ADVANCING THE BEHAVIOR MODELING AND VISUALIZATION OF ENTITIES IN THE GROUND VEHICLE SIMULATION LABORATORY

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ABSTRACT

The U.S. Army Tank Automotive Research, Development, and Engineering Center's (TARDEC) Ground Vehicle Simulation Laboratory (GVSL) has provided warfighter- and hardware-in-the-loop simulation of current and future vehicle systems for several years. Gaps remain in GVSL capability regarding the visualization and behavior modeling of human entities. Filling these gaps is necessary to create an immersive and realistic urban environment for warfighter-in-the-loop patrol or convoy simulation. The current gaps in behavior modeling and visualization capabilities are being addressed through an academic partnership. The five-year project, part of the Simulation-based Reliability and Safety (SimBRS) program, is leveraging capabilities to generate a wide range of animations in the GVSL environment from human motion capture data and to develop extended and new vehicle and pedestrian behavior models. This long-term effort will significantly impact the breadth and realism of simulations possible using the TARDEC GVSL.

INTRODUCTION

The U.S. Army Tank Automotive Research, Development, and Engineering Center's (TARDEC) Ground Vehicle Simulation Laboratory (GVSL) is responsible for designing and executing soldier-in-the-loop distributed virtual simulations to improve Army ground vehicle systems. Experiments conducted at GVSL have ranged from obtaining physiological data on situational awareness decision-making [1] to creating vehicle usage profiles for hybrid electric combat vehicles [2].

Subject feedback from these experiments has shown the need to improve on the visualization and human behavior modeling capabilities of TARDEC GVSL's framework. Suggestions included improving the wandering behavior of human entities; developing behavior code for civilian interaction to map-based points of interest; improving red force human entity engagement response to blue force entities; improving human entity response to fire, ambush, and Improvised Explosive Device (IED) events; improving human model animations within the virtual environment; and, adding animal entities to the virtual environment.

As a result, TARDEC, through the Simulation-based Reliability and Safety (SimBRS) program, has partnered with researchers in academia to begin addressing these gaps. SimBRS researchers located in Starkville, MS have modified their motion-base driving simulator to use the TARDEC GVSL simulation framework. Using the system in Starkville, MS as a development and testbed environment, researchers are working to implement multiple solutions for identified gaps. Researchers recorded realistic motions using a motion capture system and generated animations that will be implemented into the TARDEC GVSL framework.

Additionally, researchers developed behavior simulation code that shows improved adaptive behaviors for red force, blue force, and civilian entities. All animations and behaviors were demonstrated by a scenario designed around a convoy escort mission.

In 2009, a procedural pipeline was developed to streamline the animation process. As of June 2010, human model motions have been collected, cleaned, and added to the simulation framework. A new behavior was also developed that allows civilian entities to join a path at a point closest to their current location. By 2011, civilian and red force entity improvements are expected to be completed. Researchers will also investigate ways to improve vehicle behavior, which will include incorporating defensive driving practices and realistic responses from ambush and IED events.

These additions and modifications will improve the visualization and behavior modeling capability under TARDEC GVSL's current simulation framework. With improvements in visualization and behavior modeling, TARDEC GVSL will be able to develop more immersive virtual environments and realistic urban combat scenarios in future simulation experiments.

Simulation Framework

GVSL contains two six degree-of-freedom motion base simulators: the Ride Motion Simulator (RMS) and the Turret Motion Base Simulator (TMBS). The RMS and TMBS share the following general simulation framework.

Within the control room, a motion control console sends user commands to a motion controller over a dedicated Ethernet subnet (UDP). For visualization, a rack of Image Generators (IGs), each dedicated to a single monitor, generate scenes to the subjects inside the crew station of the simulator. The IG computers use an open-source simulation engine maintained by the Naval Postgraduate School. Additionally, the character models used in GVSL's virtual environments were animated using an open source 3D character animation library.

