

ENABLING TECHNOLOGIES FOR EMBEDDED SIMULATION & EMBEDDED TRAINING

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ABSTRACT

The army has placed a renewed emphasis on an embedded training capability as a result of lessons learned from the Advanced Warfighting Experiment (AWE) 97-06 on the potentials of digitization. Through the Inter-Vehicle Embedded Simulation Technology (INVEST) Science and Technology Objective (STO), the Simulation Training and Instrumentation Command (STRICOM) will develop the technology that will lay the foundation for incorporating embedded simulation into future and legacy combat vehicles. This paper presents current status and future evolution of the enabling technologies needed to fully embed these technologies into a combat vehicle. These ES systems will support both training and operational (go-to-war) enhancements for the Army XXI and Army After Next inventory of combat vehicles. The key enabling technologies for an autonomous vehicle capability include: low cost image generation, live-virtual object and terrain integration, virtual target injection into sensor displays, synchronized semi-automated player models, simulation filtering tool, intelligent tutoring system, time-based and UWB communication, and automated vehicle model development and optimization.

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By Hubert Bahr and Claude Abate, STRICOM

Introduction

To fight and win on the modern battlefield two things are required; weapons systems that out perform the opponent's weapon system, and crews that are better trained to use the weapon system effectively. A cost effective means of improving weapon system performance is Embedded Simulation (ES), which includes Embedded Training (ET) or the capability to train and maintain crew proficiency on the same equipment they will go to war on, and the Embedded Operations (EO) functions of situational awareness (SA), mission rehearsal (MR), command coordination (CC), critical decision making (CDM) and course of action analysis (COAA).

The competition for better weapons is one component of the challenge and the other involves training the crews to be more proficient than the opponent. But there are training costs associated with more complex weapons systems. To date, stand alone trainers have been employed at the school house and in the units. The power projection army of the future will have to spend more time maintaining task proficiency while stand-alone trainers cannot meet the deploying force requirements and are too costly to operate and maintain. One option that will overcome this deficiency is a training system that is integrated into the vehicle. However, any sub-system that is integrated into the vehicle becomes a luxury unless it provides improved combat effectiveness. For this reason, the proposed approach of embedded simulation (ES) technology addresses a system that provides both training support and go-to-war capabilities. An expanded discussion of ES training uses can be found in reference 1.

In this paper we are going to walk through the various levels of training applications (gunnery) from a single vehicle to multiple vehicles to multiple vehicles participating in live fire and force-on-force exercise similar to training conducted at the Combat Training Centers (CTCs) and finally go-to-war examples.

Background

While stand alone trainers such as COFT/AGTS, SIMNET/CCTT and M-1 Driver Trainers have served the Army of Excellence well, technological advances and miniaturization now present the ability and affordability for embedding crew and collective training systems into the vehicle. We will refer to these ground combat systems with an embedded training capability as "autonomous" trainers.

The goal of the Inter-Vehicle Embedded Simulation Technology- Science and Technology Objective (INVEST-STO) program is to develop and demonstrate the technology that will lay the foundation for incorporating ES and ET into future as well as legacy vehicles.

The enabling technologies and components used to run an Embedded Simulation System (ESS) are basically the same for the stand-alone trainer with the exception that they will be smaller, faster, more powerful and less expensive. Common components include image generators, simulation computer, Semi-automated Forces (SAF), data logger, terrain database, communications and instructor operator. Stand alone Image generators of today are located in large racks and wired to monitors located at the various crew stations. In the future they will be no larger than a card and the images projected directly into vehicle sights or sensors. The large rack mounted computers will be replaced by a very small and powerful lap top size computer that is accessible to the crew and loaded with software (SW) containing current ModSAF and world terrain database models. An application hardware (HW) data logger will be linked into the simulation computer to record crew actions and support AARs. The only common component that is non-applicable to an ESS is a dedicated instructor operator because that task belongs to the vehicle commander or senior cadre personnel.

