Faculty and Researchers   Faculty and Researchers' Publications

2000-09

Weapons Design Analysis Using 1-Meter Terrain Resolution Battlefield Simulators

Baer, Wolfgang; Mansager, Bard; Kemple, William G.; Illingsworth, James

Monterey, California: Naval Postgraduate School.

WEAPONS DESIGN ANALYSIS USING 1-METER TERRAIN RESOLUTION BATTLEFIELD SIMULATORS

Wolfgang Baer, Bard Mansager, William G. Kemple
Naval Postgraduate School,
Monterey CA
baer@cs.nps.navy.mil
bkmansag@nps.navy.mil
kemple@nps.navy.mil

Major James Illingworth
TRADOC Analysis Center - Monterey
Monterey, CA
illingwj@trac.nps.navy.mil

KEYWORDS

High Resolution Terrain, Real-time Simulation, Line-of-Sight, Weapon Design

ABSTRACT

Simulation of battlefield systems in operational scenarios require the calculation of concealment, cover, and detectability to properly evaluate their performance and effectiveness on the battlefield. In the past so called "high resolution" simulations such as Janus and the Combined Arms and Support Task Force Evaluation Model (CASTFOREM) typically performed such calculations using geometric line-of-sight (GLOS) on 25-meter terrain resolution and model micro-terrain effects statistically. Results provided by such simulations do not account for the individual soldier's ability to take advantage of local cover and concealment in an individual engagement while carrying out tactical missions.

New 1-meter terrain analysis tools developed by personnel at the Naval Postgraduate School(NPS), the U.S. Army Training and Doctrine Command (TRADOC), and independent contractors have allowed substantial improvement in our ability to simulate individual engagements and assess the effects of micro terrain features on tactical mission success. This paper introduces the architecture and fast ray-tracing algorithms capable of calculating realistic 1-meter terrain perspective views in real-time on PC based platforms. We then describe how this algorithm is extended to perform view-based line-of-sight calculations (VLOS) and replace the old GLOS approach. This new technique calculates a small perspective view for each simulation player pair of interest. The perspective view is then analyzed. Partial player visibility, sensor location, major obscurant, and background contrast information are now all available and can be used to perform deterministically modeled detections and engagement effectiveness calculations.

We conclude the paper with case studies conducted to analyze the effectiveness of various system designs utilizing the 1-meter terrain tools now available. We describe the ability to select routes, modify tactics, and analyze engagement opportunities when accounting for high-resolution terrain features. Sample analysis results are presented to show the effects of design alternatives on mission performance.

Report Documentation Page

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 SEP 2000	**N/A**	

4. TITLE AND SUBTITLE		5a. CONTRACT NUMBER
Weapons Design Analysis Using 1-Meter Terrain Resolution Battlefield Simulators		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Naval Postgraduate School Monterey CA	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	**SAR**	**7**	
unclassified	**unclassified**	**unclassified**			

INTRODUCTION

The objective of this paper is to describe the use of a high-resolution terrain simulation to conduct analysis of tactical operations and battlefield system characteristics. In specific we review a study conducted to determine the impact of a mast-mounted sight on a scout vehicle with respect to target acquisition opportunities and susceptibility to detection.

Research efforts supported by TRAC-Monterey and NPS faculty have developed a micro terrain visualization engine and line-of-sight generator known as PVNT. This system shows promise in providing simulated analysis of new battlefield systems in tactically realistic scenarios in order to assess the value of design features to tactical wartime operations. Using this tool, we conducted several tactical scenario experiments consisting of defining enemy defending positions and vehicle paths using a 1:50,000 scale topographic map as a decision aid. These routes are compared with routes selected after using the PVNT simulation knowledge of micro-terrain as a decision aid. Results indicate positions typically changed by 200 to 400 meters while line-of-sight times for scenarios change by 20% to 30% when micro terrain features are added to the scenario generation decision process. This reflects the more accurate use of cover and concealment by defending troops as well as better selection of view-points from which scout vehicles could survey the terrain.

Positions and routes selected interactively with PVNT were automatically densified to 1-second troop movement files using the mobility capabilities of a modified Janus model. Such troop movement scenarios were then used to calculate line-of-sight results at each second between all opposing force entities. For simulations lasting on the order of two hours of real-time resulted in over 14,000 position updates and 720,000 LOS calculations. These were statistically analyzed to quantify the effect of system design features and their use in realistic terrain.

Key to the success of these simulations was the ability to calculate LOS in a simulation environment that allowed effects such as the partial concealment of vehicles and soldiers by the micro-terrain features including trees, bushes and rocks.

PVNT High Resolution Simulation Background

The US Army test facility at Fort Hunter-Liggett, CA (FHL) had a high fidelity battlefield replication system known as Pegasus. This system provides the capability to generate a 1-meter terrain database and a one centimeter target view database for use in weapon substitution, command and control applications, and after action test review. The system has been relocated for operation at other sites such as Fort Hood, TX. Terrain databases have been generated for use in operations at locations such as Yuma, AZ. Perspective view and line-of-sight capabilities represented by the Fort Hunter-Liggett legacy systems have been migrated to low cost PC NT computers by students and researchers at NPS and is now being maintained by Nascent Systems Inc. The code is called PVNT.

