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Distributed Embedded Simulation And Training Research: Correlating Live Aimpoints And Virtual Targets

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Terminology

cep	circular error probable
CID	Commander's Integrated Display (roughly CDE/CDU of SEP)
CIG	Computer Image Generator
cm	centimeters
DECU	Digital Engine Control Unit
DFIRST	Deployable Force-on-Force Instrumented Range System
DIS	Distributed Interactive Simulation
ES	Embedded Simulation
ESPDU	Entity State Protocol Data Unit
ESS	Embedded Simulation System
ESPDU	Entity State Protocol Data Units
ET	Embedded Training
FCEU	Fire Control Electronics Unit
FCS	Fire Control System
GCDP	Gunner's Control and Display Panel
GPS	Global Positioning System
GPS	Gunners Primary Sight
HLA	High Level Architecture
IST	Institute for Simulation and Training
MBT	Main Battle Tank
POS/NAV	Position/Navigation (inertial measurement unit)
SEP	System Enhancement Package
sep	spherical error probable
TEU	Turret Electronics Unit (replaced by MPU in SEP)

1. 0 Project Overview

Embedded simulation/embedded training (ES/ET) has as its cornerstone, the Inter-vehicle Embedded Simulation Technology (INVEST) Science and Technology Objective (STO), a research program under management of the STRICOM Engineering Directorate. The INVEST STO will develop and demonstrate the technology needed to embed simulation in combat vehicles. It will also determine an architecture suitable for individuals, crews, and platoons to maintain system proficiency while in-vehicle and on-station, using an advanced distributed simulation capability with common reusable components and interfaces. The goal of the STO is to develop and demonstrate technology for incorporating ES into future as well as legacy combat vehicles.

In ground combat vehicles such as the M1A2 Main Battle Tank (MBT), the Gunners Primary Sight (GPS) and Fire Control System (FCS) are sighted so that the weapon places the round on the target at the location indicated by the gunner's GPS crosshairs. As combat vehicle system enhancements are incorporated in the conceptual environment of Embedded Training and Embedded Simulation (ET/ES), the gunner's optical display may be replaced by a digital display that allows the gunner to view virtual terrain with virtual targets, or live terrain with live and/or virtual targets.

In the conceptual environment of the INVEST STO, ES systems will have four modes of operation: *Stand-alone*, *Multi-element Stationary*, *Mission Specific*, and *Vehicle on the Move*. The *Stand-alone* mode will focus on individual and crew training with full simulation while the combat vehicle is in garrison. *The Multi-element Stationary* mode adds capabilities for inter-vehicle actions and the *Mission Specific* mode provides a mission rehearsal capability. The *Vehicle on the Move* mode is intended for use at the Combat Training Centers and complements live forces through the insertion of virtual forces, obstacles, and environmental factors.

While operating in the *Stand-alone*, *Multi-element Stationary*, or *Mission Specific* modes, the weapons system will most likely be inactive and the training will be in a virtual environment. In these modes, the ES's Computer Image Generator (CIG) has the information needed to calculate an aimpoint solution so that the impact of a fired munition is at the gunner's aimpoint. However, in the *Vehicle on the Move* mode, the gunner's GPS will display live terrain with live and/or virtual entities. An external visual scanning device provides input for the display of live terrain and live targets. The CIG injects the virtual targets into this display. In this mode, the ES's CIG will be knowledgeable of virtual targets through receipt of messages similar to Distributed Interactive Simulation (DIS) Protocol Data Units (PDUs) on entities, and through use of behavioral modeling data. But even with PDUs from live entities, the ES's CIG may not have enough information to process live targets. This inability to process live targets is a problem in virtual and live training environments that must be resolved in order for the proper visual effects to be displayed.

The research objective is to determine the ability of future ET systems to correlate the aimpoints of live entities engaging virtual targets. This project entailed research into the requirements for correlating live aimpoints with virtual and live targets. Further, this project sought to identify potential problem areas, and to recommend solutions for those problems.

