Embedded Training Alternatives for Future Dismounted Forces – An Evaluation of Gaming and Simulation Engines for Embedded Simulations

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ABSTRACT

The Defense training and simulation industry is in the process of a massive paradigm switch from site-based trainers, to embedded training that is part of the operational systems used by the war fighter. This paradigm switch poses numerous technology challenges. One of the most difficult is embedding simulation on the Dismounted Soldier. To investigate and demonstrate possible alternatives, the Research, Development and Engineering Command's (RDECOM) Simulation and Training Technology Center (STTC) has developed several prototypes such as the Virtual Warrior System that provide a fully immersive, man wearable, virtual simulation capability. The focus of these systems is deployable training and mission rehearsal. They are dependent on proven military training simulation components such as computer-generated forces, image generators and terrain databases. However, in recent years commercial gaming technologies have emerged as an attractive alternative to traditional simulations for military training. Game engines are at the forefront of graphical advances and have the ability to rapidly respond to changing training needs.

This paper discusses the findings of a trade study conducted to determine the most attractive gaming engine alternatives for embedded Soldier simulation. This study also considered low cost approaches to dismounted training such as a desktop or hand held first-person shooter environment. These low cost approaches are being investigated as alternatives to the more complex and costly fully immersive systems. The trade study assumed that game engines would allow scalability between the fully immersed and low cost approaches. In addition to presenting the results of the trade study, the paper identifies and discusses evaluation criteria such as interoperability with current database formats and simulation protocols such as Distributed Interactive Simulation (DIS) and the High Level Architecture (HLA), debrief and After Action Review (AAR) support comparable to current systems, use of physics-based models, realistic urban terrains and character animations. Costs and open source considerations are also discussed.

ABOUT THE AUTHORS

Henry Marshall is the Principal Investigator for Embedded Simulation Technology at the Research, Development and Engineering Command (RDECOM) Simulation and Training Technology Center (STTC). Prior to this assignment he worked at the Simulation, Training and Instrumentation Command (STRICOM) where he spent 11 years as lead for the Semi Automated Forces on the Close Combat Tactical Trainer (CCTT) system in addition to being a OneSAF team member. His twenty years with the Government have been mainly in CGF and Software acquisition. He received a BSE in Electrical Engineering and an MS in Systems Simulation from the University of Central Florida.

Pat Garrity is a Principle Investigator at U.S. Army Research, Development, and Engineering Command (RDECOM), Simulation & Training Technology Center (STTC). He currently works in Dismounted Embedded

Simulation conducting R&D in the area of Dismounted Soldier embedded training & simulation. Prior to his involvement with tech base division at RDECOM, he worked as the Project Director for the Advanced Concepts Research Tools (ACRT) program in PM STI at STRICOM. His current interests include Human-In-The-Loop (HITL) networked simulators, virtual and augmented reality, and embedded training applications. He earned his B.S. in Computer Engineering from the University of South Florida in 1985 and his M.S. in Simulation Systems from the University of Central Florida in 1994.

Gary Hall is the Lead Systems Engineer at General Dynamics C4 Systems, Orlando, FL. He has been involved in the distributed simulation industry for over fifteen years. He leads all R&D efforts in the Orlando Office including the development of the ModIOS® and S2Focus™ COTS products and the design of the Virtual Warrior System and previous Dismounted Soldier System (DSS). He has extensive experience in the area of 3D graphics and visualization techniques for military training. He has authored several white papers over the years in the area of distributed simulation and networking protocols (DIS and HLA) and embedded Soldier training. He has a M.S. in Computer Engineering from the University of Central Florida.

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Gary Green is a Research Associate at the Institute for Simulation and Training (IST), University experienced in management and research of training and simulation programs. His recent experience includes eight years managing research projects exploring embedded simulation and embedded training issues in support of Army research and development. He is currently the principal investigator for IST's Embedded Simulation Technology work with US Army RDECOM STTC. His MS in Operations Research is from the US Naval Postgraduate School.

