Extending Construction Simulators through Commonality & Innovative Research

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ABSTRACT

The U.S. Army's Construction Equipment Virtual Trainer (CEVT) simulators leverage commercial simulation technologies to provide virtual training on construction equipment. The currently-fielded CEVT simulators, the Hydraulic Excavator and Wheeled Loader, are standalone simulators using disparate technologies for terrain databases, terrain skin modifications, and simulation engines. This precludes interactive and collaborative training between students or across simulation applications. In addition, the terrain representations in these simulators lack the sub-surface soil model with support for soil properties and horizons, the effects of weather conditions, and the effects of physics-based interactions to provide a realistic training experience for the Soldier.

To increase realism in the simulation environment and improve the effectiveness of training, future requirements for construction equipment training are moving toward advanced dynamic terrain, physics-based interactions with the environment, weather effects, and collective and collaborative training. In addition, the emerging Army trend in reuse of major technologies across programs provides opportunities to provide cost-effective solutions for simulation enhancements.

This paper describes a Government funded research and development activity which extended the CEVT simulators into collective training platforms by leveraging a combination of major Army standards and advanced research into open, non-proprietary dynamic terrain, physics-based modeling, and distribution mechanisms. This paper will describe how Army standards such as Synthetic Environment (SE) Core terrain databases, Distributed Interactive Simulation (DIS), and OneSAF were leveraged to provide very low cost functional enhancements, commonality, and interoperability. This paper describes research and development of advanced dynamic terrain, including soil properties, physics-based interactions with the environment, and the effects of weather on the terrain. It also describes how advanced, open solutions were developed for complex physics-based terrain skin modifications in visual and SAF contexts. The paper illustrates transition of Government funded research into Army virtual simulation programs.

ABOUT THE AUTHORS

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Kien Le is a systems engineer at PEO STRI in Orlando, Florida. He has 9 years of experience in the virtual modeling and simulation field. He is currently the technical lead on the Construction Equipment Virtual Trainers (CEVT) program and has worked on small arms marksmanship trainers and Engineer unit route clearance trainers.

Hector Gonzalez is a Science and Technology Manager at the Army Research Laboratory, Human Research and Engineering Directorate, Simulation and Training Technology Center and supports research and development efforts in Synthetic Natural Environments for training applications. Hector has 28 years of experience and holds a BS in Electrical Engineering from University of Puerto Rico.

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INTRODUCTION

The U.S. Army has fielded two simulators for construction equipment, known as Construction Equipment Virtual Trainer (CEVT) (Fisher, Huffman, Sanchez, and Goodney, 2009). The original CEVT simulators, currently fielded at Fort Leonard Wood, met an immediate training need. Looking forward, however, there was interest in how future generations of CEVT simulators could make greater use of Army standards, support functional enhancements such as collective training and advanced dynamic terrain, and also serve as a foundation for technology useful to other Army simulators. This paper describes research conducted into these various aspects of construction equipment simulation with a particular focus on how two-way reuse of software and concepts could provide mutual benefit across multiple programs.

Our research leverages the Dynamic Terrain (DT) Testbed. The DT Testbed is a suite of capabilities developed for, and by, several Government funded dynamic terrain related research projects. The Testbed is located at the Dignitas Technologies facility and at the U.S. Army Research Laboratory Simulation and Training Technology Center (ARL STTC), both in Orlando, FL. The Testbed supports research, experimentation, development, and demonstrations for investigations to improve the ability of the Modeling and Simulation (M&S) community to alter the synthetic natural environment, including terrain skin geometry, features, simulated objects, subsurface soil properties, and weather. Dynamic terrain effects are an area long-neglected in the Army's largest distributed simulators, with very limited capabilities demonstrated in most fielded systems. Even the CEVT simulators, where interactive modification of the terrain surface is the core training capability, limited digging to small, preset areas of the training database did not allow simulated vehicles to work together. While our Testbed supports a broad array of capabilities in dynamic terrain, this paper will focus specifically on those that relate to construction equipment simulation and how the CEVT focused work provides benefit beyond the CEVT family of systems.

