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MediSim: A Prototype VR System for Training Medical First Responders

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Abstract

This paper presents a prototype virtual reality (VR) system for training medical first responders. The initial application is to battlefield medicine and focuses on the training of medical corpsmen and other front-line personnel who might be called upon to provide emergency triage on the battlefield. The system is built upon Sandia's multi-user, distributed VR platform and provides an interactive, immersive simulation capability. The user is represented by an Avatar and is able to manipulate his virtual instruments and carry out medical procedures. A dynamic casualty simulation provides realistic cues to the patient's condition (e.g. changing blood pressure and pulse) and responds to the actions of the trainee (e.g. a change in the color of a patient's skin may result from a check of the capillary refill rate.) The current casualty simulation is of an injury resulting in a tension pneumothorax. This casualty model was developed by the University of Pennsylvania and integrated into the Sandia MediSim system.

1. Introduction

This paper presents a prototype virtual reality (VR) system for training medical first responders. The initial application is to battlefield medicine and focuses on the training of medical corpsmen and other front-line personnel who might be called upon to provide emergency triage on the battlefield. The system consists of an immersive, multi-modal user interface and a dynamic casualty model that both changes over time and responds to the actions of the trainee. The system is built upon Sandia's open, distributed VR platform. This platform allows multiple users (displays, trackers, etc.) and multiple, heterogeneous simulation modules to be networked together to create a common, shared virtual environment. A dynamic casualty simulation provides realistic cues to the patient's condition (e.g. blood pressure and pulse change over time as a patient's condition worsens.) The casualty simulation also responds to the actions of the trainee (e.g. a change in the color of a patient's skin may result from a check of the capillary refill rate.) Our current casualty simulation is of a chest wound resulting in a tension

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pneumothorax. The prototype system also demonstrates a proof-of-concept integration of the VR trainer with the Distributed Interactive Simulation, or DIS environment, which provides a combat simulation.

2. Application Description

MediSim is targeted primarily at training battlefield medical personnel whose responsibility is to triage and stabilize multiple casualties for evacuation to field hospitals where they will receive focused medical care. This focus differentiates MediSim from other VR-based medical trainers (e.g. [Delp, Kuppersmith, Robb, Weit] and many others) whose primary goal is to train a specific procedure or task. Such systems provide highly realistic anatomical visualizations and/or multi-modal interfaces that address the visual and haptic cues involved in carrying out specific procedures utilizing appropriate medical instruments. The goal of the MediSim trainer, in contrast, is to train rapid situational assessment and decision-making under highly stressful conditions. Thus, MediSim looks to train the medic not to insert an IV, but rather to understand the circumstances under which an IV is required. The former is referred to as task training, while the latter is referred to as situational training.

The adage “practice makes perfect” is quite apropos to situational training. Lectures, books, videos, etc. are no substitute for hands-on experience -- we often learn more from our mistakes than from our successes. Unfortunately, it is difficult to provide such training for large-scale emergency medicine. Current methodology [Satava] is to use live training exercises: medics practice stabilization and wound care on animals (e.g. producing a gunshot wound in a goat) or via *moulage* (a training exercise where live soldiers are given highly realistic “fake” wounds). The shortcoming with the latter is that the medic does not get to practice wound care, while with the former it’s the growing concern over using animals for such purposes. Virtual Reality has the potential to augment current training by providing a dynamic, hands-on simulation of a battlefield environment with casualties that both manifest the physiology of a given wound dynamically over time and who also respond, positively or negatively, to the medic’s actions. MediSim is a prototype of such a trainer.

2.1 Primary Assessment

MediSim’s initial training procedure is the primary assessment. This is the first stage of triage and is carried out for all wound types. Primary assessment involves evaluating each of the following in this order: Airway, Breathing, Circulation, Disability and Expose. The procedure for each of these contains a number of steps used to diagnose and stabilize the casualty. For example, the Breathing procedure consists of looking for chest wall motion and rate; listening for respiratory distress; and listening to the lung fields and trachea for absence of breath sounds or a high-

pitched percussion note over the chest. Disability checks for consciousness, responsiveness, and normal reflexes. Expose is a visual check for wounds on the body. The primary assessment provides information on patient condition that allows the medic to diagnose the injury and decide on an *intervention* -- a treatment intended to stabilize the patient for evacuation.

2.2 Tension Pneumothorax

The initial wound type implemented in MediSim is a tension pneumothorax. This is a common battlefield wound, and occurs when a small penetrating chest wound causes air to be drawn into the cavity between the chest wall and the lungs. As the patient breaths, bringing more air into this pocket, the lung becomes compressed and the patient begins to suffocate. Important findings during the primary assessment that indicate a tension pneumothorax are respiratory distress; unilateral absence of breath sounds; distended neck veins; dropping blood pressure; and increased capillary refill time. The intervention is a needle aspiration, which consists of inserting a needle into the chest and drawing out enough of the trapped air to allow the patient to breath freely. Signs manifested by the patient that indicate the intervention is working include improved level of consciousness, improved vital signs, and improved breath sounds.

