by having the solution tested by practitioners of first aid live-training, the aim of this thesis is to provide an idea of the value of this technology for this field.

As a lot of the Augmented Reality equipment available is relatively new, I expect there to be areas where the technology needs to be changed or improved to allow for full-scale integration. By describing the technologies, and hypothesis to use it, I believe I will be able to identify opportunities, both present and future, where current training can be complemented or improved by AR.

This MSc thesis is the result of a multidisciplinary approach. To approach the problem at hand, I explored the following domains:

- **Software Engineering:** my focus is to utilize this domain to create a prototype to attempt to provide an improvement to the current first aid training.
- **Health:** The potential improvements I try to investigate are intended for the health domain. The sub-area of the domain I focus on is that of first-aid training where I had to gain knowledge on how the current training is performed and different aspects of the problems encountered
- **Electronics:** This domain is represented with the design and creation of a sensor module for measurement of force. For that we needed sensors that could measure multiple points of force

to be integrated into the software and used to calculate correct feedback in the representation.

1.5 Limitations

Because my focus is on software engineering, potentially important results in health-literature regarding training might have been missed. The goal was to see the training activity as a whole, without too much detail on individual parts. This was done in a manner to analyze it and discover technology settings and techniques to improve the training. The complexity of this process and the time necessary to define the relevant evaluations resulted that certain compromises had to be made regarding the evaluations. The overall goal of this MSc thesis is to examine the use of AR for improving first-aid training.

1.6 Overview

The rest of this report is organized as follows:

- Section 2 gives a description of related work, available technologies and theories used.
- Section 3 explains the methodology chosen for this thesis work, and the reasoning behind it.
- Section 4 provides an overview of the definition of the current training, including desired improvements from practitioners.
- Section 5 describes the design of the prototype and its current implementation.
- Section 6 details the results of the evaluation.
- Section 7 contains discussion regarding the evaluation results, possible future work and technological maturity.
- Section 8 concludes the project.

2 Background

In this section terminology used in this thesis will be introduced, relevant technologies detailed and insight provided into research this work builds upon. It begins with explanations of some important underlying concepts for digital viewing technologies. Sensor fusion, which is important for creating an immersive augmented reality experience, and which in this work is expanded on with the use of additional sensors, is also detailed. In the second section the core technologies used in the creation of the prototype are described.

2.1 Terminology

Following are some definitions that are relevant throughout this thesis. The terminologies described are relevant to the viewing technology and sensor use.

2.1.1 Reality-Virtuality Continuum

To classify a visual scene based on the source of its elements, the Reality-Virtuality Continuum was proposed by Milgram et al. (1994):

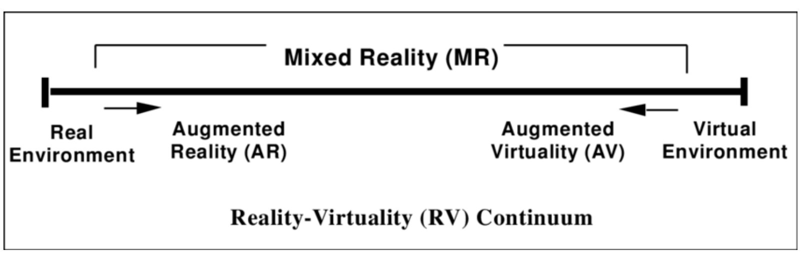


Figure 1: Simplified representation of a RV Continuum from (Milgram et al. 1994)

The real environment, located to the far left in the continuum, is characterized by a lack of digital elements. With the presence of both real and digital elements, the experience is classified by the overarching Mixed Reality (MR) terminology. As more digital elements are introduced to the users view, the further one moves to the right of the continuum, until there are no real elements left and the user is experiencing Virtual Reality (VR). The classifications in this representation are detailed below:

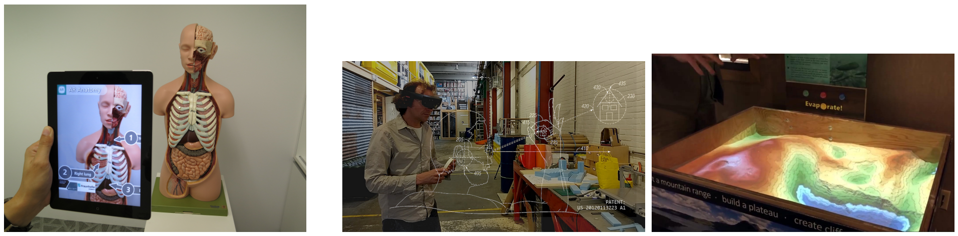
Augmented Reality (AR)

When the basis of the scene is real but there are digital elements put in to be a part of it, it is called Augmented Reality. The digital elements are seen as an augmentation of the real world, by adding more to it and letting the user experience it in a different way. There are aspects that increase this augmentation, such as location, lighting, interaction and occlusion.

- **Mobile phone and tablet** With the prevalence of mobile phones and tablets in the world, this is an area of AR with a lot of interest. The most famous example is probably Pokémon Go [29]. This is a game where the user has to move around in the real world to move his avatar on a map of the real world. This is a way of augmenting by adding digital information and interaction. One of the goals are to find and capture monsters called Pokémon. When capturing these monsters there is an AR-mode where the camera can be used to provide the environment where the Pokémon are displayed as a part of the real world. This is done in a relatively basic manner: the digital element is overlaid on top of the real world and has shadows that creates an illusion of presence. Another use is to process the information in the image and perform an overlay corresponding to the content as seen in Figure 2a.

- **Head Mounted Display (HMD)** By affixing the screen to the head of the user, movement in the real world is facilitated, which is also helped by the HMDs used for AR usually being untethered. The way most AR-HMDs are created is by instead of regular lenses, they are equipped with waveguide lenses. The way they work is by sending the information to be displayed through a construction that guides the electromagnetic waves to the users eyes. There are different types of AR-HMDs such as the HoloLens which has holographic capabilities, as seen in Figure 2b and the Google Glass which presents a Heads-Up Display (HUD).

- **Projection** Instead of using screens or lenses to provide the information directly to the users eyes it can instead be projected on to the real world. An example of this is the Augmented Reality Sandbox (UC Davis 2018), which can be seen in Figure 2c. This is a system that uses the shape of sand mounds in a box to project the topology on top of it. Water simulation is also performed and visualized on top of the sand.



(a) Tablet [33] (b) Head Mounted Display [9] (c) Projection [49]

Figure 2: Augmented Reality technologies

Augmented Virtuality (AV)

When a digital world is the base, with real elements presented in it, we have Augmented Virtuality. This is perhaps the least-known of the definitions in the Reality-Virtuality Continuum. A common way of presenting this is by use of a fully enclosed HMD and external cameras. The HMD is equipped with lenses that create a notion of depth and screens that provide the visuals. A virtual world with elements of reality provided by the cameras are provided to the user.

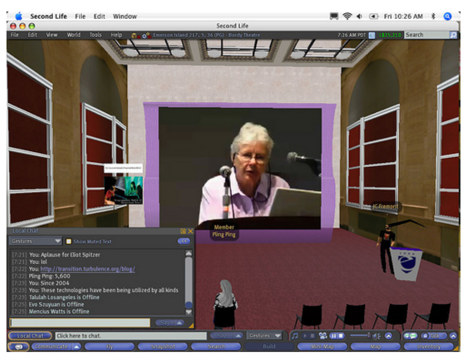


Figure 3: Augmented Virtuality in Second Life [12]

Virtual Reality (VR)

Virtual Reality is on the far right side of the RV-continuum, opposite of reality. This is a fully digital space with no vision of the real world. This is usually experienced through fully enclosed HMDs to block out the real world and allow for a fully virtual visual experience, while still allowing for motion. Virtual Reality has VR HMDs are usually equipped with one lens for each eye to create a sens of depth. The HMDs can be classified into two categories:

- **Tethered:** These types of VR HMDs physically connect to computers or consoles and use their computing power when generating graphics. Oculus Rift, HTC Vive and Sony Playstation VR are the leading HMDs in this market. There are also advances in making powerful, wearable computers for use with VR HMDs, such as the HP Z VR Backpack PC.

- **Untethered:** To allow maximal movement and portability there are HMDs that work without having to be tethered. While most of these are of the type as Google Cardboard and Samsung Gear VR, which work by inserting a phone and using it as the screen, standalone VR HMDs such as the Oculus Go are becoming available.

(a) Tethered VR [3] (b) Untethered VR [6]

Figure 4: Virtual Reality Head Mounted Displays

2.1.2 Sensor Fusion

Sensors are important to provide AR. Video cameras and depth sensors are used to provide information of the environment that allows for integration of the digital elements with the real world. To allow for interaction with the AR-content, one can use sensory input such as voice, gesture recognition, eye tracking [23], [24] and input from external sensors.

This act of combining different types of sensory input and/or from different sources, to gain a higher level of understanding/information than they would provide separately, is known as sensor fusion. Algorithms such as the Kalman Filter (Kalman 1960) that uses historical readings and produces more statistically accurate estimates. Humans themselves perform sensor fusion, for example by using vision and sound to navigate an environment. This can also be used when creating immersive experiences by the use of computer equipment by having historical data and realtime input affect the output.

2.2 The chosen technologies for this thesis

Several different hardware and software technologies has been utilized in this work. The most substantial ones, which I describe in this section, are:

- **Microsoft HoloLens:** At the time I began work on the prototype, this was the AR-HMD that I found to be best suited for the project. I describe some of the hardware capabilities that I found important to my choice of HMD, such as the spatial mapping.
- **Unity:** I have used Unity as the game engine when developing this prototype. Its support for HoloLens development and other useful libraries was the basis for this choice.
- **Arduino:** To be able to gain information regarding non-visual interaction in the training scenario, I have used an Arduino microcontroller board because of its good support for prototyping.
- **Force Sensitive Resistors:** I ended up creating a dynamic digital model of a bleed and needed a way of gaining information about the pressure exerted on the wound area. The form factor, accuracy and ease-of-use were reasons for choosing this.

2.2.1 Microsoft HoloLens

The Microsoft HoloLens is an Augmented Reality HMD. It is self-contained, the first of its kind. It provides the capability of spatial AR with placing content in the world and having it persist. It runs Windows 10 and supports deploying Universal Windows Platform (UWP) apps.

Figure 5: The Microsoft HoloLens Augmented Reality HMD [34]

Following are some relevant features of the HoloLens:

- **Holographic Processing Unit (HPU):** For processing the input data and create a holographic experience, the HoloLens is equipped with a custom-made processing unit.
- **Waveguide lenses:** To let the user have vision of their environment while being able to see digital elements placed in it, waveguide lenses with RGB-capabilities are utilized for providing the visuals. The glasses are see-through with a square field in front that provides the holographic visuals. The field of view of this area is 35 degrees.
- **Video camera:** The users view can be recorded or streamed by use of the video camera.
- **Spatial mapping:** A depth sensor is utilized to provide the ability to scan the environment and generate a digital 3D-model of it. By creating a this representation of the real world it allows this data to be used as the "base world" that programs can have objects interact with. This also allows for occlusion of the digital objects, for example if a digital object is placed in a room and you walk out of it and tries to look at it through a wall, it (usually) is not seen. There are some issues with this technology when it comes to reflective surfaces where the mesh generation will not work properly. The model can be visualized, but is usually hidden.
- **Spatial Sound:** Utilizing the spatial mapping, sound sources can also be placed in the environment and further augment the user experience.
- **Fixed location:** To aid the device in correctly orienting the environment and keeping the holograms in the correct position relative to the HoloLens, it is equipped with an Inertial Measurement Unit (IMU) and four environmental understanding cameras.
- **Optional wireless tethering:** The HoloLens has the capability to be connected to a computer and utilize the graphical power of its GPU. This can be very useful as the one within the unit is comparatively restricted because of space limitations. This is done by using the Holographic Remoting Player to connect to an instance of Unity. The program is run natively on the computer and gets access to sensor values from the HoloLens.

2.2.2 Unity

Unity is a game engine widely used in the game industry as well as in product development, visualization and more. It is the recommended engine to use when developing virtual environments for

HoloLens [26]. Games using the Unity Engine are created by writing C# scripts and utilizing the Unity Editor and consist of scenes that are built up of game objects with behaviour and visuals decided by the components added to them.

The Unity Editor provides a graphical user interface and underlying functionality that provides tools for creating games in the Unity Engine. The basic window layout consists of:

- **Scene:** This is an editable view of the game objects in the scene.
- **Game:** What is visible through the active camera is shown here. During Play-mode, this area is interactable and reflects how the game build will look and behave.
- **Hierarchy:** The contents of the scene are listed in hierarchical order.
- **Project:** A built-in file explorer for the contents of the project.
- **Inspector:** While an object is selected this window will give information about it, show its components with their exposed properties and allows the addition of new components.
- **Console:** Messages, warnings and errors are provided here.

Unity has an extensive asset store with both paid and free assets. Four of these were used in the project:

Obi Fluid

This asset provides particle-based, high-quality, small scale fluid simulations [44]. If set up correctly and provided adequate processing power, the look and behaviour of the particles can provide a large degree of realism. It has a range of customization options available in the inspector that can also be changed at runtime in C# scripts.

It has a large range of components, with the ones used in this thesis described here:

- **Obi Emitter:** Creates the Obi Fluid particles and provides control over the speed, lifespan and other aspects of them.
- **Obi Emitter Shape Disk:** This acts as the "faucet" through which the particles are poured through. It has to be provided with the emitter it is to affect. It allows you to set its radius and turn on edge emission.

- **Obi Collider:** It uses a basic Unity collider as a source and makes it possible for the Obi Particles to collide with it. Phase, thickness and use of distance fields are added as parameters.
- **Obi Particle Renderer:** The shader, particle color and radius scale can be set here. Simple particle rendering can be performed by this component, which is useful for testing and is less computationally demanding than rendering them as fluids.
- **Obi Fluid Renderer:** This component renders the Obi Fluid particles as fluids. It also lets you choose the color material and the fluid material as well as setting the blur radius and the thickness cutoff. The Obi Emitters from the scene that are to be rendered has to be provided.
- **Obi Solver:** Global values and graphical optimizations for Obi Fluid are provided by this component.

