Physics-based Damage in a Combat Medic Training Simulation

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ABSTRACT

Combat medic training simulations should be immersive and realistic. Research has shown that immersive training results in better training and increased learning. Two distinct benefits have been shown; trainees achieve the training objective more quickly, and better retain the lesson.

For a combat medic training simulation to be realistic, injuries should correspond to the situation being simulated. In other words, in a combat environment where IEDs would be encountered, a trainee should see injuries consistent with IED attacks. This situational training will lead to fewer surprises for combat medics in the real battlefield. To increase training immersion, we propose using realistic scenarios and appropriate munitions for those scenarios. Injuries should be driven by the munitions in the engagement event.

This paper presents a methodology for integrating a game-engine based combat medic training simulation with a physics-based human injury model. For the combat medic training simulation, we will use the Tactical Combat Casualty Care Simulation (TC3sim). TC3sim will provide the game engine and training interface with which trainees interact.

We will use the Real-time Physics Effects Library (RPEL) for the physics-based human injury model. It will respond to detonation events sent from TC3sim, calculating the injuries to the individual combatants in the area. To accomplish this, RPEL will use well-established, validated fragment and blast models. These models will have to be adapted for real-time use.

Once these initial injuries are calculated, the results will be sent back to TC3sim. TC3sim will then display the injuries and run its own time-based physiological model, using the initial conditions determined by RPEL.

We will lay out a strategy for mapping RPEL's blast- and fragment-related injuries to TC3sim's supported injury model. We will also cite the research that has shown value in immersive training, and show how it justifies our work.

ABOUT THE AUTHORS

Jeff Lyons is an engineer at Applied Research Associates. He has a Bachelor of Science degree in mechanical engineering from Florida State University and a Masters in mechanical engineering from the Massachusetts Institute of Technology. Jeff's experience spans the mechanical engineering and software engineering disciplines. He has experience in structural analysis, CAD design, manufacturing support, and test support. Most recently he has worked in simulation and software design for military training and testing systems. Jeff leads the development of the Real-time Physics Effects Library (RPEL), which aims to advance the state of the art in real-time casualty assessment.

Alex Turek is an engineer at Applied Research Associates. He has a Bachelor of Science degree in computer engineering from the University of Central Florida. Alex has worked on the Real-time Physics Effects Library (RPEL) almost since its inception. He's also worked on the Area Weapons Effects Simulation (AWES), a component of the Combat Training Center Objective Instrumentation System (CTC-OIS).

Howard Mall is Vice President of Engineering at Engineering and Computer Simulations, Inc. He has spent the last five years building various kinds of training systems. He led efforts for the Navy to develop training solutions deployed on cell phones and hand-held computers. For the Army, he delivered the Tactical Combat Casualty Care (TC3) Simulation used by combat medics to learn triage and medical decision-making on a virtual battlefield. He led the development of the Emergency Management Nexus, a next-generation synchronous training platform for the National Guard Bureau that has become a virtual world platform serving myriad federal agencies. He currently oversees multiple engineering efforts at ECS.

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INTRODUCTION

As simulation technology advances and computers become more powerful, military training is becoming more realistic. Models and simulations leverage advances in gaming technology, including powerful physics engines and graphics processors (Mann et al, 2008). This increased level of realism and fidelity has been shown to help warfighters meet training objectives (Roman and Brown, 2008).

Also in recent years, several tools have emerged to help combat medics better train and prepare to treat warfighters injured in the battlefield. Live, virtual, and constructive training tools help these medics rehearse the proper actions that should be taken when injuries occur.

Physics-based models have also come on the scene as powerful tools for real-time training. Until recently, physics-based models had been too slow for real-time use. Real-time training and simulation software used gross approximations to estimate injuries due to weapons effects. With the advent of commercial-grade, freely available physics engines, real-time models exist that can accurately assess the effect of fragmenting munitions on vehicles, buildings, and humans (Mann et al, 2008).

This paper proposes the combination of these two modern technologies: a game-based combat medic trainer and a physics-based weapon effects model. The Tactical Combat Casualty Care Simulation (TC3sim) is a game-based combat medic trainer. This virtual training tool teaches medics how to care for injuries in the battlefield. The Real-time Physics Effects Library (RPEL) is a library of weapons effects models that uses a physics engine to calculate the effects of weapon events in real-time.