The MediSim system incorporates a dynamic casualty model (see Section 3.3) that manifests these symptoms. If the medic/trainee does not properly diagnose tension pneumothorax, the virtual casualty dies. If the trainee successfully performs the assessment and intervention, then the virtual patient manifests the conditions indicating that the treatment is working and stabilizes. It is important to note that in both the actual and the virtual case, this injury *must* be assessed and treated quickly. Even if the trainee performs all steps correctly, if they are not done in a timely manner the patient will die. Fortunately, in the case of MediSim, the trainee is permitted to make such a catastrophic error, with its accompanying lessons learned, without causing a real-life fatality.

3. MediSim System Description

Figure 1 diagrams the system components for the MediSim trainer. The system is built upon Sandia's open, distributed VR platform. This platform allows multiple users (displays, trackers, etc.) and multiple, heterogeneous simulation modules to be networked together to create a common, shared virtual environment. It has been the basis for multiple prototype training systems addressing situational training and action-consequence awareness [Shawver, Stansfield1, Stansfield2]. Below, we describe each component in greater detail.

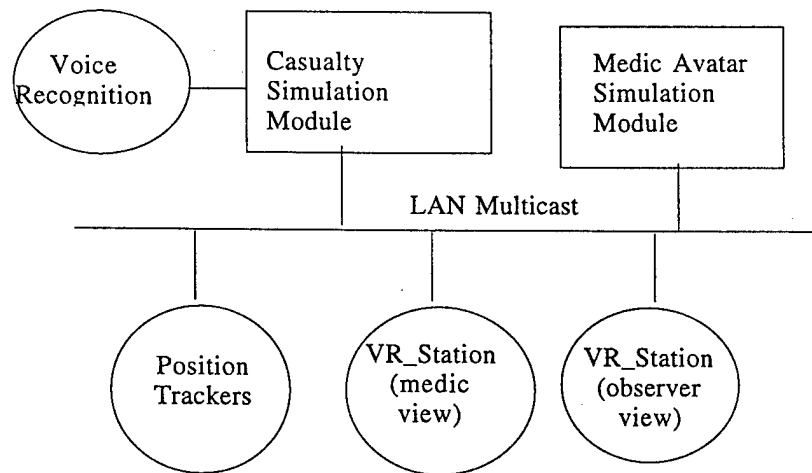


Figure 1: MediSim system diagram

3.1 The VR Interface

The VR interface for MediSim is immersive -- the medic/trainee wears a headmounted display and a set of four position trackers (on the head, the lower back, and each hand.) The system is capable of supporting multiple trainees, although we have only tested the system with one to date. The primary interface modules are:

- **VR_Station:** the display driver for the user. Typically there are multiple instances of VR_Station, each running on a dedicated CPU and graphics pipe (e.g. an SGI Crimson/RE1). Trainees and observers each have an instance of VR_Station that allows them to independently control their viewpoint and motion within the virtual world. Real-time updates of the view of objects in the world are either remotely driven by position trackers worn by the user (in the case of trainees) or locally driven via mouse and keyboard (in the case of observers).
- **Tracker input modules:** obtain the positions of the trackers worn by all users and provide this information to other modules that require it. For example, each VR_Station utilizes the position of the user's head tracker to update his/her view of the world. The avatar driver (see Section 3.2) utilizes all four trackers worn by a user to update the position and posture of that user's graphical body.
- **VR_Multicast:** permits all simulation and interface modules to share information concerning the state of objects (including users) within the simulation environment. VR_Multicast is implemented using Ethernet

multicasting of UDP datagrams on a local area network (LAN). Each module independently loads data files for those portions of the world for which it is responsible. As a module changes the state of its portion of the world, it multicasts this information, making it available to all interested simulation and interface modules (for example, each VR_Station simultaneously obtains and displays these changes.)

- **Voice Recognition:** MediSim contains a voice recognition component that permits the user to request information, such as vitals, and also to command certain actions, such as evacuation. The voice recognition component is implemented on a PC using the Dragon Systems, Inc. Dragon VoiceTools®. The voice recognition module communicates directly with the casualty model software via a socket interface.

3.2 The Medic Avatar and Virtual Object Manipulation

Small team situational training applications, such as MediSim, require that participants be represented within the virtual environment with a much higher fidelity than do other applications. It is important, for example, that team members be able to see each other as full human figures. Position, posture, gesture and body language are all vital components of team coordination and communication. In addition, VR imposes several additional requirements on the representation of the user. First, and most important, the behavior of the participant's virtual self, which we call his/her Avatar, must be updated at near real-time to reflect the immediate actions of the user. In addition, the number of sensors/trackers used to obtain information concerning the participant should be small to minimize the amount of data which must be collected and processed, and also to avoid encumbering the user.

