Using One World Terrain in a Live Training Environment

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ABSTRACT

As the Army moves to converge Live, Virtual, and Constructive simulation domains for the Synthetic Training Environment (STE), the need for One World Terrain (OWT) capabilities greatly increases. However, as more OWT standards, services and datasets evolve and mature, the focus now shifts more to terrain content in support of live training engagements which has implications on the terrain production strategy, representation of battlefield effects, and service availability at the Point-of-Need (PoN). In order to minimize fair fight issues such as improper hit adjudication or potential negative training outcomes, the digital terrain to real world approximation will require increased spatial, geometric, and semantic resolutions that exceed traditional virtual or constructive simulation needs. In the evolution of the STE for Live Training System (LTS), OWT will serve as the core authoritative terrain content that can then be further extended for the STE-LTS use cases toward adjudicating and providing accurate battle damage assessment from simulated weapons engagements. The Army has a wide variety of weapons with associated penetration capabilities depending on the cover provided by the terrain. High fidelity terrain characteristics coupled with ballistic and effects models are necessary to simulate the effects of various weapons in multiple engagement scenarios. This paper presents initial experiences from the LTS community focused on hosting and delivering OWT services during live training exercises. This data will highlight areas where OWT capabilities can be augmented and extended to address live training integration challenges in the STE. Additionally, these experiences may support enhancements to geospatial data collection and distribution while encouraging developers to incorporate OWT capabilities into future training devices; thereby promoting wider community acceptance and further refinement of the OWT standards and architecture.

Keywords: 3D, ADAPTABILITY, ARCHITECTURE, AVATAR, CONCEPTUAL MODELING, DATA, ENVIRONMENTS, TERRAIN, URBAN ENVIRONMENT

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1 Introduction – Where the Army is Headed

1.1 Background

The Army has identified One World Terrain (OWT) to be a critical dependency in the path to revolutionize the collective live training environment. The Live Training System (LTS), a major program within the family of the Synthetic Training Environment (STE), uses microelectromechanical systems and sensor fusion technologies to exercise approximately 40% of Army weapons in force-on-force environment, eliminate the realism gaps brought by the current laser system and fully immerse synthetic combat participants into live training. To achieve this vision, the digital terrain produced by STE-Information System (IS) must match with a high degree of accuracy the actual/real terrain observed by live participants. The below sections will discuss in detail the limitations, challenges, accomplishments, risks, opportunities, and the path forward to achieving the Army's goals.

A key program objective is to converge the traditional Live, Virtual and Constructive simulation domains that govern the architecture of the current training systems into one cohesive integrated training system. This convergence is imperative to bring the complexity, fidelity and repeatability for sharpening the warfighting skills and simulating threats brought by each of the warfighting domains; Land, Air; Maritime, Space and Cyberspace. An accurate and common operating picture is necessary for this effort. Thus, U.S. Army instituted a program called One World Terrain that is chartered to provide geospatial needs for all training and tactical systems used in Multi-Domain Operations (MDO).

1.2 OWT Stakeholder Center of Gravity

The STE Cross Functional Team (CFT) and the Program Executive Office Simulation, Training and Instrumentation (PEO STRI) are leading U.S. Army organizations in establishing and executing training enablers for modernization strategies. In a supporting role, DEVCOM Soldier Center STTC (SC-STTC) is providing Science and Technology research and development to reduce capability gaps in these modernization strategies. The prime objective of these organizations is to produce materiel capabilities that ensure combat readiness in MDO environments. The new warfighting doctrinal approach requires an architecture that allows for an effective, accessible, and realistic experience for individual and collective training from the soldier and squad through the highest Army echelons. STE CFT seeks to construct an enterprise architecture that encompasses the technologies, processes, and infrastructure to meet this mission.

The STE is developing foundational capabilities comprised of the STE-Information System (STE-IS) and STE-LTS. STE-IS consists of the Training Management Tool (TMT), the Training Simulation Software (TSS), and OWT. TMT will provide capabilities allowing exercise support staff to plan, prepare, execute, and assess multi-echelon Army training exercises. TSS will supply the gaming engine and other software fundamental to running a simulation. STE-LTS develops the engagement solutions that will meet the live training needs. The Army expects OWT to deliver 3D global terrain data as a virtual representation of the physical earth and the details for the exercise environment.