When units deploy to a combat zone in response to a rapid deployment mission in the next century, the benefits of autonomous

trainers become readily apparent. In addition, the dual-use design of the ESS can be used to enhance operational effectiveness.



Figure 1A
Assembly Area or Motor Pool Training



Figure 1B
Range Dry Fire Training

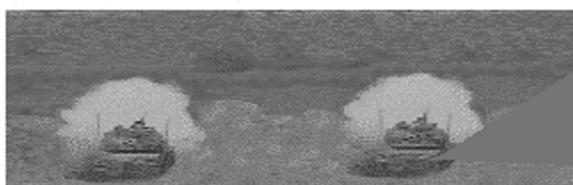


Figure 1C
Range Live Fire Training

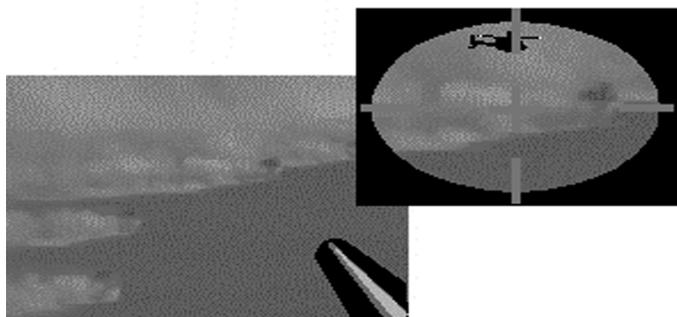


Figure 1D
Force on Force Training



Figure 1E
Combat Operations

Figure 1

ESS Training Applications

Let's assume that in any future combat system the crew will have to be trained to maneuver and engage targets using a highly sophisticated suite of fire control sensors and devices. The design of the ESS will be such that the crew can hone its maneuver and gunnery skills by projecting selected training exercises into vehicle optics or sensor systems. Due to advances in technology and miniaturization, the graphics card and open scene visual processing will be capable of displaying a terrain database (world models support SW), and the SAF (CGF support SW) will display the target array on to the database. These SAF entities will be fully functional (move, shoot and maneuver) and replicate enemy capabilities. The on-board data logger will record all engagements for follow-on After Action Review (AAR) by the unit cadre or vehicle commander. This training can be conducted in the motor pool, assembly area or enroute to a combat theater. Training can be tailored to meet individual or crew (collective training) needs in terms of tactical conditions (offense/defense), force ratios, degree of difficulty in terms of probably of hit & kill, and environmental, terrain and light conditions. This provides a virtual 360-degree battlefield with ground and air targets.

Training Example

Training will follow the normal crawl, walk, run strategy starting with a stationary single crew exercise and progress to multiple moving vehicles in a combined arms live fire exercises. However, autonomous trainers require a further segregation of exercises in terms of simulation mode, i.e. (1) live vehicle firing virtual rounds vs. virtual target on virtual terrain; (2) live vehicle firing virtual rounds vs. virtual target on live terrain and (3) live vehicle firing live rounds vs. virtual target on live terrain. The technology / engineering challenges associated with each mode are listed below.

1. Live vehicle firing virtual rounds vs. virtual target on virtual terrain requires:
 - a. geometric pairing vice laser pairing
 - b. aim point determination
 - c. realistic fire on target effects
 - d. scenario generation

- (a) Geometric pairing will be required because a laser pairing system will not work between live and virtual targets (no vehicle present to provide a laser return). In virtual on virtual simulation shooter-target pairing is practically inherent because the locations and orientations of the vehicles and weapons are known almost perfectly in the simulation world. Engagements are simulated by computing the ballistic flyout of simulated rounds and determining where they impact on target or the terrain. The geometric pairing solution takes place at the time of ranging to the target (in the shooter's sight picture). The on board simulation computer calculates the distance to target and stimulates the vehicle to enter the appropriate range return in the gunners sight.
- (b) Aim point determination will be calculated by capturing, at the instant of firing, the crosshair location with respect to the target. In a virtual on virtual engagement, the locations and orientations of vehicle are known essentially perfectly (they are synthesized by the simulation) and their orientation relative to each other are easily derived from their world coordinates. The simulation computer knows the relative position of crosshair to the target and stimulates the appropriate burst on target effect. Location of impact is also needed to determine target and casualty effects.
- (c) Realistic fire on target effects models are stored as part of the terrain database and will be generated by the IG at the time of round impact on the target. Obscuration, gun recoil and visual tracers will also be stimulated in the sights of the firing vehicle at the time of firing.
- (d) Scenario generation would be accomplished at the battalion level and in accordance with published gunnery tactics, techniques and procedures. The scenarios developed in this example, would be a series of crew gunnery exercises or firing tables designed to train or sustain crew proficiency. All targets would be virtual and arrayed to match current enemy fire and maneuver