1.1 Research Strategy

IST reviewed various modes of operation for ES, determining that the *Vehicle on the Move* mode was the most challenging and difficult case to resolve. Therefore, this research was conducted from the point of view of a live combat vehicle in the *Vehicle on the Move* mode. The research strategy used by the Institute for Simulation and Training (IST) focused on the engagement of both virtual and live target entities by a live entity in the *Vehicle on the Move* mode.

First, an overview of an engagement process was used to develop the data requirements necessary to correlate an aimpoint with virtual targets and with live targets. Next, the available data was examined to determine its potential for accuracy and precision in correlating the aimpoint with the target. The data the ES/ET system can use for correlation may be provided from various sources, including the ownship combat vehicle, the MODSAF or its replacement, and sources within the ES/ET such as the virtual terrain database. IST also investigated the available alternative sources for accurate data, in case the data used is not sufficient in resolving the correlation problem.

1.2 Approach to the Problem

IST investigated a solution to the correlation problem by dividing the problem into disjoint cases. The type of target and the location of the GPS crosshairs at the time the weapon is fired determined the cases. The possibilities are shown in Table 1.1.

An analysis of the engagements with the crosshairs off the target, a "missed the target" situation, indicates the problem is identical for both live and virtual targets. Therefore, the approach to the correlation will address:

1) engagement of a virtual target with a hit on the target;
2) engagement of a live target with a hit on the target; and
3) engagement of a target without a hit, missing the target.

	Crosshairs on Target	Crosshairs off Target
Engagement of Virtual Target	X	X
Engagement of Live Target	X	Same as above

Table 1.1 Engagement Possibilities by a Live Entity

1.3 Assumptions

During the course of this research, several assumptions were developed concerning the equipment to be used for live/virtual force-on-force simulations, the equipment capabilities, and the communications architecture.

- First, some type of instrumentation for live force-on-force engagements will augment live simulation.
- Live entities will send Entity State Protocol Data Units (ESPDU) through the additional equipment used to augment the live simulation. Virtual entities send ESPDUs when entity state changes occur, and for position updates in the event the virtual entity behavior exceeds the behavior parameters established in the entity behavioral model. An entity behavior model is the subject of another ongoing research effort within the INVEST STO. Live vehicles will send ESPDUs when their position exceeds the parameters of the Distributed Interactive Simulation (DIS) dead reckoning model [1].
- The host combat vehicle will have the capability to make internal information available to the ES on some type of data bus, assumed for this research to be the MIL-STD-1553 databus.
- For this research, DIS standards and terminology will be used.
- Position data on live and virtual entities will be maintained with reference to a virtual terrain database for the operational area in use.
- On occasion rounds that are fired with the crosshairs on the target will miss the target, and rounds fired with the crosshairs off the target will hit the target. For this research effort, rounds fired with the crosshairs on the target will hit the target and those rounds fired with the crosshairs off the target will miss the target.

2.0 Crosshairs on the Target with Virtual Targets

For situations in which a live combat vehicle such as the M1A2 System Enhancement Package (SEP) MBT engages a virtual target while in the *Vehicle on the Move* mode, the engagement process is logically divided into two possibilities. The first possibility occurs when the gunner's crosshairs are on the virtual target as the gunner fires the weapon, scoring a 'hit on target.' In the second case, the gunner's crosshairs are off the target as the gunner fires the weapon and misses the target.

For every engagement that occurs with a virtual target, the CIG must determine whether the crosshairs are on or off the target, a key element of information. In the M1A2 SEP, which is currently in development, the gunner's optical display is upgraded to a digital display called the Gunner's Control and Display Panel (GCDP). The GCDP will allow the gunner to view virtual terrain with virtual targets or live terrain with live and/or virtual targets.

When digital displays are used, the CIG generates the target and the crosshairs, placing the target and crosshairs over the surrounding terrain. Since the CIG generates the display, it is able to determine whether the center pixel of the crosshairs is on a pixel that is part of the target.

2.1 Engagement of a Virtual Target with the Crosshairs on the Target

The sequence of events in which a gunner fires a weapon with the crosshairs on the target, engaging the virtual target, occurs as follows.