The primary objective of our Government funded research was to investigate and develop open, non-proprietary technologies to improve CEVT simulators. One of the key research objectives was to add realism to construction equipment training with advanced dynamic terrain and physics-based interactions with the environment. Our research focused on the excavation and plowing aspects of dynamic terrain and physics-based interactions. Another key objective was to research and develop a subsurface soil model with soil properties, horizons, profiles, support for soil mechanics, and physics-based soil resistance with construction equipment simulators. Weather conditions and the effects of the weather on the simulated environment and construction equipment was also an important objective. We also investigated reuse of common Army modeling and simulation components, such as Synthetic Environment (SE) Core, and how they could benefit CEVT simulators in the areas of interoperability and collective training. A final objective was to transition the technologies and concepts developed on this and related dynamic terrain research projects to current and future training programs including CEVT.

KEY CONCEPTS

Dynamic Terrain

A core component of our research is very high-resolution, interactive terrain skin modifications to support interactive digging and plowing operations performed by construction equipment simulators. To support this capability, we developed a high resolution terrain grid that is overlaid on the default terrain skin which runs at decimeter resolution in our Testbed. In visual systems, use of a grid facilitates use of shaders; in OneSAF's polygonal terrain skin, it helps to avoid problems with slivers. Complex terrain skin modifications are distributed over the network via experimental Distributed Interactive Simulation (DIS) Protocol Data Units (PDUs) to support collective training and interoperability. We extended OneSAF to receive and process complex terrain skin changes from the experimental PDU. OneSAF extensions include updates to the OneSAF Plan View Display (PVD) to show terrain skin changes and the ability of OneSAF entities to interact with the modified terrain.

Our dynamic terrain capability provides support for terrain modifications anywhere on the terrain database. There are no limitations to where the simulator can perform digging or plowing operations. This provides freedom in planning training exercises and mission rehearsal scenarios. The terrain skin can be modified to any depth or any height supporting digging and piling of soil to depths and heights required for the training tasks.

The high resolution terrain grid, or height map, is referred to as a dynamic terrain page and represents an area of dynamic terrain. It is a 2-Dimensional (2-D) rectangular grid with a configurable number of rows and columns. The coordinate system for a dynamic page is in meters and uses a z-up coordinate frame with the x-axis representing east and the y-axis representing north. The page's local origin is located in the southwest corner at column=0 and row=0. A grid coordinate represents an (x, y) integer Cartesian coordinate within a given dynamic terrain page. A page post represents the specific height at a location along the grid. As an area of the terrain is modified, through digging or plowing operations, the page post at one or more grid coordinates will be modified. At locations where terrain is removed, post heights will be decreased, and at locations where soil is stockpiled either through excavating or spillage from plowing, the height will be increased.

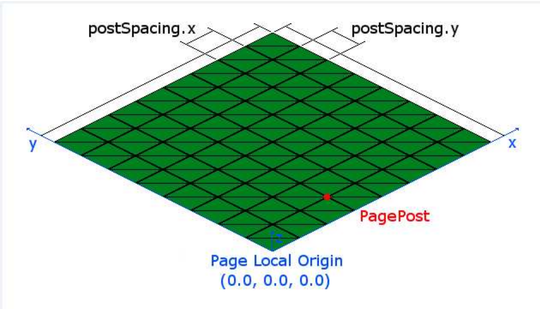

Figure 1: Dynamic Terrain Page Model

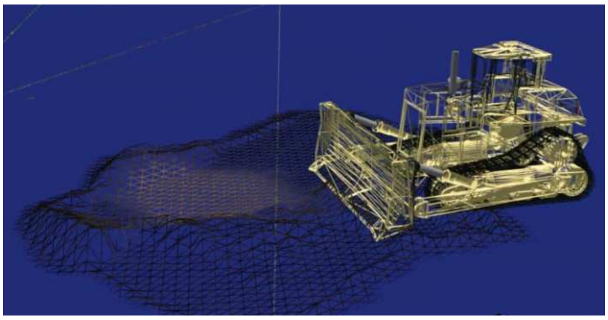

Figure 2: Dynamic Terrain Page in DT Testbed

As a proof of concept we integrated the Dynamic Terrain Page into the DT Testbed. In this implementation, the Testbed only creates Dynamic Terrain Pages in the areas of the terrain where construction operations are to occur. We leveraged SE Core terrain databases, which use a Triangulated Irregular Network (TIN) terrain skin (i.e. polygonal). To avoid converting the entire terrain to a grid we create dynamic terrain pages only as needed where the terrain modification is to occur. These pages then override the TINed terrain skin in systems such as OneSAF. Figure 2 illustrates the dynamic terrain page only in the area of the terrain where modifications occurred.