Uduino

This asset handles communication with an Arduino connected to the computer Unity is running on [46]. There are two ways of configuring this asset:

- In the Unity inspector window you can perform simple setup: set the Baud Rate, discover and close ports on the connected Arduino and set their mode.
- Code in a Unity C# script can perform more advanced setup, request information from the board, read and write pin values and more.

Simple UI

Some icons for the user interface from this icon package [45] were used .

Vuforia

This asset is optionally bundled when installing Unity [48]. It provides target tracking capabilities, which allows for automatic placement of digital content relative to a target. The available tracking methods are:

- **Model Targets:** 3D-models are provided as the targets.
- **Image Targets:** Images are provided as the targets.

- **Multi Targets:** This is for targets containing multiple flat sides or multiple images.
- **Cylinder Targets:** Specialized for applying digital content to cylindrical objects.
- **Object Targets:** Lets the user scan objects that are used as targets.
- **VuMarks:** Works in the same way as Image Targets, but have some additional functionality regarding design and generation.

2.2.3 Arduino

Arduino is an open-source microcontroller platform designed for prototyping electronics. It is also suited for use in final applications. There are many models with different sizes, inputs and other hardware capabilities. This is a flexible and feature-rich platform that can have its input and output behaviour programmed.

The standard way of programming it is by using the downloadable Arduino Software IDE or their online IDE. The language used is a subset of C/C++. You write a program, called a sketch, which you upload to the board via USB.

MKR1000

The MKR1000 [2] is the Arduino board used in this thesis work. Following are some relevant features of this board:

- Small form factor: 61.5mm x 25mm
- Supports powering from Li-Po battery
- WiFi-chip
- 7 Analog input pins
- 5V output pin

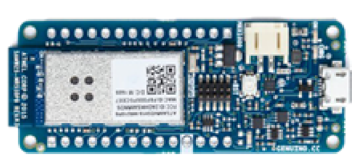


Figure 6: A MKR1000 model Arduino board

2.2.4 Force Sensitive Resistors

Force-Sensitive Resistors (FSRs) are electronic components used for measuring force. They have two interchangeable active pins, where one is to be used for input of electrical current and the other provides output. At the end of the FSR, the sensing area is located. The current that is being sent through the FSR is affected by the resistive force of the component which is inversely related to the force applied to the sensing area. Using the difference in voltage input to output one can get a value that can be used as a measurement of relative force. They come in different sizes, shapes, materials and capabilities.

FlexiForce A201 Sensor

In the prototype the FlexiForce A201 sensors (Tekscan 2018) were used. Different versions are available and the one chosen is the longest and has a high force range of 445 N. In a standard setup it can measure about 45kg, but with alterations in the circuit it can measure up to 450kg. Following are some relevant properties of this FSR:

- Thickness: 0.203 mm
- Length: 190.5 mm
- Width: 14 mm
- Sensing area: 9.53 mm in diameter

Figure 7: The FlexiForce A201 Force Sensitive Resistor

2.3 First aid and live training theory

To further ensure that the work in this thesis is done on a basis of knowledge, theory regarding first aid and live training has been reviewed. Descriptions of these areas are provided in this section.

2.3.1 First aid

First aid is the initial aid given to an injured person. The primary aim of the treatment is to save lives with the secondary aim of minimizing injuries. There are many ways of organizing first aid, some relevant protocols will be explained here.

By virtue of helping save lives and reduce injury, first aid training is seeing constant effort for improvement, with focus on increasing the quality and effectiveness, reducing cost and solving ethical issues. An example of this is the use of animals to train on, which has been a staple of first aid training, especially for militaries (Martinic 2011). This has primarily been done by putting the animal, often pigs, under anesthesia, according to Martinic (2011), whereas they afterwards injure the animal to reflect the desired scenario and the training revolves around treating the wounds. This method has been used because live tissue from animals is more similar to human tissue than synthetic currently is. Animals are still used in training, but because of ethical issues it is being phased out and there is a continued effort to completely replace it (Gala et al. 2012).

The use of synthetic body parts and other physical equipment has become the standard for first aid live-training. Realism is acquired by applying moulage to actors, equipping them with systems that pump blood from fake wounds and having them wear suits with synthetic skin to cut in and fake organs. Advanced patient simulators are widely used, where techniques such as CPR can be tested without danger of harming an actor (Mabry 2005, Ziv et al. 2000).

ABCDE-approach

Currently the ABCDE-approach is recognized as one of the best structured approaches to first aid (Thim et al. 2012). The name is a mnemonic and refers to the following steps to be performed:

- **Airways:** Ensure that the airways are free.

- **Breathing:** Check if the person is breathing properly
- **Circulation:** Look for problems with the circulatory system by performing checks such as pulse rate and capillary refill time.
- **Disability:** Check for neurological issues and assess using the Glasgow Coma Scale (GCS).
- **Exposure:** Expose as much of the body as necessary to uncover potential damage.

This approach has seen changes throughout the years and there has been recent work on the effectiveness of changing the Circulation part to the beginning (Ferrada et al. 2018). It was found that this way has been used for a while at some places. This shows the importance improvements in this area could have.

ISBAR

This is another mnemonic used in first aid and healthcare. It is a set of communication steps taken to ensure proper care is performed (Marshall et al. 2009). ISBAR consists of the following steps:

- **I**dentify yourself
- **S**ituation described
- **B**ackground history provided
- **A**ssess the situation
- **R**ecommend further treatment

Glasgow Coma Scale (GCS)

Initial assessment of neurological damage to the patient, and the degree of it, is often performed by use of the GCS. This scale was proposed by Teasdale & Jennett in 1974 and has since then seen broad adoptment as well as some adjustments. By assessing the patients motor, verbal and eye response a score of maximum 15 points is gained. When presenting the score, the total as well as each element is used, e.g. "GCS 14 (E4, V4, M6)". The scoring steps are as follows:

Table 1: Simplified Glasgow Coma Scale scoring guide

	Observation	Score
Motor response	Obeying commands	6
	A localising response	5
	Flexor respons	4
	Abnormal flexor response	3
	Extensor posturing	2
	No response	1
Verbal response	Orientation	5
	Confused conversation	4
	Inappropriate speech	3
	Incomprehensible speech	2
	No response	1
Eye opening	Spontaneous	4
	Responding to speech	3
	Responding to pain	2
	No response	1
Classification	Severe injury	0-8
	Moderate injury	9-12
	Normal to mild injury	13-15

2.3.2 Live training

To be able to acquire training in as realistic manners as possible, live training is used. This is a way of training where possible real situations, relevant to the field, is imitated.

Live-training sessions are regarded as highly valuable for personnel from military, police, firemen, disaster first-responders and more. It is used to learn new skills and to maintain proficiency for situations rarely occurring. An example of this is where fire-prevention has led to few situations for firemen to practice . Training for extraordinary cases such as fires involving explosive gases, natural disasters and terrorism are also performed in this way.

The value of the live-training is directly proportional to the realism it can provide. This is evident in that the very basis of live-training is to emulate real-life situations to be prepared for them. The type of situations can differ a lot, ranging from general scenarios to highly specialized scenarios. This depends on the function of the participant in the potential real-life situation.

(a) Firefighters simulating putting out a fire [32]

(b) Medical personnel training [36]

Figure 8: Live training examples

Several different techniques are used to enhance realism and immersion, following are some of them:

- **Moulage:** To give the illusion of injuries moulage is applied to actors and dolls.
  - **Moulding:** Fake wounds can be made by use of makeup, silicone etc.
  - **Blood:** A mixture of concentrated red liquid can be mixed with water to create fake blood. This blood can be pre-applied or exposed from blood packs and pumping systems.
- **Acting:** The training situation can involve actors. The participants are acting as well, but are more defined by their roles as trainees. These actors can act as simulated patients, casualties, bystanders, adversaries and more.
- **Facilitators:** To ensure the training goes as intended, human facilitators are used. They provide instructions, verbal information and answer questions.
- **Props:** The use of props to create detail to the scenes and add to the immersion is common. The props should be similar to what might be around and feasibly available in the real locations. If you're training out in the woods, you might not necessarily have access to much medical equipment, in contrast to if you are at an oil rig.
- **Location:** Using a location that is similar to, or could be, a location of a real situation, is beneficial and often done.

(a) Moulage being applied to an actor [37]

(b) Training prop [40]

Figure 9: Live training techniques

3 Methodology

To support my research into the possibilities of incorporating Mixed Reality in first aid live-training, I based this thesis on a "Design and Research" methodology (Oates 2005). This approach should be well-suited for testing assessing the possibilities in a new domain for a technology. I made a proof of concept by developing a prototype solution utilizing an AR HMD, external sensors and a computer. This was tested by practitioners in first aid training and technology experts.

The approach to the development of the prototype used aspects seen in Domain-Driven Development. This is particularly visible in the focus on continuously obtaining domain knowledge from the domain experts in first aid training and utilized this knowledge in the development of the prototype. This minimized the chances of developing something not suitable for their needs. It also provided valuable feedback during the process, that complemented that from the testing.

A danger with the "Design and Research" methodology is that the development itself can get too much focus, and do not consider state-of-the-art research in this process(Oates 2005, p. 114). To counteract this, I took care in formulating the research questions in such a way that they guide the design and development process.

Following is a description of how the methodology was approached in the research questions:

- Q1 pertains to establishing a baseline of the current training, so as to find areas of potential improvement. The baseline was defined by listening to practitioners, observing current training situations and examining actual supporting documentations supporting this. I repeated this process multiple times as the development went on, as increased knowledge of each presented new questions in the other.

- Q2 relied on the results from Q1, but the focus was on supportive AR technologies. I also utilized information found through literature research, practical knowledge gained from developing the prototype and testing by practitioners in first aid and technology experts. By performing these actions in an iterative, cyclic manner, the increased knowledge and experience helped uncover potentials and limitations (Oates 2005, p. 111-112).

- Q3 is answered through a combination of research of state-of-the-art technology, practical experience with it through prototyping and the knowledge of current difficulties in training gained through this thesis work.

3.1 Strategies

Now that the underlying methodology for the thesis has been explained, the process used throughout the work will be detailed. The process has been split into three phases: "Domain Knowledge Acquisition", "Development" and "Evaluation". Following from the methodology the two first phases (excluding the introductory meeting) were performed in an iterative, repeating process, with 3 complete cycles.

3.1.1 Domain Knowledge Acquisition

To acquire the necessary domain knowledge I got in contact with practitioners of first aid live-training from Ferdighetssenteret at Haukeland University Hospital. By interviewing them and observing their training, a baseline to work off of was gained. This work in itself could prove valuable for others to use in improving the field.

Introductory meeting To get an initial description of how their training is performed, we had an introductory meeting. This allowed me to start researching possible ways to incorporate Augmented Reality into their training. It also provided me with information regarding their preferred areas of improvement. The focus was to figure out:

- What they do.
- How they do it.
- Why they do it.
- What aspects they would like to be improved.

Pre-observation interviews Before each observation session I performed a semi-structured interview. This was done to get answers regarding issues that surfaced during development, opinions regarding design decisions and more. These interview were had with the facilitators and the living marker.

Observations A central part of the process was to observe the scenarios. The setup for these were:

- **Personnel:** consisted of 2 facilitators, 1 living marker and 5-6 participants.

- **Equipment:** available was the same for
- **Area:** Two of the observations were done in one of Ferdighetssenteret's rooms. One was performed in the ventilation room at Haukeland University Hospital.

Post-observation interview After each observation a second interview was had. The focus was to clarify and expand on aspects observed in the scenario.

3.1.2 Development

Each development phase began with compiling the information gained from the "Domain Knowledge Acquisition"-phase. Features and designs were altered depending on the feedback gained and new information was researched through literature.

3.1.3 Testing

To evaluate the final prototype tests were performed. It was done as a combination of demonstration and hands-on testing. The sensors were placed on the inside of a silicone wound band. This was connected to a PC, with the user interface intended for the facilitators presented on a large screen. The HoloLens was wirelessly tethered to the PC through Unity's Play Mode simulation. The participants took turns testing the prototype. It was tested by putting on the HoloLens, starting the simulation and letting them try to stop the bleed.

This was done to be able to identify what parts of the prototype were successful, which needed more improvement, did not work and future improvement, thus contributing to all three research questions/goals.

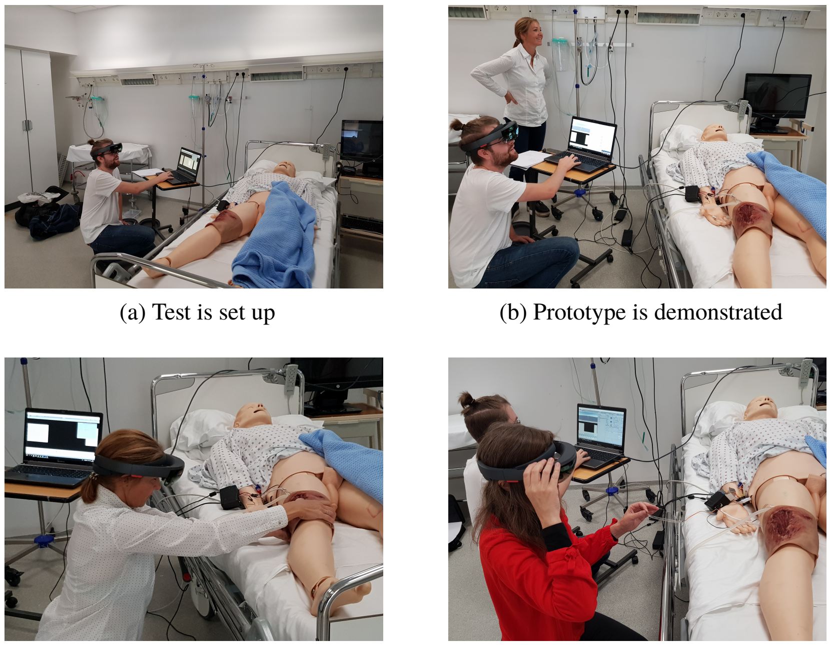
The solution was tested by two groups.