1. The ES receives ESPDUs from virtual entities and calculates a dead reckoning position using data from the last ESPDU received.
2. Entity State PDUs are processed and ES determines which entities are detectable by ownship and in the user's field of view.
3. Entities which are detectable and in the user's field of view are displayed by the CIG.
4. The main gun is loaded and the gunner enters into the GCDP the type of munition that was loaded.
5. The gunner selects a target and aims by placing the crosshairs over the target.
6. The gunner determines the range to the target in one of the following methods:

   - The gunner lazes the target. If the gunner chooses to laze the target, the ES will calculate the range based on the location of the ownship and the location of the virtual entity.
   - The gunner uses the stadia pattern matching to determine the range. When a match is selected, a range is automatically determined.
   - The gunner manually enters the range into the GCDP.
   - The preset Battle Sight range is used.
   - The last range set in the system is used.

7. The gunner goes through the motions to fire the round, however the ES actually fires only a virtual round.
8. The fire PDU is calculated and the message sent.
9. Since the gunner has fired at a virtual target, the ES creates and sends the detonation PDU.
10. The CIG displays the detonation effects for the ES. If the target is hit, vulnerability analysis is used to determine and display damage effects.
11. Finally, the ES sends an entity state PDU on the target status.

2.1.1 Engagement Process and Data Requirements

The engagement process can be analyzed to determine the data requirements for the Correlation of the Aimpoint for Virtual Targets. The ES, which is located in the vehicle, will receive ESPDUs. The ESPDU contains DIS specified information on the virtual entity that is needed by the ES for the engagement calculations. Also included in the ESPDU is additional data that, while not required for the engagement calculations, is convenient for the simulation because it is useful in the construction of future DIS/HLA messages. Information contained in the ESPDU that is pertinent to the ES is displayed in Table 2.1.

The crew manually enters some of the information required for the firing solution prior to the engagement. This information, the type of munition and subdesignation, is required by the vehicle's Fire Control System (FCS) during live firing. This information is also required for the ES to calculate the trajectory, construct the detonation messages and display the special effects on impact of the round. The gunner has several methods to determine the range to the target. The gunner:

1. can laze the target
2. use the stadia pattern matching to determine the range to the target
3. manually enter a range
4. use the preset Battle Sight range or
5. use the last range set into the FCS.

If the gunner decides to laze the target, the ES calculates the range to target using the ownship position and target position taken from the ESPDU information. Otherwise, the system will use a range that has been entered. Once the round is fired, the Fire PDU is sent, followed by the Detonation PDU. Upon receipt of the Detonation PDU, the ES uses the vulnerability model to determine and display the damage to the virtual target.

Table 2.2 shows the ownship data requirements necessary to complete the engagement of a virtual target.

2.1.2 Data Precision and Error

When the M1A2 SEP engages a virtual target, the location of the virtual target may contain errors injected in the process by the virtual database, coordinate conversions, and the ownship location.

2.1.2.1 Virtual Database Errors

The location or spatial correlation of the virtual target entity may vary due to sources of error such as the virtual terrain database, coordinate conversions, processing of terrain for the simulation system, and the rendering pipeline of the graphics display system. This research investigated the error caused by the virtual terrain database and coordinate conversions.

The ES will use a virtual terrain database to manage the location and movement of virtual entities. Because the virtual entities are associated with a virtual terrain database, they will inherit the error found in virtual databases.

Source	Variable/Field Information	How Used by ES Message, Display, Calculation	Unit of Measure	Precision	Location
ESPDU	Entity Identification	M	-	-	ES
ESPDU	Force Identification	M	-	-	ES
ESPDU	Number of Articulated Parameters	M,D	-	-	ES
ESPDU	Entity Type	M,D	-	-	ES
ESPDU	Alternate Entity Type	M,D	-	-	ES
ESPDU	Entity Linear Velocity	M,D,C	Meters/Second	32 bit float	ES
ESPDU	Entity Location	M,D,C	Meters	64 bit float	ES
ESPDU	Entity Orientation	M,D	Radians	32 bit float	ES
ESPDU	Entity Appearance	M,D	-	-	ES
ESPDU	Dead Reckoning Parameters	M,D,C	Meters	32 bit float	ES
ESPDU	Entity Marking	M,D	-	-	ES
ESPDU	Capabilities	M,D	-	-	ES
ESPDU	Articulation Parameters	M,D	-	-	ES

Table 2.1 Data Received from Entity State PDU

Virtual database errors result when comparing the database to the source terrain. The errors are, for the most part, not readily noticeable during completely virtual simulations because the source terrain is not available for comparison. However, in the INVEST STO *Vehicle on the Move* mode, virtual targets are placed on real terrain displayed in the gunner's GPS using data received in the ESPDU, where the referenced world model for the virtual entity is the virtual terrain database.