Soil Model

In addition to terrain skin modifications, Dignitas developed technology to model subsurface soil in a training environment. The soil model provides support for soil properties and layers as well as modeling soil behavior due to weather and interactions with construction equipment simulators. We extended DIS with a new experimental PDU to exchange subsurface soil properties which are not available in typical M&S predistributed geospatial databases. This data is distributed over the network when the soil and terrain skin are modified during interactive digging and plowing operations. Soil erosion, saturation, and displacement are modeled, and may vary based on soil properties or future changes to soil compression, fluidity, and aggregates.

Soil is composed of solid particles and the empty space between the particles which is filled with water, air, or a combination of both. The solid particles in soil are made up of varying percentages of clay, silt, and sand. Sand is the largest particle, followed by silt, with the smallest particle being clay. The soil model we developed is based on the above soil composition description and consists of a percentage of solid particles, water, and air, along with mass

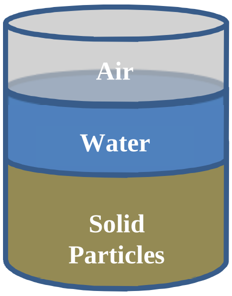

Figure 3: Graphical Representation of Soil Composition Model

and volume. From these properties we derive other soil properties including bulk density, porosity, void space, consistency, cohesion, and plasticity. Figure 3 provides a high level graphical representation of our soil model. In addition to modeling soil properties we model soil profiles. A soil profile is a collection of soil layers, also known as soil horizons. A soil horizon is defined as an individual layer of soil approximately parallel to the terrain surface and distinct from the layer above and the layer below based on physical characteristics such as texture, color, and composition. Figure 4 shows a typical soil profile with three major horizons. Bedrock is typically below the third horizon but this is configurable in our model. In a Dynamic Terrain Page the posts are associated with soil attribution and horizon information. The horizon information is represented by a set of one or more soil attribute segments. Each soil attribute segment includes the depth of the segment and soil attribution data consisting of the soil properties. We implemented the soil profile model as a proof of concept in the DT Testbed. For a particular dynamic terrain page the set of all posts (with the associated segment data) defines the soil profile for the page. The soil properties and horizons that comprise the profile are configurable. For example, the percentage of clay, sand, and silt can be set along with the amount of water in the soil horizon to support a particular application. Also, the number and depth of each horizon within a profile can be configured to meet different training needs. Figure 5 illustrates the different soil horizons in the Testbed. Figure 6 demonstrates a soil profile with three distinct horizons with the Testbed in debug mode. In this example,

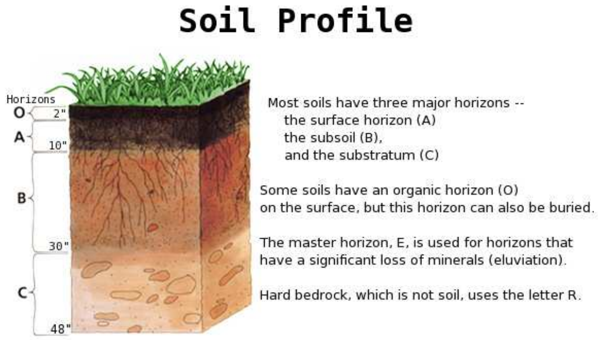

Figure 4: Soil Profile

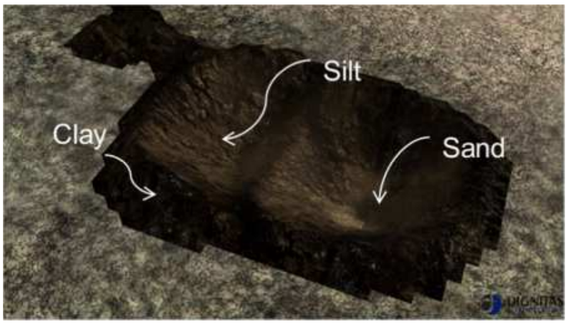

Figure 5: Visual representation of soil horizons

there are three horizons where the top layer is 100% clay, the middle layer is 100% silt, and the bottom layer is 100% sand, and each separate horizon is clearly seen. In a simulation, as digging occurs through the various layers the soil layers become mixed and the percentage of soils change. We researched soil profiles for three distinct regions of the world and implemented the profiles in the DT Testbed. One is a desert soil profile, which can be used for training in places like southwest United States or Afghanistan, and is characterized by horizons with predominately sandy soil, less than 20% silt, and relatively no clay. Another profile represents the central United States. This is defined by horizons made up predominately of clay and silt with very little sand. The third soil profile represents the Fort Leonard Wood Training Area-244. This is the Army's training site for construction equipment. This profile is unique in that it has a single horizon 50 inches deep and made up of 50% silt, 40% clay, and 10% sand. As stated earlier, Army modeling and simulation terrain databases do not provide subsurface soil information. We resolved this gap in data by mapping the three soil profiles to three Army simulation terrain databases. We mapped the desert profile to SE Core Afghanistan, the central United States profile to SE Core Ft Riley, and the Ft Leonard Wood profile to the Common Driver Trainer

