Virtual Medical Trainer

Patient Assessment and Trauma Care Simulator

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The Virtual Medical Trainer (VMET) combines multimedia sound and graphics with physiological engines, medical-procedures databases, and 3-D patients to produce an interactive environment that can mimic the cognitive pre-hospital assessment and care demands of a real emergency. VMET uses a reconfigurable component software and training framework that allows a uniform user interface, ease of increasing training complexity, and expansion of the software components. VMET provides an opportunity to experience a range of trauma scenarios prior to the challenge of an actual trauma situation.

1.0 Introduction

Both military and civilian emergency medical training need a realistic environment to ensure that the inexperienced student can fully appreciate the complexities of immediate, pre-hospital trauma care. Training that relies on printed media and moulaged-actor simulation lacks the ability to simulate a wide range of combat injuries, scenarios, and the dynamic physiological consequences of trauma and treatment. Although conventional classroom instruction, practice with passive or instrumented manikins, and group exercises in mock disasters each contribute to the learning process, each has well-recognized shortcomings. High student-to-instructor ratios constrain the variety of decision-making situations that are practical in a training program, while low availability of high-end fully-instrumented manikins constrain student throughput.

Once a student has completed the initial training and is a member of the emergency-medical caregiving community, the problems of sustainment training, continuing education, and recertification arise. Realistic training for the experienced caregiver suffers the same limitations as those for the initiate.

There are many computer-based training aids available for use within and outside the classroom, and these range in complexity from text-based scenarios for triage to multi-system physiological simulators with various levels of graphics. As with conventional instruction, each has strengths and limitations, but none appear to be designed with the intention of teaching trauma care to a range of emergency-medical specialists.

The work reported here describes a demonstration project for teaching trauma-patient assessment and trauma care that integrates elements of virtual reality with multi-media information and real-time physiological engines. The demonstration systems provide an engaging, realistic, and physiologically-accurate environment for teaching, while also supporting administrative functions such as student demographic data and performance records. In addition, the demonstrations run on affordable PCs and thus can be deployed in greater numbers than the high-end simulators.

2.0 Purpose

The purpose of the project was to provide a framework, an architecture, and a meaningful step towards equipping the Army medical community with a family of practical and affordable casualty simulator/trainers. To meet these objectives the specific aims were to:

(1) Develop a Virtual Medical Trainer (VMET) for trauma patient simulation comprising models of
   (a) physiological systems and functions,
   (b) the physiological dynamic consequences of trauma on these systems,
   (c) the effects of medical intervention on these systems, and
   (d) the effects of interaction with anticipated military medical technology.

(2) Provide an accurate and engaging visible, audible, and behavioral trauma simulation environment for the practice of emergency trauma care.

(3) Develop a scaleable system architecture that is suitable for individual/home study, team learning, distance learning, and fully immersive advanced learning environments such as 21st-century classrooms.

3.0 Methods

The VMET Trauma Patient Simulator (VMET-TPS) design is a result of close examination of the materials used by the Army for training its medics [1] and physician assistants (PAs)[2]. These materials closely follow civilian guidelines for both Basic Trauma Life Support (BTLS) and Advanced Trauma Life Support (ATLS)[3-4]. Our examination suggested that a combination of resource-based and procedure-based design would offer flexibility for responding to changes in caregiving guidelines, for extending the simulator/trainer to higher levels of medical care, and for accommodating changes in medical devices and procedures. This approach allows the caregiver level to be set by the choice of resources (equipment, devices, fluids, drugs, etc.) and procedures (e.g., intubation, thoracentesis) rather than by defining a separate simulator/trainer for each.

For example, regardless of whether the first-responder in combat is a medic, a PA, or a physician, assessment resources in the field are essentially limited to what can be perceived about the casualty scene with eyes, ears, and senses of touch and smell. Only a few diagnostic tools (e.g., stethoscope, flashlight) are available, and treatment may be limited to establishing an airway, bandaging bleeding wounds, splinting broken bones, giving intravenous fluids, and transporting the patient.