2 Background - Why is OWT Important?

2.1 Data is foundational for simulation

Data is the foundation for every simulation, be it Live, Virtual, or Constructive. OWT has changed the way the Army Generates 3D terrain. OWT's approach involves collecting data from satellites, drones, crowd-sourced data and combining the datasets using automated algorithms to produce an accurate, realistic and quickly built terrain. Figure 1 below illustrates the steps taken to produce digital terrain. OWT's main emphasis is on areas one and two in support of area five. Collection involves the acquisition of source data (e.g., remote vs. local, active vs. passive sensors). Creation involves using collected data to generate useful terrain data sets for the location and intended runtime environment. Storage is the mechanism to manage and store large holdings of data. Distribution of data is provision of data to the point-of-need (e.g., cloud or local need). Application is the use of the data within the intended environment.

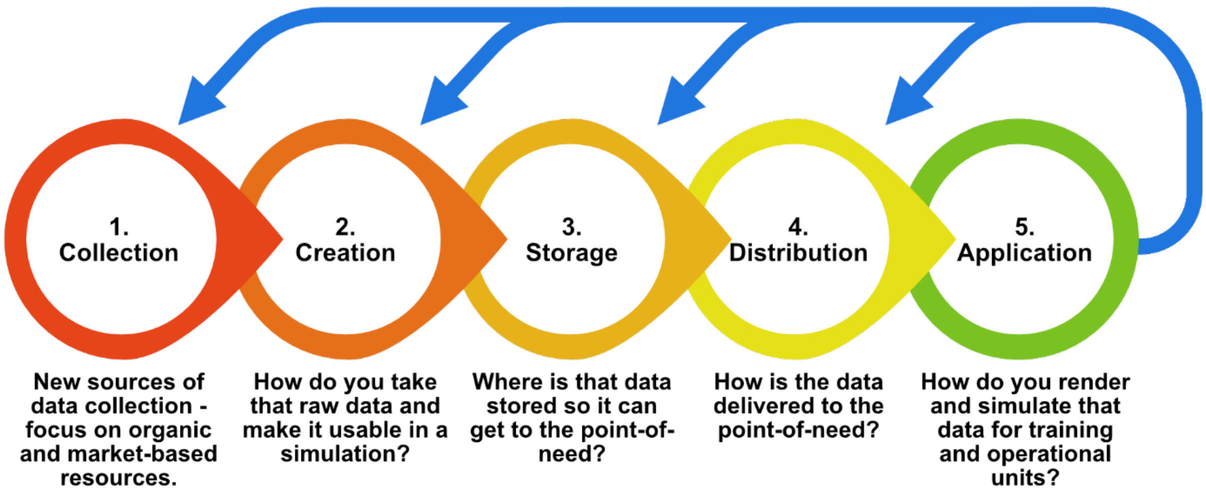

Figure 1: Steps to Produce Digital Terrain

During a training exercise, each training environment, be it in the Live, Virtual, or Constructive, must utilize a common source as the fundamental basis for all engagement and shot adjudications to minimize fair fight concerns and enhance training realism. A fair fight concern is multiple participants using different terrain databases as the basis for the shot flight path or physics calculations. When this occurs, it is possible that the result of each participants' adjudication based on their own database could be different. In such cases, the simulation could identify a target as 'killed' when clearly in a position of cover. This situation would provide the participant with negative training, which is never the goal. The Army's intent is to have all participants leveraging the same terrain database to provide equivalent data baselines for adjudications within live training engagements.

Types of Training Simulation

Live, Virtual, & Constructive (LVC) Simulation is a broadly used taxonomy for classifying Modeling and Simulation (M&S). However, categorizing a simulation as a live, virtual, or constructive environment is problematic since there is no clear division between these categories. The degree of human participation in a simulation is infinitely variable, as is the degree of equipment realism.

The LVC categories as defined by the United States Department of Defense in the Modeling and Simulation Glossary (U.S. DoD, 2020, pp. Section 3.1, P2) are as follows:

Live - A simulation involving real people operating real systems. Military training events using real equipment are live simulations. They are considered simulations because they are not conducted against a live enemy.

Virtual - A simulation involving real people operating simulated systems. Virtual simulations inject a Human-in-the-Loop into a central role by exercising motor control skills (e.g., flying jet or tank simulator), decision making skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a C4I team).