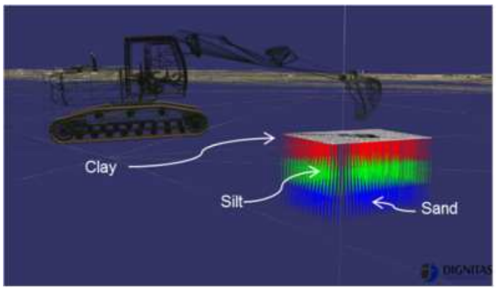

Figure 6: Subsurface Representation of Soil Horizons

program Fort Leonard Wood TA-244 terrain database. In the Testbed, when one of these terrains is loaded for an exercise, the corresponding soil profile is loaded to provide subsurface soil properties for construction equipment interactions.

Physics-based Effects

Realistic interactions with the environment are necessary for high fidelity virtual simulations, especially for construction equipment training. Fielded CEVT simulators offer little physics-based resistance to digging and no resistance based on subsurface soil properties. In addition, realistic interactions with objects on the terrain or with objects buried fully or partially below the terrain is lacking. Our research addressed these and other physics-based improvements for construction equipment simulators. We developed a number of moveable objects with physical attribution as a proof of concept to demonstrate physics-based interactions within construction equipment simulators. We developed moveable boulders, logs, hollow steel pipes and culverts, tires, and crates. Additionally, we developed physical representations of the excavator and bull dozer. We then integrated an open source physics engine into the Testbed to demonstrate the physics-based interactions between construction vehicles and objects in the environment (see Figure 7 and Figure 8). We are currently investigating an approach to efficiently distribute the results of the physics-based interactions to all simulators in an exercise.

Figure 7: Hollow Steel Pipe with Tire and Cinderblock Inside

Figure 8: Bulldozer Interacting with Physics-based Objects

We believe future CEVT training tasks will involve greater interactions with objects such as pipes, rocks, boulders, and cables both on the terrain and below the terrain surface. In addition, the simulation operator must have the ability to accurately place objects where the training will be most effective. This will require precise placement of objects in the environment and sometimes stacking objects and placing them inside of other objects. We developed a 3D placement capability that provides the operator tools to place objects on or below the terrain, on top of each other, or inside other objects. The figures below illustrate the results of creating and placing objects in the environment using the DT Testbed. Using the Testbed's simulated construction equipment we are able to interact with the objects whether on the terrain, stacked on objects, or placed below the terrain.

Figure 9: Objects Placed Below Terrain Surface

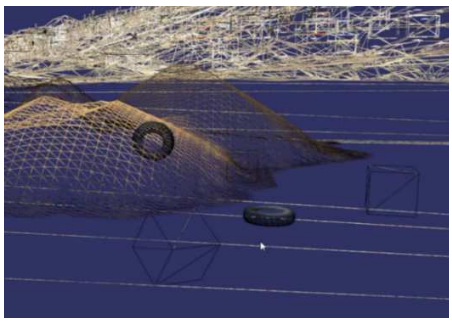

Figure 10: Wireframe View of Objects Placed Below the Terrain Surface

CEVT stakeholders are very interested in physics-based soil resistance to digging and plowing. We researched approaches to model the soil resistance between an excavator bucket and soil (Patel, Prajapati, Gadhvi. 2011 and Park, 2002). The model we developed uses derived soil properties to determine the soil resistance forces. These forces represent the forces necessary to overcome soil forces to displace the soil. The derived soil properties used in the algorithm are density, cohesion, surcharge pressure, and soil compaction. The model also uses the terrain height information, current position of the bucket, and bucket characteristics such as width, depth, and teeth length. The model provides soil penetration resistance, separation resistance, and other resistances associated with collisions between the sides and bottom of the bucket and soil surface. We developed a proof of concept demonstration to illustrate our soil resistance model. In the figures to the right the bucket is shown penetrating and separating from the soil. The colored bars represent the associated forces: red represents soil penetration force, green represents soil separation force, and blue represents the other forces that occur when colliding with the soil. Based on the composition of the soil (i.e., percentages of clay, silt, sand, and water) the density and cohesion values will vary resulting in different penetration and separation forces necessary to dig. We developed a similar model for the interaction between a blade and the soil.