The avatar driver used for this work is described fully in [Hightower]. It combines several techniques: general-purpose kinematic solutions are first generated using the inputs of the four sensors worn on the user's body. Special heuristics are then applied to prune the number of solutions down to one that is reasonable. Heuristics are based on knowledge of the human body and of the probable motions of limbs (e.g. where an elbow is more likely to be positioned when a user is waving.) The Avatar also acts semi-autonomously during certain motions requiring fine manipulation. For example, when a user reaches for and grasps an object, the motion and placement of the arm is controlled by the user. The Avatar's hand posture, however, is selected automatically based on the object that the user is trying to grasp. The virtual objects also contain knowledge and use this to aide the user. For example, surgical gloves place themselves on the user's hands when they are grasped and the fingers are touched. Figure 2 shows a user (a) and the posture of his associated Avatar (b).



(a)



(b)

Figure 2: A user (a) and his Avatar (b)

3.3 The Virtual Casualty

The virtual casualty model was developed by the University of Pennsylvania and is fully described in [Chi1, Chi2]. The underlying physiological simulation is based upon the Trauma Score -- a method used by emergency medical personnel for estimating the severity of a patient's injuries. The trauma Score ranks basic assessment parameters for the respiratory and circulatory systems, as well as the neurological state (obtained from the Glasgow Coma Score.) and then combines these rankings to provide a single Trauma score. A higher score indicates a greater likelihood of survival. The casualty model utilizes the assessment parameters to provide an indication of the state of the casualty at any given time. These are presented as measurements (e.g. blood pressure and pulse) or as physiological manifestations (e.g. a change in the color of the skin). The casualty model also generates appropriate changes to the state of the casualty brought about by the actions (treatment procedures) carried out by the trainee.

The casualty model is implemented using Parallel Transition Networks, or PaT-Nets, that provide a mechanism for creating and running communicating parallel state machines [Badler]. Four types of PaT-Nets are used in defining the casualty model [Chi1]:

- A Controller network that receives messages regarding the Trauma Score assessment parameters and computes the current casualty state on a minute-to-minute basis.

- Injury networks that specify the physiological changes resulting from specific medical conditions and send appropriate messages to the controller network.
- Treatment networks that specify the physiological changes resulting from administered treatments and send appropriate messages to the controller network.
- Assessment parameter display networks that generate the visual effects of changes in Trauma Score rankings and respond to user input.

These PaT-Nets are embedded within the Jack® human model, which provides the visual effects and behaviors representing the casualty. To integrate this model into the MediSim Virtual Reality environment, additional code was developed within Jack® to allow communication with other simulation and display modules within the system. The casualty was graphically modeled using the Jack® geometry residing locally within each VR_Station display module. Physiological changes were multi-cast from the Jack® casualty model and were picked up and displayed at each VR_Station. Actions and requests generated by the user were communicated to Jack®, processed via the embedded PaT-Nets, and the resulting casualty changes multicast.

Figure 3 shows the medic avatar and the virtual casualty manifesting a chest wound such as would result in a tension pneumothorax.



Figure 3: Medic Avatar with virtual casualty

4. Additional Capabilities

Two additional capabilities were briefly explored for the MediSim project. The first was the integration of the high fidelity MediSim trainer into the larger, but lower fidelity, DIS simulation environment used by the military for training large-scale actions. The second was to show a proof-of-concept demonstration utilizing the simulation environment to explore the use of prototype medical devices before a

functioning real-world device is built. Satava and Jones [Satava] discuss the potential benefits of both of these capabilities in training the battlefield medic.

4.1 Integration into the digital battlefield

The reasons for incorporating the high fidelity MediSim trainer into the larger DIS simulation environment are two-fold. First, it is important that the medic be exposed to the larger action in which he will carry out his duties -- this environment will produce additional stressors for the trainee (e.g. sniper fire or munitions exploding while the medic is triaging casualties.) Since decision making is different under such stressful conditions, it is important in training situation awareness that the trainee be a part of this larger battlefield environment. The second reason for incorporating the medic into the digital battlefield is to demonstrate the very real impact on the squad of the wounded soldier and the dedication of resources to his care.