Constructive - A simulation involving simulated people operating simulated systems. Real people stimulate (make inputs to) such simulations but are not involved in determining the outcomes. A constructive simulation is a computer program. For example, a military user may input data instructing a unit to move and to engage an enemy target. The constructive simulation determines the speed of movement, the effect of the engagement with the enemy and any battle damage that may occur.

2.2 Characteristics of Data

Terrain/environmental **Data Quality** can be defined as a set of measures and established reference levels that identify the suitability of the data to meet an application's/task's objectives. As an example, some live training tasks (such as using urban objects for cover) will depend on the position and state of those objects. Since data currency can be a measure of quality, live training will require the current position and state data, while in contrast constructive training will not need that level of currency.

The ISO Data Quality standard (International Organization for Standardization, 2022) also provides definitions and specifications for various aspects of data quality, including data quality management and processes, vocabulary, and terms. A few definitions and associated terrain/environmental examples follow.

Completeness can be defined as the measure of how much of the potential data for a given task or objective has been provided.

<u>Example:</u> *A terrain database that is intended to serve both visual systems and constructive systems is incomplete, if it includes the appearance data (e.g., geometry, color, texture) but not the data that describes non-visual concepts (e.g., connectivity/topology, land cover, visibility).*

Consistency can be associated with different aspects of the data and can apply at different levels. These may include consistency across different data products, consistency in how data values are represented (in format, precision, semantics), consistency across resolutions / details of the same object, or any number of other consistency criteria important to the tasks and objectives.

<u>Example:</u> *Inconsistent visual detail in the icons (3D models) of different trees or buildings in the same vicinity can create a visual distraction that may be counterproductive to the training objectives.*

Currency can be defined as the measure of how well the most recent state of the real world or entity is or can be represented by the data.

<u>Example:</u> *If the presence of fog during a live training event cannot be added to the digital twin until after the fog has dissipated, the degradation of shooter-target computations will not reflect the training participants' experience.*

Accuracy expresses how correctly the data represents a real world or reference object, event, or condition. Measure of accuracy is often the objective comparison between what is and how well it is represented (within the scope of a given application's objectives). An accurate but not very precise representation (or data value) is more valuable than a highly precise but inaccurate one.

<u>Example:</u> *The 3D model of the interior of a building is inaccurate because it depicts three doors along a hallway and each door opens into separate rooms, when the real building contains five doors, one of which opens into the hallway to reveal a small closet.*

The OWT modernization effort is establishing the 3D Foundational Data and supporting infrastructure to permit the establishment of content pools serving the needs of focused mission areas or communities. Existing governance procedures and data life cycle management frameworks will enable quality assurance and control of 3D content for training and beyond.

3 OWT Addresses Live Runtime Environment Needs

High-Resolution Data. Live use cases require precise high-resolution data for their training areas. The need includes accurate heights for buildings, buildings with full interiors, precise road placement and geo-specific trees and shrubs. The data will be used for many activities, including ballistic calculations, and must be very accurate to support direct fire, short-range indirect fire, and causality assessments. The TRADOC Proponent Office (TPO) for Live requires imagery and elevation data with an accuracy error that is less than 5cm/1cm (threshold/objective) horizontally, less than 5cm/1cm vertically, and less than 10cm/1cm to support geo-registration (object positioning) accuracy (U.S. Army, Abbreviated-Capability Development Document (A-CDD) For Synthetic Training Environment – Live Training System (STE-LTS), 2021). This accuracy level is particularly challenging, as current OWT data contains a foundational dataset with an accuracy that is equal to or less than 3m (satellite derived) with occasional datasets from Drone collects that can supplement the foundational data, approaching the 7cm accuracy level.

Figure 2: An example of drone captured terrain with 7cm accuracy.