3.1 Constraints

An ideal trainer/simulator would allow the student to perform all of the tasks associated with a level of training. Because an affordable system* will not be able to mimic all of the physical attributes of and interactions with a trauma patient, we separated tasks into those that are primarily cognitive and those that require motor skills. Virtual-reality(VR)-based trainers are ideally suited for the former, while manikins and other hardware excel for the latter. Learning partitioned this way provides three benefits. First, medical decision making, emergency protocols, physiology, and relative spatial relations between anatomy and medical devices can be learned on a relatively inexpensive simulator. Second, a wide variety of scenarios can be presented to improve decision-making skills. Third, if an expensive, fully-instrumented manikin or a moulaged actor is available, the amount of time a student requires on the limited resource can be reduced by first developing the cognitive skills on the less-expensive simulator.

* Affordable is defined as costing less that $7500 by December 1998.

3.2 Information accuracy

The virtual casualty does not require a complexity approaching that of the NIH Visible Human data. For the purposes of VMET-TPS, the casualty does not even need to be solid. Because definitive-care procedures such as major surgery and others that require detailed viewing of the interior of the body were not immediate needs of this project, wounds can be represented as texture maps rather than as 3-D objects, thus reducing the required polygon count and the load on the graphics processor.

There should be, however, a link between body-surface appearance of a wound and the damage to underlying structures. For example, a gunshot wound to the upper arm with the same external appearance may or may not be associated with a humeral fracture, partial or complete nerve transection, major artery or vein transection, etc. Managing the relation between primary injury, associated injuries and pathologies is essential for presentation of signs and symptoms and for imposing plausible physiological consequences.

Presentation of accurate physiological cues and information on a time scale consistent with real-body behavior is essential for introducing the importance of time in pre-hospital trauma care. This requires a real-time physiological engine that simulates the major organ systems, internal circulation, and material exchanges with the environment. The physiological simulation should also respond to medical interventions (incorrect ones as well as correct ones) realistically.

3.3 Presenting tactile information

Presentation of tactile information that is critical to patient assessment and treatment is a challenge. Interactions with the virtual patient are constrained to navigating in "virtual space" and activating body-surface "hot spots" with a mouse, or other pointing device. In a previous VR-based patient simulator [1], we presented tactile information (pulse, skin temperature, bleeding, etc.) as a popup when the "Touch" procedure and appropriate body parts were chosen. Both instructors and students accepted this presentation, hence it is retained in the VMET-TPS. Similarly, patient manipulations such as intubation can be indicated by procedure selection, the result presented in the VR

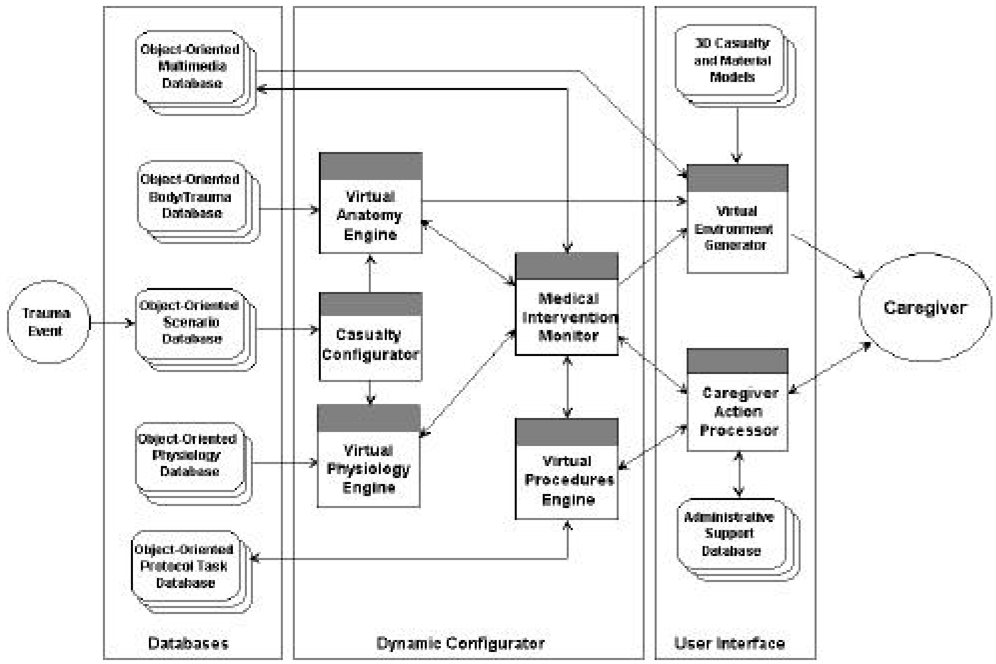

Figure 1. Top-level functional diagram of the VMET-TPS system architecture.