First test

This was performed at Ferdighetssenteret. The participants were:

- 3 from Ferdighetssenteret: 2 of which usually facilitate and 1 who acts as a living marker.
- Supervisor

- Nurse teacher
- 1 AR researcher/developer
- 1 guest at Ferdighetssenteret



(a) Test is set up

(b) Prototype is demonstrated

(c) Pressure is applied to wound

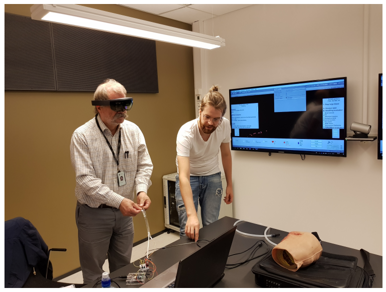
(d) Sensors are tested directly

Figure 10: First test

Second test

This was performed at Western Norway University of Applied Sciences. The participants were:

- Supervisor
- 2 representatives from HVL with specialization in graphics
- 1 representative from HVL with specialization in application of information technology in healthcare
- 1 representative from HVL with specialization in wound treatment
- 1 representative from HVL with specialization in electronics



(a) Sensor response is tested

(b) Testing, with interface in background

(c) Tester observers bleeding on wound

Figure 11: Second test

3.2 Ethical considerations

By utilizing a methodology based upon creation, I am effectively trying to influence the world. As soon as I am not simply observing or testing some pre-existing phenomena, I have to consider if the work is ethical.

There is also the issue of whose interests does this work serve. If it is driven by the economic gain of a single company and not by the public interest, the research is arguably not ethically solid. In my case I collaborate with Ferdighetssenteret at Haukeland University Hospital. If the direct work with the prototype turns out to be of use to Ferdighetssenteret, and it becomes a product for sale, they wish to be able to use it at a reduced price or similar benefit. This is out of the scope of this thesis and does not infer any obligation to leave out information from this thesis.

Haukeland University Hospital, and thus Ferdighetssenteret, are owned by the Norwegian state, this also is true for the University of Bergen and Western University of Applied Sciences. This indicates that there should be no gain from excluding content from the thesis that is disclosed to Ferdighetssenteret. By attempting to contribute to saving lives and reducing injuries, it could be argued that it indirectly serves the greater good.

Seeing as the use of this technology in this area is an emerging field, there are possible economic gains to be had by upselling the value of it. To do my best to counteract this, I provide literature to back up claims made.

4 Training Process Definition

In this section I describe the current first aid live-training process. The research and development process used in this thesis emphasizes domain knowledge, which required collaborating with domain experts. Through interviewing and observing I have defined the current training method used by *Ferdighetssenteret* at Haukeland University Hospital. This is the regional hospital for most of western Norway and has an ongoing co-operation with the University of Bergen. Ferdighetssenteret is a facility located here, dedicated to skill-based training for health personnel and workers. They facilitate solo-based training, such as surgical techniques, as well as training scenarios for teams. While I will focus on one particular case here, it is representative of how they structure other scenarios in their "Emergency Medicine - Simulation Training"-program. My research also indicate this is how state-of-the-art first aid live-training is performed throughout the field.

4.1 Documentation

The case I detail here is one used by Statoil/Equinor for training and certification of their platform workers. The supporting document used for this case can be seen in appendix A. It provides a broad overview of the case in shorthand writing. This document is written and maintained by the team at Ferdighetssenteret.

Statoil/Equinor themselves also provide a supporting document, called "Akuttmedisinske Behandlingsprotokoller". This document contains their internal practices for medical emergencies and adheres to local laws and regulations. Important aspects such as their treatment protocols and the roles of the participants are also defined in this document. Ferdighetssenteret uses this as a basis for when they plan and prepare the cases for the workers from Equinor. As they have the responsibility for the certification of rig workers, adhering to this type of documentation is vital.

4.2 Personnel

At each course there are usually 4 teams of first-responders. Each of these teams consist of 1 nurse and 5-6 workers.

Personnel from Ferdighetssenteret consists of 2 facilitators and 1 simulated patient. The facilitators primary function is to observe the participants, score them, act as SAR phone operators and in general facilitate the training. During the course the simulated patient acts as the injured person.

4.3 Course Schedule

Before the trainees arrive at Ferdighetssenteret, they are expected to have completed an online course on first aid. The entire course takes place over several days. The nurses are there for 4 days while the other first-responders are there for two and a half. During these days the trainees participate in classroom, skill practices and different types of simulation training. The case that I will describe is performed towards the end of the course. It is a culmination of what they have been taught and practiced for. Here they get to practice all their skills in a realistic manner and are tested on their execution.

4.4 Equipment

The participants have a bag of medical supplies, shown in Figure 12, and some other equipment with them. This is similar to what they have available at platforms. It consists of the following:

- Compresses
- Medications
- Intravenous fluids
- Tourniquet
- Digital sphygmomanometer
- Phone to contact SAR
- Stretcher
- Form to document the procedure
- Surgical gloves
- Bandages
- Digital thermometer
- Bag Valve Mask
- Blanket

Figure 12: Medical bag used in scenario

The use of these items in the training is as close as possible to how they would be in a real situation. There are some exceptions:

- Medications are handled in a realistic manner when it comes to proper preparation such as identification and extraction into syringe. The differing part is in the injection itself, which for safety measures is omitted.
- Intravenous fluids are connected to a fluid catheter that is attached, but not injected, to the hand of the simulated patient.
- Tourniquets use basic principles, but are difficult equipment to handle properly(CITE). In the scenario, where a simulated patient is used, proper application of it has to be avoided, to avoid the pain and damage it could incur. They put it on, but only fasten until secured.

4.5 Preparations

There is a significant amount of preparation before the execution of a scenario. Planning for how to execute the scenario, where to have it (Figure 13d) are done before the course starts. The rest of the preparations can be classified for 3 different roles; simulated patient, facilitators and participants.

- The simulated patient has to
  - Create fake blood by mixing water and concentrate, shown in Figure 13b.
  - Fill up the liquid compartment in the backpack with the mixture.
  - Attach the tube of the backpack to the pump, then the appropriate silicone wound band to the pump.

  - Put the silicone wound band on the left thigh.
  - Put the backpack on.
  - Put on a coverall that looks similar to ones they use on the platforms.
  - Tear a gap in the coverall, indicating where the splinter went in.
  - Tape plastic to the floor to avoid the fake blood staining the floor, see Figure 13a.
  - Sit down on the plastic and lean against the wall.
  - About a minute before the participants enter the room, start the pump to get some blood on the coverall and the floor as seen in Figure 13c.
- The facilitators has to
  - Prepare the score sheet.
  - Discuss with each other which points to focus on, depending on how the group has been doing in the classroom sessions.
  - Decide if there will be changes from the regular way the scenario is performed.
- The participants has to
  - Put on coveralls, both to protect their personal clothes, but also to aid in immersion.
  - Put on helmets, to aid immersion.

(a) Floor covers

(b) Fake blood

(c) Wound

(d) Environment

Figure 13: Preparations for scenarios

4.6 Briefing

As the scenario is about to start, the facilitators brief the participants on the case they are about to take part in. The briefing details are as follows:

This case centers around the treatment of a 38-year-old male who has had an accident with an angle grinder. While operating the tool, a splinter flung into his left thigh, causing a puncture of the femoral artery. The first person at the scene removed the splinter in an attempt to help, which made the bleeding more severe and the worker is in danger of dying. The participants act as a team of first-responders that enter the scene as the patient is in this critical state. Through the use of pre-established protocols, they have to systematically go through steps to attempt to save the mans life while minimizing the damage to his leg.

4.7 Scenario

I will now detail what the participants, simulated patient and facilitators do during the scenario.

Participants

The scenario begins as the team enters the room. The simulated patient has blood pulsating from his left thigh and he is screaming in pain. The participants now have to quickly assess the situation and take appropriate action according to the ABCDE approach, which is explained in section 2.3. The ABCDE-approach is used for initial assessment and treatment of the patient. It is also used for re-assessment during the scenario, this is to be done until Search and Rescue (SAR) arrives. By doing this it helps in uncovering problems that weren't discovered the first time, whether from oversight or symptoms becoming clearer over time, as well as new issues that might arise. Following is a list of the steps they have to go through, what they need check and the initial clinical findings they will get.

- **A**irways
  - Check that the airways are free and unobstructed.
  - Clinical findings: The airways are free and unobstructed
- **B**reathing

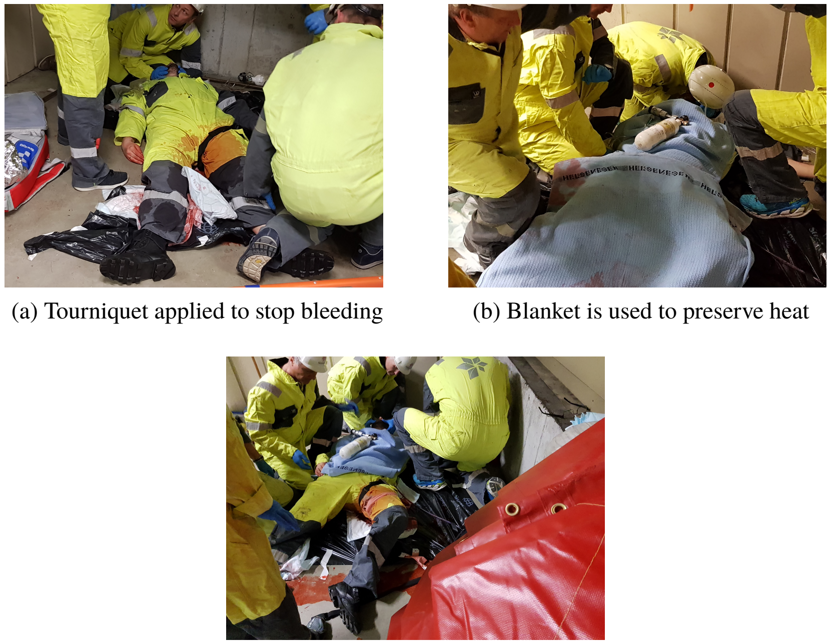
  - Check if the breathing is regular, whether it is deep or shallow. Also listen for abnormal lung sounds such as rales, rhonchi or weezing.
  - Clinical findings: He is breathing rapidly, 36 breaths per minute and it is bilaterally symmetrical.
- **C**irculation
  - Check radial pulse initially by putting fingers on the artery at the wrist. Then look for indications of internal bleeding by checking if the abdomen is soft or hard. When possible, attach sphygmomanometer to monitor blood pressure and pulse.
  - Clinical findings: Radial pulse is initially 120/min, blood pressure is 105/65 and the abdomen is soft.
- **D**isability
  - Figure out if the patient has suffered neurological damage. Perform the Glasgow Coma Scale(GCS) check, which is explained in section 2.3, to get a score indicating the potential damage. Check pupillary reaction and whether they are bilaterally symmetrical.
  - Clinical findings: Patient is conscious, scores 14 on the GCS (4 eye, 4 verbal, 6 motor) and has bilaterally symmetrical pupils.
- **E**xposure
  - Examine the rest of the body of the patient to uncover inner and outer bleeding or other problems.
  - Clinical findings: Large pulsating bleed at inner left thigh.

(a) Initial assessment and treatment (b) Protocol is read and notes are taken

Figure 14: Scenario in progress

Based on these findings the participants should focus on treatment of the bleeding and its side effects, while continuously checking for other issues. The treatment should encompass the following:

- Stop the bleeding
  - Initially, the bleeding should be reduced by applying pressure on the wound. Point pressure on artery by use of fingers could also be done. This should be followed up by laying the patient vertically and lifting the leg up, to reduce blood pressure in leg, while increasing it in vital organs and brain. As soon as the situation is assessed, the wound area should be exposed and bandage should be applied.
    - ∗ The applied pressure is lower than would be necessary in a realistic situation, due to the comfort of the simulated patient.
  - If the bleeding is not contained, application of tourniquet is the next step. As the wound is severe and the patient has to be transported this usually is recommended. As this stops the entire blood flow through the leg, this needs constant monitoring. This involves intermittent loosening which allows for circulation to reduce the risk of further damage to the leg. The risks of this needs to be considered as it results in some additional blood loss.
- Provide oxygen
  - Bag Valve Mask should be used to aid in the patients breathing.
- Establish IV-transfusion
  - As the patient has lost a lot of blood, his blood volume should be increased by transfusion.
- Administer medication
  - Medication should be considered to help lessen the patients pain and reduce the bleeding. Cyklokapron is suggested for this purpose.
- Prevent hypothermia
  - The patient should be covered with a blanket to preserve heat. As this also occludes the view of the patients body, the practitioners have to be extra careful to re-evaluate injuries underneath.



(a) Tourniquet applied to stop bleeding (b) Blanket is used to preserve heat

(c) Reassessment of the wound

Figure 15: First aid treatment

Communication is vital to ensure proper treatment. The following points are emphasized to this end:

- Communicate with the patient
  - The ISBAR communication tool should be used for this purpose, which you can read about in section 2.3.
- Communicate within the team
  - To avoid mistakes and to best utilize resources it is vital that the team communicates extensively. The nurse in the rescue team is the one leading the effort. They are tasked with having an overview of the situation, delegating the others and administering medication. One person is assigned to fill out a form with patient details and the steps taken, such as time and amount of medicines.
- Contact SAR
  - As the patient is severely injured, local treatment wont be enough. SAR has to be contacted to organize transport to a hospital. This should be delegated as soon as possible for the

patient to get necessary treatment with minimal delay. Contact with SAR should be maintained at all times. The scenario ends as soon as SAR arrives.

When SAR is about to arrive, the team has to prepare for transportation of the patient. This is done by lifting the patient on a stretcher and securing him. This can be seen in Figure 16.

(a) Stretcher is prepared

(b) Patient is lifted on to stretcher

(c) Bands are used to secure patient

(d) Patient is ready for transportation

Figure 16: Preparation for transportation

Simulated patient

Through this thesis the name simulated patient is used for a marker, a person who follows a certain role in order to make the simulation believable. Fro this case they have to act as an injured human, a patient. Throughout the scenario the simulated patient stays in character. He tries his best to show the pain and fear that such a wound would entail. As the condition of the patient changes, he will reflect this in his acting, such as pretending to lose consciousness or showing that pain medication is starting to wear off. This aids in the immersion of the participants and prepares them for handling persons with real injuries. At times the simulated patient has to break out of his acting. This is usually due to comfort issues.