Live training engagements are dependent upon accuracy of the underlying source data. Many of which will require conflation of multi-source and disparate data. For example, the accuracy and fidelity of a terrain model based on low altitude drone collect, while a large improvement over satellite imagery, may still fall short of some live engagement needs. However, when combined with satellite data, a hybrid approach begins to satisfy live engagement use cases. The Live and OWT developmental teams concur with the required terrain resolution specifications and are exploring various avenues to push envelopment of the current terrain architecture to fulfill the live use case to include materiel solutions to capture geo-data at the Point of Need (Dukstein, Nielsen, & Dumanior, 2017) (Marrou, 2018). To ensure the data is collected properly, the OWT team will provide a specification on the required format and details necessary so that the collection will provide the highest level of benefit. The Live team will provide the collected data to the OWT team so they can re-use and roll this high-resolution collect into the underlying OWT source data. We believe a collaborative effort between OWT and Live teams is the best method to solving the High-Resolution problem. For example, initial Live team feedback suggests that satellite data may be sufficient to extract objects in support of some of live engagements (e.g., indirect fire), a number of engagements (e.g., direct fire) would require higher-resolution data sets (e.g., drone or soldier born sensors) to fulfill spatial and geometrics needs.

Damage States. Another challenging area is the ability to accurately show damage and destruction of objects and models within the scene. This damage can be caused by collisions, but most notably, it is damage caused by the use of weapons affecting the environment. The weapons can range from large artillery down to small firearms. The Army's legacy systems took an overall simple but effective approach of using a few damage states for each model consisting of a pre-built/canned healthy, partially damaged, or destroyed state for each model. However, this approach will not be sufficient for the emerging Live requirements which will require a more complex physics-based approach. A physics-based solution could ultimately provide a very realistic, accurate and complete damage effects package to cover everything from collision damage to weapon effects. The OWT team's plan is to provide all the metadata or attribution necessary that is required by the physics-based algorithms. The OWT team has selected the Ground-Warfighter Geospatial Data Model (GGDM) as its standard to ensure the correct collection, structure, and storage of data. The OWT team's plan is to work closely with Live team to ensure its feature attribution needs are met and needs that fall outside of the latest GGDM will be extended and rolled back into the standard (U.S. Army, Ground-Warfighter Geospatial Data Model, 2021).

Material Coding. Detailed Material Codes, a type of metadata, that describe or define the material from which an object, section of ground/terrain, or building is made. These codes will be necessary for Live to provide answers to questions like, "Could a round pierce this wall based on its material code?" In addition to material type, the codes must include densities and dimensions (or thicknesses) that will allow the Live Training System to distinguish between different effects of munitions through physics calculations. For example, the ground materials will need sufficient details to discern sandy soil and dense clay for cratering calculations. For physics calculations on walls, the materials must include supporting data to describe a concrete block vs. corrugated metal. From Live requirements, "This is necessary to determine round or shrapnel penetration as well as accurately modeling the effects of explosive rounds on these objects regarding rubble and creating shrapnel that could affect personnel."

The OWT team's solution to meeting the need for Material Codes will follow a similar approach as Damage States - it all comes down to attribution. The team is working with SC- STTC on several efforts relating to enhancing the terrain attribution, including a data validation service for attribution, improving attribution related to critical infrastructures, and data model enhancements for building models, soil attribution and overall expansion of attributions. The capabilities resulting from these enhancements will provide a more robust Material Code solution, getting us closer to meeting the needs for live training.

Figure 3: Attribution to support physics-based damage states.

Feature Placement. OWT, and the location of all its features, must exactly match the live environment. It is extremely challenging to have features such as tree canopies, trees, bridges, building structures, and light poles placed so that the synthetic terrain matches the real world for Live. Historically, Army synthetic environments were focused on virtual training, which required the placement of features to be accurate enough to support navigation for pilots or drivers. In this scenario, if a building was off by a meter or two it was not noticeable and did not adversely impact the training objectives (Morton, van Diggelen, Spilker, & Parkinson, 2021). In a live scenario, if a soldier is hiding behind the same building, even if only misplaced by approximately 30cm, this could mean the difference between a miss or an incorrect catastrophic kill, resulting in a negative training experience for the Soldier.

The currency of feature placement is critical for immersion and a successful training experience. However, feature placement is a challenge that is being overcome through the efforts of the OWT team working closely with TSS/TMT developers in meeting the needs for live training capabilities. Each week, the TSS/TMT developers provide feedback to the OWT team resulting in continuous improvements to the OWT team's processes, algorithms, and data sources. Using a scrum approach to guide the collaboration, the OWT team is able to advance the geometry, accuracy, and attribution of data to support the broader training community. This development has improved the accuracy of the OWT foundational data from approximately 3m to less than 1m. These incremental developments, when combined, will create an improved Feature Placement capability for all STE participants and allow for adjustments to data quality (e.g., level of detail) to be defined prior to mission training.