window (e.g., showing the airway in place). For skills training, the student may be directed to perform the procedure on a part-task trainer (e.g., Laerdal® Airway Management Trainer, Wappingers Falls, NY) to retain the temporal aspects of the procedure.

4.0 Results

Using the constraints noted above, along with the project objectives, we have developed a simulator/trainer to demonstrate important elements of trauma-patient assessment and trauma-patient care for a limited number of injuries and care settings.

4.1 System architecture

VMET-TPS comprises three primary components as shown in Figure 1: databases, a dynamic configurator, and a user interface. The databases contain information that can be modified to accommodate changes in procedures, new medical devices and equipment, and new visual and physiological representations of patients and their wounds. Each database provides information to the dynamic configurator, a set of programs that creates the virtual casualty and its setting, and operates on intervention information to produce responses for the user. The user interface processes and logs navigation and procedural choices made by the caregiver and controls the presentation of the virtual casualty.

Software modularity allows components to be replaced without redesign of the system. For example, each database, the 3-D model, and the physiological engine are complete entities with defined interfaces to the simulator/trainer. As 3-D graphics capabilities improve, the virtual body can be upgraded in appearance and complexity without altering other parts of the system. Similarly, as physiological models become more accurate and accommodate a wider range of capabilities (e.g., responses to more drugs, drug interactions, hypothermia), the physiological engine may be replaced, and the change will be transparent to the user.

VMET-TPS was developed to execute under the Windows 95 operating environment, employing Microsoft's DirectX3-D video drivers for virtual environment support. As DirectX3-D becomes fully operational in Windows NT 4.0, TPS should also execute well under Windows NT. The software was coded in Microsoft Visual Basic (user interface and simulator), Microsoft Visual C++ (virtual environment), and Microsoft Access Basic (database support). Extensive use of object-oriented data structures and program code enhances modularity and eases intermodule communication via the Microsoft Component Object Model (COM) architecture.

4.2 Casualty models

The initial virtual body was a rigid Viewpoint Data Labs (Orem, UT) man with approximately 55,000 polygons, which was judiciously reduced to approximately 12,000 polygons[5]. The polygons were grouped to parse the body anatomically into approximately 100 regions (e.g., left and right front upper arm; left and right back upper arm), any of which can be represented by a normal body part or one that has an injury. The present articulated-body model was created in Poser (Fractal Design Corp., Scott Valley, CA), has approximately 17,000 polygons.

The nude 3-D human model was augmented with soldier clothing (shirt, pants, helmet, and gear). For a limited set of injuries (chest penetration, arm penetration, arm laceration, and thigh contusion), additional 3-D models of the affected body parts were developed for the initial injury and for post-treatment visualization. Wound texture maps were adapted from photographs of real injuries.

4.3 System operation

VMET-TPS has three operating modes that can be selected at the beginning of a training session: Learning, Mentoring, and Simulation. Learning mode gives step-by-step guidance through a set of procedures, much as conventional classroom instruction does. In this mode, the student is presented with a breakdown of the steps in the procedure being attempted. The student must follow the set of predefined steps in each procedure before being allowed to progress to the next procedure.

In Simulation mode, the virtual casualty is presented, and the student is free to execute any diagnostic or treatment procedure consistent with the level of training. This is a free-play mode that may be used as an examination of the student's accomplishments. No feedback, other than physiological information that is requested by the student, is given, but all decisions made by the student are logged for later review by the instructor. The student is permitted to advance any care-giving action or procedure in any order. This is similar to a real-life situation in which the status of the patient depends on the skill of a caregiver who is operating from an internal knowledge base.

