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The MediSim system extends virtual environment technology to allow medical personnel to interact with and train on simulated casualties. The casualty model employs a three-dimensional animated human body that displays appropriate physical and behavioral responses to injury and/or treatment. Medical corpsmen behaviors were developed to allow the actions of simulated medical personnel to conform to both military practice and medical protocols during patient assessment and stabilization. A trainee may initiate medic actions through a mouse and menu interface; a VR interface has also been created by Stansfield's research group at Sandia National Labs.

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Contents

MediSIM: Simulated Medical Corpsmen for Medical Forces Planning and Training

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Abstract

The MediSim system extends virtual environment technology to allow medical personnel to interact with and train on simulated casualties. The casualty model employs a three-dimensional animated human body that displays appropriate physical and behavioral responses to injury and/or treatment. Medical corpsmen behaviors were developed to allow the actions of simulated medical personnel to conform to both military practice and medical protocols during patient assessment and stabilization. A trainee may initiate medic actions through a mouse and menu interface; a VR interface has also been created by Stansfield's research group at Sandia National Labs.

1 Introduction

The MediSim system allows medical personnel to interact with and train on simulated casualties in a virtual environment. MediSim seeks to overcome the difficulties associated with battlefield simulations that use actual human beings and military equipment. For general casualty management and medical decision-making, MediSim eliminates the cost of military equipment and actors portraying casualties by using virtual objects and humans. It also eliminates any danger to trainees on the simulated battlefield. Further, MediSim provides additional realism in the portrayal of injuries, since it is difficult for healthy actors to display such pathophysiological attributes as cyanotic skin color, varying respiratory rate, and abnormal chest movements. It is anticipated that such virtual casualty training will result in improved and effective triage procedures under live fire conditions.

In this paper, we first describe the current interface for our casualty-medic simulations. Then, we describe the underlying physiological model for our human casualties. Next, we discuss our dynamics module for enhancing the physical realism in our simulations and our penetrating path module which aids in identifying injuries that correlate with visible wounds. We conclude with possible extensions to our work.

2 Casualty-Medic Simulations

MediSim is a first step towards enabling a medical corpsman to train on simulated casualties in a virtual environment. MediSim simulations display real-time images of animated casualties and medics using the articulated human figures in *Jack*®[2] on SGI workstation displays (Fig. 3). Users interact with the scene through commands selected from a series of menus or entered at the command line. Stansfield's research group at Sandia National Labs has also created a voice-activated virtual environment interface [10, 11]. In addition, MediSim was designed as a set of networked application modules to enable its integration into Distributed Interactive Systems or other virtual environments, though it requires a finer grain of human representation and movement detail than presently supported in standard DIS protocols.

Casualty simulation begins with a stealth instructor specifying a set of medical conditions sustained by the victim. Currently, the modeled injuries include penetrating wounds to the chest and/or abdomen resulting in any combination of the following conditions: tension pneumothorax, abdominal bleeding, hemothorax, pericardial tamponade, distended abdomen, and flail chest. The casualty's physical and behavioral responses follow from these conditions.

The simulation tracks the casualty's vital signs over time in terms of the Trauma Score [3], which reflects basic assessments of the respiratory, circulatory, and central nervous systems (detailed in Section 3). Fig. 1 shows the Trauma Score rating system. Plots of the changing Trauma Score parameters may be displayed during the simulation, although this gives additional clues to the trainee which are not directly accessible in real-life situations. During the training process, it can aid the trainee in associating physiological states and consequences with the performance (or omission) of specific medical procedures.