Facilitators

The main responsibility of the facilitators is to, as the name indicates, facilitate the execution of the training. They will minimize interruptions that impact immersion, while assisting where necessary. Following are the facilitating aspects they provide:

- They answer questions that might arise regarding aspects of the training. This can be about how to perform actions that are hard to role-play, deviations from the equipment they are used to and more.
- Most of the vital values are provided verbally by the facilitators as they see the participants check for them. This includes heart rate, breathing rate, blood pressure, respiration sounds, state of airways, whether the abdomen is soft or hard and pupillary response.
- To aid in the realism of the SAR-contact, the facilitators act as their phone operators. They ask questions, accept status updates and provide estimates of the time SAR arrives throughout the case. Based on the facilitators need for additional assessment, this time can be extended.

One other important role for the facilitators is to evaluate the participants. The facilitators will update the point sheet, see appendix B, as the case goes on. Here they will receive scores on whether they performed certain actions relating to aspects regarding the treatment. They also write complementary notes regarding the performance, that will be used in the debriefing.

4.8 Debriefing

After the scenario has concluded the participants have a small break while the facilitators convene and talk through how the case went. A central piece for this discussion, and the debriefing as a whole, is a point sheet (appendix B) that is used to assess the participants. This point sheet is based on the ABCDE-approach while also incorporating aspects of communication, use of protocols and the ISBAR-tool. Each major section without sub-fields gives 5 points, with some sections having sub-fields which gives 1 point per sub-field. To pass the case there has to be attained a minimum of 38 points out of 74 possible.

When the facilitators are ready they gather the participants for the debriefing. A major focus is to get the participants to describe and reflect upon the experience, touching upon things they did well and points of improvement. In the end the facilitators summarize what they have gone through and how the scenario went.

4.9 Cleanup

This is primarily done by the simulated patient, as the facilitators and participants are preparing for the debriefing. The cleanup, with parts shown in Figure 17, consists of:

- Drying up the fake blood.
- Packing together the plastic that was on the floor and throwing it away.
- Washing the floor if anything got on it.
- Putting away the medical equipment used in the scenario, restocking if necessary.
- Showering to remove fake blood and reduce staining.
- Undressing and putting on dry clothes.
- Emptying the fluid compartment in the backpack.
- Cleaning the silicone wound band.
- Putting the equipment away.

Clothes have to be cleaned as well, which is done later. In addition the participants undress and attempt to scrub away the stains on skin and potentially clothes.

(a) Equipment is packed
(b) Pumping system is put away
(c) Fake blood is cleaned up
(d) Soaked coveralls and equipment

Figure 17: Cleanup after the scenario

4.10 Desired improvements

Now I will describe the major areas of improvement that is desired by the practitioners. Some of these were expressed at the introductory meeting, while some surfaced during the repeated contact.

Material Cost

The current methods are costly. The equipment, including a year supply of blood mixture, pump, backpack and several different silicone bands cost 80.000 NOK. Each training session uses about 500 NOK value of fake blood. For each course there are 4 sessions and courses are run 10 times a year. That is $10 \times 4 \times 500 = 20000$ NOK a year in running costs of the fake blood mixture.

Another cost is that of ruined clothing. The participants use coveralls to simulate their work environment, as well as protect their personal clothing underneath. There are two costs associated here. The coveralls will often get messed up with fake blood, which necessitates changing them out after a while. The second is that coveralls don't always protect the personal clothes well enough, thus resulting in the clothes being ruined. The clothes of the simulated patient are extra susceptible to staining, as they are soaked in blood throughout the session.

(a) Front view of simulated patient (b) Blood on patient and floor

Figure 18: Blood spill

Time usage

Spending less time on preparation and cleanup would be beneficial. This allows to either spend that time on other work tasks or save money on personnel hours. The current times used are as follows:

- **Preparations** 20 minutes
- **Briefing** 5 minutes
- **Scenario** 20-30 minutes
- **Debriefing** 30 minutes
- **Cleanup** 20 minutes (excluding cleaning of clothes)

As can be seen here, a significant amount of the time of a simulation is spent on preparing and cleaning. In contrast to the briefing, scenario and debriefing, there is no direct benefit from the time spent.

Comfort

The comfort issues in the current solution are mostly affecting the simulated patient. During the scenario they are soaked in fluid and the backpack with the pump is uncomfortable to wear in many positions. The case can take upwards of 30 minutes to complete and experiencing discomfort throughout this time detracts from the focus and performance of the actor.

Realism

The equipment in use heightens the realism of the scenario significantly, compared to acting on its own. There are however areas of improvement relating to this, as well as for the facilitator role in the scenario:

- With the current solution blood flow is started and stopped by clicking a button attached to the pump. This means that the actor has to focus on whether the pressure exerted on the wound area is sufficient to stop the bleeding and he has to keep track of the button, which impacts the acting. The blood flow is either on or off, there is no gradual decrease or increase relative to the pressure, as there would in a real situation.
- The backpack and tubing are additional elements brought into the scenario that serve a functional role, but would not be present in a real one. At times the items can get in the way of placing the simulated patient and care has to be exercised to avoid decoupling of, or damage to, the equipment. Figure 15b and 15c show the pressure tank of the pumping system getting in the way, and in Figure 16d, the backpack of the system.
- The plastic taped to the floor is an element of the scene not present in a real situation.
- The use of verbal communication for the state of vital signals is something that could be improved upon. An example here would be having a way of getting haptic feedback when feeling for the pulse of the simulated patient.

Data

In the current solution there is information that is unavailable or that a better way of collecting is desired.

- Timings of actions and events throughout the scenario:
  - Bleeding stop
  - Tourniquet applied
  - Medication

  - Items on the point sheet
- Values and amounts:
  - Blood loss amount
  - Pressure exerted, including consistency and pressure areas
  - Vitals such as blood pressure, heart rate and respiration rate
  - Amounts of medication administered

This data would be useful for the debriefing and in improving the training.

Lessons from live training and possibilities for AR support

In order to understand live training, I discussed the planning of the training with instructors and observed a number of training situations according to current guidelines from Equinor. Table 2 is a sketch of the process I observed (in column 1), tools that help this training today (in column 2) and possibilities to be supported by AR (column 3).

Table 2: The training process, support from today and possibilities to support it by AR technologies

	Support	AR support
Planning the training (choosing places for groups)	Documents, guidelines, procedures for specific treatments	Not investigated
Illustrating the case for a group of learners	Discussion with instructors	Not today, but AR has potential, right before the training, but also on the working fields
Supporting the group to arrive to the scenery	Pysical instruments: Instructors prepare the scene with markers and objects.	Not investigated. Preparing the scene can be supported by simulations as well.
Presenting the scene/situation	Physical objects, instruments and markers	AR should have great potential by augmenting the accurate scenario with digital objects, e.g. different wounds and bleeding situations
Treatment	Physical objects, instruments and markers. Instructors use paper and pen to note the results - based on systematic training approaches.	AR can support learners by showing reactions to their actions (e.g. applying correct pressure to stop bleeding, see different wounds, context and reactions). AR can support teachers by e.g. recording more evidences for debriefing (statistics, simulation data, camera feed etc.)
Finishing treatment and leaving the scene	Physical objects, instruments and markers	Not investigated
Debriefing	Discussions based on the notes from the instructors and experiences from learners	Not investigated enough, especially for different mixed reality technologies. AR should have great potential to collect evidences by recordings, following the instructors notes and eventually using
Cleaning the scene	Manually	This may not be needed when using AR technologies patient simulators and data.

5 Design and Implementation

This section starts out with an explanation of the overarching design of the prototype. Afterwards, aspects of the implementation will be described.

5.1 Design

Through the insight gained from defining the current process in Section 4, some key points were identified as potential candidates for improvement by inclusion in the prototype. Aspects of interest that could not be included because of time restrictiveness or technological limitations are discussed in Section 7. The aspects chosen because of their perceived difficulty of implementation, usefulness and possible with current technology were:

- **Digital blood:** Comfort, time usage and cost could be potentially be improved by creating a digital blood flow. Additional functionality such as a dynamic blood flow seem to potentially be of value.
- **Point sheet:** By creating an interactive point sheet and integrating it into the prototype, time could be saved and a better workflow achieved.
- **Case planning:** Having the tools to create and plan scenarios within the software could smoothe the planning process for the facilitators.
- **Vital signs:** Integrating and simulating the vital signs of the patient opens up new possibilities for the scenario and adds more data to the debriefing.

Overall design

One goal was to design the prototype in a modular, extensible manner, which is conducive to the iterative "Design and Research" methodology described in Section 3 and also opens up for future work. The project is meant to explore a subset of possible uses, and create a basis for further development.

The prototype consists of three major components:

- **Unity:** Graphical computations, input handling and communication with the other components is handled by the Unity program.

- **HoloLens:** The augmented reality visuals are provided by the waveguide displays of this HMD. Sensor data regarding spatial mapping, orientation etc. is sent to the Unity program, that sends graphical data about the scene to be displayed back to the HoloLens.
- **Arduino:** This module handles measurement of pressure applied to the wound area and sends this data to the Unity program.

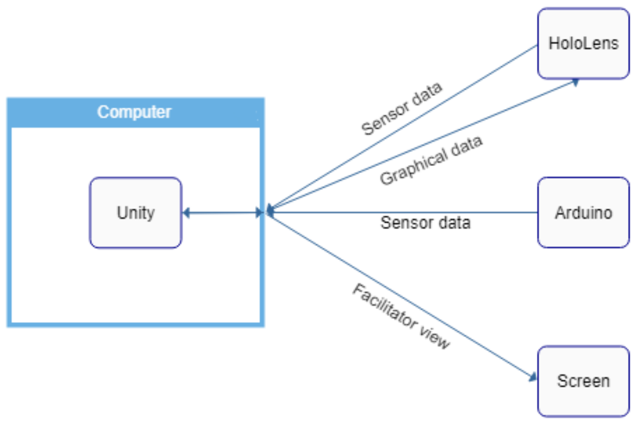


Figure 19: High-level architecture of the prototype

AR HMD

One of the main reasons the HoloLens was chosen as the AR device in this project, was because of its spatial mapping capabilities that allows placing objects in the room. This provides the potential to visualize a stream of blood that we place on the wound area, which could be expanded to other things such as a fully digital wound or bruising as on overlay over the real skin.

Sensor module

The Arduino platform was chosen because of its ease of use and flexibility. It provides the ability to create a circuit with FSRs, connecting it to an board and then send the live data of the FSR state to the Unity program. The Arduino model used is the MKR1000, which has a small form factor, supports powering from a lipo battery, built-in WiFi chip and a good amount of analog ports.

FlexiForce A201 FSRs from Tekscan were picked for their thin and flexible form factor, durability and high force range. First aid involves rough handling, so these were important aspects.

Tracking technology

To be able to dynamically place the bleeding area in the correct spot, and to move it if the patient moves, is a large factor for user immersion. We considered several technologies to see if they could aid in achieving this.

Multiple technologies considered are based on triangulation. This method uses the identification of three, or more, pre-placed transmitters and their signal strength to a receiver, which is placed close to the area to track. Such solutions using Bluetooth and WiFi are widely available and inexpensive. However, bodies and other objects attenuate the signal, while other devices can cause interference, causing a reduction in tracking accuracy (Faragher & Harle 2014). Steps can be done to reduce the impact of such disturbances, by restricting movement of participants and choosing an environment without wireless devices. This would however negatively impact the immersion of the participants and the make many necessary training situations impossible. Ultra Wideband(UWB) systems were also considered. They provide high accuracy, down to a few centimeters, and does not suffer as much from interference (Alarifi et al. 2016). However, the low availability and high price of systems that perform to the needs of the application were deterring factors for choosing this technology.

The technologies that seemed to provide the best compromise in regards to cost, accuracy and availability were image- and object-based tracking. 3D-models and image data is analyzed to find the proper area to track. Vuforia Engine has direct support for the HoloLens and can utilize its sensor data for the tracking. This fit very well with the hardware choices and became the solution aimed for in the prototype. As explained in Section 2.2.2, it also allows simultaneous tracking of multiple areas of interest, which in our case are wound areas. As they can be individually identified, further extension is possible, which is another reason for the choice.

5.2 Implementation

In this section the implementation of the prototype is described. At first the User Interface for use by the facilitators is described, then the simulation experienced by the users and lastly how the sensors were integrated to provide input.

5.2.1 User Interface

To provide an improvement over the current training and save time for the facilitators I focused on making the interface easy to use. To this end I tried to create a visually simple and intuitive interface, that also showcases the possibilities of the prototype. The program consists of three scenes: Setup, Simulation and End. I will go through each of the three scenes and describe them.

Setup scene

To let the facilitators customize the simulation to the case, they are first presented with a setup page.

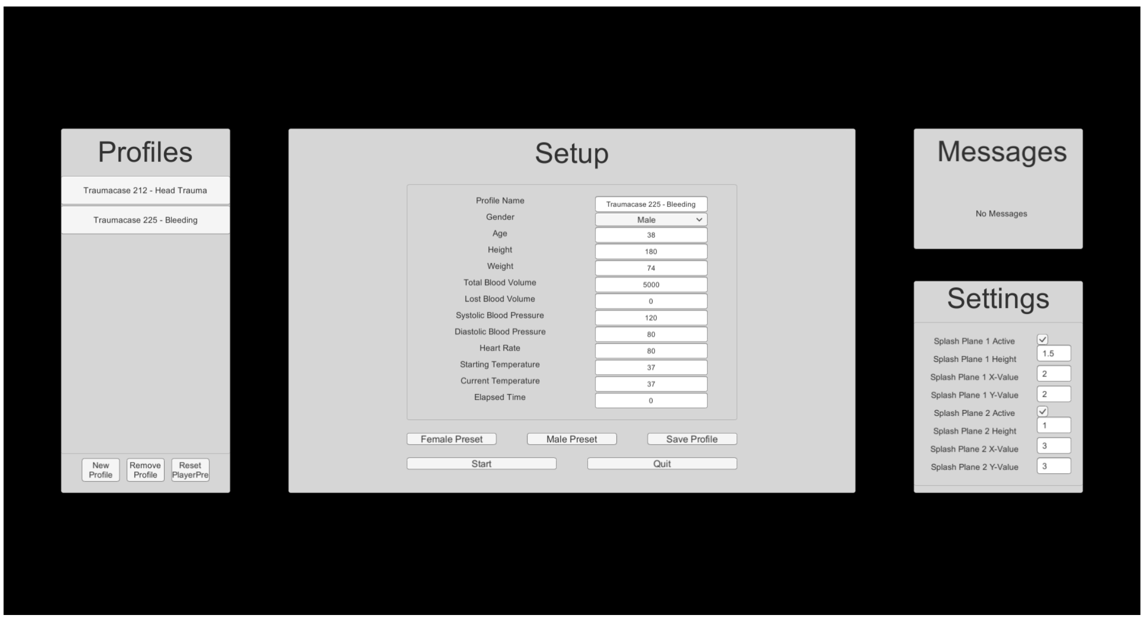


Figure 20: Image of the main menu of the prototype

The setup page consists of 4 interface panels:

1. **Profiles:** To make the swap between cases and the possibility of preparing as much as possible beforehand, this area show the currently saved profiles and allow for more to be created.