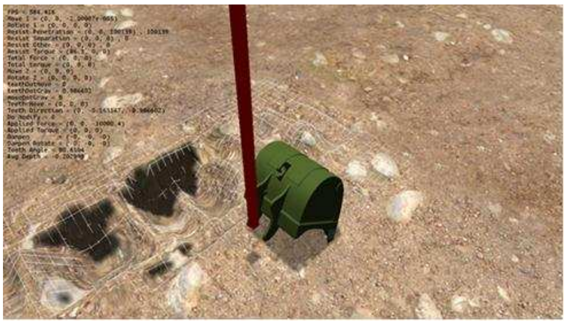

Figure 11: Penetration Force

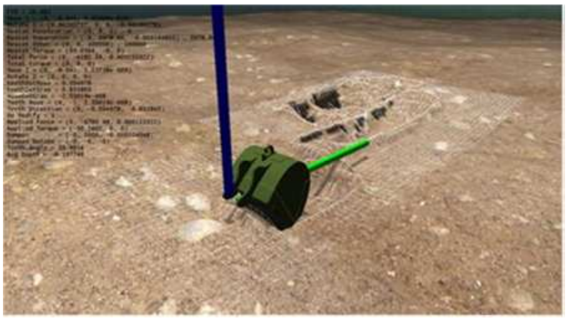

Figure 12: Separation Force with Additional Force Caused by the Bottom of the Bucket Pushing on the Soil

Weather Effects

Weather can play a significant role in simulation, ranging from effects on mobility to altering the resistance of soils to digging operations. We are implementing weather effects in the DT Testbed to demonstrate capabilities such as rain increasing water saturation levels in the soil, wet soil eroding differently than dry soil, vehicle mobility being affected by rain and ice, and soil compression, resistance, and weight varying with weather conditions. We also added the visual effects of snow, fog, rain, time of day, and dust to support integration activities and add realism. In the case of dust and smoke, our solution utilizes a particle system to increase the realism of these effects.

To support soil erosion and traction in the training environment we developed a soil saturation model. As precipitation (rain) occurs in an area of modified terrain, soil begins to absorb water. Water content in the soil increases over time, passing through several phases from dry, to partially saturated, and finally to fully saturated. As the water content increases, the air in the soil decreases until all void spaces contain water. We also model the accumulation of rain water. In areas of the terrain where holes have been created, rain water will accumulate over time based on the rate of precipitation (Figure 14). The accumulated water is represented using Dynamic Terrain Page Posts with the soil attribution data set to 100% with no solid particles or air (Figure 13). The height of the Page Posts increases over time until it is level with the original terrain skin. We limit rain water accumulation to the modified areas of the terrain because that is where training occurs and there is little training value in creating puddles throughout the training environment.

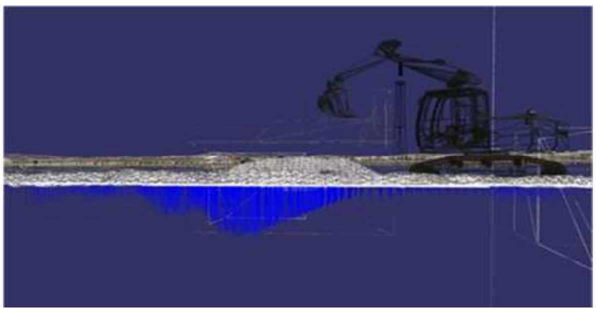

Figure 13: Blue Posts Represent Accumulated Rain Water

Figure 14: Rain Water Accumulation over Time

In addition to modeling rain water accumulation, Dignitas is also experimenting with snow accumulation. To support future CEVT snow removal training tasks we researched and prototyped a capability that adds a new snow layer above the original terrain surface. We used the same approach that we used to represent subsurface soil layers. In this case, a Dynamic Terrain Page is created to represent the layer of snow with the Page Post height set to the height of the layer of snow and the soil attribution set to 100% water. The simulator interacts with the layer of snow in a similar manner as it would interact with a layer of soil. When snow precipitation is enabled the height of each of the Page Posts in the Dynamic Terrain Page representing the snow layer increases over time based on the precipitation rate, effectively causing snow to accumulate in the environment.

