Virtual augmentation of a simulated scenario for first aid operators training

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Figure 1: (left) Wound on the patient's left arm displayed by the AR headset; (center) An operator providing first aid, during a simulation; (right) Bleeding wound on the patient's chest displayed by the AR headset

Abstract

Simulations are frequently used in first aid training to help first aid operators experience real-world scenarios in a controlled, safe environment. In these simulations, special effects can be used to enhance the realism of the scene, such as fake blood and makeup. Although these offer very high realism, they are also non-reusable and have a long setup time. In this paper, we propose an augmented reality (AR) system to provide a platform for designing and implementing special effects for first aid simulations. The AR system was implemented with a focus on the simulation of bleeding wounds, and later tested on 18 operators from the local Red Cross section. Data collected with the questionnaires show that all operators provided medical assistance during the simulation, and all rated the AR experience as useful. Furthermore, 13 did not find any difficulties in using the AR system, while 7 mentioned realism as a positive aspect. However, 3 described the video clarity as insufficient and 3 noted the absence of sounds. Overall, the collected feedback indicates that the AR system can be a useful tool for training Red Cross operators in first-aid scenarios, and participants' opinions provided valuable suggestions for further development.

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CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; **Empirical studies in HCI**; • **Applied computing → Life and medical sciences**; **Interactive learning environments**.

Keywords

Augmented Reality, First Aid, Simulation, Training, Remote Manipulation, User Evaluation

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1 Introduction

Simulations are used to immerse first aid operators in situations they may face in a real world setting without risk for the patient. In these simulations, a manikin or an actor plays the role of the injured patient. When indoors, typically two rooms are employed. One stages the first aid scenario and hosts the operators and, sometimes, a confederate actor. The other hosts the trainer or trainers, who can survey the operations in the adjacent room through a one-way transparent glass, listen to the operators, and enable vocal feedback from the manikin. In order to increase the realism of these simulations, make-up, fake blood and other special effects are used. These are not always easy to utilize and are often expensive and have to be cleaned up after the simulation (especially when using fake blood). Holding these issues, we propose to use augmented reality (AR) to simulate blood and wounds.

The augmentation is realized by superimposing a 3D virtual human body on top of a first aid manikin, in ways that users wearing an AR headset (or a virtual reality (VR) headset with AR support) can observe visual effects while physically interacting with a touchable body. The trainer animates the 3D model depending on the training situation. This allows dynamic control over what the operator is seeing and how the patient reacts to the treatment provided during the simulation. As an example, the trainer may start the simulation with a wound on the patient leg that starts to bleed only when the operator begins the chest compressions.

This paper describes the design, implementation, and user evaluation of the proposed system.

2 Related work

VR has been used in the literature to create training applications for cardiopulmonary resuscitation [4, 6, 16], showing that VR/AR/mixed reality (MR) training is as effective as face-to-face training, or even more effective in the short term [7]. For instance, a study shows how a VR application proved to be effective in improving the quality of the basic life support process compared to web-based training [12]. However, a study highlighted how, during the use of a VR training environment, the fidelity of user interactions and movements in VR proved atypical, which seemed to disrupt participants' attentional and motor responses [2]. Beyond VR, AR applications have been developed with the aim of facilitating first aid operations by trained and untrained personnel [1, 5, 14, 20]. These, however, tend to focus only on a specific scenario. Several off the shelf applications are available, but they either focus on VR [3, 8, 9, 11, 19, 21], or give constant guidance to the user during the simulation [3, 9, 11, 13, 21], which, while beneficial for learning, may not foster independent decision-making or adaptability in dynamic situations.

Rather, our aim is to realize a multi-user software architecture that can instantiate a variety of special effects, managed by the trainer. These will be paired with the existing simulation tools used at the local section of the National Red Cross Society (LNRCS), to enable the trainer to better match reality during the simulations.

3 System design and implementation

Some requirements were discussed with a LNRCS representative.