By bringing RPEL and TC3sim together, we will increase the realism, immersion, and fidelity of the combat medic training experience. In this paper we will give the background for the models used and explain how the integration effort brings it all together. We will also cite research that has shown the benefits of increased training realism.

Medical care for soldiers injured in combat is a critical part of our military. Giving these medics the best training possible is of the utmost importance to our military and warfighting effort. We believe that this work can advance the combat medic training state of the art.

COMBAT MEDIC TRAINING

There are a number of tools for combat medic training available to the warfigher. In the virtual domain, one of these is the Tactical Combat Casualty Care Simulation (TC3sim, Sotomayor et al, 2007). This game-based tool has scripted scenarios that allow trainees to interact with virtual injured warfighters. The medic-in-training must select which of several possible actions he should perform to treat the patient. The trainee’s success depends on whether or not he performs the correct actions, and how quickly he performs them. Depending on the scenario, the trainee must deal with multiple patients and perform proper triage.

While this training is valuable and effective, TC3sim operates in a very scripted fashion. The injuries that occur depend on the scenario setup; simulation actions or events do not affect injuries. As part of this effort, we upgraded TC3sim to send the engagement event to the Real-time Physics Effects Library (RPEL) for calculation of the appropriate injury.

PHYSICS-BASED HUMAN INJURY MODELS

The Real-time Physics Effects Library (RPEL) is a library of physics models that serves as a simulation framework for real-time physics-based weapons effects calculations (Mann et al, 2008). RPEL uses a physics engine to simulate first principles physics. (We’ve used both PhysX and Bullet physics engines.)

This library includes models for human casualty assessment. In this section we will discuss the models used for this assessment.

Kokinakis-Sperrazza

In January 1965, the Ballistic Research Laboratories at Aberdeen Proving Ground published a report authored by William Kokinakis and Joseph Sperrazza titled "Criteria for Incapacitating Soldiers with Fragments and Flechettes" (1965). The report provided estimates for the probability that a hit from a single steel fragment or flechette would incapacitate a soldier. They based their estimates on testing done on gelatin and goats.

According to the report, the probability of incapacitation given a fragment hit is:

$$P_{i/h} = 1 - e^{-a(m{v_0}^{\frac{3}{2}} - b)^n} \tag{1}$$

Where m and v_0 are the fragment mass and initial striking velocity respectively, and a, b, and n are constants determined from the tactical situation and time at which incapacitation occurs. The values for these constants (a, b, and n) are in the report.

The Kokinakis-Sperrazza method (sometimes referred to as KS for brevity) has provided a closed form approximation for human incapacitation due to fragmenting munitions for over forty years. Though few people know it, KS is the underlying methodology for many models and simulations that are currently used for training. For example, the human RTCA data in CCTT and OneSAF came from a model that used KS.

While KS is an excellent approximation tool, it has limitations. Beyond the application of the survivor rule, cumulative effects are not considered. (The survivor rule aggregates injuries by aggregating their corresponding incapacitation probabilities. Thus it does not truly aggregate events, as it treats all injuries as independent and unrelated.) Also, KS does not model specific injuries.

Axelsson

Axelsson and Yelverton (1996) showed a strong correlation between chest wall velocity and non-auditory blast injury. They developed an equation that mapped chest wall velocity to the Adjusted Severity of Injury Index (ASII):

$$ASII = (0.124 + 0.117\,V)^{2.63} \tag{2}$$

ASII is a standard tool for evaluating blast injuries. It can evaluate blast injuries in terms of trauma to the whole animal as well as individual organs. In (2), V is the maximum chest wall velocity. Axelsson proved this correlation through live testing on animal subjects.

Axelsson and Yelverton (1996) use a single chamber, one lung model, assuming pressures are identical on both lungs. Bowen et al (1965) and Fletcher (1970) originally developed this lung model based on a spring-mass system.

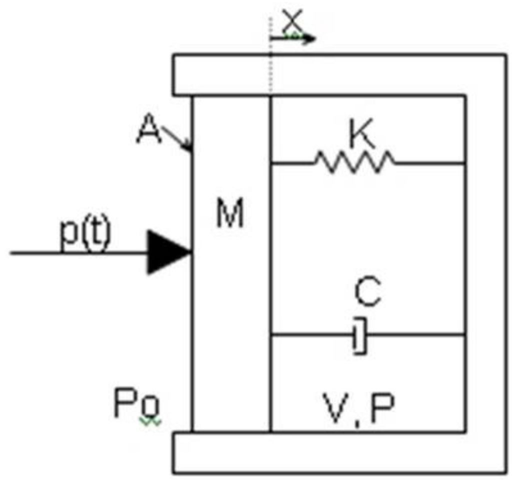

Figure 1. Single-Chamber One-Lung Model used by Axelsson

In this model, A is the effective area, M is the effective mass, V is the initial gaseous volume of the lungs, x is the displacement, C is the damper coefficient, K is the spring constant, Po is the ambient pressure, p(t) is the overpressure over time, and γ is the polytropic exponent for gas in lungs.