2. **Current Profile/Setup:** A collection of input fields with corresponding tags are provided. This is at the core of the program and is placed in the middle of the page. The values in the input fields can be saved to a profile and also have average values for each gender filled by clicking the preset-buttons. This is also where you start or quit the program in this scene. If Start is clicked

and the fields are filled, the simulation will start with the values in the fields as a starting point.

3. **Messages:** This is used to indicate invalid user actions and the reason for it. For example: The user has not selected a profile and attempts to start the program. The user will then get the message "No active profile! Choose or create a profile before starting the simulation."

4. **Settings:** This panel provides the ability to choose whether splash planes are active, their positions and size. Wounds and placement of them are also set here.

Simulation scene

This is the page that is visible for the facilitators during the simulation. In the main area the blood flow is visible. Currently the video stream is not available to see the augmented reality together with the UI, but the HoloLens desktop application allows for video streaming separately.

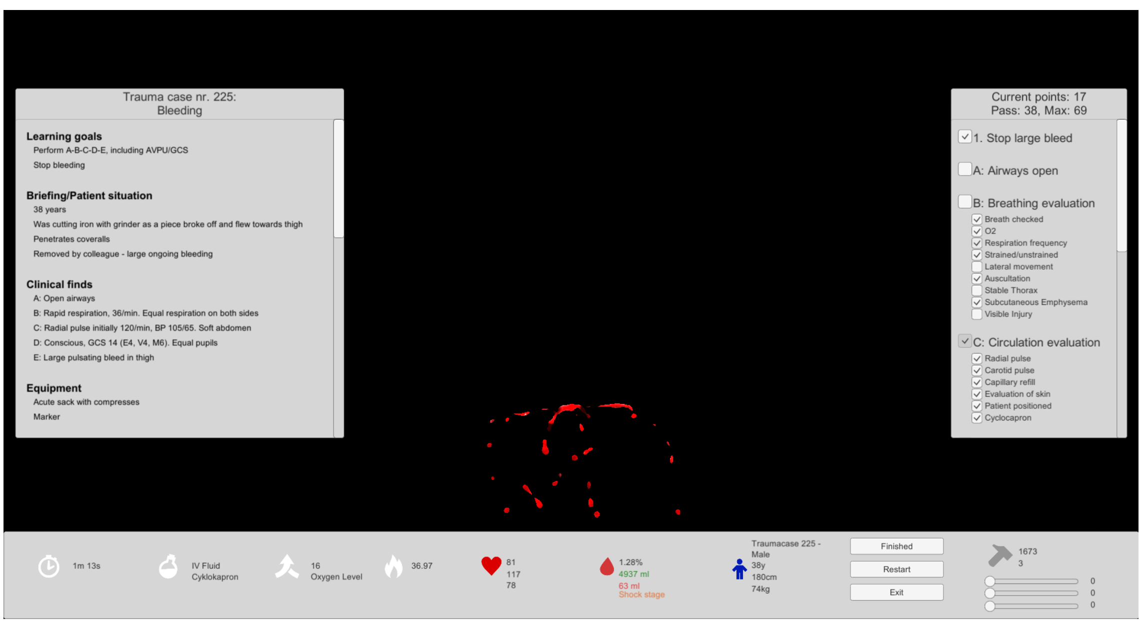


Figure 21: Image of the simulation screen of the prototype - facilitator view

There are 3 panels in this scene:

- **Case Details Panel:** Located in the left of the screen is a panel that contains the details of how the case is planned. This is saved in the profile. By having this information here it possibly removes the necessity for having the case printed out on paper, while also allowing to have most of the interesting information on the same screen as other information, thus increasing the ease of access of information.

- **Point Panel:** A digital version of the point sheet is provided on the panel on the right side. It is designed in the same way as the current one, but with the difference that it consists of toggles and the total score is automatically generated. Each major field gives 5 points. Fields with sub-toggles have two functional changes: toggling the main toggle toggles all the sub-toggles while toggling all the sub-toggles toggle the main toggle. Having this point toggle possibly removes the need for a printed version and has some improvements. Additionally, the score gets saved for later use and is incorporated into the post-simulation statistics screen.

- **Statistics Panel:** In the bottom of the screen a live-update of the vitals of the Digital Human Model is provided, along with the pressure applied to the sensors. Buttons for finishing, exiting and restarting the simulation are also provided.

End scene

The end screen contains a summary of the simulation.

Figure 22: Image of the end screen of the prototype - facilitator view

The case details are available, which might be useful for the review and debriefing. Statistics regarding the best and worst values of vital signs, such as heart rate is provided. Values such as amount of blood lost is displayed and could be incorporated into the assessment. The user can restart the program or exit it from here.

5.2.2 Simulation

One of the goals of this prototype is to replace the physical fake blood with digital blood. This is done in an attempt to improve on the problems described in Section 4.10, while maintaining a comparably immersive experience. In addition, adding dynamics to the blood flow is done to add an element of immersion that is not present in the current training. This is achieved through use of sensors that reduce the bleeding relative to the pressure applied to the correct areas. The integration of the sensors is explained more in Section 5.2.3.

The simulation as seen from the HoloLens is where the augmented reality in the application is experienced. This is provided as a particle-based fluid simulation by the use of the Obi Fluid asset.

Figure 23 shows how the fluid flows from the wound and pools on the floor. As the spatial map of the HoloLens is not supported by the fluid simulation application, an invisible cylinder is placed within the leg and an invisible plane on the floor level. These have Obi Colliders applied to them to allow the fluid to interact with it. The sensor module with the FSRs sensing areas placed underneath the wound area are also visible in the image.

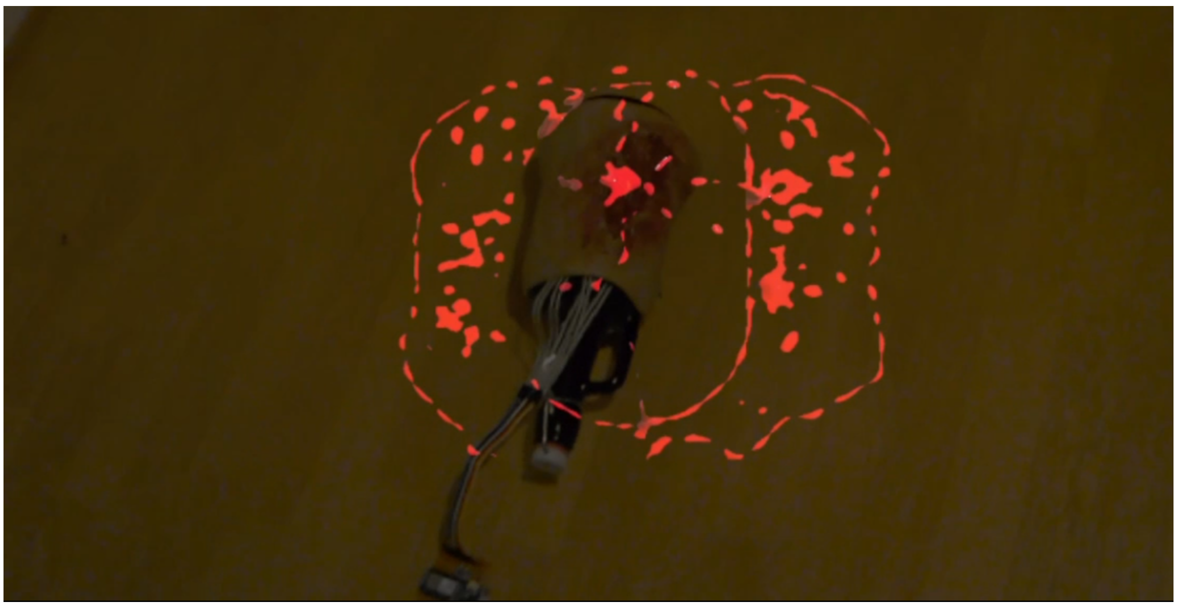


Figure 23: Top view of the HoloLens simulation

Occlusion

The simulation has occlusion of the blood possible. This uses the spatial mapping capabilities of the HoloLens.

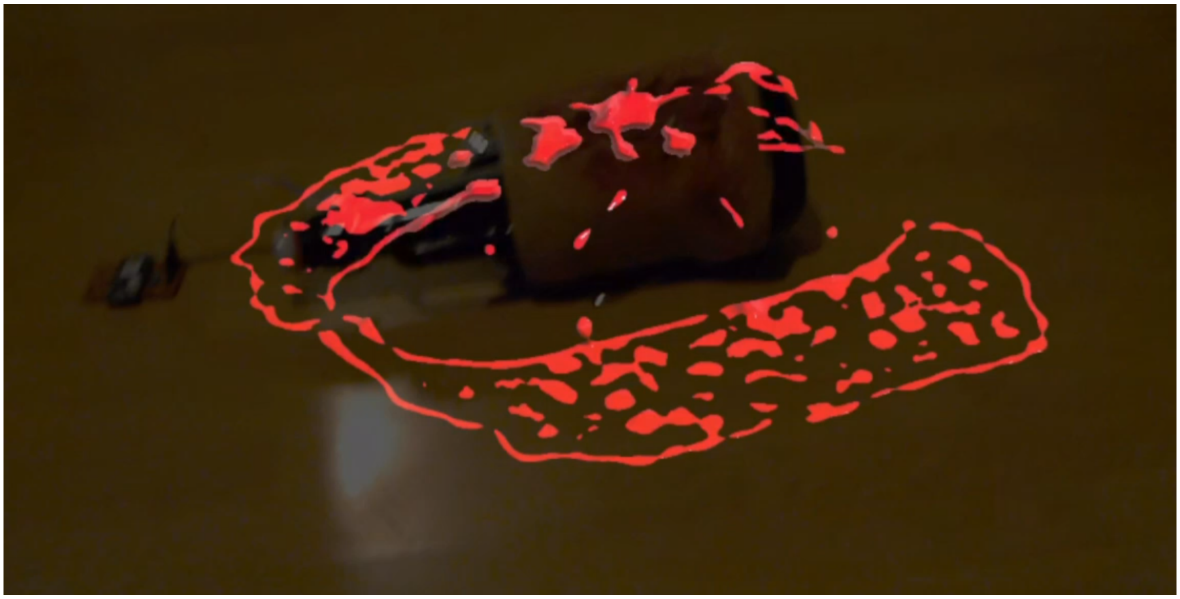


Figure 24: Side view of the HoloLens simulation showing occlusion of the blood

Because of technological restrictions near-field occlusion, such as by hands or other close persons or objects, is not possible with the HoloLens. This leads to problematic visuals as seen in Figure 25.

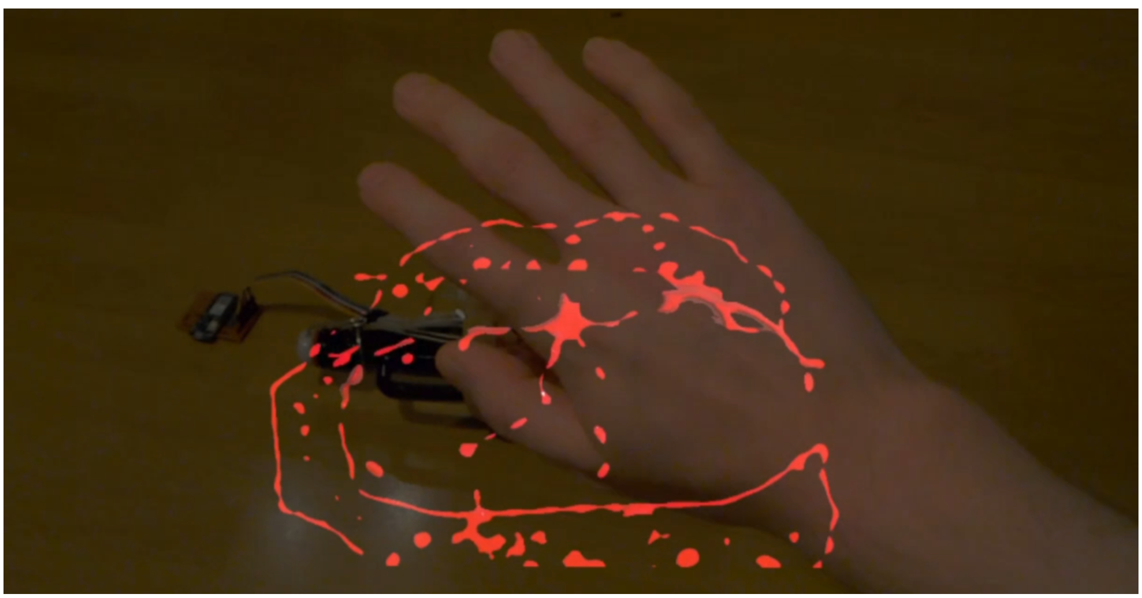


Figure 25: Hand occlusion issue

Digital Human Profile The digital human profile is a concept I created for defining the basis of the human in the simulation. There are several points of information of the patient that are relevant to use in a simulation. These different statistics are useful as an estimation of how a real person would respond to the damages. There are many outliers that cannot be trained for and there are no "hard-limits" that every person responds similarly to. As a way of counteracting this, I allow for these statistics to be set in the setup. The interaction values between these statistics could also be possible to alter. The possibility to add manual overrides to the preset blood loss limits and their effects allow the possibility to shape each case to the wants of the facilitators.