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INTRODUCTION

The US Army Research, Development and Engineering Command (RDECOM) Simulation and Training Technology Center (STTC) has a current Army Technology Objective (ATO) called Embedded Combined Arms Team Training and Mission Rehearsal (ECATT/MR) that is exploring mounted and dismounted embedded training issues. While the final design for embedded training may differ from any described here, the ATO vision highlights some of the new technologies that will be necessary to move to an environment that fully integrates training and operational systems.

One of the goals of the ECATT/MR ATO is an embedded training (ET) and simulation capability for the Dismounted Soldier. Embedded training capabilities are defined as follows:

- If a training capability is present or could be loaded as software on the equipment or hardware that the Soldier takes with him to the battlefield without use of additional hardware, then that training capability is said to be *fully embedded*.
- If it requires attaching/connecting additional equipment or hardware, then the training capability is classified as *appended ET*.
- If it requires linking individual systems to achieve the training objectives, then the training capability is classified as *networked ET*.

The ECATT/MR goal is *fully embedded training*. This is consistent with the FFW design goal of no appended training unique hardware. Ideally, the operational hardware, whether for mounted or dismounted forces, should be designed to allow easy access to the training software and permit the Soldier to interact naturally with the operational hardware and software during training.

Embedded Training can support training, assessment and control of exercises using the operational equipment with auxiliary equipment and data sources as necessary (US Army Training Support Center, 2004). When activated, ET starts a training session by overlaying the system's normal operational mode with a training or assessment mode.

The Unit of Action (UA) program has selected embedded training as the user's preferred training option for Future Combat Systems (FCS) (US Army Armor Center, 2004). This will require an analysis of both FCS operational and training needs to avoid having the two domains diverge to the point that a significant number of appended training-unique systems are required. Figure 1 illustrates a possible future embedded training or mission rehearsal exercise under field conditions.

In Figure 1, the unit has a mix of mounted, dismounted and robotic assets and is training with embedded simulation. The scenario starts with the commander planning a training exercise or mission rehearsal for a future operation, either of which will be conducted using embedded simulation. The mounted crew participates virtually in the exercise using the operational displays inside their vehicle. The dismounted Soldiers employ a mix of constructive simulation (using a hand held device), virtual simulation (using the hand held device with a 3D view), or immersive virtual simulation (using a helmet mounted display with a 3D view). It is envisioned that dismounted Soldiers would switch from constructive to virtual, then to immersive virtual as their participation in the exercise increases. At the conclusion of the exercise intelligent agents from an embedded After Action Review (AAR) application would aid creation of the leader's or commander's AAR. The AAR would be distributed among all the players via their embedded systems as opposed to current AAR techniques that require a meeting area or theater. After the AAR is completed, the exercise could be modified or saved into Command and Control (C2) systems for mission rehearsal or as an operational plan.

The UA focus on combined arms warfare in a network centric environment will require that embedded training systems train the many collective aspects of combined arms operations. One of the outstanding mounted/dismounted issues is how embedded training will evolve as the FCS and FFW concepts

