E-MAT + TC3sim: A Tale of Two Sims

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ABSTRACT

HapMed's Extremities-Multiple Application Trainer (E-MAT) Arm provides Army personnel a simulated arm with sensors and an on-board computer that determines whether they have applied a tourniquet correctly. It is great for learning this extremely important manual skill. Extremity hemorrhage is one of the three major preventable forms of death highlighted in the Army's Tactical Combat Casualty Care (TC3) program. TC3 is an initiative that teaches combat medics how to do point of injury care in a tactical environment. TC3sim is a game-based simulation that allows the player to take on the role of a combat medic and make decisions about triage, treatment, and tactical safety. But, it does not support any hands-on training.

This paper will discuss the work to combine these two simulation systems. TC3sim provides training for tactical situational awareness and high-level decision-making. HapMed's E-MAT Arm provides training for hands-on medical skills. An interface between TC3sim and HapMed's E-MAT Arm is authored to allow data to be shared. HapMed's E-MAT Arm physiological data about bleeding rate and tourniquet effectiveness are sent to TC3sim to incorporate into its larger scenario. The virtual wounded soldier's wounded state, simulated by TC3sim, now incorporates data from HapMed's E-MAT Arm. Effectively, HapMed's E-MAT Arm now simulates the soldier's amputated arm. The trainees have the opportunity to practice their medical decision-making knowledge and their tourniquet application skills. They get the best of both worlds: a low resource impact substitute for a live exercise and an effective training tool for manual medical skills.

ABOUT THE AUTHORS

Paul Kelly is a Senior Software Engineer at Engineering and Computer Simulations. He has over fifteen years experience in real-time simulation. He has authored papers for the Computer Generated Forces Conference, Simulation Interoperability Workshop, and for the book Game Programming Gems 3. He holds a B.S. and M.S. in Computer Science from the University of Central Florida.

Howard Mall has spent the last three years at Engineering and Computer Simulations, Inc., building various kinds of training systems. He led efforts for the Navy to develop training solutions deployed on cell phones and handheld computers. For the Army, he delivered the Tactical Combat Casualty Care (TC3) Simulation used by combat medics to learn triage and medical decision-making in a virtual tactical environment. He is currently creating the Emergency Management Nexus, a next-generation synchronous training platform for the National Guard Bureau.

Todd Lazarus is a Research Scientist at the Institute for Simulation and Training at the University of Central Florida. His main focus is on the understanding of physiological requirements of virtual environment interactions and how to design plug-in systems to achieve sensory input. Todd has lead the hardware development on the Navy

VIRTE Haptics STTR Phase I & II, Army Haptics SBIR Phase I & II, HapMed SBIR Phase I & II and RAVES Olfactory Research projects. He has created devices, such as; Virtual Environment Stimulus Tool (VEST) that is a one size fits many tetherless haptic garment, Buddy-Aid Glove (BAG) that generates medical first responder's tactile feedback and Extremities Multiple Application Trainer(E-MAT) that is a dynamic multi-sensory populated prosthetic for realistic feedback regarding tourniquet application and assessment. Todd received his B.S.E. in 2004 in Electrical Engineering from University of Central Florida.

Teresasita Sotomayor is a Science and Technology Manager for Medical Simulation Technologies in the U.S. Army Research Development and Engineering Command, Simulation and Training Technology Center. She is currently working various aspects of a joint Army Technology Objective (ATO) Program and various Small Business Innovation Research projects. Ms. Sotomayor has over seventeen years of experience in military modeling and simulation. She received a B.S. in Industrial Engineering from the University of Puerto Rico and a M.S. in Operations Research from the George Washington University. She is currently a PhD Candidate in the University of Central Florida Modeling and Simulation PHD program.