- The system must be quick and easy to deploy.
- The trainer needs to have remote control on the simulation.
- Operators must not be encumbered in their movement. Restrictions, such as keeping the operator stationary or seated, are considered not acceptable.
- The system should be scalable in terms of users, features, and devices used, allowing the LNRCS to upgrade the technology and implement new features.

The system consists of two main parts: an application running on a host computer, from which the trainer can manipulate the simulation, and a client application running locally on one or more AR headsets. This setup enables operators to interactively participate in the simulation, observing the real-time effects of the trainers' commands in response to their actions. The client and server applications are wirelessly connected. Specifically, the chosen technology includes a laptop running the server application and a Meta Quest3 where the client is installed.

Both applications are developed in Unity, giving the possibility to build the source code for both the headset and host computer, using Netcode for GameObjects (Unity high level networking library), allowing the trainer to manipulate the simulation and trigger events (for example, making a wound bleed or making the patient cyanotic). The connection can be established only in LAN and needs to be created by sharing the IP address of the computer with the headsets, meaning that the computer takes the role of the server while the headsets the role of the clients. Networking is also used to share the simulation configuration. This is achieved by performing the positioning of the 3D model on only one headset, then sharing it to all the other headsets and the trainer application.

The AR features are handled via the OpenXR Plugin "... an open, royalty-free standard developed by Khronos that aims to simplify AR/VR development by allowing developers to seamlessly target a wide range of AR/VR devices."[1] in order to keep the development "device-independent", allowing other VR headsets to be used. The user's hands are tracked to avoid hand occlusion by the 3D model.

In order to represent the 3D model, the Unity asset UMA2[2] is used. This allows us to define the model attributes like gender, age and hair and edit them at runtime, allowing the adaptation of the 3D model to the scenario the trainer aims to reproduce.

The positioning of the 3D model is done manually. Handles were implemented (in the AR application) to set position, rotation and scale of the 3D model. Another set of handles is used to match limb positions, using them as targets of an inverse kinematic system. All these handles can be manipulated from the AR application using the headset controllers or hands directly (by pinching with the thumb and index finger, and dragging the handle in the virtual space) thanks to the Meta Quest 3 hand tracking feature. This covers the main system development which offers the backbone onto which features, capable to simulate different first aid situations, can be implemented.

During development, wounds on the patient and bleeding were elected as the two features to implement first. These would then be part of the first test on the system. Blood has been implemented with round red particles. These have physical properties that allow the blood to react to the manikin, flowing on top of it, react with the floor, creating a small puddle as it falls off the 3D model, and

[1] https://docs.unity3d.com/Packages/com.unity.xr.openxr@1.0/manual/index.html
[2] https://assetstore.unity.com/packages/3d/characters/uma-2-35611

react with the hands of the operator, being able to be pushed with the palm of the hands. Blood originates from wounds. Wounds are images, created at runtime and dynamic, that are projected onto the 3D model. They have fixed positions: one on each arm, one on each leg, and two on the chest, for a total of six wounds.

The trainer has to set-up the system from both the headset and the host computer. Firstly, a networked connection must be established: this is done by starting the server on the host application, and using a floating interface in the AR application, which allows one to input the data necessary to connect the clients (AR headset) to the host (Trainer computer). In order to accommodate a variety of simulation scenarios the positioning of the 3D model is executed dynamically. This requires the trainer to wear the headset (before the simulation starts) and position the 3D model of the human to match the position of the manikin, if present. Finally, the position can be shared (from the AR application) with the trainer software, which then shares it to other headsets, if present. After positioning the 3D model the trainer can animate the wounds and bleeding to fit the desired simulation.