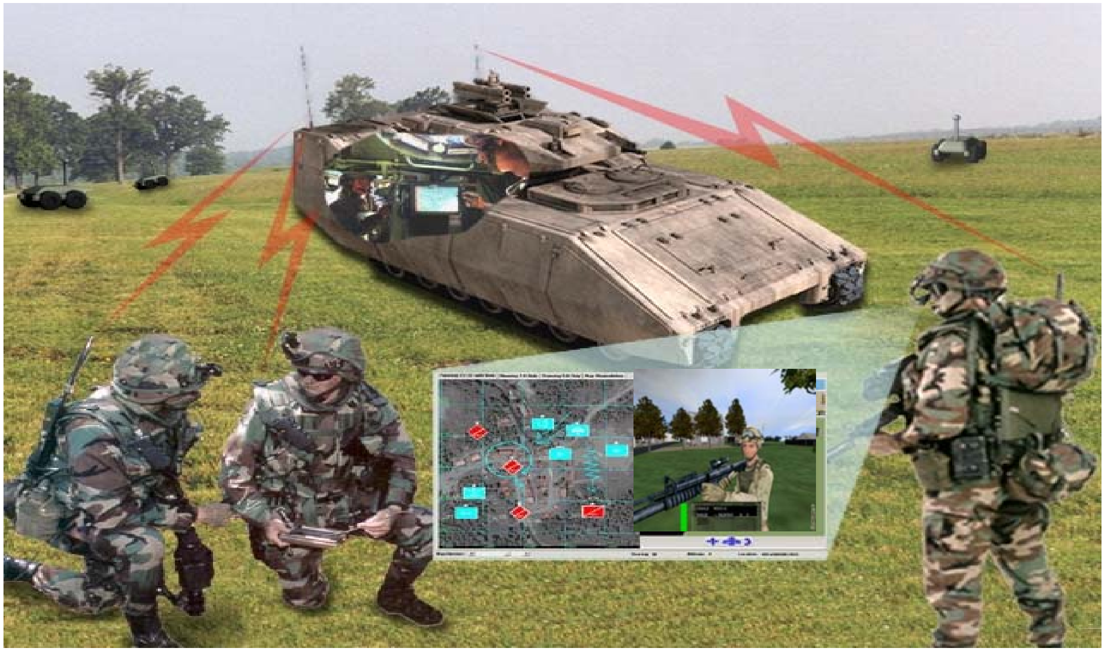

Figure 1: The Future –Fully Embedded, Interoperable Mounted & Dismounted Mission Rehearsal and Training

merge. Since the Organization and Operations Plan for the UA shows a significant number of dismounted forces, the mounted and dismounted forces must have integrated training and communications capabilities in order to be successful. Although the ECATT/MR ATO is addressing both mounted and dismounted embedded training and their interoperability, the focus of this paper is dismounted embedded training.

DISMOUNTED EMBEDDED TRAINING SYSTEMS

The Land Warrior and Future Force Warrior programs are in the process of merging. One of the greatest technology challenges for a combined LW/FFW program is embedded training and mission rehearsal capability within the constrained computational, power and weight limitations of the LW/FFW system. These technology risks have caused embedded training to move to the outer spirals of the LW/FFW development.

The General Dynamics Virtual Warrior System, under the ECATT/MR ATO's Immersed Mobile Mission Embedded Reality Soldier Trainer (IMMERST) project, is one of the primary testbeds being used to research some of these technology risk areas. The ATO is using the Virtual Warrior and other embedded testbeds for research to improve embedded training interoperability, mission rehearsals and after action reviews between mounted and dismounted forces. These dismounted systems are targeted for transition to the FFW Advanced Technology Demonstration in FY07.

Virtual Warrior is a fully immersive, virtual, man-wearable embedded training system for Dismounted Soldiers. The system uses a wearable computer to provide video and audio outputs to the Soldier's helmet mounted display (HMD) and earphones. The system has several six degree of freedom (6-DOF) tracking sensors on the operator's back, leg, head and weapon to track movement and orientation. The solider machine interface (SMI) consists of a small joystick and several buttons mounted on the instrumented weapon. This SMI allows the operator to "move" in the simulated environment and make changes to the weapon system such as zooming the sight picture. Figure 2 shows a solider outfitted with the Virtual Warrior system.

Figure 2: VW Man-Wearable Trainer

The 3D synthetic battlefield is presented to the Soldier via the HMD using the embedded computer system. The computer system replicates the Soldier's 2D situational awareness display (currently presented to the Soldier using a monocular HMD on the LW and FFW systems) superimposed over the 3D synthetic battlefield as shown in Figure 3. The 3D synthetic environment is generated using 3D graphical rendering software running on a computer system equipped with a dedicated Graphics Processing Unit (GPU) to support the high 3D imagery-processing requirement.