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INTRODUCTION

According to a memorandum (Kiley, 2005) to the Deputy Chief of Staff, the casualty rate for Operation Iraqi Freedom was 11%. That is the lowest rate for any conflicts the US has fought. But, there are still ways to improve that statistic. The memo recognizes the first ten minutes after a soldier has been wounded as one of the areas where medical treatment training can further reduce casualties. This time period, also known as "The Platinum Ten Minutes"(Kiley), greatly determines the fate of a casualty. During this time the treatment of the three main causes of battlefield deaths (hemorrhage, airway compromise, and tension pneumothorax (Kiley)) is critical. HapMed's Extremities-Multiple Application Trainer (E-MAT) Arm (Lazarus, Martin, Nayeem, Fowlkes, & Riddle, 2008) and TC3sim were created to provide training to Combat Medics and Combat Lifesavers to improve performance during the Platinum Ten Minutes in the hopes of reducing the number of casualties.

RDECOM funded a proof of concept for combining the two training systems. HapMed's E-MAT Arm is a haptic-task trainer. TC3sim is a desktop simulation. Both have their inherent strengths. A haptic-task trainer teaches physical skills whereas desktop simulations are better at teaching decision making. A haptic-task trainer is similar to a part-task trainer in that it provides a physical device to interact with. The difference is that in the haptic-task trainer's case it provides a haptic device (a device which interfaces with the user via the sense of touch). The resulting new system exhibits the complementary strengths of HapMed's E-MAT Arm and TC3sim.

This paper describes the process of combining HapMed's E-MAT Arm and TC3sim into one training system. This development showed how to take two complementary simulation styles and put them together. This is research and did not result in a product fielded to the warfighter. However, this paper will cover the techniques and lessons learned from the process that could be used in the future for a complete system that exercises both cognitive decision-making and psycho-motor (hands-on) skills.

The paper will begin with a background section describing the training domain and the two simulations. Then it will cover the choices made and the methods used to coordinate HapMed's E-MAT Arm and TC3sim in an effective way. With this proof of concept being a purely technical exercise, the paper will conclude with a discussion of further research to be done in this area.

BACKGROUND

The background section starts by describing the application of a tourniquet to a casualty. This is where HapMed's E-MAT Arm and TC3sim overlap, so having a basic understanding of it will help understand the rest of the paper. The Tourniquet Application section is followed by two sections that detail the HapMed's E-MAT Arm and TC3sim projects.

Tourniquet Application

Both TC3sim and HapMed's E-MAT Arm train the use of tourniquets. The Army's technique is to apply the tourniquet two inches above the wound. The reasoning for this method is to try to save as much of the limb as possible.

There are two other tourniquet application methods. The first method teaches to apply the tourniquet at the middle of the bicep. This method increases the chance of losing more of the limb to amputation. But, it reduces the chance of not stopping the bleeding completely which can happen when applying the tourniquet right above the amputation on smaller body types. The second method is to first attempt to stop the bleeding by applying the tourniquet two inches above the wound. If bleeding does not stop, then a second tourniquet is applied around the bicep. The application of a second tourniquet is usually only necessary on lower limb amputations.

HapMed's E-MAT Arm

HapMed's E-MAT Arm is an instrumented mannequin arm (see Figure 1) developed for RDECOM-STTC by the Institute for Simulation and Training (IST) for training the proper application of a tourniquet. The arm was developed as a part of the Small Business Innovative Research Program (SBIR) with CHI Systems HapMed project. At the center of the HapMed project is a ruggedized instructor PDA used to teach the Army's training doctrine for applying and evaluating tourniquets. The PDA can control the E-MAT Arm in the same fashion as the proof of concept for teaching proper tourniquet application. The haptic arm is used as a haptic-task trainer for giving the student a physical device to interact with. The haptic arm portion of the HapMed project is the E-MAT Arm. This is the haptic arm that the proof of concept will interface.