The Mentoring mode is a free-play mode similar to Simulation, but, as in the Learning mode, the student must follow the set of predefined steps in each procedure before being allowed to progress to the next procedure. Also, if the student attempts an incorrect intervention, the mentor presents an "Inappropriate-Action" message. This mode is especially useful for relatively well-defined procedures such as the ABCs of immediate care.

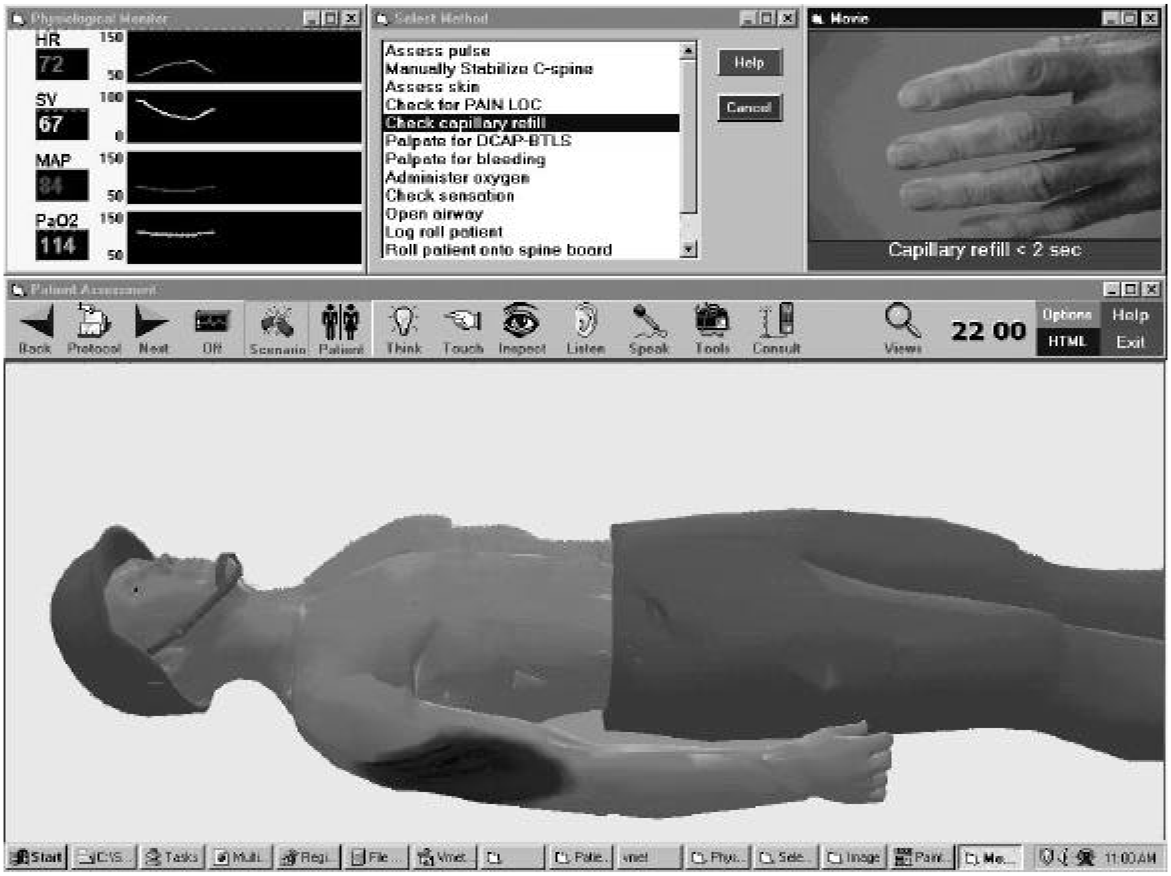

Figure 2. User-interface showing VMET-TPS multimedia and VR displays.

For patient assessment, there are underlying guidelines based on BTLS that can be bought up in an information window. The guidelines are organized into an hierarchy of protocols, tasks, and actions. Each protocol has a set of one or more tasks, each of which has one or more actions. For example, in patient assessment, the "Initial Assessment - Trauma" protocol has a task for "Assess Circulation". The actions are assess skin, check pulse @ wrist, check pulse @ carotids, and check capillary refill. The student carries out the actions via menu selections and 3-D body interactions. Software methods interpret these actions and produce multimedia responses and physiological effects. These guidelines are a useful reference for the free-play Simulation and Mentoring training modes.