Because the current DIS protocols do not support the high fidelity required by the MediSim trainer, the integration was carried out as a transitioning of the medic/trainee between the two simulation environments. The chosen scenario had the medic as part of a five man fire team whose task was to clear a nearby building. The mission begins within the DIS environment, where all soldiers, including the medic, are computer generated forces (the medic is "slaved" to his CGF proxy avatar). DIS packets provide the communication mechanism. As the team proceeds, a sniper wounds one of the team members and the medic must attend to him. As the medic/trainee begins treatment, he issues a vocal command to "begin patient treatment". At this point, he is transitioned to the high fidelity MediSim environment where he is presented with the virtual casualty. Within this environment, he may carry out the primary assessment and the intervention required to stabilize the patient. The rest of the DIS participants, however, do not need to be presented with such fine detail -- all they really need to be aware of is that a man is down, that the team is halted, and that the medic is working. This is accomplished by sending out packets indicating the "frozen" position and posture of the team members within the DIS environment. Once the medic has completed his task, he issues a vocal command to "evacuate patient" and is transitioned back into the DIS environment, where the patient is evacuated by helicopter and the team is freed to continue its mission. This limited demonstration shows how a high fidelity trainer, such as MediSim, might be incorporated into a large theater of war simulation. The DIS components of the above scenario were developed by the University of Central Florida, Institute for Simulation and Training, using their Computer Generated Forces Model [Reece]. The DIS environment was displayed using the Naval Postgraduate School's NPSNet software [Macedonia]. Figure 4 shows the CGF team, including the medic and wounded soldier, within the DIS environment.

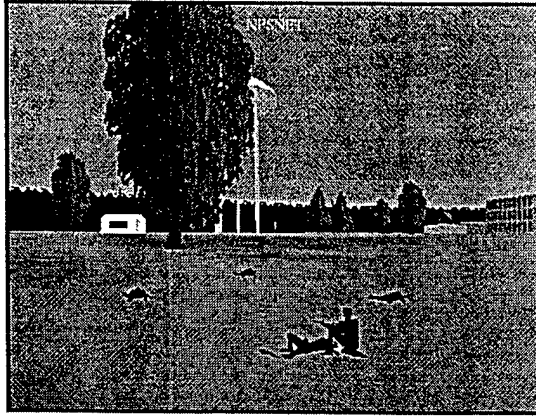


Figure 4: DIS medic and casualty

4.2 Virtual Prototyping

A second extension of MediSim intended to show proof-of-concept was the integration of simulated prototype devices. Simple models of the Personal Status Monitor (PSM), a device that presents the location and status of each team member to the medic, and of the LSTAT, or trauma pod, were incorporated into the MediSim scenario to show how they might be used by the medic on the battlefield. Figure 5 shows the model of the trauma pod, an instrumented stretcher intended to maintain the stabilized patient and to telemeter his status back to the field hospital in preparation for his arrival.

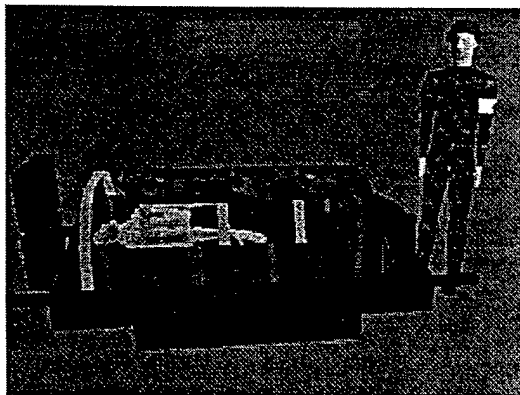


Figure 5: Trauma pod

5. Conclusion

5.1 Preliminary Human Factors Results

A preliminary human factors evaluation of this work was carried out consisting of a three part assessment including: workload assessment; system-interface design assessment; and human-system performance evaluation. This phase of the effort succeeded the medical scenario/algorithm validation employing Subject Matter Experts (SMEs) from the first responder community. SMEs were representative of the normal population in all demographic profiles tested to include: age; gender; training; experience in the patient care arena and computer use.

The three part human factors evaluation involved a cohort study with a control group. The effort was blinded. A between-groups analysis was performed for analysis of variation. Preliminary results of this effort indicated statistical significance between groups for all three evaluation areas.

5.2 Future Work

Several extensions to the MediSim trainer are currently being implemented or are planned. The first is to extend the trainer to other types of wounds (two forms of head trauma are currently being developed) as well as to allow the virtual casualty to manifest multiple wounds (e.g. a chest wound and head wound.) Such a capability is vital to the training of medics -- the head wound might look like the more severe of the two, but it is the small chest wound, and the resulting tension pneumothorax, that will cause the patient to die.

The second extension is to incorporate multiple casualties into the trainer. This will permit the training of both the initial triage (assigning priorities to wounded) and of individual casualty care. Currently, it is our plan to implement this extension within the context of a biological contamination scenario which will also permit the training of other aspects of this special type of emergency response, such as decontamination procedures and placement of detectors by first responders.

6. Acknowledgments

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manipulation software; Monica Prasad, who developed the graphical models; and James Singer, who developed the sound server and the DIS communication extensions to MediSim. We would also like to thank Rick Satava for his enthusiasm and support.

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