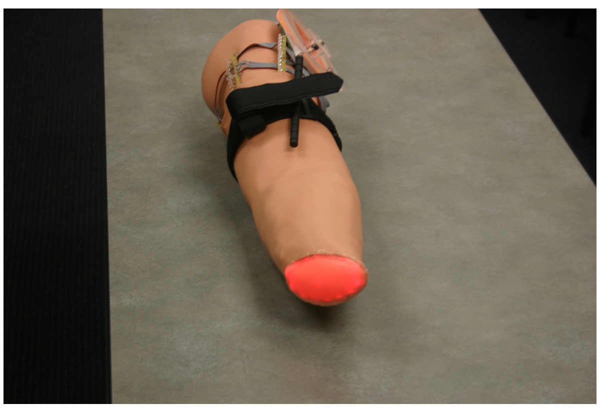

Figure 1. A photograph of the E-MAT Arm. A tourniquet is applied to the arm.

The E-MAT Arm has several characteristics. It has two modes of operation. E-MAT Arm can be used as a stand-alone haptic-task trainer or it can interface to applications using the Bluetooth protocol. The arm's construction is similar to human anatomy in that there is an inner support layer acting as the bone and then there is an intermediate layer to act like muscle tissue and finally there is the skin, so when manipulated or used in training it reacts very similarly to a real human.

The E-MAT Arm has several hardware features that support bleeding control training. First, there are four groups (one for each wound type) of LEDs along the arm to represent different bleeding rates. The available wounds are located at the wrist, forearm, elbow, and bicep. The second hardware feature is pressure sensors. Pressure sensors are placed along the arm to detect the application of a tourniquet. Another hardware feature is tactors which allow a pulse to be felt along the entire arm. Finally, the arm has a control panel. It allows for setting the body type (child, small adult, large adult) and wound location, and it also has stopwatch controls for assessment.

The E-MAT Arm has a microcontroller that allows it to have programmable behaviors. A physiological model simulates a bleeding wound. The physiological model behavior decreases the pulse rate and decreases heart beat intensity as the modeled wound continues to bleed.

The E-MAT Arm has the capability to wirelessly communicate with other devices. It uses the Bluetooth protocol to expose its functionality to other training systems. The arm interfaces as a client to a host server device. It has two sets of messages: one set of messages for the host to control the arm parts and another to report arm data to the host.

There are several advantages of using an instrumented mannequin arm for training. The biggest advantage is that the student can physically apply a tourniquet. This gives the student an accurate sense of the necessary torque (pressure) needed to stop severe bleeding wounds. Multiple body types allow the student to learn the different pressures necessary for different body sizes. Different wound locations also give the student a sense for the necessary pressure needed to stop bleeding at those wound locations. Another advantage of using this particular arm is that it can interface wirelessly with a host system, so it doesn't require wired connections which makes it much more mobile and easier to setup.

There are some disadvantages when training using the E-MAT Arm. Microcontrollers have limited memory that allows for only rudimentary physiological models to be implemented. Any features that could be added by modifying the firmware could potentially require the control panel to be modified to expose the new functionality. Microcontroller hardware limitations also makes it difficult to add AAR capabilities comparable to that found in PC applications. Another limitation is that wounds are restricted to only an arm at present and new hardware would need to be developed for different tasks and body parts.

TC3sim

TC3sim is a desktop Combat Medic training application (see Figure 2) developed for RDECOM-STTC and the U.S. Army AMEDD by ECS, Inc. It uses game technology to create single-player battlefield scenarios. TC3sim trains users in medical decision-making based on the tenets of Tactical Combat Casualty Care (TC3). It is primarily designed to rehearse decision-making in a tactical environment. They are presented with single or multiple casualties and must choose the priority and course of treatment by choosing menu items displayed in the context of the casualty and body part the student has selected.

Figure 2. A screenshot of TC3sim. A tourniquet is applied to the casualty's arm.