4 Use-Cases and Terrain Challenges for Live Training

The U.S. Army established a Combat Training Centers (CTC) program to provide realistic joint service and combined arms training in accordance with Army doctrine. The CTC program was designed to provide training units opportunities to increase collective proficiency on the most realistic battlefield available during peace time. In other words, provide a Live Training Environment (LTE) using go-to-war systems, orchestrated by synthetic training systems, on real terrain, across the full range of battlefield environmental conditions. Force on Force (FoF) is the use of non-lethal training that provides Soldiers and units the ability to employ their full range of combat systems against an opposing force in realistic operational scenarios. Force on Target (FoT) involves training exercises for a training unit firing live ammunition at targets, which may be moving targets and targets that shoot back (using simulated weapons) acting in accordance with predefined scenarios. Figure 5 illustrates the various live training engagements that fall within FoF/FoT (e.g., direct fire, indirect fire, counter defilade, etc.) or span Multi-Domain Operations (MDO) (e.g., cyber across domains), whereby Soldiers employ various weapon systems to achieve and experience weapons effects. For more information on the engagement types shown in Figure 5, see the A-CDD for STE-LTS (2021).

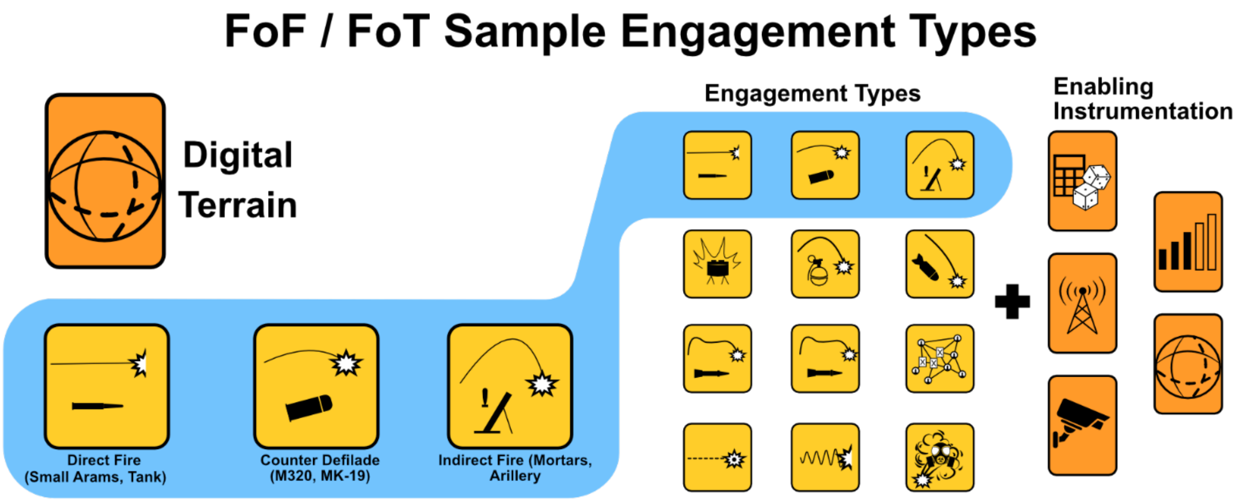

Figure 4: FoF/FoT Live Training Engagement Types

4.1 Use-Case 1: Structure Destruction

The explosion of a virtual mine under a bridge is triggered in a live training and maneuver site. Immediately, the resulting bridge collapses and the surrounding terrain deformation is computed in the physics-based digital twin of the live training area. Within a second, the trainees, through their Augmented Reality (AR) headset, see the digitally destroyed bridge and terrain deformation superimposed on the actual region. The size and shape of the debris and deformations seamlessly adjust to the positions and view angles of the participants as they move through the training area.

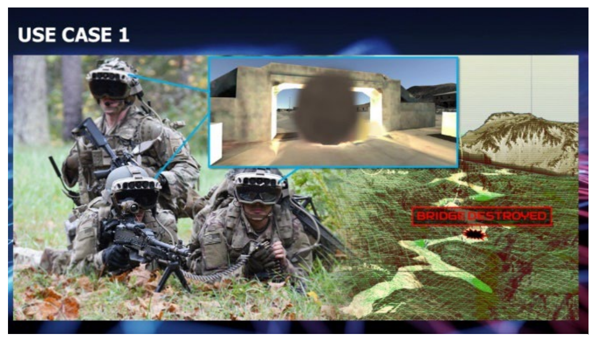

Figure 5: Use case example of what live Soldier sees during an engagement.