On the simulation side, GVSL uses both open-source and commercial software packages to generate forces and implement vehicle models. A commercial product is used for modeling vehicle dynamics, for generating vehicle engine sounds, road noise, firing and detonation sounds, for logging Distributed Interactive Simulation (DIS) communication, and as a framework for integrating subsystems. Another commercial product is used to record video and audio of the subjects, and to record simulation data from the vehicle model. The One Semi-Automated Force (SAF) Testbed Baseline (OTB) is used as the computer-generated forces (CGF) system. Finally, to maintain interoperability in its systems, GVSL uses the DIS standard.
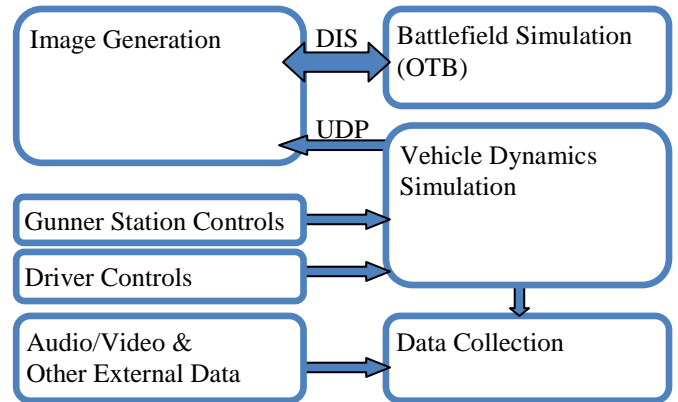

Figure 1: High-Level diagram of the GVSL simulation framework.

Scenario

To demonstrate the improved visualization and behavior modeling of the entities, a scenario designed around a convoy escort mission was developed in OTB. In this scenario, a convoy composed of blue forces passes through a small urban area, while civilian entities walk along routes in an operator-defined space. At some point in the blue force convoy's route, an Improvised Explosive Device (IED) is placed, and a group of red force human entities prepare for an ambush on the blue force convoy.

During a scenario simulation run, participants are tasked with manning the lead vehicle in the convoy. One participant acts as the driver with at least one additional participant controlling a simulated CROWS station. As the participant-controlled vehicle approaches the red force ambush location, an IED blast detonates in the middle of the roadway, nearby civilians flee the scene, and red force entities move into position and begin firing on the participant vehicle. The CROWS station participant is expected to engage the red force entities while the driver drives through the contact zone.

HUMAN ENTITY VISUALIZATION

The character models used in GVSL's virtual environments have a limited set of animations: idle, walk, run, kneeling, lying prone, firing weapon, fall down, and dead. This limited set of animations constrained the ability to properly visualize human entity activities in the GVSL IG. In order to alleviate these constraints, SimBRS researchers in Starkville, MS implemented an animation pipeline allowing them to generate animations compatible with the existing character models using motion capture and commercial-off-the-shelf software.

Animation Generation

The GVSL simulation framework uses an open-source animation library, as implemented in an open-source simulation engine, for character animation. The library manages storage and playback of animations for character models. The library defines a collection of files used to store character model data. The characters consist of five files: a configuration file, a skeleton file, a set of mesh files, a set of animation files, and a set of materials. The configuration file describes how the collection of files represents a character. The skeleton file defines a hierarchical bone system describing the structure of the character. The mesh files describe the 3D geometry representing the character's form and relationships between the surface geometry and the underlying hierarchical skeleton. The material files describe material and texture data for painting the surface of the geometry. In order to extend the capabilities of the GVSL characters, new animation files, compatible with the already existing skeleton file, were created.

The animation pipeline process is a multi-step process starting with 3D marker motion data and ending with animation files. Figure 2 depicts the stages in the pipeline.
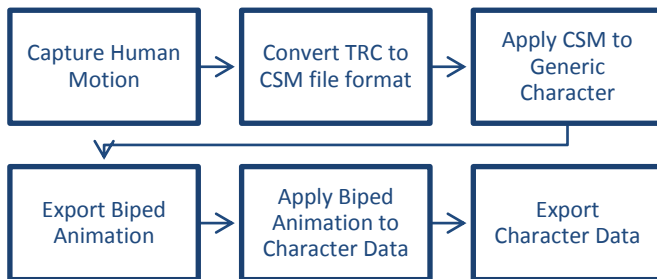

Figure 2: Animation generation pipeline.