Every virtual database has differences from the source terrain. The magnitude of those differences is a function of the terrain database resolution. The differences or error could be significant and the resulting virtual target image may appear as though it is floating above the terrain as shown in Figure 2.1, or in other situations, sinking into the terrain.

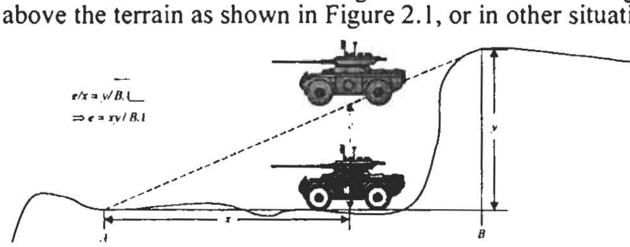

Figure 2.1 Terrain Database Inherent Error

The virtual terrain database problem can be simplified as depicted in Figure 2.1. The database error e can be represented as $e = xy/\overline{BA}$, where x is the distance from terrain post -A to the location of the combat vehicle, y is the elevation of terrain post -B above terrain post -A, and $\overline{BA}$ is the distance between terrain posts.

The virtual terrain database linearly interpolates between terrain post positions A and B, as shown by the dotted line in Figure 2.1. The source terrain can be very different as shown by the solid line; however, the source terrain cannot be too different, or the virtual terrain developer would have chosen closer terrain posts to reduce error. A reasonable worst case assumption is that the source terrain follows a cubic or spline curve from A to B, instead of a linear ramp. The difference is then $\delta = xy/\overline{BA} - (xy/\overline{BA})^3$ which reaches a maximum at $x = \overline{BA}/\sqrt{3} \cong 0.58\overline{BA}$, giving an error $e = 2y/3$. The typical error in a database with 100 meters between data points and $y = 15$ meters would be $e = 10$ meters. If the database resolution is increased to 1 meter between datapoints with $y = 15$ cm, the error is correspondingly reduced to **10** cm.

These problems are similar to those dealt with by the IST ZCAP (Z-Correlation Analysis Program) for the comparison of two virtual terrain databases. The techniques used in ZCAP should be adaptable to ES/ET problems.

It is evident that higher resolution databases reduce error, however, one must consider the development, storage, processing time, and maintenance of high-resolution databases. A very high-resolution digital elevation model of the U.S. Marine Corps' live fire range (Range 400) at 29 Palms, California has been constructed by the Topographic Engineering Center, Ft. Belvoir. This database features vertical accuracy to 0.1 meter and includes data points every 1-meter horizontally over an area of approximately 3.2 km by 2.1 km. The storage requirement is 14 Mb of mass memory. Studies using this database, and decimated databases derived from the original, provide clear indications that digital terrain data bases, at resolutions less than 10 meters horizontal spacing (meaning more than 10 meters between data points), are inadequate to support mission rehearsal training for dismounted infantry forces, because too many key terrain features are not represented. Additionally, this study indicates that 2-meter or 3-meter databases can produce results that compare favorably with those generated from a 1-meter database [2].