I also allow to add some variables that are used as a base to define what has happened with the patient since the injury and has happened before the simulation starts. Following are all the statistics of the patient:

- **Age:** If the person is young or old, medications and shock stages can be impacted.
- **Gender:** The sexual dimorphism of humans are taken into consideration of the model. Relevant differences in blood volume, height etc. are covered in the rest of the statistics. No generally applicable differences in treatment based on gender have been discovered. It is however relevant in regards to the dignity considerations of the Exposure step in the ABCDE-approach.
- **Height:** The height is currently not used, but could aid in the accuracy of the application with regards to integration of tilt-sensors and calibration of hologram placement.
- **Weight:** The total mass of the patient impacts the effect of medication.
- **Total Blood Volume:** Low volume means less blood can be lost before severe effects, including death, occurs.
- **Lost Blood Volume:** The amount of blood lost influences blood pressure, temperature, heart rate, the effect of medication and shock stages.
- **Shock Stage:** As the patient loses blood, he enters different shock stages depending on the amount. The more blood is lost, the more severe the symptoms are.
- **Blood Pressure- Systolic and Diastolic:** With low blood pressure, effects such as faintness can occur.
- **Initial Heart Rate:** A starting point for the heart rate is provided.

- **Current Heart Rate** Acts as a starting point for the heart rate, while also affecting the blood loss per time unit, dependant on the current heart rate Lower heart resting heart rate usually indicates a more efficient cardiovascular system. This means that each heart beat pumps more blood through the body than the heart beat of a person with a higher resting heart rate.
- **Current Respiration Rate:** Depending on pain levels, heart rate and oxygen level, the current respiration rate is calculated.
- **Initial Temperature:** A starting point for the temperature is provided.
- **Current Temperature:** The current temperature depends on the starting temperature, blood loss, room temperature, amount of clothing and whether a blanket is applied.
- **Intravenous Fluid:** As the patient loses blood, IV-fluid should be administered. This is saved as an amount and also impacts the blood volume.
- **Cyklokapron:** The amount of medicines administered to the patient is kept track of.
- **Oxygen Level:** Depending on the breathing of the patient, mask bagging and his blood loss, the oxygen level is determined.

Following is a table of the values in the model. The default values are the ones used in this particular case as the average state of the patient before the accident. The effects and notes are general.

Table 3: Patient standard values

Age	Height	Weight	Gender	Blood	Blood Pressure	Pulse	Respiration	Temperature
38 y	180 cm	74 kg	Male	5000 ml	120/80	80/m	15/m	37°C

5.2.3 Sensor Integration

To be able to provide the pressure input on the wound to the program I created a module with an Arduino and Force Sensitive Resistors.

Circuitry

The circuit schematic is as follows:

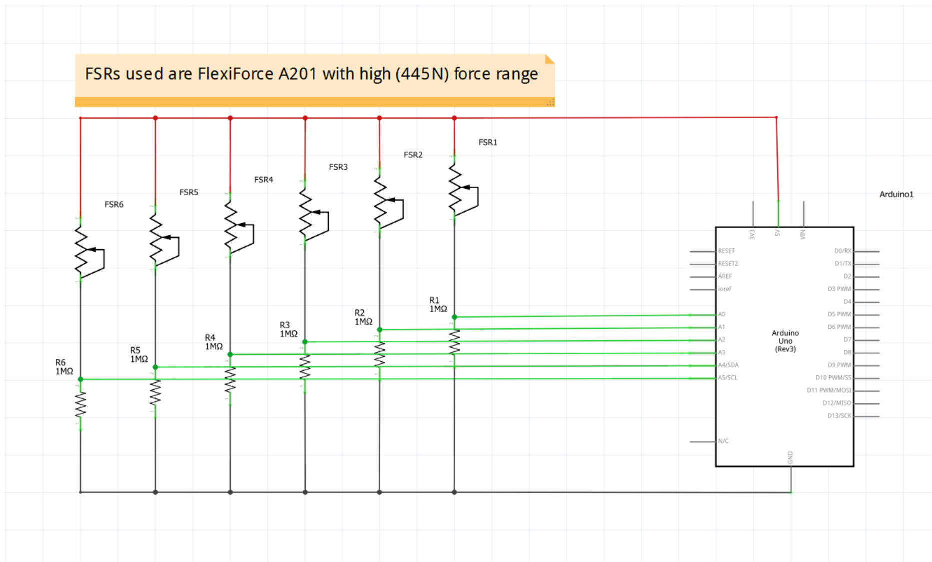


Figure 26: Schematic of the Arduino with voltage divider circuitry and force sensitive resistors

The component consists of an Arduino MKR1000, 6 FSRs, 6 regular 1M resistors and wiring. 5V power is provided by the Arduino and is provided to each of the FSRs. The FSRs and the regular resistors are set up as voltage dividers, with a wire to the analog input pins between them and a wire to ground from the regular resistors. As force is increased on the FSRs sensing area, its resistance goes down. This increases the voltage to the analog pin of the Arduino which interprets the voltage as a value between 0-1023. Thus, by reading the voltage we get a relative value of the force applied to the FSR, which is used as a measure of pressure on the wound area.

The final component looks as following:

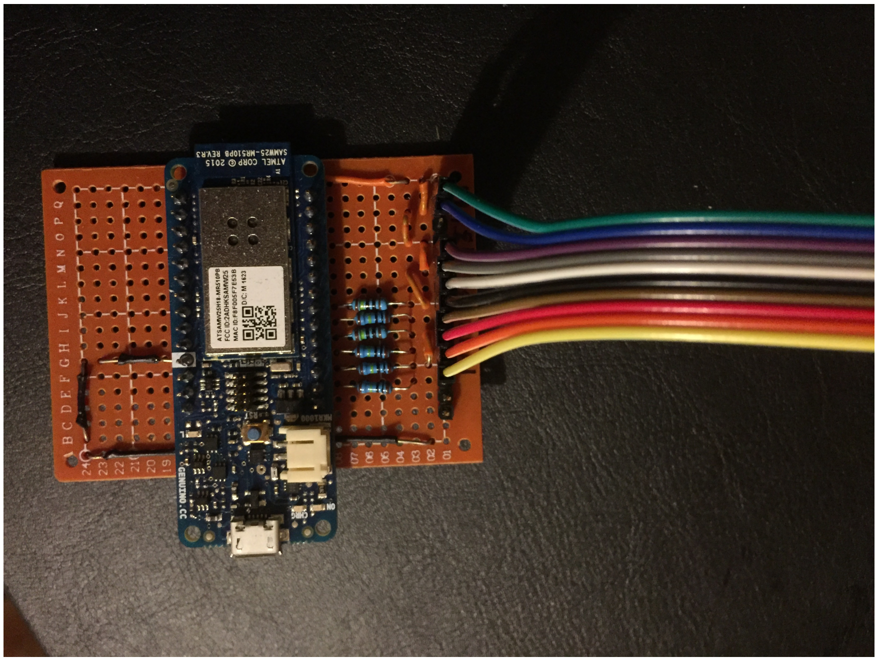


Figure 27: Image of the Arduino component used for sensor input

The FSRs are connected by DuPont wires to the pins on the circuit board. A perfboard is used as the base for the circuit. The Arduino, resistors and circuitry is soldered to it.

Arduino-Unity Integration

To get the data of the Arduino to feed into the Unity program in real-time, several options were explored. The one used was Uduino as it was up-to-date, reliable and well-documented. 5 analog pins on the Arduino were configured to read, and the values were used ion conjunction with the weighting of the sensors, to reduce the blood flow.

6 Evaluation

In this section the feedback gained regarding the prototype will de detailed. This is a combination of the feedback gained from the iterations as well as from the testing. The data has been grouped by: feedback on several aspects of how the prototype performs, usability and technological maturity.

6.1 Feedback

Here I provide the feedback on the potential of a solution based on the prototype, regarding the desired improvements stated in section 4.

6.1.1 Time Usage

Potential decrease in time usage for the scenario was identified in the preparation and cleanup phases.

Preparation

Following are the actions of the preparation that can potentially be skipped with use of a Mixed Reality solution:

- Printing of point sheets
- Taping plastic to the floor.
- Mixing fake blood.
- Connecting the pump and putting the backpack and the silicone band on the simulated patient.
- Starting the pump before the participants enter the room, to get blood on the coverall and the floor.

The steps necessary for setting up the prototype are listed below:

- **Can be done before the course starts**
  - Setting up the computer.
  - Creating or modifying profiles for cases.

- **Steps performed before each simulation session**
  - Putting HMDs on the participants.
  - Linking the computer with the HMDs.
  - Starting the program on the computer and choosing a case.

The steps necessary for the prototype setup were considered faster than the steps in the current setup.

Cleanup

The testers listed the following steps in the cleanup phase that the prototype provided the possibility of removing:

- **Eliminating the following steps**
  - Drying up the fake blood
  - Removing plastic bags on the floor and washing the floor if anything got on it.
  - Removing and cleaning of the backpack, pump, silicone wound band and tubing system.
  - Showering to remove fake blood and reduce staining.
- **Allowed for the following improvements**
  - Reuse of coveralls
  - Less cleaning of coveralls and personal clothes

The following steps are introduced by the prototype solution in the cleanup phase:

- **Once per course**
  - Putting the computer away.
- **After each simulation session**
  - Shutting down the program on the computer.
  - Taking the HMDs off of the participants.
  - Charging the HMD batteries if necessary.

For the cleanup phase the differences in time usage were seen as significant by the testers.

6.1.2 Material Cost

The current training method has the following material costs:

- One-time cost of the bleeding system of 80.000 NOK.
- Running costs of blood mixture of 20.000 NOK a year.
- Running costs of ruined clothes, plastic covers, coveralls at unknown cost.

The HoloLenses used in the prototype can be acquired either by buying them directly or renting them:

- **Alternative 1:** One-time cost of 5 HoloLenses at 25.000 NOK each comes out at 125.000 NOK.
- **Alternative 2:** Running cost of 5 HoloLenses at 2.800 NOK a month on a 2-year contract comes out at 14.000 NOK a month Microsoft (2018*d*).

The feedback regarding the material costs were that they thought the one-time cost of the prototype setup was high, but competitive with the current method.

6.1.3 Comfort

The comfort of the Mixed Reality solution used in this work removes some comfort issues, while adding others:

- **Comfort gains**
  - Removing the need for the backpack, pump and blood improves the comfort of the living marker.
- **Comfort detractors**
  - The addition of the HMDs add an additional piece of equipment the participants have to wear.
  - The current form factor of the HoloLens was regarded as a bit bulky and heavy.

The testers thought the prototype provided a small net-gain in comfort, but that with improved form-factor this gain could be significant.

6.1.4 Realism

The prototype solution adds realism in certain areas while detracting in others.

- Added realism:
  - Removes the need for plastic bags underneath the living marker resulting in a more realistic ground surface.
  - Having a dynamic, gradual increase and decrease in the blood flow.
  - By not having to focus on the pressure exerted to the wound area to determine if it is enough to stop the bleeding, the living marker can focus more on acting.
  - Removing the need for the backpack and tube which would not be there in a real scenario. This also allows the living marker to focus more on the acting, as they have to be careful to keep the tube attached and avoiding the equipment breaking.
  - Removing the need for the facilitators to provide the values for blood pressure, heart rate etc.
- Detracts realism:
  - No real fluid removes the tactile sensation one would have in a real situation. This also leads to less mess, which there would be in a real situation, as the digital blood currently cannot be transferred and soak. This could be somewhat alleviated by adding some water to the area, but that again adds some discomfort to the living marker.
  - Having a HMD on that would not be there in a real situation. The facilitators stated how important eye contact is in first aid situations. The fact that the HoloLens has a see-through screen instead of a full enclosure helps. It is however an added factor between the participants and detracts from the realism.
  - Occlusion issues
    - The lack of near-field occlusion means that hands were not occluding the blood flow.
    - The leg was not uniform enough for the HoloLens to properly spatial map it.

    * The update frequency of the spatial mapping of moving objects, such as persons, was lacking. This resulted in blood showing through other persons for a few seconds.

  - Limited field of view

    * While the users got used to it after a while, it removes the possibility of seeing the bleeding state in their peripheral vision. A the participants should continually check the wound directly, this was not regarded as a large issue.

    * It is very sensitive to how you wear the HMD. For some testers it worked well, but for others the adjustment of the HoloLens to provide the field of view was difficult. This also leads to possible difficulties during setup.

    * As first aid training necessitates that persons move quickly there is a danger of the HMD being displaced. This directly impacts realism, while also possibly indirectly making the participants act differently to avoid getting too close to others HMDs.

The testers did not think the current prototype provided a net-gain in realism over the current training method. This was mostly attributed to the blood flow visuals and its placement, as well as the occlusion issues.

6.1.5 Data

The testers were very positive towards the gain of additional data from the scenario. They felt this could be very useful in the debriefing. One aspect here was that it could allow them to more accurately assess how the participants performed. Having the Digital Human Model as a basis where the interactions between the different vitals were updated in real-time was seen as a great improvement over the current method. The integration of the point sheet into the program was well-received as it creates less work for the facilitators and makes the information more accessible.

Some additional features they found interesting:

- Exporting results of scenario to PDF-format.

- Live-viewing and saving of all the video feeds from the HoloLenses to be able to see the view points of the participants.

- An interactive timeline of key events and vitals that could serve as the basis for the debriefing. Integration of the video feeds here was also of interest.
- Semi-automatic control over the vitals, such that they could increase the heart rate manually and have the other vitals react accordingly.
- A preset of impulses they could choose to activate during the scenario. An example here could be the patient becoming unconscious.

6.2 Technological maturity

When asked about what they thought of the use of current augmented reality technology in first aid live-training, the verdict was that it was possibly beneficial, but further improvement could solidify it as a staple of modern training. Following are the areas feedback regarding improvement was given:

- **Form factor of the HoloLens**.
  - The weight and size of the HMD was more than they would want.
  - As a result of the weight and size they were worried that the HMD would be too easy to knock off or displace.
- **Improved processing hardware and tethering**
  - The testers believe it would be beneficial with an improvement in the tethering function or hardware of the HoloLens to allow for a more stable solution and better fluidity of the animations.
- **Improved field of view**
  - While the field of view was large enough to support an augmented reality solution, the testers missed a more immersive experience they believe a larger field of view would give them.

7 Discussion

In this section the possibilities of further work with this prototype, the maturity of the technology used in this work and possible use of this will be discussed. This is based on the results of the evaluation and the literature research.

7.1 Further Improvement

The application is a prototype intended to showcase the potential of augmented reality technology in the space of medical emergency training. During the development both technological limitations, design issues and limited development time has lead to several areas that could use some improvement. In the following,insight into areas of possible future improvement based on my experience and the feedback gained throughout the process and tests will be provided.