In the first stage, a 14-camera near-infrared passive IR motion capture system was used to collect human motion data. Motion capture technology provides the capability to quickly create a wide range of realistic human motions. Animations were collected using a single male actor. The actor was marked with 42 motion capture markers. A custom marker set was developed that was a superset of a commercial marker set. Figure 3 illustrates the positioning of the markers on a human figure.

The motion capture system generates 3D position data over time for each marker. During the task, visual noise and environmental objects obscure markers and create duplicate markers. Automated and manual clean-up procedures are used to process the captured motion data into a continuous track of all of the markers. This clean marker motion data is stored in a TRC file format.
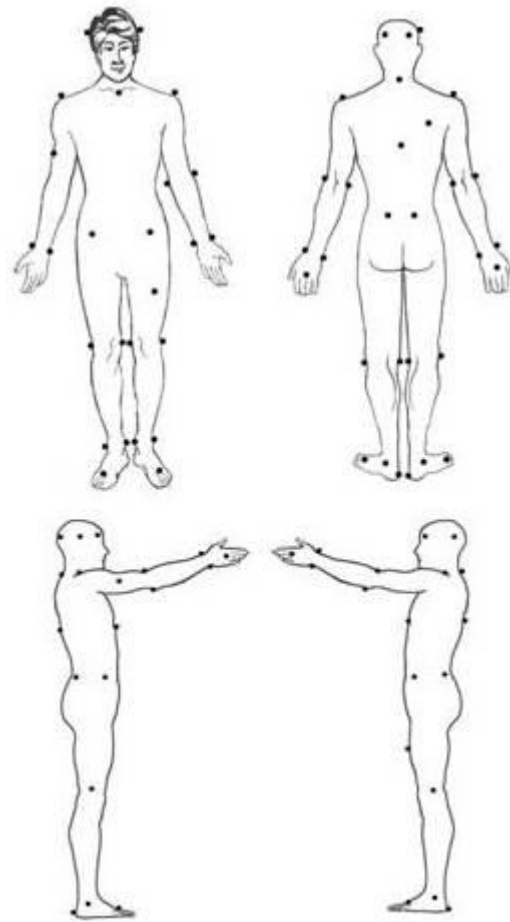

Figure 3: Custom marker set for motion capture data collection.

Once the motion capture data is collected and processed, the data must be converted from marker motion data to hierarchical skeletal motion data and exported to an animation library. Multiple methods of generating animation files were explored. A commercial modeling, animation, and rendering software package proved to be the most effective method for converting motion data to character data for the GVSL characters.

The commercial modeling software package provides functions to import the raw marker motion files and apply them to the character files. The commercial modeling software package uses the imported CSM data to drive the motion of the character model based on the motion of specific markers at known location on the surface of the body.

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Advancing the Behavior Modeling and Visualization of Entities in the Ground Vehicle Simulation Laboratory, Carruth, et al.
Page 3 of 7

Table 1: Animations Created for GVSL Characters.

Animation	Type	Description
Idle – Slow Shift	New	Entity stands in one location slowly shifting weight from one foot to the other.
Idle – Impatient	New	Entity stands in one location shifting weight from one foot to the other and occasionally tapping one foot.
Idle – Look at Watch	New	Entity looks at his/her watch.
Walk	Replacement	Basic walking gait.
Run	Replacement	Entity appears to be on a quick jog.
Limp	New	Entity limps on his/her right leg.
Crawl	New	Entity moves while remaining prone.
Firing Weapon while Standing	Replacement	Entity fires his/her weapon from a standing posture.
Firing Weapon while Kneeling	New	Entity fires his/her weapon from a kneeling posture.
Stand/Kneel Transitions	Transition	Entity kneels down and entity stands up.
Stand/Prone Transitions	Transition	Entity drops down into a prone position and stands up.
Hit by Gunfire	New	Upper body jerks in response to being hit by gunfire.
Fall Down	Replacement	Entity responds to being hit and falls down.
Dead	Replacement	Entity lays in the final position after falling down.
Kneel	Replacement	Static pose for kneeling. Replaced old kneeling static pose to match stand/kneel transitions.
Prone	Replacement	Static pose for prone posture. Replaced old prone animation to match stand/prone transitions.