The trainer can decide, via the host application, if the 3D model has clothes or not (in order to allow access to the wounds), if each of the wounds are visible, whether they are bleeding or not, and the type of bleeding (arterial or venous). The trainer can also make two defibrillation pads appear on the 3D model, which can stick onto the patient body: the idea was to make them appear on the 3D model once the operator has applied them to the patient. Finally, the trainer can lock the 3D model positioning from its application, removing all the set-up interface from the headset application, hand the headset to the operator, and start the simulation. Once the simulation has begun, operators cannot edit the position of the 3D model, wounds, or bleeding directly.

A short video (Video 1 in the supplemental material, dubbed in English through generative AI), shows the salient aspects of the simulation from the trainer's and the operator's viewpoint.

4 User study

In order to verify whether the system could be used in a simulation, a test protocol has been defined consisting of a situation (identical for all test subjects) and a questionnaire. 18 LNRCS operators participated in the test, 8 female and 10 male. Age ranging from 32 to 83 years with a mean of 54.28 years. Participants had varying level of experience in the LNRCS from 2 to 376 months, with a mean of 107.6. The overall experience with AR and VR headsets is very small: 8 used one such device in their life before this experience, for a global mean of only 1.25 total hours.

The scenario was the following: during a festival, a first aid operator is asked to respond to a distress call from the kitchen. A person had suffered a cut caused by a glass (no glass is present on the scene, so that the area is to be considered safe). The operator is requested to begin assistance. The patient is conscious, reporting pain in the left arm. Respiratory rate is increased, with a weak and rapid peripheral pulse. An actively bleeding wound is present on the left arm. Each session was planned as follows:

(1) According to the standard protocol followed by the LNRCS, the operator was briefed about the test situation.
(2) The operator received the medical equipment needed for the simulation. This was a kit consisting of chlorhexidine, sterile gauze pads, and bandage.
(3) The operator wore the headset outside the simulation room while not being able to see the 3D model. This had the aim of allowing the operator to get used to wearing a headset and to check that he or she could see the real world without obstructions.
(4) The simulation was started, prompting the operator to enter the simulation room and see the patient with a bleeding wound on his/her left arm.
(5) After the operator provided assistance to the patient by pressing the gauze over the wound for a couple of seconds, bleeding was stopped by the direction and the simulation would end. In case the operator did not intervene, the simulation would end in 120 seconds.
(6) At the end of the simulation, a questionnaire was administered to the operator.

4.1 Questionnaire

The questionnaire is divided into four parts:

- Demographic questionnaire.
- A specifically designed set of questions to evaluate whether the system was "transparent" to the operators.
- The Igroup Presence Questionnaire (IPQ) [15].
- The User Experience Questionnaire (UEQ) [10].

The custom designed questionnaire was structured as follows:

(1) Was the patient conscious? [Y/N]
(2) Was the patient wounded? [Y/N]
(3) How did you realize he was/was not wounded? [Open]
(4) Was the patient bleeding? [Y/N]
(5) What made you realize that the patient was/was not bleeding? [Open]
(6) Did you provide assistance? [Y/N]
(7) How did you provide assistance/Why did you not consider it necessary to provide assistance? [Open]
(8) What did you like about the AR experience? [Open]
(9) What did you not like about the AR experience? [Open]
(10) Did you find any difficulties in using the augmented reality system? [Y/N]
(11) Which difficulties? [Open]
(12) Which aspects of the system you think should be improved? [Open]
(13) What would you change about the augmented reality experience? [Open]
(14) Overall, do you think the augmented reality experience was useful? [Y/N]

The first half of these questions (1-7) deliberately puts emphasis on first aid skills of the operators. In reality, by looking at the answers, the experimenter can get information about the level of transparency of the system, without asking for it directly. In the answers to these questions, in fact, expressions like "looked like blood" suggest that the user recognized the blood effect as something disconnected from the real world, whereas "hemorrhage"

Table 1: Yes/No questions analysis

Question number	"Yes" answers	"No" answers
1	16	2
2	18	0
4	18	0
6	18	0
10†	4	13
14	18	0