Chest wall response (displacement, velocity, and acceleration) and intra-thoracic (lung) pressure can be calculated for different complex blast waves and ideal blast waves as well. The equation for the model is:

$$M\,\frac{d^2x}{dt^2} + C\,\frac{dx}{dt} + Kx = A\left[p(t) + P_0 - \left(\frac{V}{V - A*x}\right)^{\gamma} P_0\right] \tag{3}$$

The model parameters for (3) are given in Table 1.

Table 1. Model Parameters for a 70 kg Mammal (Axelsson and Yelverton, 1996)

Parameter	Units	Value
M	kg	2.03
C	Ns/m	696
K	N/m	989
A	m^2	0.082
V	m^3	0.00182
γ	unitless	1.2

Using equation (3), we determine the chest wall velocity V, and plug that into equation (2) to get the ASII level. Table 2 shows what injury levels can occur at different velocities and ASII levels.

Table 2. Injury levels and corresponding ASII levels and velocities (Axelsson and Yelverton, 1996)

Injury Level	ASII	V (m/s)
No injury	0.0 – 0.2	0.0 – 3.6
Trace to slight	0.2 – 1.0	3.6 – 7.5
Slight to moderate	0.3 – 1.9	4.3 – 9.8
Moderate to extensive	1.0 – 7.1	7.5 – 16.9
> 50% lethality	> 3.6	> 12.6

Table 3 shows how ASII levels map to particular lung injuries. Similar tables exist for pharynx, larynx, trachea, the gastrointestinal tract, and solid abdominal organs.

Table 3. Injury Levels and Associated ASII Levels for the Lungs (Axelsson and Yelverton, 1996)

Injury Level	Description or Signification	ASII Level
Negative	No injury	0
Trace	Scattered surface petechiation or minimal ecchymoses involving less than 10% of the organ.	3
Slight	Areas of extensive petechiation to scattered parenchymal hepatization involving less than 30% of the organ.	3 – 4
Moderate	Areas of hemorrhage ranging from isolated parenchymal contusions to confluent hepatization involving less than 30% of the lungs.	3 – 4
Extensive	Isolated parenchymal contusions and confluent hepatized regions encompassing areas equal to or greater than 30% of the organ.	4 – 5

ORCA

The Operational Requirements-based Casualty Assessment (ORCA) software system allows users to determine if an injured individual is still capable of performing his assigned duties (Partch et al, 2003). If he is not capable of performing his duties, an operational casualty has occurred. ORCA is a set of models capable of assessing injuries from various insults including blast, penetration, thermal exposure, toxic gases, blunt trauma, abrupt acceleration, and directed energy. Based on these insults, ORCA degrades the subject's initial capabilities and compares the degraded capabilities to the required capabilities.

ORCA takes into account more factors than KS and Axelsson. It is more complex and realistic than those methods. However, it is a slower model and has not been adapted for real-time processing. Neither RPEL nor TC3sim currently use ORCA, though we are interested in evaluating its real-time potential.

REALISM IN MODELS AND TRAINING

When designing a model or simulation for training, one must assess the realism and fidelity needs for the use case. The requirements depend on the learning objectives for the model's or simulation's end users.

In IITSEC 2008's best paper, Dr. Roman (2008) showed how, in three or four separate experiments (including one of his own), realistic, immersive game-based training achieved better training in less time. In some cases, the objectives were achieved twice as often, in half the time, compared to training that was non-immersive without games.

Mantovani (2003) also showed how higher levels of immersion yielded improved learning outcomes. John Mann (2008) demonstrated that lookup table approaches to RTCA (real-time casualty assessment) can lead to inaccurate effects and negative training. Dr. Singer (2008) argued that the lack of simulated injuries is a deficiency in game-based training.