The simulation also displays a 3D *Jack* human casualty figure, which looks and behaves in accordance with its Trauma Score values at any given time. A trainee may determine the state of the casualty through visual cues displayed on the figure or by probing the casualty using the set of given commands. The simulation can display various physical and behavioral manifestations of injury, including distended neck veins, cyanosis, thrashing, and

Respiratory Rate	10-24/min	4	**Glasgow Coma Scale**		
	24-35/min	3	**Eye Opening**	Spontaneous	4
	36/min or greater	2		To Voice	3
	1-9/min	1		To Pain	2
	None	0		None	1
Respiratory Expansion	Normal	1	**Verbal Response**	Oriented	5
	Retractive	0		Confused	4
Systolic Blood Pressure	90 mmHg or greater	4		Inappropriate Words	3
	70-89 mmHg	3		Incomprehensive Words	2
	50-69 mmHg	2		None	1
	0-49 mmHg	1	**Motor Response**	Obeys Commands	6
	No Pulse	0		Localized Pain	5
Capillary Refill	Normal	2		Withdraw Pain	4
	Delayed	1		Flexion (pain)	3
	None	0		Extension (pain)	2
				None	1

Figure 1: Trauma Score (Champion et al., 1981)

chest movements for breathing. The command list allows the trainee to ask the casualty questions to assess the situation as in real emergency medical situations. There are also several commands corresponding to treatment procedures which, when invoked, generate appropriate changes in the state of the casualty. Fig. 2 lists the user commands available in the current system and their corresponding response types. The Medic Action Commands are implemented as medical procedures carried out by a (semi-)autonomous *Jack* medic (Fig. 3). These procedures were derived from video recordings of Dr. Annette Sobel (Sandia National Labs) demonstrating them on a medical mannequin as she does when training medical corpsmen and other medical personnel. The other commands and queries are implemented only as input commands which invoke an appropriate visual, audio, and/or physiological response from the casualty.

3 Modeling the Wounded Soldier

We designed and implemented our casualty model in such a way that a casualty's condition over time follows from the type of injuries sustained and any medical intervention performed [4]. For our prototype implementation, we have used a simple, discrete scale for approximating the condition of a patient. This is the Trauma Score [3], a method endorsed by the American Trauma Society that is widely used by emergency medical personnel for estimating the severity of injuries. It reflects basic assessments of the respiratory and circulatory systems, and incorporates the Glasgow Coma Score which represents a casualty's neurological state. At any given time in the simulation, a casualty's physiological state is defined

DIAGNOSTIC COMMANDS		
Assessment Parameter	**User Command**	**Response Type**
Respiratory Rate	`query-RR`	numeric display
Respiratory Expansion	–	visual
Blood Pressure	`query-BP`	numeric display
Capillary Refill	`take-CR`	visual
Eye Opening	`open-your-eyes`	visual
	`apply-sternal-pressure`	visual
Verbal Response	`name?`	written, audio
	`I.D.?`	written, audio
Motor Response	`move-your-foot`	visual
	`squeeze-my-hand`	visual
	`apply-sternal-pressure`	visual
SITUATION ASSESSMENT COMMANDS		
	`are-you-ok?`	written, audio
	`what-happened?`	written, audio
	`do-you-have-pain?`	written, audio
	`where-does-it-hurt?`	written, audio
THERAPEUTIC COMMANDS		
	`needle-aspiration`	state changes
	`give-fluids`	state changes
	`occlusive-dressing`	state changes
	`stabilize-flail-chest`	state changes
MEDIC ACTIONS COMMANDS		
	`check-responsiveness`	visual
	`check-airway`	visual
	`expose-wound`	visual
	`percuss-chest`	visual
	`auscultate`	visual
	`check-vital-signs`	visual
	`check-capillary-refill`	visual
	`listen-to-heart`	visual
	`check-neck-veins`	visual
	`evacuate-patient`	visual