doctrine. Firing scenarios can either reside on the vehicle simulation computer HW, on a CD-ROM or ported down to the using unit or plugged into the removable storage application HW.

2. Live veh firing virtual rounds vs. virtual target on live terrain requires:

- a. terrain fidelity and terrain correlation
- b. injection of virtual target into a live scene

(a) Terrain fidelity and terrain correlation supports a clear image of the virtual target that is spatially correlated to the live terrain. For example, the virtual target must realistically move over the live terrain and not give the appearance of floating above or sinking into the terrain.

(b) Injection of virtual target into the live scene or augmented reality involves the process of generating virtual images that appear to fit seamlessly into the real-world environment. A critical requirement is image clipping or removal of those virtual images that should be partly or fully obscured by intervening real-world objects.

3. **Live veh firing live rounds vs. virtual targets on live terrain requires:**

- a. GPS location of firer
- b. Vehicle/ hull attitude
- c. Gun/turret orientation (AZ & Elev.)
- d. Safety overwatch (observer console)
- e. Aim point determination (GPS Interferometry)
- f. Geo-pairing

(a) All vehicles will be equipped with a global positioning system (GPS). This system accurately identifies the location of the firer in terms of its X & Y coordinates and every other friendly or enemy vehicle in the exercise can be tracked and geo-paired for gunnery purposes.

(b) The hull attitude of the virtual target is important to determine the strike of round and to calculate vehicle damage. Orientation of a virtual vehicle influences its vulnerability and ability to identify and engage the live vehicle. The simulation

computer on the live platform is generating this information.

(c) Gun orientation further defines the virtual vehicle's ability to identify and engage the live vehicle. The simulation computer on the live platform generates this information.

(d) If this technology is used to replace wooded targetry on live fire ranges at home station or at the CTCs, then it is essential to have tower or safety officer overwatch in order to see the live engagement of a virtual target. Safety over watch can only be accomplished by providing a safety-overwatch console with the virtual target array similar to those on the firing vehicle. A simulation computer and image generator (IG) capability must be available to safety personnel or sent by telemetry from the firing vehicle to overwatch element sensors.

(e) When crossing the boundary between live and virtual (or engaging real targets that cannot be seen) the orientation of the real shooter vehicle with respect to the world becomes important. This situation requires solving the problem of measuring accurately not only the position of the shooter and target vehicles, but also the pointing angle in world coordinates of the shooter's gun.

(f) In the real world of live-instrumented vehicles on training ranges, it is not possible to determine locations and orientations very well. Geometric pairing from shooter to target is determined using geometry, namely the locations of the vehicles, the pointing angle of the shooter's gun and the line from shooter outward toward the target.

1. **ESS in support of multi-echelon combined arms (collective) training conducted at our Combat Training Centers requires an additional set of enabling technologies. (The fact that multiple players are participating means communication links become pacing items for successful execution). These technologies include:**