Each casualty has a physiological model that reacts to treatments and wounds. A casualty's physiological model has several parameters: blood volume, blood oxygen level, heart rate, and breathing rate. A casualty's wound effects the performance of these parameters. The physiological model then calculates physiological metrics that define the state of the casualty's health and the visible behavior. These include blood pressure, pulse rate, and level of consciousness. By selecting menu items that conduct tests on the casualty the student can get a report of these metrics. Similarly, the student can apply treatments that have positive or adverse outcomes based the state of the physiological model at the time of application.

An early look at the data of an ongoing Training Effectiveness Evaluation of the TC3sim (Sotomayor, Peters, Riddle, and Parsons, 2007) is suggesting TC3sim's appropriateness for rehearsing cognitive planning. It has many advantages in terms of cost, availability, flexibility, and safety. The lack of hands-on skills training is, however, a significant disadvantage. The development of psychomotor skills are paramount to preparedness in emergency situations. "The actions and protocols should come naturally; they should be second nature." (Moyer, 2004) RDECOM-STTC saw the integration of a decision-making, virtual simulation with task part trainers as a natural fit for medical training. And, a way of developing a student's cognitive integration of knowledge and skills.

Combining the E-MAT Arm and TC3sim

The E-MAT Arm and TC3sim were combined to create a proof of concept. A wireless interface is used to send messages to coordinate behaviors of the two systems and keep shared data of the two systems consistent. The system configuration has the PC act as the server and the arm act as the client.

The project experimented with creating a training exercise that uses both TC3sim and E-MAT Arm. The training exercise begins with the student in a TC3sim scenario. The scenario contains a casualty with an amputated arm. When the student selects to treat the casualty, TC3sim activates the E-MAT Arm. The student then switches to using the E-MAT Arm. When the student applies the tourniquet correctly to the mannequin arm, the casualty's bleeding stops in TC3sim. Once the casualty's treatment is completed using E-MAT Arm, the student proceeds with the training exercise using TC3sim.

The project had a small budget which weighed heavily in all project decisions. This usually resulted in not being able to implement the most desirable approach to combining the two systems. It also limited the amount of features that could be implemented that took advantage of combining the two systems. The design choices and features will be discussed in the rest of this paper.

ENHANCING DESKTOP TRAINING WITH A HAPTIC-TASK TRAINER

Combining a desktop simulator and a haptic-task trainer can create an enhanced training experience by taking advantage of the strengths of both types of training. This section discusses choices that must be made when combining these two different types of training systems. The choices made for the E-MAT Arm-TC3sim proof of concept project will also be discussed.

Overlapping/Duplicate Items

There are duplicate data and behaviors between the E-MAT Arm and TC3sim. This will most likely be the case when combining a simulator and a haptic-task trainer. In this project's case, the systems have duplicate physiological model outputs, duplicate physiological model behaviors, duplicate wound types, and several body type sizes. A choice of what to use must be made for each area of overlap. In general, when overlapping exists between systems, the choices are to use only one of the systems' data or behavior or a combination of both. Whatever the choice, the overlapping areas should be consistent as possible between the systems. Otherwise, inconsistencies between the two may confuse the user and ruin the training experience.

Duplicates: Physiological Model Outputs

First, let's look at the duplicate E-MAT Arm's and TC3sim's physiological model output. After identifying the specific duplicate output, alternate choices for handling the overlapping output will be discussed as well as the choices made to handle duplicate output for the proof of concept.

The E-MAT Arm's physiological model output has six bleeding rates, ten pulse rate values, and four pulse intensities. Each of the six bleeding rates is an incremental value with the largest value being unrestricted arterial bleeding and the smallest value being no bleeding. Each of the ten pulse rates are incremental values as well with the values ranging from 0 to 200 beats per minute. The four pulse intensities range from strong to weak.

TC3sim physiological model output for bleeding and pulse have continuous values over the same range of values as E-MAT Arm. TC3sim's pulse intensity values are similar; there are three values: weak, normal, and strong. There are differences in the range of physiological model outputs between the two systems. The differences need to be reconciled so that the simulations produce the same results.