Figure 2: User Commands

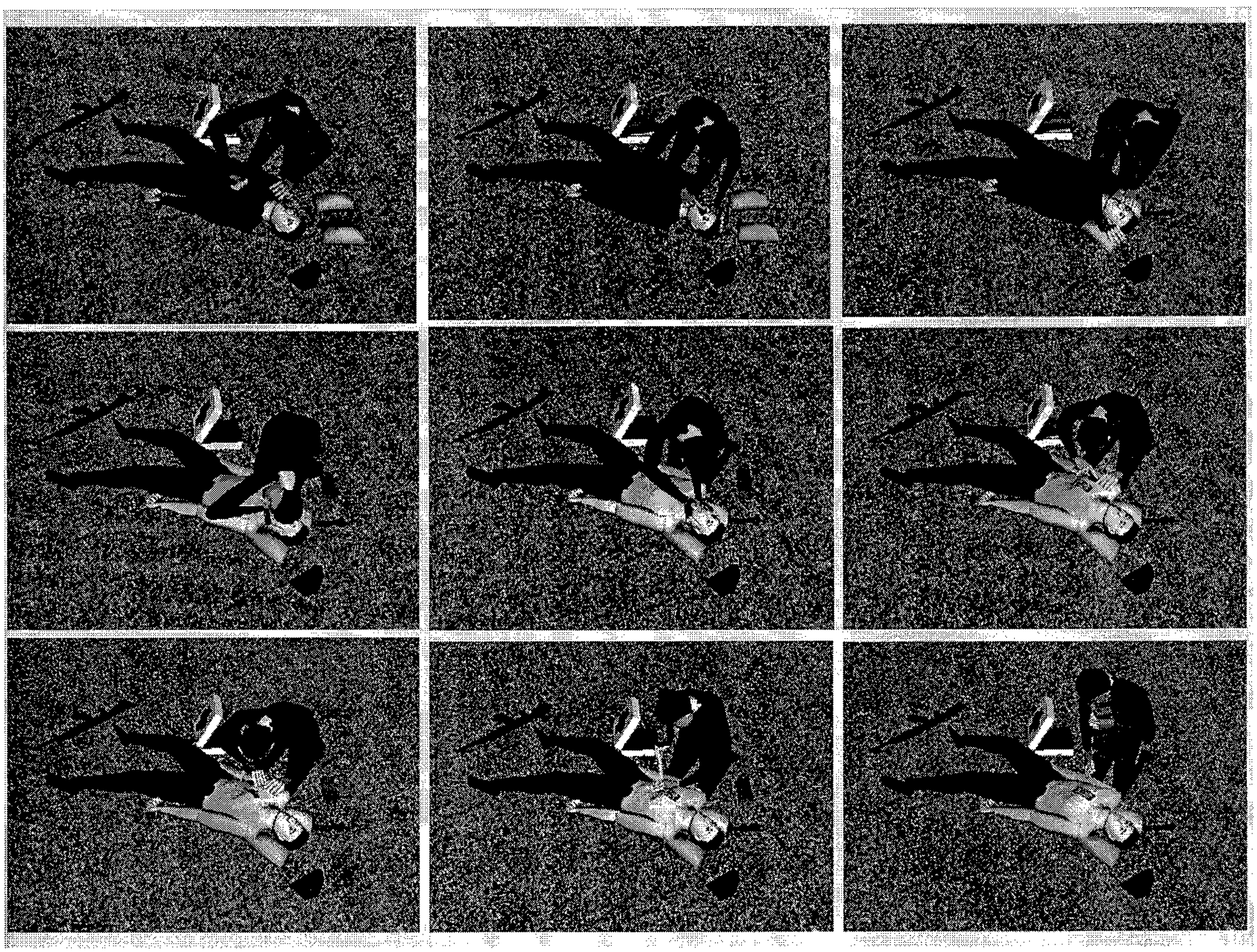

Figure 3: Medic Actions Commands (left to right, top to bottom): Check Responsiveness, Check Pupils, Stabilize Cervical Spine, Check Airway, Check Capillary Refill, Auscultate, Percuss Chest, Perform Needle Aspiration, Call to Evacuate Patient

by his/her Trauma Score values. We selected the Trauma Score as the basis of our casualty model for its comprehensive nature and its accuracy and reliability in predicting a trauma patient's condition.

We model the casualty using a package for creating and running communicating parallel state-machines, which we call Parallel Transition Networks (PaT-Nets) [1, 2]. Since we characterize the state of a casualty in terms of Trauma Score rankings, states in a state machine are a natural representation for changing patient conditions. Also, PaT-Nets are good at sequencing actions based on conditions such as the passage of time. Since injuries and treatments are modeled by the time-based, physiological changes that they generate, PaT-Nets provide a reasonable computational model.