- a. Digitized terrain database

- b. Optimal live/virtual registration (Geometric pairing combined with GPS, vehicle attitude and gun orientation)
 - c. Synchronized SAF
 - d. Increased communications bandwidth / reduced comms / distributed processing
 - e. Automated vehicle / smart models
 - f. Communications / sensor surrogates
 - g. Intelligent tutoring system
 - h. Automated battlefield information filtering tool
 - i. Scenario builder / modification tool
- (a) High resolution digitized terrain databases are essential for any live-virtual exercise. Resolution must be to Digital Terrain Elevation Data (DTED) level 4 with horizontal resolution at 5 meters and vertical resolution at 1.5 meters or less. All databases should be standardized & interoperable or compliant with Synthetic Environment Data Representation & Interchange Specification (SEDRIS) conversion mechanisms.
 - (b) Implementation of geo-pairing for direct fire and non line-of-sight engagement simulation is based upon accurate GPS position location measurements and accurate GPS-based turret angle measurements (shooter-target pairing and accurate visual representation of live vehicles in the virtual world).
 - (c) Synchronized SAF or the Collective Observation of a Common Entity (SAF) is designed to synchronize the SAFs generated on each player platform. For example, in a platoon exercise all tanks will see exactly the same view of the Opposing Force (OPFOR) as they move or as they are attrited by platoon direct fire. The advantage of synchronizing is the reduction of update communications traffic between friendly players as actions take place affecting the status of the SAF entities. The technology involves the modeling of the SAF entity at a high level (in terms of behaviors) so that only infrequent updates to the model are required.
 - (d) ESS has more stringent comms requirements than any stand-alone system. These requirements include weight, volume, range, power, and bandwidth management. With multiple players in the simulation exercise they must be constantly reporting current state (a few updates per second at a minimum) and interaction information to ensure proper representation. The use of ultra wideband (UWB) technology shows promise with handling the high data bandwidth load. It uses less power for given range, has urban environment capability and a low probability of detection & interception. This UWB technology also has the potential for the longer term "go to war" tactical internet communications requirements.
 - (e) By accurately modeling the behavior of a human player, each live or virtual entity can use this behavior model to predict the state of other live entities on the battlefield; and thus reduce the comms bandwidth required to update operational and status information exchange between all entities. The optimization of model information can be using on-board computational resources (simulation computer and vehicle modeling SW).
 - (f) Communication and real-time sensor surrogates will employ UWB technology. UWB has the capability to be used as precision radar with the inherent benefits as a communication system. Use of this capability in an imaging array can provide an electronic video camera and provide a more accurate live/virtual vehicle registration; as well as providing terrain database updates that were not present when the database was produced and thus avoiding costly high resolution database generation.
 - (g) A SW application connected into the simulation computer system will be an embedded intelligent training system. The SW will duplicate as closely as possible the trainee undergoing on-the-job training in a crew position task environment without benefit of a human instructor. Students can train in an interactive environment towards a particular goal or task that will include challenging training scenarios, monitoring & evaluation of the trainee actions, meaningful feedback comments to errors and response to trainee requests for information.
 - (h) A SW application connected to the simulation computer system will be designed to process tactical information and/or use intelligent agents to filter out

extraneous information not readily needed by the commander. This system will automate the collection & dissemination of critical information automatically allowing rapid decision-making. This system will prevent information overload by eliminating non-essential information, reducing communications bandwidth, and uncluttering the commander's display.

- (i) The TRADOC community will provide a standard library of ARTEP scenarios and the units will have the capability to develop their own scenarios or modify existing ones to meet METL requirements. This technology will be located at battalion staff level and interfaced to the automated Battle Planning System (BPS).

5. Go-To- War Operational Enhancements:

ESS in support of operational enhancements makes the technology more affordable than a single training enhancement system. An expanded discussion of ES uses for the AAN can be found in reference 2.

- a. Situational awareness
 - b. Battlefield visualization
 - c. Mission planning/rehearsal
 - d. Course of action analysis
 - e. Critical decision making.
 - f. Command & Control (staff uses)
 - g. Information overload reduction (Info Filtering Tool)
- (a) Situational Awareness (SA) can be enhanced by an ESS. The rapid processing and sharing of enemy and friendly location information in a structured format can assist the commander with making timely decisions. ESS can be used to automate the Tactical Decision Making Process (TDMP) because the computer can collect and compile essential enemy information and filter out non-essential information and display as either a 2D or 3D view. The simulation computer can compare old and new enemy situational templates to predict possible enemy actions or intentions. As the enemy closes the computer can display on screen weapon range arcs to alert the crews of their vulnerability to enemy direct or indirect fire. SA will not be

degraded by extended distances because UWB technology has the multi-path over the horizon connectivity which can use every vehicle as a store-and-forward relay platform and by operations in a built-up area because UWB is immune to signal interference caused by man-made structures.