Table 2: Igroup Presence Questionnaire results

Scale	Mean	Percentile Range	Threshold
General Presence	1.2778	50-75	Moderate
Spatial Presence	0.8111	50-75	Moderate
Involvement	0.0833	<50	Low
Experienced Realism	0.2361	75-90	High
Overall Score	0.6021	50-75	Moderate

Table 3: User Experience Questionnaire

Scale	Mean	Threshold
Attractiveness	1.66	Good
Perspicuity	1.53	Above Average
Efficiency	1.49	Above Average
Dependability	1.04	Below Average
Simulation	1.63	Good
Novelty	1.63	Excellent

points to a better transparency of the same effect during the simulation. The remaining questions (8-14) ask for direct feedback on the AR experience.

The IPQ allows operators to self-report the level of presence they experienced during the simulation [15]. Although IPQ is designed for VR applications and the use in AR of VR questionnaires comes with significant limitations [17], we decided to use it to determine whether the system negatively affects the sense of presence.

5 Results

Regarding our custom designed questions: one operator answered "yes" to Question no. 10, yet (s)he answered "none" when asked about the difficulties (s)he found. For this reason his/her answer was removed (tag † in Table 1).

The IPQ results can be seen in Table 2. Data has been analyzed following the guidelines[3]: using a benchmark on 162 studies, our results were classified according to the percentile interval which they fall into [18] (Low, Moderate, High, Very High, Exceptional).

The UEQ results can be seen in Table 3. Data were analyzed with the tool provided[4], then classified based on the percentiles of the benchmark of 468 studies (Bad, Below Average, Above Average, Good, Excellent). The UEQ automatic analysis flagged an operator for giving the same answer to 17 out of the 24 questions, furthermore expressing inconsistencies within the same scale concerning two of them (Attractiveness and Perspicuity). Hence, these answers were removed from the analysis (data in Table 3).

[3]Available at https://igroup.org/pq/ipq/data.php

[4]Used Version13, available at https://www.ueq-online.org/

6 Discussion

Reaching the High threshold on the Experience Realism scale in the IPQ (Table 2) and Good on the Simulation scale in the UEQ (Table 3) signal positive feedback, allowing us to determine that the system provides experiences that are close to reality. However, 3 users mentioned the absence of sound, offering constructive feedback regarding the next steps in the development.

The Low value of Involvement in IPQ may be due to how the related questions were designed: asking the user if his/her attention was completely captivated by the virtual world and if it did not pay attention to the real world stimuli [15]. Provided that the system implements AR, users should not disconnect from the physical world since the application aims at enhancing the simulation, not obfuscating it.

A perceivable misalignment between the 3D model and the manikin was mentioned by 4 volunteers, suggesting that a more robust alignment procedure and system is needed.

The Below Average score on the UEQ Dependability metric is likely due to the unpredictability of the system. The data show that only the item "unpredictable/predictable" has a negative mean (-0.5), while all others have a strong positive mean (>=1). Furthermore, one operator praised the simulation for being unpredictable, mimicking a real world situation. Finally, 2 operators mentioned insufficient training in the use of the VR headset. This evidence links to an overall little experience with AR or VR headsets, suggesting a more structured introduction of the operators to AR technology.

7 Conclusions

The developed system proved to be a helpful tool to the trainer, allowing special effects to be introduced and controlled during first aid simulations. Operators who participated in the test found the system useful, while giving constructive and coherent feedback that will be used to further develop its software components and adjust the aspects deemed insufficient or lacking.

The system is designed around scalability, allowing for introduction of new features with arguably low development effort. Furthermore, application scenarios have been proposed by the LNRCS personnel during the development of the system: patient vomiting, cyanosis, or mottled skin, the trainer speaking from the patient's mouth, using spatial audio and headset speakers, integrating the use of an actor in place of the manikin or adding distracting elements or elements of risk to the simulation through AR (for instance, an open fire). These improvements will further expand the versatility of the system, reinforcing its potential as a flexible and adaptable platform for simulation enhancements.

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