We currently use four types of Parallel Transition Networks to define our casualty model:

- 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, and
- *Assessment parameter display networks* which generate the visual effects of changes in Trauma Score rankings and respond to user input.

The controller network ensures that the Trauma Score values remain within their valid ranges. Physiological conditions that result from injury are modeled as individual PaT-Nets. These injury networks specify the timed transitions in the Trauma Score values as a result of a given medical condition. Similarly, the patient's condition, reflected in the Trauma Score, is set to deteriorate or improve at the appropriate times, depending on any performed therapeutic intervention defined by any activated treatment networks. Since a casualty may receive multiple conditions as result of injury (e.g. a penetrating abdominal wound may result in hemothorax, pericardial tamponade, and abdominal bleeding), when multiple conditions occur, the lowest value of each Trauma Score value is used as the overall value. The current networks were built based on estimates from one of the authors, an experienced trauma surgeon (Clarke).

4 Enhancing Physical Realism with Dynamics

Physical realism is an important factor in creating natural-looking motion for simulating medic procedures and involuntary behaviors of a casualty. Our dynamics module allows us to add dynamic properties to the humans and objects present in a scene, and thus, easily generate convincing-looking motions. Each segment of a human figure as well as any tools used in a medical procedure are assigned realistic mass and inertia values. Using our forward dynamic simulation system, we are able to automatically generate physically consistent motions for the casualty. We have therefore reduced the need for tedious keyframing and kinematically-generated motions while achieving a high level of realism in our scenes.

We built a fast forward dynamics simulator for computing the motion of arbitrary articulated figures in *Jack*. The simulator is based on the articulated-body method developed by Featherstone [6]. Featherstone's technique is a recursive algorithm whose complexity grows linearly with the number of links in the simulated figure. It has been proven to be one of the fastest numerical algorithms available and is versatile enough to handle any figure defined in *Jack*. Only the mass (or density) of each figure segment needs to be provided in order to compute dynamics-based motion. Our dynamic simulator generates motion in real-time for articulated figures of medium to high complexity (with about 30 degrees of freedom).

To further enhance the realism of the dynamic simulation, we have built a system that automatically detects and handles collisions between objects in a physically correct way. To detect collisions between two segments we have used the *I_COLLIDE* library developed at the University of North Carolina [5]. This collision detection library reports the pairs of segments in the environment that are in contact at any time instance and feeds this information to the collision handler we developed. Collisions are handled in two distinct stages: impact and contact. The simulation goes into the impact stage immediately after a collision is first detected. At the impact stage, instantaneous changes in the objects' velocities which reflect the impulsive effect due to the collision are computed. If the two objects stay in contact, the simulation enters the contact stage where at every time instance, contact forces that prevent the penetration of the colliding objects are automatically computed and fed back to the dynamic simulator. The collision handling techniques were developed with computational efficiency in mind and therefore real-time performance can be achieved even when multiple collisions exist. For more detailed information on the dynamic simulator, the collision response, and control techniques, see [7].

The dynamic simulator supports much of the realistic behavior of casualties and corpsmen in MediSim. The realistic response of a soldier being wounded by a bullet to the chest is simulated by applying a large impulse to the dynamically simulated human figure and letting it fall freely to the ground. Dynamics also supports the simulation of various procedures performed by the medic on the casualty, such as the log-roll and casualty evacuation. In the log-roll procedure, the medic rolls the casualty over prior to placement on a stretcher. Here, the casualty's body is simulated dynamically and the contact of body parts with the ground is automatically handled, giving an overall convincing motion with little effort from the animator. During evacuation, a casualty is placed on a stretcher which is being carried by two corpsmen. Again, the motion of the casualty's extremities is automatically generated through dynamic simulation, which adds substantial realism to the simulated procedure.

A robust dynamic simulator has been key to generating physically correct animations. While current DIS and other live simulations cannot utilize such diverse and detailed motions, future systems with real-time, whole body performance can show much more accurate and context dependent dynamic action.