- (b) Tactical information from the various ground and airborne sensor systems can be ported into the battalion Tactical Operations Center (TOC) for use by the commander and staff to make timely decisions. If necessary this information can be displayed on every vehicle tactical display instantaneously to give every crew a clear picture of enemy action. The rapid graphic display of enemy info like a Family of Scatterable Mines (FASCAM) minefield becomes a powerful tool that can save time and lives. Operations orders and graphics can be transmitted electronically and thereby reducing report preparation and distribution times.
- (c) Mission planning and rehearsal can be realistically accomplished by conducting a virtual reconnaissance of the battle area or a virtual look back at the defensive position, and a virtual rehearsing against a GGF on the same terrain database and using similar light & environmental conditions. Electronic planning and stealth reconnaissance will maximize the use of planning time and minimize exposure to enemy observation and fire. Because of the inherent covertness of UWB technology, critical information can be passed freely during both planning and rehearsal phases. Stetliminating some of the unknowns and reinforcing proper execution while rehearsing enemy "what if" situations. The concept of "Perfect practice makes for perfect execution" would enhance crew confidence.
- (d) Developing the best course of action can be made easier by running the various Blue courses of action virtually against the Red courses of action. Quick simulations can be run to determine possible results of the various courses of action. The commander can make his final decision based upon the result of the computer comparative analysis and risks involved.

- (e) An ESS can automate the collection & dissemination of key information (SA) automatically, thereby allowing rapid decision making based upon the most recent information available and models of enemy tactics, techniques, procedures and order of battle information. Using the ESS to reduce the commander's information processing duties can abate the stresses of combat decision making. ESS contributes to digitization as a force multiplier.
 - (f) Command, control and communication will be expedited and improved by using the on-board processing capacity, smart models, intelligent agents, covert digitized communications, and the real time display of enemy and friendly activity / status. Graphical displays vice verbal transmission of critical information will save time and standardize information exchange. Commanders and staffs can overwatch unit personnel & logistical status and anticipate support requirements.
 - (g) ES can be used to perform as an intelligent agent to filter out extraneous information and provide non-redundant transmission of information that is crucial to decision making. The resultant filtered output to the human decision-maker will permit faster and more accurate decisions and prevent information overload and display clutter. The system can be embedded into the Advanced Tactical Command & Control System (ATCCS) and the display tailored to show information the commander considers critical to his decision making process.
- (2) Fully embed ES into the vehicle subsystems by adding or upgrading the vehicle's own computer and SW architecture to accommodate the additional requirements to support ES. Advantages would be not requiring any extra space and use of the current video interface. Disadvantage is that new components would have to be militarized and integrated with the existing system and the associated costs.
 - (3) A hybrid or combination of 1 and 2. In this approach the idea would be to find the optimal approach that utilizes as much of the vehicle computer and networking capability, but anything new or to costly to militarize is put in a separate subsystem. The disadvantage of this approach is that it will still require extra space.