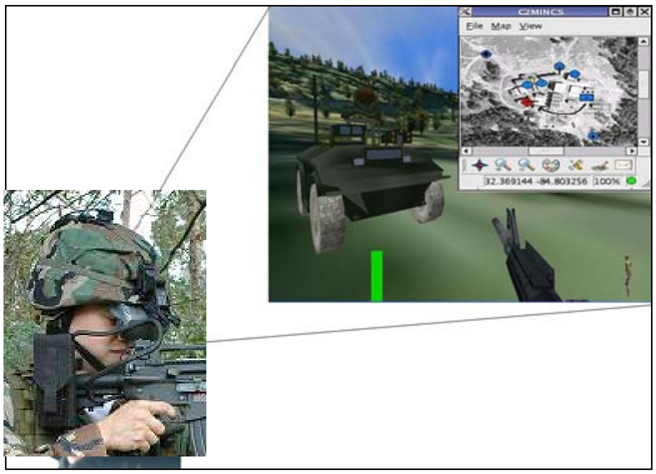

Figure 3: Simulated Monocular SA Display in HMD

While this immersive system provides a realistic experience for the Soldier, it currently uses relatively expensive hardware technologies that can be cost prohibitive for embedded Soldier training. Although research is ongoing to reduce the size, improve performance and reduce cost of these technologies, it will still remain an expensive option for the near term. Because of the expensive nature of these types of systems, research is also being conducted in less expensive alternatives. One alternative is the use of lower cost hand held devices (PDA, tablets, etc.), which are readily available for embedded Soldier training. Another is the use of game engine technology.

In addition to the cost factor, another need for scalability is derived from conversations with Soldiers now operating in Iraq. Soldiers indicated that when they are in their base camps at night they typically take off their operational equipment. At this point they would prefer doing mission rehearsal or training with laptops or other systems that could be used in this more leisurely environment.

GAME ENGINE TECNOLOGY

The image generator (IG) system is one of the more expensive and complex pieces of the current dismounted embedded training systems. IG's are used primarily in military simulations. These software packages generally provide an applications programmer interface (API) that extends existing low level 3D rendering APIs such as OpenGL® by providing services such as scene graph and management, camera and object management, collision detection, and special effects. During the late 1990's and early 2000's these software packages were ported to the Personal Computer (PC) platform and became known as PC-Image Generators (PC-IGs). Most traditional IG engines have large development fees (>$10K) and runtime fees ($1K-$5K) that can prevent large scale deployment to every Soldier. Game engines offer an attractive alternative to conventional PC-IGs for embedded training.

Fueled by the entertainment and gaming industry's desire for more and more visual realism, commercial gaming engines are on the forefront of graphic technological advances. With a much broader audience than the traditional military PC-IG engines, more and more very powerful game engines are available today with graphics capabilities well beyond those of typical IGs. These game engines take better advantage than do IGs of the latest graphic hardware and latest versions of low-level software rendering APIs (mainly OpenGL® and DirectX™). These game engines and their modeling tools and APIs also take advantage of the latest technological advances such as software definable Pixel Shaders for realistic lighting and special effects. In addition, tools like Discreet's 3D Studio Max® and Alias' Maya® have proven themselves capable of simulating lifelike animations and virtual worlds for the entertainment market. These advances are primarily based on the size and competences of the entertainment/gaming market.

Based on the growing game engine advances, investigation into applying a game engine technology to embedded Soldier simulation began in late 2003. The APEX SDK® from Dynamic Animation Systems, Inc. (DAS) game engine was initially selected. The APEX SDK was marketed as a game engine solution for the military simulation and training community. While there was some initial success integrating this game engine (see Figure 4), several issues were identified during the investigation and development of the game engine implementation.

Figure 4: Graphics rendering using the APEX SDK

The main issues identified are listed below and are discussed later.

- Source code unavailable
- Inadequate support for existing military terrain databases (in OpenFlight™ format)
- Limited Scene Graph support
- Limited collision detection and scene management
- Limited customer support
- Run-time license fees (~$1.5K USD per display)
- Next generation of the SDK unavailable (no growth path)

TRADE STUDY

In late 2004 an investigation began into alternatives to the APEX SDK® game engine implementation. Based on this previous experience a list of criteria was defined for a more exhaustive trade study into existing game engine software development kits (SDKs). Based on the existing system's software design, code and terrain models the study was limited to only true SDKs and did not focus on existing games that are modified through extensions (such as Half-Life).