As mentioned earlier, there are a couple choices for deciding how to reconcile system overlapping. The choice to use the TC3sim's output value types is eliminated since the E-MAT Arm is restricted by hardware limitations. For example, each wound's bleeding rate of the E-MAT Arm is restricted by the number of LEDs that can be illuminated (which is 5 red LEDs for bleeding plus 1 green LED for no bleeding). Something that could represent continuous values would be needed for E-MAT Arm bleeding rate (a replacement for the 6 LEDs) would be needed to use TC3sim's output value for bleeding.

Another choice is to have the TC3sim use the incremental values that E-MAT Arm uses for its bleeding rates. TC3sim bleeding rates would need to be quantized to match the incremental values of E-MAT Arm. The effect of this choice would be seen in the bleeding particle effect for the amputated arm. The bleeding particle effect is a visual special effect that is made to look like spurting blood from a wound. In this case, the spurting blood is starting from the amputation site. As the tourniquet is tightened and the bleeding rate decreases, the bleeding particle effect would stair-step to match the incremental values. The stair-step effect would only be noticeable for the heart rate only if something like the value is continuously reported in a GUI. If the heart rate is only reported whenever the pulse is checked, then the incremental values wouldn't be noticeable.

The third alternative is for each system to use its own value types. For the proof of concept, this alternative was selected. The inconsistency in value types is noticeable when applying the tourniquet. The LEDs (representing the flow of blood) on the arm turn off as the tourniquet is tightened. But, the particle effect on the TC3sim casualty's arm remains constant until the bleeding is completely stopped. Both the E-MAT Arm and TC3sim bleeding rates are used in the proof of concept. E-MAT Arm uses the intermediate values to turn off the wound LEDs to show that the tourniquet is being applied correctly and that the bleeding is being reduced. However, the TC3sim only uses two values for its physiological model output in the proof of concept: unrestricted arterial bleeding and no bleeding.

The recommendation for model outputs is to select the output type that is more restricted. Idealy, both systems values would be continuous. For example, the bleeding rate should use the continuous values that are defined by TC3sim. In the proof of concept, this would force the E-MAT Arm to rework the LED approach. Consequently, the continuous values would avoid the stair-stepping effect that would be seen on the TC3sim during bleeding rate reduction.

Duplicates: Physiological Model Behavior

The physiological model behavior is another area where the two systems overlap. Since the E-MAT Arm can operate stand-alone, it has behavior that models severe amputation bleeding. Another decision is how to coordinate this behavior with TC3sim's behavior for the severe amputation bleeding.

One option is to use the E-MAT Arm's behavior. The E-MAT Arm is ambiguous to behavioral models for tourniquet application, so guidelines would have to be set. TC3sim would have to use the pressure values from E-MAT to determine when the bleeding rates change (this is how the E-MAT Arm interface works). TC3sim can input a pressure value into its physiological model to determine its other outputs.

Another option is for TC3sim to control the bleeding of the E-MAT Arm. The arm's interface reports pressure values to the TC3sim. Those pressure values can be used to determine the bleeding rate for TC3sim. As bleeding is reduced, TC3sim sends messages to the E-MAT Arm to turn off wound LEDs. This presents the best approach since TC3sim's physiological model can be more complex since it doesn't have the same microcontroller hardware limitations. TC3sim could implement all of the tourniquet behaviors. Also, if the casualty has multiple wounds the previous approach could not take into account the additional wounds in its physiological model. Last, the pressure values that are reported by E-MAT Arm have a large range of values. This allows for a more precise bleeding rate to be computed. This computation will have a higher resolution than 6 values of the E-MAT bleeding rate.

For the project, both systems' behavior was used – this is another alternative to the methods described earlier in this section. As mentioned earlier with the bleeding rate data, this option produces incorrect results. The TC3sim bleeding particle effect didn't match for all values of the E-MAT Arm's wound LEDs. Both systems' behavior matched only for the states of no bleeding and some bleeding.