7.1.1 Program stability

During the testing issues regarding stability of the program were experienced. It resulted in variable fluidity of the simulation and intermittent freezing and crashing. I have identified the following possibly sources of these problems:

- **Weak performance of computer and/or wireless network**
  - Both the computer and the network used in the testing was different from what was mostly used during development. The HoloLens sends its spatial mapping input to the computer which uses this when it renders frames sent back. While some issues persisted, there was significantly less problems experienced while using a private network and a powerful desktop computer connected via Ethernet.
- **Suboptimal configuration of the software**
  - Depth buffer sharing was not turned on because of a bug in the Unity version used. This is on by default in newer Unity releases and allows the HoloLens to automatically create

a focus point. This reduces the effects of network latency on the simulation Microsoft (2018*a*).

- **Use of asset not supporting UWP**
  - Obi Fluid, the fluid simulation asset used in the prototype, is not supporting UWP yet. By streaming the content from the computer via Unity I did not have to build it for UWP and were able to use the asset in the prototype. There might however have been some unknown issues with this approach making this a possible source of instability.
- **Problems with content streaming software**
  - Play Mode in Unity was used to stream content from the computer via the Holographic Remoting Player on the HoloLens. During the testing there were seemingly random disconnects and while still connected, with the interface on the computer working, the content stopped being streamed to the HoloLens. Establishing a connection and experiencing false-positive connection was also frequently encountered. This might stem from problems in my configuration, but no indications of this were given. I believe this was caused by the streaming software itself. my advice is to not rely on the tethering functionality until it is further improved, but instead create separate applications running natively and communicating over a private network.

7.1.2 Wound simulation

Here some possible improvements to software and sensor usage that could improve the prototype will be described.

Additional parameters

To add flexibility and support more use cases I have some suggestions for additional parameters to make available to the users:

- **Bleeding type:** It can be either venous or arterial. This can be visualized by the colour of the blood: dark red for venous and brighter red for arterial.

- **Bleeding rate:** Currently the factor of the blood stream intensity relative to the pressure exerted is not exposed. Allowing this to be set would be useful for different cases.

- **Special treatment:** There are some wound types that require a particular type of treatment. To treat a shallow venous bleed in a large area you do might not be able to stop it with just hand pressure. A better approach could be to use bandages to compress the entire area. To allow for this either a manual input for the facilitators could be made or RFID-chips could be embedded int the bandages that can be read by a RFID-reader within the fake wound. An even pressure throughout the wound area in combination with it being recognized as a bandage could be required. Additionally, proper times between bandage changes can be checked by equipping the bandages with unique RFIDs.

Variable sensor impact

Multiple sensors are currently used for a single wound, but each sensor has the same maximum impact. This could be useful for a scraping wound where a lot of capillaries are bleeding and thus general pressure on an area is necessary, compared to point pressure for punctured veins.

Having one sensor as the main sensor that overrides the others could be useful in some scenarios. One example would be for the case of having several bleeds in the thigh that all are connected to the main artery. By applying pressure, either by pressing a finger directly on the artery higher up, or putting a tourniquet on, one could stop all the bleeds. This is something that can be useful to train on for real life situations where you have trouble getting control over the wound area.

Multiple wounds

By utilizing this flexibility one could end up with a highly flexible system. Sensor placement is something that creates a lot of flexibility compared to old system. By changing Having different markers for each bleed it is theoretically possible to uniquely identify several different bleeds.

- **Individual bleeding severity:** Every individual bleed can have different rates of bleeding. These rates can then be impacted based on pressure on the individual sensors.

- **Combination of bleeding types:** By utilizing the previously mentioned bleeding type system handling different types of wounds in the same case could be trained on.

- **Hidden wounds:** There might be one obvious wound with one or several others that are harder to uncover. This can be useful in training on exposure.

There are some technical limitations regarding use of multiple wounds:

- Vuforia supports simultaneous tracking of 5 image targets Vuforia (2018). This is compute intensive and the current HoloLens might struggle with the maximum amount.
- The Arduino MKR1000 used in this prototype has 7 analog pins Arduino (2018). I have tested the impact of having 5 sensors coupled in series with a single 5v power source. There were some cross-influence between the outputs because of this, but this should be negligible.

Wound library

To reduce the time spent creating new cases, a feature allowing the users to create and save wound types and compositions to create a wound library would be beneficial. This could also encompass combinations of multiple wounds.

One could create complex wounds such as "Grievous inner thigh wound", which could consist of a set of three different wounds that have preset values and wound types. If you combine this with a separate wound on the arm for example, you end up having a way of making complex cases. This could also be randomized to benefit solo-training.

Control types

The degree of control available to the facilitators could be presented as a choice in the program. Following are three such approaches:

- **No control:** This would be a fully scripted, but dynamic, case. The case leader initiates the case with a profile including the statistics of the human, the wounds and potential impulses such as spasms.
- **Semi-control:** The basis of this mode could utilize the same type of preset as in the "No control" mode. The difference being that during the case some predefined subset of the parameters can be affected. This subset can differ depending on case and be manually set before each. Important parameters here could be heart rate, temperature and blood flow as well as impulses.

- **Full control:** This mode could have a simple Digital Human Model as a basis. On top of this full control of impulses and changes of parameters could be allowed. By having parameters interact with each other the effects can sometimes be a bit too far-reaching, so an override where simply heart rate goes up for a while could be useful.

The "Semi-control" one was the one that garnered the most interest of them, as the facilitators want to be able to impact certain aspects during the training to be able to test the participants on specifics that they see fit. Having the ability to create presets of impulses and parameters could be beneficial.

Improved blood visuals

To improve on the realism of the simulation there are several aspects regarding the look of the blood to consider:

- **Bleeding types:** To differentiate between types of wounds and make the bleeds more true to life there should be flowing blood for venous wounds and spurts for arterial ones.
- **Blood visuals:** Tuning of parameters such as viscosity, color and particle sizes could make the blood look more realistic. As liquid simulation is a resource intensive task this is partially limited by hardware.
- **Blood interaction:** To make the blood look more as a part of the world the splashing and pooling of the liquid should be improved.

Wound placement

The wound is currently placed at a specific offset from where the HoloLens is at the start of the simulation. This is very rigid and does not move the bleed together with the physical wound. To fix this issue the prototype could be made as an app deployed to the HoloLens utilizing Vuforia with image markers as described section 5. To allow for sensor input this would require this application to connect to the Arduino or to a mediating computer to read its input. An alternative, if the tethering solution is viable, could be to implement image recognition that utilizes the input sent from the HoloLens to Unity.

Additional features

There are several potentially useful features that could be added to the solution.

- **Bruising:** To indicate internal bleeding a digital bruising could be presented over the simulated patient's skin.
- **Skin colour:** Change in skin color such as bleakness can indicate lack of blood in the body part. This could be useful for indicating when to perform actions such as loosening a tourniquet.
- **Pupillary reactions:** To let the participants more realistically evaluate whether the patient is under the influence of drugs or have neurological damage a digital representation of the pupils could be added.
- **Breathing sounds:** The spatial sound capabilities of the HoloLens could be utilized to make the action of checking the sounds from the simulated patients breathing and lungs.

7.1.3 Statistics

The statistics page shown on the computer at the end of the simulation has some improvements that hold a lot of potential:

- **Timeline** This could prove beneficial in the debriefing. A timeline with exact time stamps of events that could be viewed and navigated for more information is a potential implementation of this. These events can consist of both automatically generated events such as the times the bleeding was stopped and when a blanket was put on as well as manual entries such as time of SAR call and auditory checks. A visual representation of the course of the case has the potential to greatly add to the flow of the debrief, while also bringing up points not previously reflected upon.
- **History** If the participants has completed the case at an earlier training session, their history can be incorporated into the results screen. This could have extra viability in a solo-case where a special technique is iterated upon. This provides goals to reach and a concrete overview of progression and regression. (Source of paper talking about benefits of this)
- **Scoreboard** To facilitate friendly competition, give a relative pointer of how well the participant

performed and show special points that needs improvement, a scoreboard could be implemented. The values weighted on the scoreboard should be a balance of such statistics as speed, consistency and blood loss so as to encourage a holistic approach and avoid too much focus on individual aspects. A limited amount of scores could be shown to reduce negative feelings of placing far down.

- **Automated assessment** The program could have an automated assessment-function added. Depending on the case, different areas could be chosen to have a larger impact on the assessment. This could be very helpful for solo trainers and act as a base for the facilitators to further assess the participants.

- **Manual assessment** Drop-down menus and text fields could be added as supplements to the point sheet to be filled during the course of the scenario. Afterwards, in the discussion between the facilitators before the debriefing, these evaluations could be reassessed. The facilitators could also add things during the debriefing regarding their reflection of the training.

This could all be sent to the participant as a PDF-file or printed out. A detailed textual and visual feedback is currently not something handed out. It could also inspire friendly competition between groups.

7.1.4 Sensor component

Here some potential improvements to the sensor component will be provided.

Form Factor

The sensor component should have its form factor improved for proper integration into a training scenario.

- **Encapsulation:** In the process of stopping a bleed, there is usually rough handling involved and application of a large amount of pressure. The microcontroller and the circuit should be enclosed in a sturdy case as the electronics are prone to break if exposed in such an environment. Rough edges should be avoided so that the risk of injuries and discomfort are minimized.

- **Circuit Size Reduction:** The current component consists of an Arduino microcontroller and its circuit soldered on a perfboard with pins for the FSRs. While better than using a breadboard, its size and layout could be further improved. The next step here would be to recreate the circuit as a Printed Circuit Board. This would allow for a specialized layout, reduce the weight and make the size as small as possible.

Ease of use

Following are some steps that can be taken to increase the ease of use of the solution.

- **Pre-configured Sensor Enclosures:** A possible improvement would be to have a pre-configured placement of sensors for use in scenarios. This could reduce the time necessary for setup and wear and tear to the sensors while increasing the stability of the sensor placement and accuracy of the input. This could be done by having engraved ridges in silicone pads (picture?) where it would be simple to place the sensors to the labelled areas and get ready. By labeling the pads it would be easy to keep track of a large amount of them. And additional benefit of such a solution is that it allows having many different configuration pads while using the same sensors. This should also be a comfortable solution for the simulated patient.

- **Hot Swap:** The current method of coupling the wires from the FSRs one-by-one to the pins on the circuit board should be improved to allow for fast and easy addition and removal of sensors. This could be done by affixing 2-pin DuPont- or IDC-connectors and having small spacers between each socket to avoid connecting the wrong pins. This would also allow for less wear and tear of the cables and connections.

Additional modules

To expand the functionality of the solution, additional hardware modules could be added. Here I present some I believe would be useful:

- **Heart Beat Wristband:** The current way the participants gain information regarding the rate and type of pulse is by getting it read out loud from the facilitators. To improve on this there could be made a wristband with a mechanical part that indicates the pulse on the simulated patient. The mechanical part could be a vibration motor (as in cellphones or game controllers) that is placed inside the wristband on top of the artery area. This then vibrates with the intensity and frequency of the simulated pulse sent from the program. While not fully realistic it adds dynamics and immersion by having to perform the check as one would in a real situation, instead of having it read out loud.

- **Arterial Flex Band:** One way to stop an arterial bleed is to apply point pressure to the artery above the bleeding area. Using a tourniquet is a highly effective, but risky, way of doing this. Thus, proper training on the use of this is important. A tourniquet does not pressure a single spot, but applies it uniformly around the leg. The current sensors in the prototype are not optimal for measuring this. Flex sensors could be used for this purpose by being placed along the artery and thus perpendicular to the tourniquet. This will make a larger area available for measurement of the force applied by the tourniquet. To avoid severe discomfort and potential injury to the simulated patient, the force values necessary for the blood flow to stop has to be lower than a real life situation would require.

- **Tilt sensor:** One technique (though disputed (REF)) is to heighten the bleeding extremity, thus allowing gravity to assist in reducing the blood flow, while also keeping blood in vital organs and the brain. This could be measured by integrating one or more tilt sensors or gyroscopes in the solution. Using the initial state as the baseline and calculating the correct tilt from that, we could get the state of the foot tilt and thus reduce the blood flow accordingly. This also could be included into the statistics gathering.

7.1.5 Improvements without AR

The current solution could also be improved on without the use of AR, following are some suggestions for this:

- **Adding dynamics to the blood flow:** Currently the blood flow is either on or off by the toggle of a button. The human marker is the one toggling it based on his or her subjective judgment of the pressure applied to the wound area. To improve this and make the blood flow more dynamic, sensors could be integrated into the current solution. This could be done much the same way as in the proposed prototype in this thesis. By placing the sensors on key points in the wound area, then have the program on the Arduino control the valve mechanically based on the limits set, you could get a dynamic blood flow based on the pressure on the key points.

- **Gathering of statistics:** Adding statistics gathering could be done by simply utilizing the proposed sensor solution, connect the Arduino to a PC and use a program suitable for data gathering. This could be done in Unity as it is in the prototype, and also incorporate graphic visuals for the facilitators. I believe this could be a great addition to the current method, where everything is manually noted down based on a checklist.

7.2 Technological state of AR for use in first aid training

A key point in this thesis was to figure out where the current technology stand with regards to being implemented into a Mixed Reality solution for use in First Aid training. Following are the different technologies used in the prototype and my assessment of their maturity based on my use.

7.2.1 Arduino

The Arduino as a platform is extensive and has a plethora of ways to implement external sensors for use in a Mixed Reality setting. It performed well as the central piece of the sensor component and for use with further additions of electronic modules. I found it very well suited for prototyping and also see it fit as a possible part of a market product.

A specialized solution built from scratch offers more in terms of minimizing the form-factor and savings in mass-scale production. However, in a Mixed Reality environment, the cost of an Arduino module is small compared to the cost of the HMDs in use. For the purpose of the particular prototype developed in this project, the Arduino solution was more than sufficient.

7.2.2 Force Sensitive Resistors

The FlexiForce sensors used in the prototype provided the necessary flexibility and accuracy necessary. They were easy to use, non-obtrusive and provided the necessary data for the simulation. The aspect we do not have enough experience with is the longevity of the sensors with the rough handling of first-aid training. By adding proper protection, this will probably not be an issue.