For example, the movement of the foot is driven by up to five markers: outer ankle, heel, outer metatarsal, inner metatarsal, and toe. Imported CSM motion data must be calibrated for differences between the 3D character model and the human actor. Figure adjustments correct for differences in bone segment lengths. Pose adjustments correct for differences in posture then applied to a biped character. Once the animation has been calibrated, the animation may be adjusted to improve smoothness of playback, ensure that the animation will loop, and otherwise improve the quality of the animation. The final animation is then saved as a BIP animation file that can be applied to any biped-based character.

The BIP animation file format is a hierarchical animation data format that can be applied to a character using the biped bone system for animation. The GVSL characters are built on the biped bone system. The exported BIP animation file format is then applied to the GVSL character's biped and the resulting animation is exported to an animation file.

With the pipeline in place, the existing animation set was modified and extended. Three types of animations were collected and exported: replacement animations, new standard animations, and new transition animations. Replacement animations are simply new versions of the animations that already existed but were not satisfactory. For example, the original running behavior for the red force entities did not accurately reflect a typical posture and

motion for running with a weapon. New animations were added to visualize postures reported by OTB but not currently available in the GVSL. Transition animations depict movement between postures, i.e. changing from a standing posture to a kneeling posture. Table 1 lists the animations created for the GVSL characters.

The first pass of new sets of animations are still limited in scope and do not cover the full set of possible states that are reflected in the DIS Entity State Update PDUs. However, a pipeline is in place for generating additional animations quickly on an as-needed basis. Additional animations will be created in future stages of the project to accurately visualize the state and activities of human entities in the simulated environment.

Animation Variability

While new animations will significantly improve TARDEC's capability to visualize human activities in the simulation framework, simply adding new animations will not solve all of the immersion issues. A reported issue in the TARDEC GVSL is the synchronized playback of animations across multiple entities and an accompanying break in immersion for subjects. All of the GVSL digital human models share similar sets of animation data. If many entities initiate an animation, i.e. walk, at the same moment, the playback of the animation in the IG will be synchronized in an artificial and immersion-breaking manner. Figure 4

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Advancing the Behavior Modeling and Visualization of Entities in the Ground Vehicle Simulation Laboratory, Carruth, et al.
Page 4 of 7

shows a group of US soldiers running with the same animation. For every soldier, his left heel is striking the ground, his right knee is flexed at a 90° angle, and his weapon is held up in front of him. The lack of variability in the motions of multiple entities does not match reality and can capture a subject's attention during a simulation.

Figure 4: US soldier models running after a simultaneous start.

SimBRS researchers in Starkville, MS are employing two methods to introduce animation variability: multiple animations for a given task and pseudo-random start delays. For certain tasks, i.e. "stand idle", researchers have created multiple animations to avoid every "idle" character playing the same animation at the same time.

The stand idle animation depicts a relatively slow shifting of weight from one foot to the other and is suitable for repeated playback. The idle look at watch depicts the avatar looking at a wristwatch to determine the time. While not suitable for repeated playback, idle actions like these break up the repeating animations and create apparent activity in the visualization of the characters. The idle impatient animation is similar to the stand idle animation but depicts a faster shifting of weight, additional arm movement, and foot tapping. By generating multiple animations for common states, we can significantly increase the variability in our animations.

However, with a large number of entities in an environment, there remains a high likelihood that several entities will select and play the same animation. Additionally, certain animations are more likely to be noticeable than others. If even 2 of 20 entities play the idle look at watch animation at the same instant, this may be noticed by subjects and may distract them from their task as they contemplate the simulation environment and not the task at hand in the scenario.

In order to avoid the simultaneous playback of an animation, we apply a pseudo-random delay at the start of

the animation. This creates an offset in the animation playback across two characters. Figure 5 depicts a group of soldiers running with a start delay offset. This offset increases variability in playback and reduces the likelihood that entities will begin the same animation simultaneously.