In this use-case, the correlated visualization of the real and digital twin events is critical for participant situational awareness and training realism. Failure to augment the real view with a destroyed bridge will lead to training discontinuities as participants attempt to use an operational bridge (that is now destroyed). Current Army research efforts being conducted by SC-STTC are attempting to answer how virtual events can be displayed on participant-worn systems and to provide the real-world augmentation with effective digital content to allow accurate participant engagement; in this case, as if the bridge is destroyed and unusable.

4.2 Use-Case 2: Run for Cover

A skilled real machinegun specialist positioned at a hiding spot on a rooftop of a multi-story building at a training site fires electronic (and real blank) bullets in the direction of the oncoming real trainees who are acting as the opposing force. Upon hearing the gunshots in their earpieces, the opposing force takes cover behind closest protection each can find. As the machine gun traces some of their paths, the real-time computation of the electronic bullets determines what or who has been hit. Some e-bullets hit concrete walls, some hit glass windows or wooden window shutters, and some members of the opposing force. The real-time physics-based digital twin computations determine which opposing force members sustained a direct hit or near-miss injury and which were protected by the cover material.

Figure 6: Use case example of Soldier using cover during engagements.

In this use-case, the accuracy of the digital twin environment plays a significant role in fair fight and engagement realism. Failure for the digital twin to sufficiently represent the real-world cover and concealment will result in negative training. Current Army research efforts being conducted by SC-STTC are attempting to baseline the current digital twin terrain accuracy, validate the needed vertical and horizontal accuracy necessary to avoid fair-fight issues, and establish a workflow to meet those requirements.

4.3 Use Case 3: Hide 'n' Seek

At a real open range training site, a Soldier with a shoulder-mounted Javelin hides in the bushes near a dirt road as two virtual T14 tanks roll by towards their targets. Through their AR headset, the Soldier can see and hear the virtual vehicles passing and waits for the right moment. The real crew of the T14s are located at a combat training center a few miles away and are monitoring their surrounding as they move but have not used their infra-red (IR) sensors to notice or detect the Soldier in the nearby bushes. As the tanks get further away, the Javelin operator moves to the side of the road and prepares to fire at the rear T14's turret, which is now nearly hundred meters away and is about to disappear into a natural depression in the road. The experienced Javelin operator fires the e-round with confidence at the target.

Figure 7: Use case example of live Soldier engaging virtual entities on real world terrain.

In this use-case, once again, the accuracy of the digital twin environment plays a significant role in fair fight and engagement realism. Failure for the digital twin to sufficiently represent the real-world cover and concealment of the bushes would have resulted in detecting the Soldier by the virtual T14's. Currency of the digital twin is important as elevation and terrain features may be altered by weather or by preceding engagements.

4.4 Use Case Challenges Summarized

These three use-cases also fall under the need to understand how digital twin environments must be optimized to operate at the PoN in network- and computing-constrained environments. The research at SC-STTC is baselining the current known network and computing constraints and offering data-tailoring solutions that align with digital twin terrain accuracy requirements.

For effective live training, multiple hurdles must be overcome to realize these use-cases. Common elements across these challenges include the acquisition, use, processing, and computation of accurate data for positions, orientations, structures, natural objects / phenomena, material attributes, and time. Under perfect conditions, the fidelity of the digital twin matches every aspect of the real world every time. Several difficult problems must be solved to achieve a reasonable approximation, but the right aspects of the real world at the right time for the specific training objective can be made possible.

The computation and data challenges in the end-to-end chain, from reality to digital twin and back, include the following:

- Gathering accurate and current horizontal and vertical positions of all real objects and their geometry – from small terrain undulations to man-made structures, and everything in between that will matter to the training objectives; generally, this data acquisition happens ahead of a training event, at times incremental changes must also happen during an event;
- Incorporating the appropriate characteristics (such as material properties) of any object that can impact the training objectives;
- Obtaining reasonably accurate and continuous positioning and orientation data for all training participants (individuals and vehicles) and their weapons;
- Receiving data for events and actions triggered by participants during live training;
- Incorporating live natural phenomena (e.g., fog, smoke, rain, wind, temperature, and humidity);
- Using these data with appropriate physics-based modeling to compute effects and outcomes (hit, miss, deformations) from events and activities with reasonable fidelity at or near real-time;

- Sending the appropriate updates and results to affected participants and observers;
- Performing these within affordable measures and sometimes under constrained conditions.