Source	**Variable/Field Information**	**How Used by ESS** Message, Display, Calculation	**Unit of Measure**	**Precision**	**Location**
GCDP/CID	Munitions Type	C	Enumeration	-	1553 Bus
GPS or POS/NAV with GPS	Ownship Location	C	Lat/long & MGRS	6m - 16m CEP (< 1m with DFIRST)	1553 Bus
ESS Calculation	Range to target	C	Meters	1.0 (when lazed)	ES
POS/NAV	Ownship Heading	C	Degrees	0.1	1553 Bus

Table 2.2 Data Required from M1A2 SEP

2.1.2.2 Coordinate Conversion Errors

The second type of location error comes from coordinate conversions. Coordinate systems are used by the CIG to portray an accurate view of the entity or process terrain information for subsequent display. Converting from one coordinate system to another introduces error that can contribute to correlation problems. Many processes in the ES, such as Behavior Reckoning, often require coordinate and datum conversions to be conducted multiple times in each simulation cycle.

Coordinate conversions are mathematical operations and as such should be ideally free from error. However, experience with DIS has shown that coordinate conversions can on occasion negatively impact accuracy. Conventionally, the DIS expresses coordinates geocentrically, that is, relative to the center of the earth. This has the result that all coordinates have absolute values of the order of 6000 km (the radius of the earth). If coordinate calculations are conducted in single precision (24 bit floating mantissa) arithmetic, then computational roundoff will add 35 cm to the position error. When the trigonometric complexity of coordinate conversion calculations is considered, the error added by single precision arithmetic can be much larger.

Thus, it is essential to carefully structure coordinate systems to avoid large absolute values, as they are engendered by geocentric coordinates. If large values cannot be avoided by use of local coordinate systems, because of existing standards or other reasons, then the organization of coordinate computations must be carefully considered. Steps in the computation where precision is lost due to the inadvertent use of single precision or integer values must be avoided.

Conversely, representing an entity's location by a number with greater precision will not yield better results, and may degrade performance in real-time systems. There is a limit to accuracy based on the number of decimal digits used to represent the fractional part of a coordinate, and coordinate conversions are accurate to within ± 1 meter. This level of coefficient accuracy impacts the use of actual terrain data in creating virtual environments; if actual terrain data source material is used as a reference, no greater than ± 1 meter correlation can be expected between the virtual and the source terrain [3].

2.1.2.3 Ownship Location Errors

Another possible source of location error occurs due to ownship location. Ownship location must be very accurate because it is the reference for most of the calculations that occur in the ES.

Several sources were investigated to determine the accuracy of the Global Positioning System (GPS) and Position Navigation System used in combat vehicles. Each source provided a different level of accuracy for the GPS and the Position Navigation System. The specification for the GPS requires a 50% circular error probable (CEP) of 16 meters. Subsequent test data collected by the GPS Program Office shows a 95% SEP of 10 meters.

The result of research on the GPS indicated that one could expect accuracy to range from 6 meters spherical error probable (SEP) to 16 meters CEP. The GPS Program Office indicates that, by the fiscal year 2000, the GPS accuracy should reach 1 meter to 3 meters CEP.

The accuracy of the Position Navigation System in the M1A2 SEP is required to be within 2% of the distance traveled in one hour with a 68% probability. For a vehicle traveling 1 kilometer in an hour, the 68% CEP is calculated to be twenty meters. When coupled with GPS, the error radius is reduced to 10 meters CEP [4].

The ownship location accuracy problem can be solved by the use of the Deployable Force-on-Force Instrumented Range System (DFIRST). The system uses GPS differential corrections to calculate the ownship position once per second. The position, now accurate to ± 1 meter, is readily available to the ES via the MIL-STD-1553 data bus [5].

3.0 Crosshairs on the Target with Live Targets

For situations in which a live combat vehicle such as the M1A2 System Enhancement Package (SEP) MBT engages a live target while in the *Vehicle on the Move* mode, the engagement process is also divided into two possibilities. The first possibility occurs when the gunner's crosshairs are on the live target as the gunner fires the weapon, scoring a 'hit on target.' In the second case, the gunner's crosshairs are off the target as the gunner fires the weapon, but misses the target.

For engagements that occur with live targets, however, the CIG does not have sufficient information to determine whether or not the crosshairs are on the target. This causes a problem since the ES does not have adequate information to calculate the engagement for this case. To provide additional information so the CIG can make a determination concerning the crosshairs and live targets, we have assumed each live target will transmit ESPDUs and maintain a dead reckoned model of itself as specified in the Standards for Distributed Interactive Simulation–Application Protocols [6].