Figure 5: US soldier models running with start delay offset.

Height Variability

Obviously, a population of humans will not have identical height and weight. However, when populating an environment with a limited set of digital human models, the variation in the height of the human entities visualized in the environment will often be very low. In order to introduce variability to the visualization, we can apply a scaling factor to the character data. Using standard random number generation codes will result in a collection of pseudo-random numbers in a linear distribution (see Figure 6). Human height is more appropriately modeled using a normal distribution (see Figure 7). A Box-Muller transform (Equation 1) can be applied to two linearly distributed pseudo-random numbers, U1 and U2, to generate a standard normal deviate [3]. The deviate is applied as a simple scaling factor.
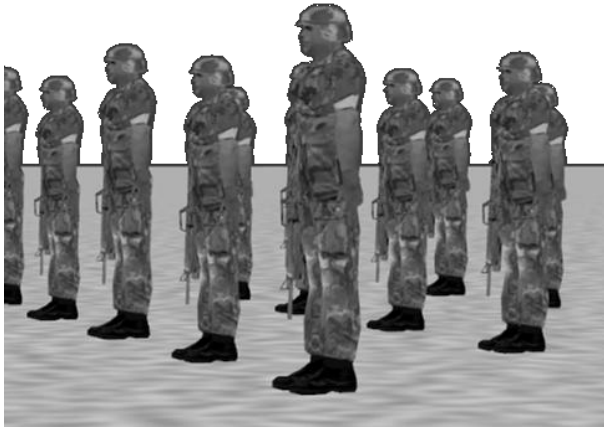
$$Z_0 = \sqrt{-2\ln U_1}\cos(2\pi U_2) \qquad (1)$$

Advancing the Behavior Modeling and Visualization of Entities in the Ground Vehicle Simulation Laboratory, Carruth, et al.

Page 5 of 7

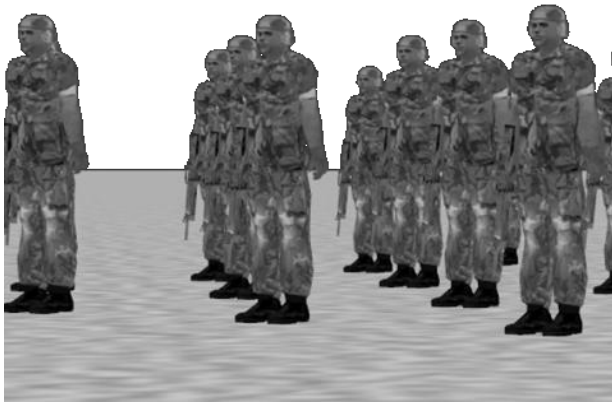**Figure 6:** US Soldier models with uniformly distributed height variability.

Figure 7: US Soldier models with normally distributed height variability.

HUMAN ENTITY BEHAVIOR MODELING

The convoy escort mission scenario requested by TARDEC requires revision and extension of entity behaviors to fill gaps identified in the available OTB behaviors. OTB uses a sequence of task frames for modeling entity behavior. A set of tasks is available for entities (the exact set varies by entity type) and each task simulates the desired behavior.

For example, the Move on Exact Path task directs an entity to move along an operator-defined path. The Move on Exact Path task is effective for creating ambient civilian traffic on the sidewalks and in the alleys of the urban environment. However, Move on Exact Path has two major weaknesses: First, entities executing the Move on Exact Path have limited awareness of events in the environment and do not react appropriately to combat-related events. Second, Move on Exact Path expects the entity to join the path at the beginning of the path. This assumption is reasonable if only one entity (located near the beginning of the path) is using

the path. However, for civilian ambient traffic, creation of a path for every civilian entity is impractical and it would significantly reduce operator effort if a generic path through an environment could be defined with many entities using the same path.