This work includes an experimental integration of the Environmental Data Cube Support System (EDCSS) (Pfeiffer, Holdzkom, Lowe 2013), which provides historical or live weather data at a higher resolution than seen in, for example, OneSAF's METOC database. This allows us to experiment with localized weather effects, wherein rain is occurring in one region but not another.

Distribution of Dynamic Terrain Data

To accurately represent interactive construction equipment operations like digging and plowing, we needed detailed subsurface information to be available to all simulation participants. In addition to construction operations, subsurface information plays a role in areas such as crater calculations and mobility (e.g. slippage and sinkage). Our chosen solution was to provide subsurface soil characteristics as-needed at run-time, including support of modifications to the default layers during scenario generation or at runtime.

The current DIS specification does not provide support for the distribution of complex high resolution terrain skin and subsurface modifications. For this reason we defined two new experimental DIS PDUs. The Scaled Height Map PDU communicates heights at regular intervals inside a predefined rectangular area. Each data item in the PDU represents a height post along the grid. The heights are scaled in order to allow more of them to be packed in a PDU. The Soil Attribute Map PDU communicates soil attributes inside a predefined rectangular area of the terrain. Each data item in the PDU represents an attribute of the soil, represented by an enumerated value for the particular attribute type. This PDU represents a terrain grid. At each point within the grid (this is the grid post), the soil is described using a set of attributes. Each grid post is made up of one or more segments (up to 255). Each of these segments is described with a value for each attribute type.

DEVELOPMENT OF DT TESTBED

To support advanced dynamic terrain research for CEVT, such as that described in preceding sections, we developed and extended the DT Testbed. The DT Testbed supports research efforts beyond CEVT, spanning many aspects of Army M&S changes in the environment. The testbed provides a flexible platform for research, prototype development, integration of related technologies, and demonstrations of research and developed functionality. The testbed was easily integrated with SE Core technologies and OneSAF as described below, thus demonstrating the value and ease of leveraging open, common components and how they can benefit not only CEVT but other simulation systems. The testbed provides a number of ownship simulator models that can be interactively controlled by an operator, including construction equipment and a tracked robot. The simulator models have basically the same reuse architecture as the CCTT and AVCATT manned modules thus providing a test and demonstration capability similar to actual training systems. An open, low cost 3D visualization capability was developed to visualize research in the testbed. This capability has since been transitioned to other programs requiring a model viewer, development and test tool, and a lightweight 3D viewer.

As part of the testbed we developed a soil server. The soil server addresses a fundamental Synthetic Natural Environment (SNE) capability that is lacking in virtual simulations: the lack of subsurface data. The soil server provides subsurface soil and height map data on the fly to simulators interactively modifying the terrain skin and subsurface soil properties.

REUSE OF ARMY COMMON COMPONENTS

Our research looked beyond showing a standalone solution to a single problem. Instead, throughout our work, we factored in the needs of real-world Army M&S programs to facilitate transition and also considered how reuse of, and interoperability with, existing simulations could be facilitated. This section summarizes some of our key focus areas on reuse of common Army solutions. It should be noted that our work reused many other more broad technologies, including OpenSceneGraph, COLLADA, PhysX, and Bullet.

OneSAF Integration

From the earliest phases of our research, we selected key areas of Testbed capabilities to be fully integrated with OneSAF. For example, we integrated the high resolution terrain skin modifications into OneSAF, both as a part of internal components and through updates received from experimental DIS PDUs. Our work built upon the Virtual OneSAF capabilities developed by OneSAF and SE Core in support of CCTT and AVCATT (Dukstein, Watkins, and Deakins 2007 and Hughley, et al, 2006). Integration included the ability of the DT Testbed to display OneSAF entities in the scene, updates to OneSAF's internal terrain format so that OneSAF entities would recognize the terrain skin geometry changes (i.e., fall into holes), updates to the OneSAF PVD to display areas where high resolution terrain skin changes had occurred, and display of construction equipment vehicle icons on the OneSAF PVD. We targeted our OneSAF updates based upon capabilities of high interest to current customers, and thus we did not implement the ability for OneSAF entities to create the high resolution terrain skin changes, nor did we update OneSAF for all Testbed capabilities, such as physics objects.