Timely and accurate data collection is not trivial. Whether the collection is live or in advance of an event, it must be sufficiently current and it is often subject to noise and error. Addressing horizontal, vertical, and orientation accuracies not only requires precision in both hardware and software, but also in understanding and tracking the sources that contribute to inaccuracies.

Amalgamation of data from many sources is usually unavoidable as no single source can provide a complete representation. Extracting the right-resolution data from the appropriate sources, and then fusing the results, is a continuing quest. Human-involved data cleanup, alignment, and fusion is a complex and costly activity. Automation of such complex tasks, especially for live or live-virtual training, is also not trivial, and often requires the appropriate scope, intelligence, and precision embedded in software.

Especially in live training, accurate and precise position data is critical, in both horizontal and vertical dimensions. Inadequate co-registration measures and presence of discontinuities between the live environment and the corresponding virtual or digital twin will be immediately apparent.

Errors can occur anywhere along the long chain, shown back in Figure 1, that spans from the real environment through data collection and manipulation and ends in a digital model of the environment. Added to this are the errors that can occur in converting between different systems, tools, and representations. Validating the digital models (whether algorithms, terrain elevations, features, or synthesized content) requires a system view of the end-to-end process.

Another challenge is sharing the right level of updates under network or system-constrained conditions during live exercises, while ensuring accurate and up-to-date data is available to all affected participants. An important factor in addressing the live-virtual (and also constructive) training challenges is striking the right balance between science, available technology, clever engineering, innovation, and affordability.

5 State of Technology

The OWT product currently provides a portion of live training needs despite the above-mentioned challenges. Through collaboration with the OWT prime vendor (Maxar) and the user community, the OWT team shapes, sizes, and distributes the data appropriately to meet various user requirements and schedules. Though the current terrain product does not support all live training engagements, it is sufficient for some engagement types, such as indirect fire.

The OWT product was successfully used within several STE prototype air and ground simulation environments during various Soldier Touch Point (STP) events. At these events, Soldiers provided real-time feedback on their perceptions of the simulated environment where they were immersed. Some Soldiers were able to immediately recognize the environment as a familiar place. The vegetation provided cover and concealment, and the hydrology or water transitioned realistically from the shoreline to the rivers. The STE team successfully integrated OWT as an authoritative geospatial data source for live training while recognizing its current limitation and the need to mature and evolve the current architecture by addressing the challenges described above. Research continues to evolve in the areas of position, navigation, and timing technologies that will address many challenges facing the OWT landscape as we know it today.

Going forward, the geo-spatial community is increasing the use of commercially available data sources while supporting the development of high-resolution inset collection and processing workflows (e.g., exterior and interior). These developments will reduce fair fight issues and improve consistency in the training experience; while advances in digital terrain generation will enhance STE-LTS training engagements and deliver next generation warfighter capabilities to the Soldier.

6 Conclusion

To minimize fair fight issues, the OWT team is improving the digital terrain to real world approximation with increased spatial, geometric, and semantic resolutions that exceed traditional virtual or constructive simulation needs. To effectively converge live, virtual, and constructive domains within the STE architecture, the team is working to ensure appropriate fidelity for numerous use cases. To enable realistic live on live force on force engagement, the STE team is making use of high-fidelity digital terrain when it is available. OWT is already delivering 3D global terrain data as a virtual representation of the physical earth with greater the details for some select locations. The STE team is still working on getting sufficient resolution for Live Training needs including the ability to register material codes and use them to determine damage effects. The visualization of the damage states is being worked separately and will be dependent on the type of visualization system available in the training environment.

The team is continuing to develop geospatial capabilities while delivering initial datasets. The format design has flexibility to increase data fidelity in response to additional requirements or changing methodology. As the project develops technology will mature and facilitate delivery of data that meet the needs of the live training community. Technology advances will support better data collection and timely delivery to the training environment. These developments will ensure a more robust training experience for future soldiers.

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