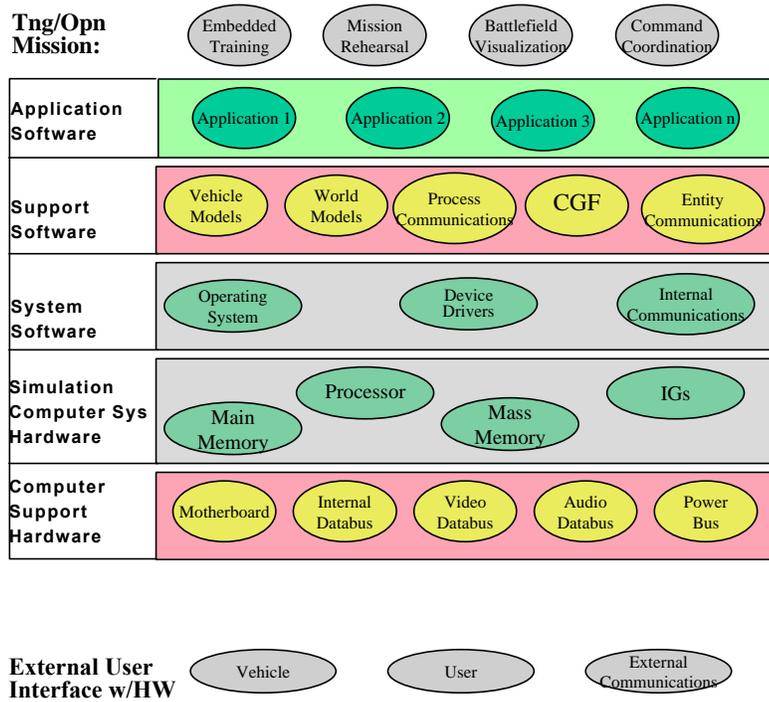
b. Stet the final decision to implement an architecture approach will be made at a later time. Hardware and software architecture for ESS must be done in a way that will allow for seamless integration in any potential vehicle platform. This will require emphasis on architecture interfaces (HW & SW) that can be fully embedded into the vehicle architecture design. Computer technology and graphic systems are improveing at such a rapid rate that the ES architecture must be designed in a way to reduce upgrade costs. ESS will be developed under an architecture-based approach that will emphasize loosely coupled interfaces and maximum use of commercial standards and software Application Programming Interfaces (APIs). . We can show with the below ES Technical Reference Model the interrelationship between the HW & SW needed for a fully ESS. Future vehicles will be designed with ES as part of the vehicle architecture.

Embedded System (ES) Architecture

- a. Three architecture approaches are currently being studied.
 - (1) A completely separate stand-alone ES subsystem with its own processing image generator and SW. Advantages would be utilizing off-the-shelf and ruggedized HW, lower cost, use of state of the art graphics cards and processors and least interference with actual vehicle HW & SW. Disadvantage is the need for additional space requirements.

c. ES Technical Reference Model

Embedded Simulation Technical Reference Model



Significant Capabilities

- Embedded Mission Rehearsal
- Embedded Training
- Battlefield Visualization
- Command Coordination
- Virtual Test & Evaluation
- Simulation Based Acquisition
- 3D Mission Visualization
- Stealth / Virtual Recon

Functional Drivers

- Vehicle Simulation Mode (i.e. weapons, mobility, ...)
- Virtual World/Virtual Target Injection
- Mission Planning/Scenario Generation System
- Terrain Database Generation System
- Stealth/Flying Carpet Mode
- Automated Exercise Manager
- After Action Review/Replay System
- Vehicle to Vehicle Simulation Communication Architecture
- Entity Generation System (i.e. ModSAF)

Figure 2

Conclusion

The enabling technologies associated with INVEST-STO are a significant first step to meet the training and operational challenges needed to support the Army After Next (AAN). The force projection army of the next century will have the benefit of an autonomous training system and dual use ESS capable of providing improved SA and other operational enhancements. This capability will give new meaning to the “train as you fight” imperative. Intelligent tutoring systems and a robust on-board training support package will ensure that the crews attain and sustain proficiency advantages over any adversary. The mental agility and information dominance gained through Force XXI will spawn the technology enablers that will make an ESS a key component of combat and training readiness in all future crew and command & control systems. INVEST-STO is at the leading edge of these future operational and training capabilities .

REFERENCES

1. **Bahr, H., Abate C. and Collins J.,**
“**Embedded Simulation for Army Ground
Combat Vehicles,**”
19th I/ITSEC Conference Proceedings,
December 1997
2. **Abate,C., Bahr, H. and Brabbs,J.,**
Embedded Simulation for the Army After
Next,
Armor, July-August 1998.

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