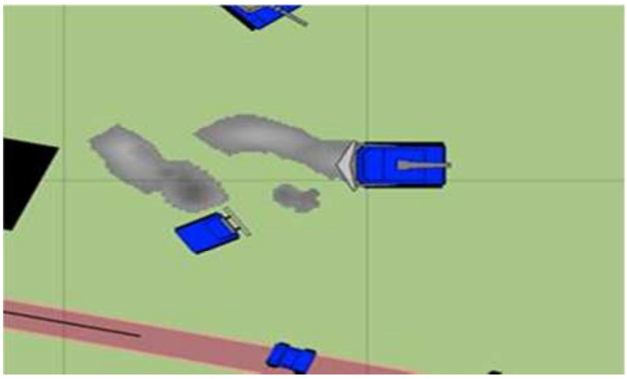

Figure 15: OneSAF PVD Representation of Altered Terrain

Figure 16: OneSAF Entities Interoperating with Testbed Simulator

Starting our terrain skin work with the mindset of integrating into OneSAF provided a number of benefits. First, another M&S application received and processed our network traffic, providing some assurance that our approach was not overly specialized to our software. Similarly, interoperability with OneSAF provided proof that our approach could support distributed simulation and collective training through software that is readily accessible to possible transition partners. Having OneSAF integrated also enhanced the Testbed environment by providing context to our scenarios (e.g. civilians or security forces moving around the construction equipment). As of this writing, our terrain skin and soil layer information are being integrated into the core OneSAF baseline.

Synthetic Environment (SE) Core

Another major area of reuse and integration was with products from SE Core, which is striving to provide common capabilities to the virtual simulation community. Our research effort both leveraged SE Core products and influenced them. From program startup, we leveraged SE Core's library of Common Moving Models (CM2). Because these models were already fully integrated with OneSAF (appropriate entity compositions, behaviors, etc.), the models enabled very low cost means to provide complex virtual scenarios. We leveraged SE Core's VDIS, which provides virtual-centric extensions to DIS, both for common things (such as entity state, object state, and fire and detonation events) as well as for experimental PDUs exchanging advanced terrain geometry and layer information. We used SE Core terrain databases, providing a quick and easy mechanism to demonstrate capabilities in a wide array of real world regions using terrain databases that are highly relevant to existing Army programs. We integrated and demonstrated with several SE Core terrain databases including Afghanistan, Korea, Fort Hood, and Foot Stewart. In several of these areas, our research program provided suggestions back to the SE Core program, including recommendations for new construction equipment vehicles to add to the CM2 library, experimental PDU definitions, and recommendations for physics attributes that could be added to CM2 models for future functionality.

Figure 17: The John Deere HyEx Operating on SE Core Terrain

Figure 18: Testbed Simulator on SE Core Terrain

Collective Training and Interoperability Benefits

Our focus on reuse of Army technologies in part supports customer objectives of proving what could efficiently be leveraged for future programs, but also supports future use cases for collective training and interoperability. At a rough architectural level (expressed in terms of interoperability and SE Core reuse), our Testbed configuration as a construction vehicle simulator looks much like a CCTT or AVCATT manned module, using the same key interoperability elements of terrain databases, network protocols, entity sets, computer generated forces application, etc. SE Core and OneSAF reuse provides extensive system functionality at low cost. In addition, reuse was very beneficial in preparing our technology for transition into use on programs of record as well as supporting interoperability.

EXAMPLE TECHNICAL THREAD

For illustrative purposes, we outline an example use case for the capabilities we've described in this paper. Starting on a raised road way, the Testbed can simulate vehicles such as the hydraulic excavator and bulldozers, digging up a section of the roadway creating a trench across the raised area. Then a pipe can be placed into the resultant trench through DT Testbed's the scenario generation tool. The pipe can then be buried again and the dirt leveled off to create a flat driving surface. This results in a culvert. Using the scenario generation tool, operators can place various physics-based objects inside the pipe, such as tires, palettes, etc. A talon robot can then be controlled through the Testbed to enter the pipe and move the objects, e.g. flipping them over to see what is underneath them or pushing them out of the culvert. These activities can all be viewed through the Testbed's 3D viewer. This scenario demonstrates the ability to modify the environment in complex ways and manipulate physics-based objects. A video of this use case can be seen on YouTube at www.youtube.com/dignitastechnologies, along with other videos showing selected pieces of Testbed capabilities.