The recommendation is to use the behavior of the server system. Using a server system allows for custom functionality regarding integration with the arm. Using the server for implementing behavior also avoids microcontroller hardware limitations (memory constraints and processor computing power). The output values given by the haptic-task trainer should use as fine a resolution as possible so that the resulting outputs of the server physiological model do not have stair-step incremental outputs. For example, the pressure values reported by the arm give a fine enough resolution that the outputs of the TC3sim are not affected.

Duplicates: Wound Locations

Wound locations are another duplicate item that needs to be taken into account. The E-MAT Arm has four wound locations: wrist, forearm, elbow, and bicep. TC3sim casualty's amputation wound locations for an amputated arm are forearm and bicep. So, there are two fewer locations on the TC3sim's casualty than E-MAT Arm's. In this case, it is easier to add wounds in TC3sim's software than to modify the E-MAT Arm. The modification to TC3sim would include modeling changes as well as software changes. The casualty's model would need to be modified to contain the wrist and elbow amputation sites. The proof of concept simply restricted amputation sites to the forearm or bicep.

The recommendation is to have both systems have the same representation. This keeps everything consistent between the two systems. This prevents the user from getting confused because some wound sites on one system are not available on the other system.

Coordinating TC3sim and E-MAT Arm

There must be coordination between the two systems to effectively take advantage of their strengths. Since they both can operate by themselves, poor coordination between the two can leave the user confused as to which system to use. The E-MAT Arm can easily be turned off and on with a message from TC3sim. This gives the project an easy method for controlling when the E-MAT Arm is available to be used. The first condition for turning on the arm is the medic's virtual environment proximity to the casualty. The second condition is the virtual environment orientation of the medic relative to the casualty. The medic must be facing the casualty. If both conditions are true, then the E-MAT Arm is turned on. This allows the student to check the casualty's pulse regardless of whether the casualty has an amputation or not. The E-MAT Arm is deactivated when not close enough or not facing the casualty. When the student attempts to apply a tourniquet using TC3sim, a warning dialog should be displayed reminding the student to use the E-MAT Arm for applying tourniquets.

For the proof of concept, the user was only able to treat one casualty with an arm amputation in any one scenario. The feature to differentiate between casualties in the simulation was unable to be completed with the resources allocated to the project.

CONCLUSIONS

The idea of combining different modes of training is highly compelling, especially for medical applications. Medical procedures and especially combat medicine requires a significant amount of multi-tasking. Combat medics must keep situational awareness and make decisions about personal and team safety, their unit's mission, triage, and treatment plans for individual casualties. They must also have the psychomotor skills to perform medical interventions effortlessly and flawlessly. The E-MAT Arm helps to develop the hands-on skills for detecting pulses and applying tourniquets. TC3sim trains the combat medic to think about the decisions they need to make in a situation with either a single casualty or multiple casualties and the danger of opposing forces.

This project examined the challenges of combining two separate and independent simulations that are designed with different modes of training in mind. Combining the two more closely approximates the context switching combat medics will be required to do in real life situations. The most significant challenge resulted from a large amount of duplicated functionality across the two systems. Decisions had to be made about which system would be “in charge” of particular aspects of physiology and user interaction. In general, the guideline used was to allow the desktop simulation to represent the true parameters and have the client arm report its data to be incorporated into the desktop physiological model. There were several incremental improvement to this integration outlined in the paper, but the project ran out of time to implement them. Regardless, the demonstration that resulted was very compelling and should lead to more research in this area. Combining full human patient simulator mannequins with tactical combat simulations is an obvious next step. Following that, rigorous experiments looking at the training efficacy of combined, multi-modal simulations should be conducted. This was a technical proof-of-concept, but it is expected that the combination of these two kinds of simulations will prove to be highly effective in developing both the decision-making and psycho-motor skills of combat medics.

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