3.1 Engagement of a Live Target with the Crosshairs on the Target

For the M1A2 SEP engaging a live target while in the *Vehicle on the Move* mode, the sequence of events is similar to that of engaging a virtual target.

1. The main gun is loaded and the gunner enters into the GDCP the type of round and subdesignation.
2. The gunner selects a target and aims by placing the crosshairs over the target.
3. The range to the target is determined by whether:
    - The gunner lazes the target. If the gunner chooses to laze the target, the ES will calculate the range based on the location of the ownship and the position of the live target entity transmitted in the ESPDU and corrected for dead reckoning.
    - The gunner uses the stadia pattern matching to determine the range.
    - The gunner manually enters the range into the GCDP.
    - The preset Battle Sight range is used.
    - The last range set in the system is used.
4. The gunner goes through the motions to fire the round; however, the ES only fires a virtual round.
5. The fire PDU is calculated and the message sent.
6. The detonation PDU is calculated and the message sent.

7. The DFIRST System uses vulnerability analysis to determine damage effects, and displays the appropriate lighting on the target to indicate a hit.
8. Finally, the live entity sends an ESPDU on the target status if appropriate.

3.1.1 Engagement Process and Data Requirements

In this engagement, the target is a live entity. The ES has very little knowledge concerning live entities in the environment because the display is developed by another source and not by the CIG. To overcome this limitation, the ES will use information received in ESPDUs to maintain a dead reckoned model for each live entity that may be viewed and engaged by the ownship. The dead reckoned model would emulate the position, the orientation, and the orientation of the live entities' articulated parts with respect to the virtual terrain database for the training area in use.

To make a determination as to the location of the crosshairs in relation to the live target, the ES must use data from the ownship's systems, shown in Table 3.1. The data is required to determine where the MBT gun tube is pointing and includes the ownship's:

Location	Pitch
Roll	Altitude
Heading	Hull Turret Relative Bearing
Barrel Droop	Lead
Tube Elevation	Vehicle Velocity

An alternative source of data, possibly more accurate and easy to implement, is the DFIRST data, which is also used to determine where the main gun tube is pointing. DFIRST calculates the MBT gun orientation once per second and provides a pointing accuracy of $\approx$ 2 milliradians [7].

The data is used to determine where the MBT gun tube is pointing through construction of a "memory image." The image consists of a simulated trajectory for the round if fired. The simulated trajectory is developed from the ownship position and the gun orientation provided by DFIRST; the "memory image" is constructed using the virtual terrain database. Also located on the virtual terrain is the dead reckoned virtual image of the live target or "dead reckoned target." In essence, the ES has used data on the ownship MBT and the ESPDUs from the live targets to create a simulation of the engagement. Using this view, the CIG can now determine whether the simulated trajectory impacts the dead reckoned target. If there is a pixel match, a hit is scored.

3.1.2 Data Precision and Error

When the M1A2 SEP engages a live target, the location of the entities is subject to the same database errors, coordinate conversion errors, and position errors as detailed with virtual engagements. Additional errors may be caused by data from DFIRST and by the dead reckoned model.

3.1.2.1 Precision of Data

As outlined in previous sections, there is a large amount of data and calculations required to accomplish live and virtual correlation in ES/ET. These include coordinates conversions, position of entities, orientation of entities, the range to target, the ownship velocity, turret azimuth and tube elevation, and computation of simulated trajectories. The large number of data variables seems to lead to a hopelessly large total error. However, the Law of Large Numbers shows that the problem is not as severe as it appears at first glance.

Analysis of data precision requirements is still on-going, but a general outline of how the Law of Large numbers reduces the impact of the large number of data types follows. Consider a function $F(d_1, d_2, \ldots, d_n)$ of *n* types of data, $\{d_1, d_2, \ldots, d_n\}$; this function might be miss distance, apparent position in the sight, or anything of importance in ES/ET. If the data are in error by $\{\delta_1, \delta_2, \ldots, \delta_n\}$, then standard linear analysis shows that the error

$\Delta F = \sum_{k=1}^{n} \delta_k \, \partial F / \partial d_k$ is a sum of the *n* individual data errors weighted by the partial derivatives of *F*.