The list of evaluation criteria used during the trade study is defined below (not prioritized):

- Support for OpenFlight terrain databases and models
- Advanced Rendering Capabilities
- License costs/fees
- Scalability of application to PDA or other hand held platform (platform support)
- Availability of source code and documentation
- Technical support and frequency of updates
- Maturity and technology roadmap
- Advanced character animation support
- Interoperable with other Army Simulations (via Distributed Interactive Simulation (DIS) or High Level Architecture (HLA)
- Physical models for individual combatants (ICs)

One of the key issues identified in previous investigations was support for existing military 3D terrain databases. Reuse of existing databases is desirable to reduce cost and improve the likelihood of close correlation with other virtual or constructive simulations using the same database. Typically these databases are of existing terrain that, for dismounted applications, often include Military Operations in Urban Terrain (MOUT) facilities and are generally available from the military in OpenFlight™ format. Since OpenFlight is primarily a military simulation format, most game engines have little or no support for it. The game engines that do support OpenFlight provide a tool to convert an OpenFlight database into the game engine's own internal format. However, the level of support for the OpenFlight specification is usually limited so that complicated databases typically fail to convert properly. Adequate support for OpenFlight MOUT databases was identified as a necessary requirement in the selection of a game engine.
Another major reason for the requirement for support of OpenFlight databases is the need for interoperability with other military simulation programs. One such program is the US Army's Objective OneSAF (OOS) program. Objective OneSAF is an entity level semi-automated force simulation that is targeted to support the FCS program's embedded training requirements. To insure interoperability with OOS, there must be correlation between OOS's internal terrain database and the embedded Soldier visual database to allow a fair fight. Currently, there exist visual databases in OpenFlight format that are correlated with OOS terrain databases.

Another issue related to database format is the design or layout of the terrain database. Most existing terrain databases were designed for legacy image generators and graphics pipelines. These databases typically do not conform to the manner in which current graphic cards and low-level graphics API are designed to receive and process 3D geometry. The 3D rendering pipeline in today's graphics cards expect large amounts of similar geometry to be grouped and transmitted together. This typically means that to achieve optimal performance from current graphics hardware; existing OpenFlight 3D terrain databases may still need to be restructured to meet the needs of new graphics hardware and software drivers. Future research may include automated tools to control from existing simulation databases in OpenFlight to a common game engine format such as QuArk.

A desirable component of the game engine was scalability among different platforms from PC desktops to wearable computers to hand held PCs and PDAs. During the trade study it became apparent that this type of scalability would be limited if available at all. Most game engines supported either PC/Console devices or mobile devices such as PDAs. The Xforge SDK had the best scalability, however their Windows platform support was limited.

Licensing fee is another criterion that was used when evaluating game engine technology. Many game engines have high initial costs. One of the benefits of these engines is that they typically include complete source code. However, given the ATO research project budget these high priced end game engines were not viable options. The Gamebryo engine by NDL was a higher cost engine but provided a lower cost binary only license option. This option, however, did not include access to the source code. Several other attractive game engine candidates were identified based on being either open source or very low cost (<$500).

The trade study identified many potential game engines, however several did not meet any several of the basic criteria and were removed from available options. One example is the

Unreal engine by EPIC Games used in the America's Army Game. Although the Unreal engine is a powerful and popular engine, its very high licensing costs and lack of support for simulation data such as OpenFlight databases eliminated if for further evaluation for this study. The following game engines were deemed viable for further investigation:

- DAS' APEX SDK®
- Fathammer's Xforge SDK
- NDL's Gamebryo SDK
- Garage Games' Torque SDK
- Delta3D SDK

The results of the trade study are summarized in Table 1. Although all the engines identified for further investigation had advantages in different areas, we focused on an engine that could meet the key criteria identified in the previous paragraphs. The Delta3D engine was very attractive, particularly as it has no license fees. However, Delta3D is still in development and lacks some of the utilities and advanced graphics features of the other game engines. New versions of Delta3D are expected later in 2005 and in 2006 that will require further investigation. The Torque SDK was also attractive due to its low cost. However, it was ruled out for integration this year due to its lack of direct OpenFlight support. Further investigation will determine its viability for integration into the Virtual Warrior system. The Xforge SDK's lack of adequate native support for the Windows PC platform limited it mainly to the mobile platform and therefore it could not be used with the current embedded computer system or other handheld PCs and tablets. As the 3D capability of mobile devices increases, engines such as the Xforge SDK will become more attractive options and will be the subject of further investigation.