A trauma event, defined by an instructor, is created from the set of databases. The instructor selects a scenario, selects a set of injuries for each virtual casualty, and selects a set of "calamities" that can be introduced at specific times or at random (e.g., a pulmonary embolus that occurs half-an-hour after a major bone fracture; obstruction of a previously patent airway). When the student's session begins, the dynamic configurator creates the virtual casualty and the virtual environment generator renders the 3-D representation of the body and scene in a VR window. A real-time physiology engine is started with initial conditions that are consistent with the wounds, traumas (e.g., severe bleeding, obstructed airway), and initial physiological status (e.g., dehydration) selected by the instructor. The physiology engine is a multiple-model/transport-model commercial simulator (BODY™, Advanced Simulation Corp., Point Roberts, WA) that was designed to train anesthesiologists and has been adapted to run with VMET-TPS.

4.4 User interface

The user interface (Figure 2), has a general layout comprising three small windows for presenting options lists and multimedia data (TOP), a mode-selection button toolbar (MIDDLE), and a 3-D-interactive virtual reality display of the casualty scene (BOTTOM). The information windows at the top of the screen present still-pictures or videos to illustrate procedures, patient information as on a patient monitor, and menus for selecting protocols, procedures, tasks, tools, and actions.

In the example screen , the VR window presents a casualty who has sustained multiple lacerations to the right arm. Using the "scissors" tool from the "Tools" list selection, the caregiver has already removed the shirt and military gear from the soldier. The multimedia windows present the following:

(1) a time-series trend display of physiological data from the physiological engine (heart rate [HR], stroke volume [SV], mean arterial pressure [MAP], and the partial pressure of arterial oxygen [PaO2]);
(2) a dynamic list of available actions performed via "touch" for selection by the caregiver; and
(3) a video representing the "capillary refill test" after selecting it from the "touch" menu list.

When VMET-TPS is running, the multimedia windows are dynamic, changing content and display layout according to data presentation, interactive care-giving, and software administrative requirements of the moment. Additional popup displays overlay the VR screen and multimedia windows, for brief presentation of casualty-related data (e.g., pulse rate upon wrist hot-spot interrogation), selection of secondary options (e.g., method for manual airway opening), step-wise protocol-task-action mentoring, and error messages.

Direct casualty interactions employ anatomical "hot spots" (e.g., neck, left) related to specific protocol actions (i.e., check pulse, inspect for bleeding) to simulate "hands-on" patient care in the virtual environment. Secondary casualty interactions employ either menu-driven (e.g., log roll to left side, back, and right side) or hot-spot related (e.g. , apply cervical collar) methods to achieve desired results. Navigation in the virtual environment is presently limited to Zoom In / Zoom Out, head to toe translation, and "leaning over" the casualty to see the other side.

5.0 Conclusion

We have developed a flexible, VR-based, user-friendly simulator/trainer for teaching cognitive skills necessary for trauma-patient assessment and elements of pre-hospital trauma care. This work-in-progress is ready for an initial evaluation by the user community to determine the efficacy of the concept, the acceptability of the user interface, the effect on time-to-acquire-proficiency, and the retention-of-learning time.

6.0 References

[1] MOS 91B Medical Specialist Instructor Lesson Plans.

[2] Advanced Trauma Management, Physician Assistant Branch, Department of Medical Science, AMEDD Center & School, 1997.

[3] Basic Trauma Life Support for Paramedics and Advanced EMS Providers, third edition, John Emory Campbell, MD, FACEP, editor, Brady Division, Prentice Hall, Englewood Cliffs, New Jersey (pub.), 1995.
[4] Emergency Care and Transportation of the Sick and Injured, sixth edition, Lynn A. Crosby, MD and David G. Lewallen, MD editors, American Academy of Orthopedic Surgeons (pub), 1995.
[5] Paul N. Kizakevich, Michael L. McCartney. "Virtual Medical Trainer (VMET): Interactive Simulation for Multiple-Trauma Patient Assessment." Final Report for USAMRMC Contract No. DAMD17-96-M-2723, Ft. Detrick, MD, RTI/6696/F, June 1997.