Since analysis of data precision requirements is incomplete, the simplifying assumption is made that the contributions to the sum are nearly equal (e.g. ownship position errors affect the miss distance as much as tube pointing errors). Also, the reasonable statistical assumption of independence of the δ_k is made. Based on these assumptions, the

Source	Variable/Field Information	How Used by ESS Message, Display, Calculation	Unit of Measure	Precision	Location
GCDP/CID	Munitions Type	C	Enumeration	-	1553 Bus
GPS POS/NAV	Ownship Location	C	Lat/long & MGRS	16m CEP by Spec	1553 Bus?
ESS Calculation	Range to target	C	Meters	1.0	ESS
FCEU	Ownship Pitch	C	Mils	0.3/1.0	1553 Bus
FCEU	Ownship Roll	C	Mils	0.3/1.0	1553 Bus
FCEU	Ownship Altitude	C			
POS/NAV	Ownship Heading	C	Degrees	0.1	1553 Bus
GCDP	Barometric Pressure	C	In Hg	0.01	1553 Bus
FCEU	Wind Velocity	C	MPH	0.1	1553 Bus
FCEU	Cant	C	Mils	1.0	1553 Bus
TEU	Hull Turret Relative Bearing	C	Mils	0.5/1.0	1553 Bus
TEU	Barrel Droop	C	Mils	0.01	1553 Bus
FCEU	Lead	C	Mils	0.01	1553 Bus
FCEU	Tube Elevation	C	Mils?	0.1	1553 Bus
DECU	Vehicle Velocity	C	KPH	1.0	1553 Bus

Note: Precision in some software is defined with two terms, accuracy and precision. Where applicable, this is noted as accuracy/precision as 0.3/0.5.

Table 3.1 Data Required for the Engagement of a Virtual Target

variance of ΔF is n-times the variance of each of the δ_k. Since the expected error is proportional to the square root of the variance, the error rises as the $\sqrt{n}$, not as n, $\Delta F \approx \delta\sqrt{n}$. This square root of n dependence is known as the Law of Large Numbers.

For example, if there are 25 types of data important to ES/ET, then the error will be 5 times the individual error, not 25 times. Thus, if each source of error were equivalent to a 1-meter position error, the total error might be 5 meters. If the goal is 1-meter total error, then this could be achieved with a relatively manageable reduction of each error to the equivalent of 20 cm. Detailed analysis is expected to show that the partial derivatives of the ES/ET functions ($\partial F / \partial d_k$) are such that some data types dominate the error sum. The Law of Large Numbers still operates in this case in modified form, so that the expected total error is reduced over what might be expected.

3.1.2.2 Error induced from Dead Reckoned Model

Each simulation application maintains a dead reckoned model of itself. Thresholds for position and orientation are established as criteria for determining if the entity's actual position/orientation has varied from the dead model. When the entity's actual position and orientation have varied from the dead reckoned position and orientation by more than the threshold value, the entity issues an ESPDU to communicate the new position and orientation information to other simulation applications and to update the dead reckoned model of itself [6].

Researchers at IST normally set the thresholds for the dead reckoned models to 10 % of the vehicle width, length, and height. For a live target the size of the M1A2 SEP MBT, an ESPDU update message is sent if the target is 0.36 meters left or right of the dead reckoned track, 1 meter ahead of or behind the dead reckoned track, or 0.25 meters above or below the dead reckoned track. The threshold for angular displacement or orientation was usually set to 3 degrees.

The ESPDU is updated at 5-second intervals, unless the limits of the thresholds are exceeded, requiring the entity to send a new ESPDU.

In the worst case situation of a live target maneuvering, the live target could vary from its dead reckoned target for nearly 5 seconds before an update is received, provided the thresholds are not exceeded. So, between updates, the dead reckoned target created by the CIG to determine when the simulated trajectory of the round is on a live target could be shifted from the location of the live target by nearly 10 % of the target's length, width, and height, causing the gunner to miss the target.