For current year activities the Gamebryo SDK was selected as the best fit based on Gamebryo's support for OpenFlight, available utility tools, advanced character animation support, documentation and technical support. Although Gamebryo did not directly support the PDA platform, NDL is investigating future support for commercially available gaming platforms such as Sony's PSP hand held game console. Other limitations of the Gamebryo SDK included lack of audio support and IC physics models. However, these capabilities already existed in the core Virtual Warrior software and thus were not of high importance. Integration of the Gamebryo SDK is currently in progress and initial results look promising over previous implementations.

IMPLEMENTATION

The Virtual Warrior software was originally designed to support easy replacement of the IG graphics-rendering engine. However, the initial investigation identified differences in the methods used in current commercial game engines and that of legacy graphics engines. To improve support for the integration of today's game engines, the software's rendering pipeline was redesigned to allow ease insertion of new game engines and other components such as network protocols and input devices. The current software architecture is shown in Figure 5. This architecture will permit investigation and support of other operating systems and platforms in future research. It will also facilitate the investigation and integration of other game engines as they mature or provide technology advances. The goal of the new design was to remove the dependency of the system on a single game engine or hardware platform.

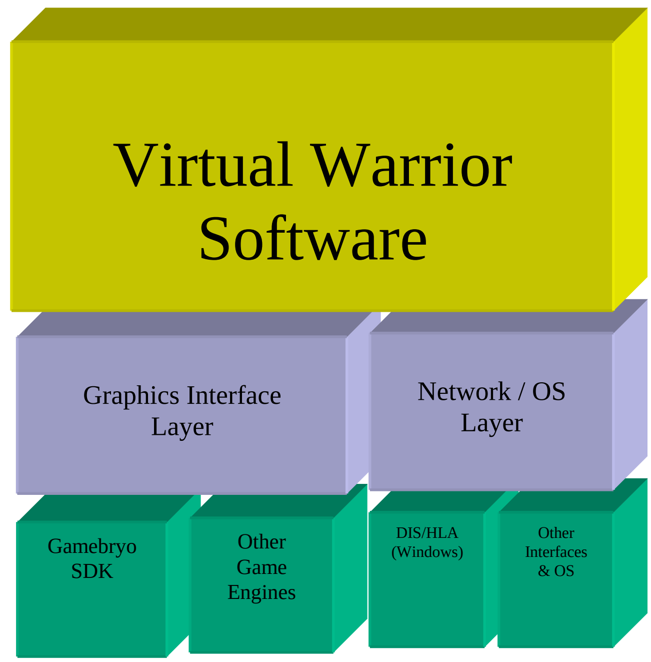

Figure 5: Virtual Warrior SW Architecture

Other Considerations

As mentioned earlier, the goal of this research was to improve embedded training for Dismounted Soldiers by identifying alternatives to expensive IG-based, fully immersive systems. The technical advancements of the entertainment industry's gaming engine technology offer one approach. Another can be found in the use of hand held devices. Hand held devices could provide training capabilities similar to the wearable immersive system, but at a much lower cost and could possibly become part of the operational hardware of future LW and FFW systems. In this scenario, the Soldier would use a hand held PDA or tablet in tandem with his tactical gear as shown in Figure 6.

The tablet would be used to perform distributed scenario development, mission rehearsal (MR), and after action review (AAR). The device would be interfaced into his existing tactical system during training to provide an immersive real-world training environment.