All the aforementioned research demonstrates that warfighters achieve training objectives more thoroughly and quickly with increased training realism and immersion. An immersive training experience leads to warfighters that are more prepared for the fully immersive battlefield. It is because of this research that we propose the higher fidelity approach outlined in this paper.

INTEGRATION IMPLEMENTATION

System Overview

Figure 2 shows at a high level the components and their interactions in this simulation.

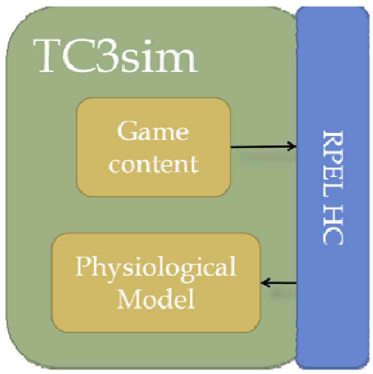

Figure 2. TC3sim and RPEL are integrated to leverage the strengths of each.

TC3sim provides the gaming engine and content. When an IED goes off with soldiers in the affected area, TC3sim sends the event details to RPEL. RPEL then invokes its HC (Human Casualty) module to determine injuries for all affected soldiers. We map the model results to TC3sim injuries, then send them to TC3sim. TC3sim uses these injuries as inputs to its physiological model. This time-based model then runs based on these initial injuries. A soldier's condition can then improve or worsen depending on the care given.

Figure 3. TC3sim sends RPEL data for the human players at ground zero. The TC3sim gaming environment is shown here.

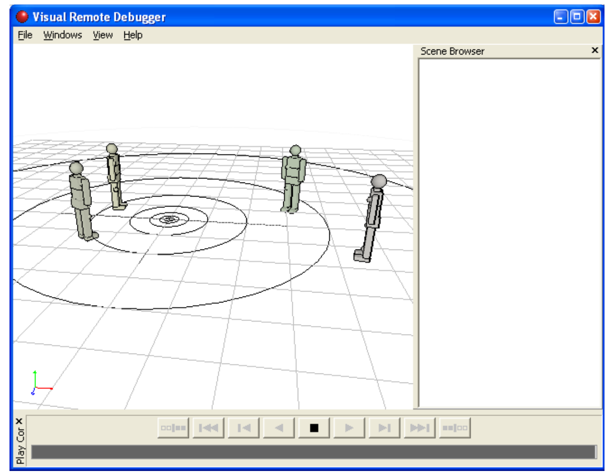

Figure 4. RPEL receives data from TC3sim for the human players at ground zero. RPEL's physics environment is shown here. (This physics visualization tool is only used for development and debugging. It is not required by the application.)

Figure 3 shows TC3sim's gaming environment and Figure 4 shows RPEL's physics environment. The gaming environment immerses a trainee into the battlefield scenario. RPEL's environment simplifies objects to their key physical attributes. The human body is divided into six functional components. These components are consistent with the Kokinakis-Sperrazza and Axelsson methodologies discussed earlier.

The IED event received from TC3sim contains the information RPEL needs to accurately place the human participants in the physics environment.

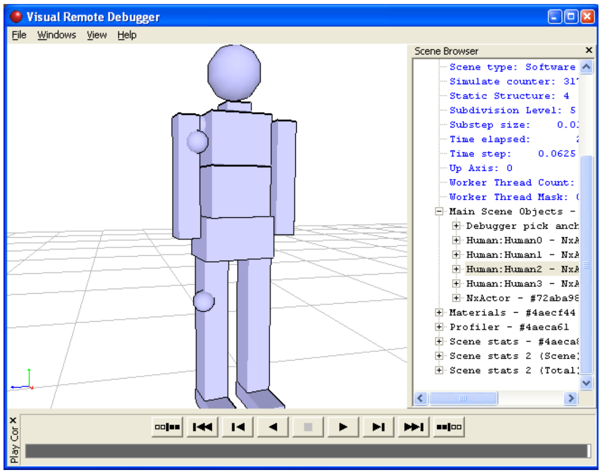

Figure 5. Based on the IED event received from TC3sim, RPEL calculates the fragment spray, determines subsequent injuries, and sends the results back to TC3sim. Fragment impacts are shown as spheres on the figure's right-hand side.

Figure 6. In the case pictured here and in the previous figure, RPEL determined significant fragment impact at the right arm and leg, which resulted in amputations in TC3sim.