4.0 Engagement of Targets with Crosshairs off the Target

The case of an engagement that takes place with the crosshairs off the live or virtual target appears more complex, because key technical data derived from the ESPDUs does not apply. However, this engagement process is, in essence, the same process as the engagement of a live target. The ES must determine, using data from DFIRST, what the gunner has in the GPS and behind the crosshairs through the creation of a simulated trajectory and memory image. The sequence of events describing the engagement occurs as follows:

1. The main gun is loaded and the munition type is entered by the crew as a round type and subdesignation.
2. The gunner selects a target and aims by placing the crosshairs over the target.
3. The range to the target is determined by whether:
    - The gunner lazes the target.
    - The gunner uses the stadia pattern matching to determine the range.
    - The gunner manually enters the range.
    - The preset Battle Sight range is used.
    - The last range set in the system is used.
4. The gunner goes through the motions to fire the round. The ES fires a virtual round however, the crosshairs are not on a live or virtual entity at the time the round is fired.
5. The fire PDU is calculated and the message sent.
6. The detonation PDU is calculated and the message sent.
7. The CIG displays the detonation effects on the terrain.

4.1 Engagement Process and Data Requirements

The analysis of the engagement process for a near miss is similar to the engagement of a live target.

Again, prior to the engagement, the crew manually enters information, such as the munition type. The gunner obtains the range to the target by lazing or using one of the other methods available. If the gunner decides to laze the target, the ES must determine where on the terrain the MBT gun tube is pointing and create a simulated trajectory to an impact point on the terrain. The range to the point on the terrain is then calculated by the ES and provided to the gunner.

When the gunner fires, the ES calculates a trajectory for the round using the virtual terrain database. It then determines whether the impact point is a "dead reckoned target" as described in paragraph 3.1.1 above. If the impact point is not a target, then this is a miss and the round impacts the environment somewhere in the vicinity of the target. A Fire PDU is constructed and sent. Additionally, the coordinates for the location are used to construct the Detonation PDU. Finally, the appropriate visual effects are displayed.

5.0 Problem Areas and Alternatives

During this research several problems were noted which have an adverse effect on the performance of the ES.

5.1 Ownship Location

The location of the M1A2 SEP lacks the precision needed for the INVEST STO to function. A recommended alternative is to augment the combat vehicles and environment with the Deployable Force-on-Force Instrumented Range System (DFIRST).

DFIRST is a low-cost, GPS-based training system. The system provides position location for all participants and engagement simulation for combatant offensive actions, including weapon firing, target indication and kill removal. DFIRST is a fully developed system and currently provides position accuracy to less than 0.5 meter [5].

The DFIRST equipment can be integrated to the ES through a variety of data connections including RS-232, Ethernet, and MIL-STD-1553.

5.2 Confusion over Engagement of Live Targets due to Dead Reckoning

The CIG can only determine when the GPS crosshairs are on a virtual target. It cannot determine if the crosshairs are on live targets or on the terrain and must construct a simulation in memory to reach a solution. The positions of the live targets in the memory simulation are only updated when a dead reckoning threshold is exceeded, and these differences between actual locations of live vehicles compared to dead reckoned locations could cause some incorrect misses or hits. The numbers of incorrect results are expected to be small since the thresholds are normally set at 10% and most gunners aim for the center of mass of the target.

An alternative solution may use Ultra Wide Band Radar in conjunction with other onboard sensors to provide the ES with information on the live entities. The Ultra Wide Band Radar may provide information that could be combined with pattern recognition techniques to distinguish live combat vehicles from the surrounding environment. Further research should be conducted into the development of Ultra Wide Band Radar and separate research should be considered in the area of pattern recognition.

5.3 Database Error

The differences between source terrain and virtual databases are a source of error that will result in visual anomalies for the ES. Further research should be conducted to determine the optimum resolution and error reduction techniques for databases to be used with ES.

6.0 Summary

The concepts under investigation in the INVEST STO represent the next logical step in the evolution of training systems. This work supports the INVEST STO by identifying several challenges and research opportunities in the areas of virtual terrain database resolution, source terrain and virtual databases differences, and registration of live targets through the use of Ultra Wide Band Radar or similar technologies.

7.0 References

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