Criteria	APEX SDK	XForge SDK	Gamebryo SDK	Torque SDK	Delta3D
Supported Platform(s)	Windows XP/2K, XBox/PS2	Linux, Windows Mobile/CE XP/2K , Symbian	Windows XP/2K, XBox/PS2	PC Windows, Mac OS-X, Linux	PC Windows, Linux
Future Roadmap	None	Yes	Yes (2.0 just out)	Yes, frequent updates	Yes (through 2006), frequent updates
Render	DirectX 9.0	Low level graphics library supporting 3D hardware acceleration via OpenGL ES.	Microsoft Direct X 9.0	OpenGL and DirectX	OpenGL
Source Code	No	Yes	Yes (with full lic.)	Yes	Yes
Terrain Format Supported	APX internal format. Converter provided for OpenFlight™.	3D Studio Max. No support for OpenFlight	Gamebryo NIF File format. Provides converter to NIF format for 3D Studio Max and OpenFlight™	Maya, 3D Studio Max, Lightwave, Blender, GameSpace, MilkShape, QuArk, Cartography Shop, Valve220 compatible map editor	OpenFlight, TerraPage, 3D Studio, WaveFront, Performer, Quake, Inventor, VRML 1.0
License Cost	$10K development license per user, $2K runtime license	$63K (no runtime cost)	$50K for full license, $10K for binary license	$500 for commercial license	Free, OpenSouce-GNU Lesser General Public License (LGPL).
Support Cost	$2,500 per year	10 hrs / month for 1 year included with purchase $7,500 per week for additional support	$15K per year	Unknown	None. Support, training & consultanting services available
Pros	OpenFlight support via converter Support for Direct X 9.0 3D Hardware Accelerator Support Native support for Microsoft Windows	Scalable. Can be run on small Windows mobile PDA device and Win XP/2K. 3D Hardware Accelerator Support. Support for next generation 3D PDAs like the Dell Axim	OpenFlight support via converter. Support for Direct X 9.0 3D Hardware Accelerator Support Native support for Win XP/2K Advanced graphics capability like shading, lighting, etc. A powerful animation sequence manager	Inexpensive Support for DirectX 9.0 and OpenGL 3D Hardware Accelerator Support Native support for Microsoft Windows Scene/Model Content packages available	OpenSource = Free 3D Hardware Accelerator Support Multi-platform support (Windows, Linux, etc) Native OpenFlight and TerraPage™ Support Integrates other OpenSource SDKs (Physics models, audio, networking, scripting)
Cons	No source code provided. No future Apex SDK versions being provided. Limited customer support and documentation. OpenFlight converter limited.	Non native support for PC Windows No support for OpenFlight (Military Standard). Product is developed in UK in a different time zone that may delay technical support responses. Expensive.	Noticed some conversion errors with OpenFlight Conversion, but may have been corrected. No Audio or IC Physics support included. Expensive for full license.	No support for OpenFlight™. Not many examples are provided. A single example working game is provided that you are to customize to your liking.	Security issues with product being OpenSource. Limited Tech Support No support for advance Direct X Shaders, but OpenGL Shaders available. May have to perform own bug fixes to source.

Table 1: Game Engine Trade Results

Figure 6: LW System and Tablet Display

A prototype hand held device being investigated by the ECATT-MR ATO is shown in Figure 7. This system has enhanced processing and 3D graphics capability over any device in its category and provides game-style controls directly on the device. This system also has the capability to run other common training applications such as Objective OneSAF to provide the necessary scenario environment for embedded Mission Rehearsal.

Figure 7: Sony Vaio Hand held PC

CONCLUSION

One goal of the ECATT-MR ATO research is to improve embedded training for Dismounted Soldiers. This paper discusses an approach that addresses game engines as an alternative to expensive IG-based, fully immersive systems. This research examined several game engine technologies that were identified as acceptable candidates for embedding into existing Soldier simulation systems. The game engine selected for integration into the Virtual Warrior system and described in this paper was chosen as the best fit, based on the defined criteria, for the current embedded Soldier training system. Future research will include investigation of other game engines such as Delta3D as it matures and new game engines as they appear on the market.

Research is also ongoing to investigate low cost alternatives for dismounted embedded training such as hand held devices that could provide embedded training via 2D or 3D applications. Future research into conversion of existing OpenFlight™ databases into formats used by the gaming industry (such as QuArk) will facilitate the incorporation of other game engines such as the Torque SDK. Technology advances in mobile computing and gaming are being identified as viable candidates to provide embedded training capability to every Soldier in support of the Army's FFW and FCS programs.

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