The second issue was corrected by simply modifying Move on Exact Path in such a way that an entity, when assigned the task, would find the closest point along the path to its current position. The entity would then move on a straight line to the closest point and join the path at that location. Using this modified method for joining the path and requesting that the entity's repeat the path indefinitely, an effective method for simulating ambient civilian traffic with a limited number of paths was created.

The resolution to the first issue is currently being investigated but will require combination of the Move on Exact Path behavior with additional behaviors designed to autonomously react to combat-related events such as detonations, gunfire, and/or casualties.

A major goal for the improvements to the TARDEC GVSL simulation framework is to make the behaviors of the civilian units more natural. Current task behaviors tend to be focused on executing a specific task and are not reactive to events occurring in the simulation environment. For example, while the civilian entities will move to avoid another civilian entity, the entities cannot otherwise interact. In order to depict more realistic civilian behavior in the TARDEC GVSL, the entities need to be able to interact not only with other human and vehicle entities but also with the environment itself. In upcoming phases of the research and development effort, SimBRS researchers are exploring integration of task behaviors into an all-encompassing autonomous task behavior that would prioritize goals and react to changes in the environment.

Future Behavior and Visualization Efforts

There are limitations of the DIS protocol that constrain our ability to fully visualize the interaction of entities with the environment. The standard PDUs cannot fully describe an entity's actions in the environment. For example, when a civilian entity moves along the operator-defined path and shifts to avoid an oncoming entity, there is no change in the contents of the PDU to reflect whether the new orientation and velocity vectors are due to movement around an obstacle or movement along the path. If we were aware of the reason for the new orientation, we could realistically visualize the interaction between the entity and the obstacle. In another example, when an individual combatant entity stops and kneels at a location, OTB's DIS PDUs provide no context to explain what the purpose of the change in movement and posture is meant to accomplish.

In both cases, by considering the IG and other events in the simulation environment, we can attempt to infer the intent of

the behavior and visualize a richer representation of the entity behavior. In the first case, in the IG, we are aware of both entities and can recognize that the two entities are near one another. Rather than playing a default walk animation, we can use a head animation to visualize the two entities looking at each other, perhaps acknowledging one another, and use a modified walk animation to rotate the shoulders so the torso is towards the other entity suggesting they are sliding by one another. In the second case, if there are detonation and fire PDUs nearby and the entity is near an object, we can infer that the entity is seeking cover by stopping and kneeling. Rather than playing the basic kneel animation, we can kneel against the obstacle visualizing the entity status in the battlefield simulation and the intent of the simulated behavior without additional PDUs. With this visualization of inferred behaviors, we can enrich the simulation for subjects in GVSL scenarios without significantly expanding the behavior modeling or extending the PDU protocol in OTB.

Another future application of the inferred behavior visualization technique will be the visualization of entity activities at generic points of interest. By inferring behaviors that do not materially impact the battlefield scenario simulation in OTB, we believe we can significantly increase the number of behavior visualizations in the IG creating a more active and natural environment.

DISCUSSION

The TARDEC GVSL requires immersive simulation environments to ensure that subject performance during soldier-in-the-loop scenarios will generate valid and accurate data. Feedback from subjects in previous research efforts using the TARDEC GVSL has revealed a need for improved visualization and modeling of human and vehicle entity behavior. As part of the SimBRS research program, researchers in Starkville, MS are working with TARDEC to respond to these needs. In visualization of human entities, researchers have implemented a pipeline for quickly generating new animations for existing character models from human motion capture data. Research efforts have also resulted in an increase in variability of character visualization through use of an increased number of animations, variable character scale, and animation start offsets. In behavior modeling, improvements have been made to TARDEC GVSL capability to model ambient civilian traffic. The modifications have reduced operator effort when defining paths and simplified the creation of paths for large numbers of entities. Research efforts are underway to enable the TARDEC GVSL IG to visualize context-dependent behaviors. Research efforts will continue to expand the capabilities of the TARDEC GVSL to visualize and model human and vehicle entity behaviors.

ACKNOWLEDGEMENTS

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Advancing the Behavior Modeling and Visualization of Entities in the Ground Vehicle Simulation Laboratory, Carruth, et al.
Page 7 of 7