Software Integration

TC3sim is the game with which users interact. Thus it was packaged as an executable. RPEL functions as a software library that TC3sim calls upon to calculate event results. Thus RPEL was packaged as a dll (dynamically linked library). We added a RPEL interface to TC3sim that made the appropriate RPEL API calls. The interface sent event details to RPEL, and listened to RPEL for the event results.

Underlying RPEL Models

Fragment and Blast

The IED event that TC3sim sends to RPEL contains a code for IED type. It could be a large pipe bomb, an IED composed of military ordnance (M155 tank rounds), a suicide bomb vest, etc. We agreed on these IED parameters beforehand and made them part of RPEL's internal database. The IEDs are characterized by their fragment pattern (captured in the ZDATA file format) and blast (characterized by explosive type and amount).

Driels sections 5.14 and 6.3 (2004) describe how a munition's fragments fly out based on its ZDATA. RPEL generally follows this established methodology. RPEL uses a commercial physics engine (we've used both PhsyX and Bullet) to perform fragment flyout and impact the target. These engines are optimized for real-time physics calculations. A munition might have many fragments, but by using a commercial physics engine and dividing our fragment pattern into discretized shotlines as described in Driels section 6.3, we are able to do a full fragment impact analysis in real time.

Kokinakis-Sperrazza Implementation

With these fragment impacts, we can apply the Kokinakis-Sperrazza equation and constants for the body component impacted. The KS model then gives us time-to-incapacitation, which we are able to map to an injury severity for that body component.

Axelsson Implementation

We derive a blast environment based on the IED's explosive type and amount. With this environment we can estimate a chest wall velocity based on the blast, which is the key parameter in the Axelsson model described earlier. From this we map to the appropriate ASII injury level.

Mapping of RPEL Injuries to TC3sim Injuries

TC3sim, RPEL, Kokinaki-Sperrazza, and Axelsson were developed independently without common goals or requirements. Therefore there is not a common set of injuries, injury severities, or body parts between the models. As part of this integration effort, to interface models and simulations together, we had to agree upon a mapping for certain body parts, postures, and injuries.

For example, TC3sim distinguishes between the upper right leg and the lower right leg. RPEL and KS only have models for the right leg as a whole. Thus when RPEL calculated an injury to the right leg, we randomly chose whether to report an upper or lower leg injury to TC3sim.

As another example, Axelsson determines injuries to the thorax or lungs. TC3sim doesn't explicitly model these organs. Thus our API mapped these RPEL injuries to chest and/or back injuries in TC3sim.

We did not gain approval from any medical authority for the mappings; we did it based on what seemed logical and appropriate. Thus the mapping is satisfactory for a prototype effort. However if this product were to be deployed, this mapping would need to be scrutinized and approved by a validating authority.

CONCLUSION AND FUTURE WORK

This paper and the corresponding work have shown that a game engine and a physics-based model can be integrated to create a product that trains combat medics in a realistic and immersive manner. We employed industry standard physics models and gaming technologies. The integration effort itself only took about three months, with one developer working on the TC3sim portion and another working on the RPEL portion.

While this prototype shows significant potential, there is much more work that could be done. The implementation was done rapidly and the product was considered a prototype. The product is not ruggedized or fully tested for deployment. If we were to deploy the product, more rigorous integration and testing would be required.

As previously mentioned, the appropriate validating authority should scrutinize the data and injury mapping. A validating authority, perhaps AMSAA, should also review the overall model.

The potential for more models and realism is tremendous. The ORCA model is a more detailed and realistic human injury model. This model has not yet been adapted for real-time use. The RPEL development team has discussed this potential with ORCA developers. Both parties believe this would be an important development for real-time training and the advancement of human injury modeling.

The human soldiers in our current model are assumed to be wearing normal clothing. Using basic penetration models that are already part of RPEL, we could add body armor to the humans. This would be a valuable training tool to show trainees the effects of body armor.

Figure 7. Body armor is critical for protecting warfighters. Medic training would benefit from modeling its effects.

RPEL has models for vehicle damage. We have not yet combined our human injury and vehicle damage models to create a vehicle occupant capability. This would be another valuable training tool to show trainees the different protective effects of varying vehicles.

Figure 8. By combining vehicle damage and human casualty models, we could have a vehicle occupant casualty assessment capability.

Combat medics and in-field warfighter treatment will improve with continued development of medical training tools. It is important for the modeling and simulation community to advance the technology, increase training fidelity, and push these solutions to the warfighter.

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