7.2.3 HoloLens

Based on my research and use of the HoloLens, I believe it is currently the best suited piece of hardware on the market for use in most HMD AR-solutions. The largest factors contributing to this is that it is untethered, has decent graphical processing power and supports spatial mapping. From the development and testing I have identified some aspects that I believe are important to improve upon:

- **Field of View:** The limited field of view available with the HoloLens is not satisfactory for use in an application as the one presented in this thesis. While it is not a large issue if the user can focus on the area of interest constantly, it is a hindrance in regards to group training. When there is many things happening at once, the ability to notice objects in the peripheral vision is important. An increased field of view would greatly improve the potential of the HoloLens.

- **Tethering capabilities:** By being an untethered device, the HoloLens grants a lot of mobility and freedom of movement. This makes it possible to use it in crowded areas and not have to worry about a cable getting caught. The trade-off for this is that it relies on on-board processing power and graphics, which means the computing power is greatly limited. The hardware of the HoloLens, while impressive for its size, can not compare to that of a desktop computer. The Holographic Remoting Player allows content to be streamed from a computer to the HoloLens. This lets you utilize the graphical capabilities of a computer with a graphics card while using the input from the HoloLens. The problem with this feature is that it is unstable and seem to be mostly intended for testing without deploying and not to be used as a basis for running the application. I think by making this functionality more stable, the HoloLens would greatly benefit from it by then supporting graphically intense applications. This would also allow the computer to act as a central hub, allowing easy integration of additional peripherals and modules.

- **Spatial mapping:** While this was a very useful and sophisticated feature, it was not well suited for mapping moving and non-uniform objects. Supporting a more fine-grained mesh with a higher updating frequency would greatly improve its potential use in live-training.

  It was possible to adjust the clipping-plane to be able to have objects close to the user, but the same was not possible for spatial mapping. This meant that the users hands could not be mapped and thus not occlude holograms. Having the possibility of using such a feature would be very useful.

- **Form factor:** The HoloLens was regarded as being a bit bulky and unwieldy. Initially it sits pretty well on the head, but extended wear gets tiresome. As it currently is made, it is not properly suited for environments with hectic and rough handling, such as in first aid live-training. Less weight and a smaller frame would make it a better candidate for such use.

To make HMD-based AR-solutions truly embraced by businesses and the public at large the above-mentioned properties should be addressed. A lot of resources are put into the development of augmented reality, so I believe we will see improvement of these aspects in the not-too-distant future. There are also promising HMD alternatives coming, such as the Magic Leap, that could provide new features and better capabilities.

7.2.4 Unity

The engine and editor has a good and flexible user interface and is a solid development tool in itself. The integration and support for HoloLens is well-documented and works almost out-of-the-box. Having the possibility of streaming the content to the HoloLens to test the application, without having to deploy it for each test, was very useful. This also allowed to input to be gained from the Arduino without having to connect to it with networking.

Two larger issues regarding Unity were encountered:

- A lot of the assets available for Unity do not support UWP. The possibility of using assets is a large benefit of working with Unity that is lost from this. Assets might work when running natively on Unity and the content can be streamed to the HoloLens, but crashes or runs into other issues when deployed.

- When using Unity's Play-Mode to stream content to the HoloLens instability and disconnects were experienced. Sometimes the content stopped streaming, but everything seemed okay in Unity. I am uncertain if the issues stem from Unity or the Holographic Remoting Player of the HoloLens.

As a whole I found Unity to be a good development platform for holographic application in HoloLens, but I believe improvement on the issues mentioned would be a great benefit.

7.2.5 Vuforia

The ability to have holograms be automatically placed on image targets, and kept there even when moving, is very valuable. I believe this will be an integral part of the future of augmented reality. While it could benefit from even more accurate placement and tracking, it is adequate for most uses.

The issue I had with Vuforia was that it did not support running through the Holographic Remoting Player. This led to having to choose between improved fluid visuals and data from the sensor module or having Vuforia, which resulted in me choosing the former. If I had more time, this could possibly be worked around.

7.2.6 AR/MR as a whole

7.3 Potential use of AR in first aid training

Based on experience and feedback gained during this project, combined with the research performed, I will discuss the current potential for use of augmented reality in first aid training.

As discussed earlier, the technology is in its emerging phase and suffers from underdeveloped hardware solutions. This is particularly evident in the HMD-market with few offerings of spatial AR. I found the HoloLens to be the most advanced and complete solution, and while the technology is impressive, the current capabilities are probably not yet suitable for a full-scale team-based solution. Future improvement in aspects such as form factor, near-field spatialization, more powerful hardware and a larger field-of-view, could however make it a possibility.

While I believe mixed reality is not ready for use in full-scale solutions, there are other potential use cases. The uses I imagine for the current technology is as a cost-effective alternative and as a tool in solo-training, detailed below.

Cost-effective training

A scaled-down solution could be utilized to alleviate some of the problems associated with current training equipment. Instead of equipping each participant with a HoloLens, the nurse could have one and the video stream from it would be presented on a screen on the wall. By having to only buy a single HoloLens, this is significantly cheaper than the current equipment.

The trade-off here is a reduction in realism by having most of the participants unable to see the blood directly on the simulated patient, but having to look at a screen for it. It does however allow for previously mentioned benefits regarding time usage, material cost, comfort and data. This could be an alternative for training facilities or schools that might be interested in these gains.

Solo-training

At the current time I believe that solo-training is the best candidate for this technology. In such a format its weaknesses are minimized and it potentially opens up a new space of training.

A mixed reality solution for this could consist of much the same as presented previously in this thesis, but with the sensor component attached to a medical training dummy. This allows the training scenario to be performed alone. By not performing the procedure on a simulated patient some realism is lost, while also gaining some by having to apply a realistic amount of pressure when using hands and tourniquet to stop the bleed.

This is a relatively low-cost approach that could lead to more people getting first aid training and allowing more extensive practice. Team-based live-training would not be replaced, but this could be a great addition to provide a basis of first aid experience to a large amount of people. To further heighten the effectiveness and value of the training, there could be incorporated auditory and holographic instructions for beginners.

Following are some potential use cases for such a solution:

- **On-site training**
  - Companies could buy or rent solutions to have available at their facilities. Having a structured or voluntary use of these could provide a heightened first aid knowledge in their workforce. There could either be down-scaled practice sessions or sessions fully supported by the software. This would not be a replacement for proper training with facilitators, but it could be a way to get every worker to get some hands on experience with first aid.
  - By providing everyone with a basis training, better aid could be given in situations where more completely trained personnel are not readily available. Reducing bleeding in that

space of time could be what saves a life or a limb.

  – Results indicate that participating in first aid training reduces the risk taking of the participants and thus potentially reduces the chance, and severity, of accidents (Lingard 2002). It was also mentioned that having all employees participate in first aid training instead of only "first-aiders", could be beneficial.

- **Education**
  – Educational institutions are always in need of additional training possibilities. By adding mixed reality solutions to training labs students could learn new skills and get extensive training on them. In these areas many different types of treatments could be incorporated, such as proper medication technique, wound treatment for diabetes patients and diagnosis.
  – This could also work well at hospitals, other emergency services and militaries.
- **Mass-training**
  – Training for the general public could be made more accessible. A way of organizing this is to have drop-in training facilities where everyone are free to come train. While having personnel available for technical assistance probably would be necessary, the amount of persons trained could be large if the software in itself educational and engaging. The mixed reality experience could be a point of generating interest as well as providing the participants with a diploma of their participation with their statistics could encourage and help spread the word.
  – This also lends itself very well for engaging the public via social media campaigns. One way of doing this is to provide the users with a digital diploma presenting their training statistics and an encouragement of others to see how well they can do.
  – Utilizing such a solution as a tool for large-scale events such as Stop the Bleed Day 5, could be very positive. At such events participants expect a fast and engaging learning situation. Adding a mixed reality solution to this could be a point of engagement as well as solidifying the skills being trained by having a visual-haptic experience.

8 Conclusion

The purpose of this thesis was to attempt to improve on current first aid live-training. To do this an Augmented Reality was developed and tested in a cyclic, domain-driven manner. The data gained from the continuous feedback, development and the final testing provided answers to the research questions.

Q1: How is current first aid training practiced?

- The current training methods were documented in Section 4. This provided a base to build off of in the prototype development phase and could provide value for other research into the field.

Q2: What can Augmented Reality improve on today's first aid training?

- Several ways of incorporating Mixed Reality into the current training were identified. Some were implemented in Section 5 and tested in Section 6, while other potential uses and improvements were discussed in Section 7. The prototype provides an extensible platform for further integration of sensor modules and new visuals. The initial expectations of AR having potential in this use, but not being mature enough for full integration into a team-based live training environment, seem to be accurate. One aspect of note is the promising use of MR- and AR-technology in solo-training, which might currently be the best suited use of this technology.

Q3: What are the first steps that AR-based systems need to handle to better support user experiences?

- Through the work with the prototype, possible improvements to the current technology was identified. We discuss these in Section 7.2. The hardware of the AR HMDs, and to a lesser degree the software, seem to be the bottleneck of the technology utilized in the prototype created in this MSc thesis.

In this work some of the possibilities of use of Augmented Reality in first aid training has been demonstrated. This has to my knowledge previously not been done in such a way, and I believe this provides value to the field.

8.1 Future Research

The work presented in this masters thesis can be used to investigate additional aspects regarding the use of AR in first aid training. A first step could be to perform a quantitative analysis of the proposed solution. Furthermore, an evaluation of AR for solo-based training could be performed by specializing the prototype and using it as a vessel for this purpose. Integration of additional sensors and analyzing their value could also be a worthy pursuit.

8.2 Closing Words

While the maturity of Augmented Reality technology might not be at a point where full-scale integration is possible, there is little doubt in my mind that there is a lot of potential for its use in first aid live-training. I am very excited to see what the future of this technology holds. Judging by the amount of resources spent on it we wont have to wait long to gain our first glimpses of it.

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Appendices

A Traumacase Details Appendix

Traumecase 225 – Blødning

Læringsmål	Utføre primærundersøkelse inklusiv AVPU/GCS Stanse blødning
Briefing/ pasientsituasjon	38 år, Kappet jern med vinkelsliper da en bit kastes mot lysken. Penetrerer kjeledress. Fjernes av kollega- stor pågående blødning.
Kliniske funn	A: Frie luftveier B: Rask respirasjon, 36/min. Sidelik respirasjonslyd C: Radialispuls initialt, 120/min, BT 105/65. Bløt i abdomen D: Bevisst, GCS 14 (Ø4, V4, M6). Sidelike pupiller. E: Stor pulserende blødning i en lyske.
Utstyr	Akuttsekk m/kompresser Markør
Hva feiler pasienten?	Arteriell blødning. Pasienten får økende HR, fallende BT og bevissthet dersom blødningen fortsetter. Kritisk skadd.
Forslag til behandling	Stanse blødning (trykk/bandasje/fingre) (Traumeundersøkelse) Oksygen Etablere iv, cyklokapron? Væske? Vaktlege/SAR
Momenter til debriefing	Stanse blødning-samarbeid/ledelse ABC
Debriefing	**Beskrivelsesfasen**: Hva skjedde med pasienten? Fasen kan brukes til at alle får snakket om et nøytralt emne. **Analysefasen**: Hva gjorde du/gruppen veldig bra? Hva vil du gjøre annerledes neste gang du står i en lignende situasjon? Anerkjenn at situasjon og utstyr er uvant. Trekk paralleller til klinikken. Stimuler til refleksjon; Hva tenkte du når du stod i den situasjonen? Hvordan tror du at du vil gjøre det en annen gang? Bruk gruppen til å forsterke positive løsningsforslag i forhold til læringsmålene. **Anvendelsesfasen**: Oppsummer.
Følgende protokoller anvendes:	7.1 Algoritme traumepasient 7.2 Hardt skadet person 7.3 Massiv blødning 8.3 Forberedelse før SAR ankommer

B Trauma Point Sheet Appendix

Traumecase nr 225: Blødning

Bestått: min 38 poeng (Max poeng 74)

59

1. Stopp stor blødning	5	5 poeng
A: Frie luftveier	5	5 poeng

B: Vurdering av respirasjon	4	*max 9 - min 4 poeng*
Sjekker pust (evt. etter besvimelse!)	1	1 poeng
O2	1	1 poeng
Resp frekvens	1	1 poeng
Anstrengt/ uanstrengt	1	1 poeng
Sidelik bevegelse		1 poeng
Auskultasjon, sidelike lungelyder		1 poeng
Stabilt thorax		1 poeng
Subcutant emfysen		1 poeng
Tegn til synlige skader		1 poeng

C: Vurdering av sirkulasjon	4	*max 6 poeng - min 3 poeng*
Radialis puls	1	1 poeng
Carotis puls	~~1~~ ?	1 poeng
Kapillærfylling	~~1~~	1 poeng
Vurdering av hud		1 poeng
Leiring av pasient	1	1 poeng
Cyclocapron	1	1 poeng

IV tilgang/ væskestøt	5	5 poeng

D: Bevissthetsvurdering	1	*max 2 poeng - min 1 poeng*
AVPU/ GCS	1	1 poeng
Pupiller		1 poeng

E: Vamekonservering	5	**5 poeng**
Blottlegging	1	1 poeng

2. Revurdering	5	5 poeng- ikke obligatorisk
3. Følge systematisk ABC	5	5 poeng - ikke obligatorisk
4. Traumesideleie		**5 poeng**
5. Oppsummering underveis	5	5 poeng - ikke obligatorisk

6. Kommunikasjon/CRM	5	***Max 6 poeng - min. 3 poeng***
Kritisk/ ikke kritisk skadd		1 poeng
Dobbeltkontroll av medikamenter	1	1 poeng
Mobilisering av ressurser	1	1 poeng
Bruke tilgj info (fra pas, journal, cave etc)	1	1 poeng
Ringe vaktlege	1	1 poeng
Closed loop	1	1 poeng

Bruk av protokoll	5	5 poeng - ikke obligatorisk

ISBAR	5	***max 5 poeng - min 2 poeng***
I -Identifiserer seg selv	1	1 poeng
S -Situasjonsbeskrivelse/hva har skjedd	1	1 poeng
B - Bakgrunnshistorie/relevant info om pasient	1	1 poeng
A - Aktuell situasjon/vitale parametre etc.	1	1 poeng
R - Råd /videre plan nå	1	1 poeng