TRANSITION OF RESEARCH TECHNOLOGY

The ultimate measure of success for our research is how it is applied to positively influence Army modeling and simulation applications. Practical transition is often very difficult for research efforts for many reasons, including the big leap from prototype to production software as well as the challenge of "fitting in" to the timeline and needs of a program of record. In this section we discuss selected transition events to illustrate both challenges for transition as well as actions we took to mitigate those challenges.

In our research, we were able to clearly demonstrate that collective training and reuse of common Army technologies is possible while providing useful knowledge of these standards. In order to facilitate this type of practical use, research contractors must support open development and focus on identifying selected capabilities that can easily transition, while simultaneously pushing the state of the art on other technology threads.

Gridded Terrain into OneSAF

One of the key successes in our research effort has been our transition of software into OneSAF to provide very high resolution terrain skin geometry changes. Our updates to OneSAF in general are described elsewhere in this paper, and the bulk of these capabilities are in the process of being integrated into OneSAF as this paper is written. While these capabilities will be of benefit to the OneSAF community, a major benefit of this transition is that the future CEVT program of record developers will have this capability available to them as Government-Off-The-Shelf (GOTS) functionality, ready for reuse in an established and maintained baseline. This capability can also benefit other programs such as CCTT which has encountered problems with slivers or triangle encoding schemes when conducting "repolygonalization" of the terrain skin for features such as craters or tank ditches. Our approach avoids this problem by providing an alternative which is not susceptible to increasing fragmentation as localized changes are made. The end result is that the Government's investment in a single research effort is improving not just the OneSAF baseline, but can also benefit other current and future programs.

Of course, this type of transition success would not be possible with closed or proprietary solutions, since our software is being directly integrated into OneSAF and must be available for integration into other system components such as manned simulators. Closed solutions such as those found in COTS gaming and physics engines are antithetical to this open, reusable, maintainable approach. In addition, coordination of such a capability across multiple baselines requires a project team that is able to look at and understand multiple use cases for how a capability can be of benefit to different users. The CEVT use case alone would not have been compelling enough to convince the OneSAF program to include the gridded terrain capability; thus usefulness to other domains had to be advocated, coordinated, and presented.

Mundus SDK

The CEVT Testbed provides a reusable Software Development Kit (SDK) supporting functionality. This SDK, known as the Mundus (Latin for "world") SDK, provides documentation, references, and examples to integrate and implement the Testbed capabilities. The SDK provides detailed information about subsurface soil conditions, providing terrain skin modifications anywhere on the terrain, providing resistance forces for soil / bucket intersections, modeling weather effects on the soil, and providing soil traction data. The SDK API was structured in such a way as to be reusable on any physics engine implementation or vehicle model. This approach should reduce cost and increase functionality for the Army in the final implementation, whether indirectly (by allowing more advanced capabilities to be developed) or directly (through reuse of research software). For this approach to succeed, the customer agency must be able to provide sufficient funding to allow the research capabilities to mature. In addition, maximum value can only be achieved if the development is open, with at least Government Purpose Rights.

CONCLUSION

The CEVT DT research effort has proven the viability of various technical threads pushing far beyond the original fielded system capabilities. We proved out capabilities such as collective training with complex terrain skin modifications, reuse of Army technologies for cost savings, and development of open, reusable technology to reduce production program cost and risk. We researched and developed a subsurface soil model that includes soil properties, layers, and profiles. It also models the behavior of the soil resulting from simulated construction equipment interactions and weather conditions such as precipitation, temperature, and wind. Using the subsurface soil and high resolution dynamic terrain models we developed a physics-based soil resistance model to represent the interactions between the construction equipment buckets and blades and the soil. We developed a weather effects model that represents rain accumulation, water saturation in the soil, soil resistance variations based on water content and temperature, and vehicle traction. To distribute high resolution terrain skin changes and soil attribution changes we defined two experimental VDIS PDUs. These technologies were implemented in the Mundus SDK and demonstrated as a proof of concept in the DT Testbed.

As a result, the CEVT research was able to push the state of the art farther, resulting in greater capability to Warfighters in the near-term. To support these objectives, the development team maintained an open development approach and a very strong transition focus through selection of development efforts and coordination with outside parties. Following these principles, many benefits were developed for Army simulation, including integration of advanced terrain skin geometry modifications into OneSAF. Development of the research Testbed continues including complex weather effects through collaboration with Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) and the Army Research Laboratory, Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC).

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