5 Modeling Penetrating Injuries

Determining the anatomical and physiological impact of penetrating wounds involves relating knowledge of anatomy with possible projectile or stab wound penetration paths. MediSim's penetration path assessment module enables a trainee to visualize 3D graphical models of different bullet path hypotheses and stab wound paths, using a rotatable 3D model of the human torso with the appropriate anatomical structures. The system identifies the anatomical structures affected for each penetration path and presents the degree of belief that an anatomical structure associated with a given penetration path is injured, expressed as a probability (within confidence limits) [8]. The penetration path assessment system is designed both for use in MediSim, to identify injuries that correlate with wounds for tutorial purposes, and in TraumAID [9, 12], to evaluate penetrating injuries to the chest and abdomen.

The three-dimensional models of gunshot or stab wound paths displayed by the system are called *wound path spaces.* A wound path space is the space of possible trajectories from an entry wound to an exit wound or a bullet lodged in the body, or the area potentially affected by an instrument used in a stabbing. By displaying 3D models of gunshot and stab wound paths and injured organ possibilities for a given set of wounds, the system provides a visual cue to their consequences; a kind of virtual CT-scan. This can help in bridging the gap between knowledge of the anatomy involved in a particular injury and the physiological manifestations associated with that injury.

Penetrating injuries caused by gunshot or stab wounds are modeled on the 3D graphical torso model. External wounds corresponding to either gunshot or stab wounds can be entered onto any location on the surface of the model. Determining the wound path produced in a stabbing is relatively straightforward; we only need to consider a single wound path space originating from a surface (stab) wound. In assessing ballistic injuries, however, the presence of multiple entry and exit wounds complicates the process of ascertaining which organs have been injured. A combinatorial analysis of the surface wounds in such cases leads to various *penetration path hypotheses.* A penetration path hypothesis may consist of one or more wound path spaces, depending on the number of wounds.

Gunshot and stab wounds have wound path space representations that correspond to their respective regions of uncertainty. The wound path space for a gunshot wound is created by taking a chord of a circle and the arc subtended by the chord and rotating the two-dimensional figure obtained 360 degrees about the x-axis to form a three-dimensional figure (Fig. 4). The region corresponding to the center of the wound path space representation reflects the area of greatest uncertainty about the deviation of a given bullet trajectory from a straight line path. For a stab wound, a truncated cone is used to model the wound path space (Fig. 5), corresponding to uncertainty in the direction of the blade (or the penetrating part of an instrument).

Once all the possible pairings of wounds for a given set of penetrating injuries have been determined, the system establishes which anatomical structures are affected for each wound path space. This is done by checking for intersections between the polygonal surfaces that make up the geometric representations of the wound path spaces and the anatomical

Figure 4: Wound Path Space for a Gunshot Wound

Figure 5: Wound Path Space for a Stab Wound

structures. At this point, identification of (potentially) affected anatomical structures is used differently in MediSim and TraumAID. For TraumAID, the system currently highlights and lists those anatomical structures determined to lie in the wound path space. For MediSim, posterior probabilities of anatomical structure involvement generated by the penetration path assessment system can be used to update the posterior probabilities of particular injuries. One or more high-likelihood injuries can then be attributed to the casualty.

6 Conclusions

MediSim demonstrates the feasibility of training military medics in a virtual battlefield environment. MediSim allows medic trainees to examine and treat simulated casualties with realistic pathophysiological behaviors. Dynamics are used to enhance the physical realism of the articulated human body simulations. For tutorial purposes, penetrating injuries may be further examined on a human torso displaying internal anatomical structures.

Possible extensions to this work include integrating a more detailed physiological model for the casualty, using automatic case generation of injuries based on probabilities, expansion of the injury and treatment databases, and implementing an intelligent module to critique the performance of trainees.

The MediSim system with virtual environment interfaces and a DIS connection was demonstrated for AUSA '96 as a collaboration between the University of Pennsylvania, Sandia National Labs, the Naval Postgraduate School and the Institute for Simulation and Training at the University of Central Florida. The University of Pennsylvania portion of the MediSim code has been licensed to Transom Technologies, Inc., for future development and distribution.

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