Several years ago investigation of porting costs, performance, and platform cost analysis had shown that both the cost and maintenance of future systems would greatly benefit from the utilization of low cost PC hardware and standard software. A combination of NPS students and research efforts has now successfully ported the perspective view generation and line-of site software to a PC NT platform. The availability of high speed low cost PC based workstations at substantially lower prices than those currently employed to host the software has greatly enhanced the cost effectiveness of 1-meter and higher resolution terrain databases.

PVNT is now operating on symmetric multi-processor platforms under NT, and Windows. The code is demonstrable, reasonably stable, and a specialized version has been perfected to the point at which it is an operational component of the Rotary Pilots Associate test being conducted by US Army Test and Experimentation Center (TEXCOM) TEXCOM at Yuma during the Summer of 1999. Sample copies of executables along with sample 1-meter terrain data are available on CDROM from Dr. Baer at NPS. The general code however is undocumented, without operations manuals, and shows instabilities, especially when run on arbitrary PC

platforms encountered at average distribution sites.

PVNT PROGRAM DESCRIPTION

The PVNT program primary function is to generate video realistic perspective views in real time from 1-meter terrain databases. In order to achieve sufficient coverage for large areas, the 1-meter terrain database [Baer93] using a 32 bit integer to describe each one meter post in a 2.5D Voxel format. Elevation is stored in the top 11 bits and represents the top of the visible feature. This is referred to as "bottom of the sky" elevation. A 10x10 sq. Km area requires 400 megabytes (MB) of data. This is still beyond the capacity of most machines. Typically 64 MB of memory are reserved for terrain, however, a 512 MB memory model has been used on large memory machines. Hence a hierarchical range dependent data structure is used to dynamically load 1, 4, 16, and 64 meter data pixels surrounding the instantaneous view-point. As the view-point moves, this data is updated. Several options exist in the program for loading alternative data volumes, rates, and patterns each one suitable for different applications. These option include:

- Cone Load – loads 1-meter data along a view cone instead of a cylindrically symmetric area
- Update Rate Control – limits the amount of data loaded per view calculation
- LOS High Resolution Update - Places 1-meter data around viewer, targets, and major ground obscurants between the target pairings.

Though memory in modern machines is continuing to drop in cost, the data volume is a primary technical obstacle. The 2.5D Voxel format requires one tenth the storage capacity of vector formats because no polygon outline is required. In order to achieve the same storage capacity using polygons requires increasing the size of a single polygon to cover several elevation postings to reduce the polygonal database size. We have found that the compaction by combining adjacent meter posts with identical element can reduce the data volume by 40% to 60%, however beyond that data loss or statistical substitution of textures is required.

The speed of the PVNT is based upon a unique all integer inverse ray trace algorithm [Baer91]. Rays are projected from the viewer's eye point by incrementing the ray tip length by one meter and testing if the ground has been hit. When hit, the terrain elements, coordinates, and view distances are stored in an array the same pixel dimension as the perspective view. If the ground has not been hit the ray is incremented once more. For a 1024x1024 view, which can scan to 20 Km, the inner loop would execute approximately 20 Billion times per picture. To allow real-time operation on PC machines several tricks are employed. These include:

- All integer ray increment in the inner loop;
- Process in vertical columns;
- Elevation calculations in shifted integers to match the terrain data format; and
- Adjust the ray increment to match the terrain resolution

With these optimizations a 1024x1024 view executes at approximately 2 frames per second (fps) on a 400 Megahertz (Mhz) Pentium machine and can process an equivalent 50 million polygons per second. This number is subject to interpretation since polygons are not used, (90 degree field of view from a 100 meter helicopter over a one meter polygon density is assumed). It should also be noted that the inverse ray trace algorithm automatically performs the painter's algorithm for hidden surface removal and avoids a Z-buffer. A Z-buffer is only used for target template insertion described below.

Besides extremely fast image processing speeds, the PVNT implementation also provides a capability to perform real time surface rendering. Stripping the elevation pixels from the terrain element and running the remainder through a rendering look-up table accomplishes this task. The look-up table is segmented for target to viewer angle. The rendering look-up table is 4 MB and can be calculated off line. This allows material surface property maps to be translated to radiometric emission values on the fly. Hence, shadowing, time of day, view angle, and some weather effects can be handled in real time.

The availability of a fast perspective view generation engine on a generic PC platform is the key to route planning and improved line-of-sight algorithms discussed below.

PVNT Route Planning

Route planning and defensive position selection proceeds as follows. The subject matter expert selects an approximate set of way-points and enters these on a PVNT map view. Once entered, he sequentially visits each point and uses the perspective view capability to examine the terrain as it looks from the position.

The route is then adjusted to account for local obscurants, elevation variations, and mission objectives.

Figure 1 shows a screen capture of a map with route points(dashed line) and a perspective view seen by the operator. Note that a view cone is outlined as a white triangle while tree sides seen on the map are colored red and seen as dark spots in the perspective view.

Figure 1- Route Point Selection In PVNT
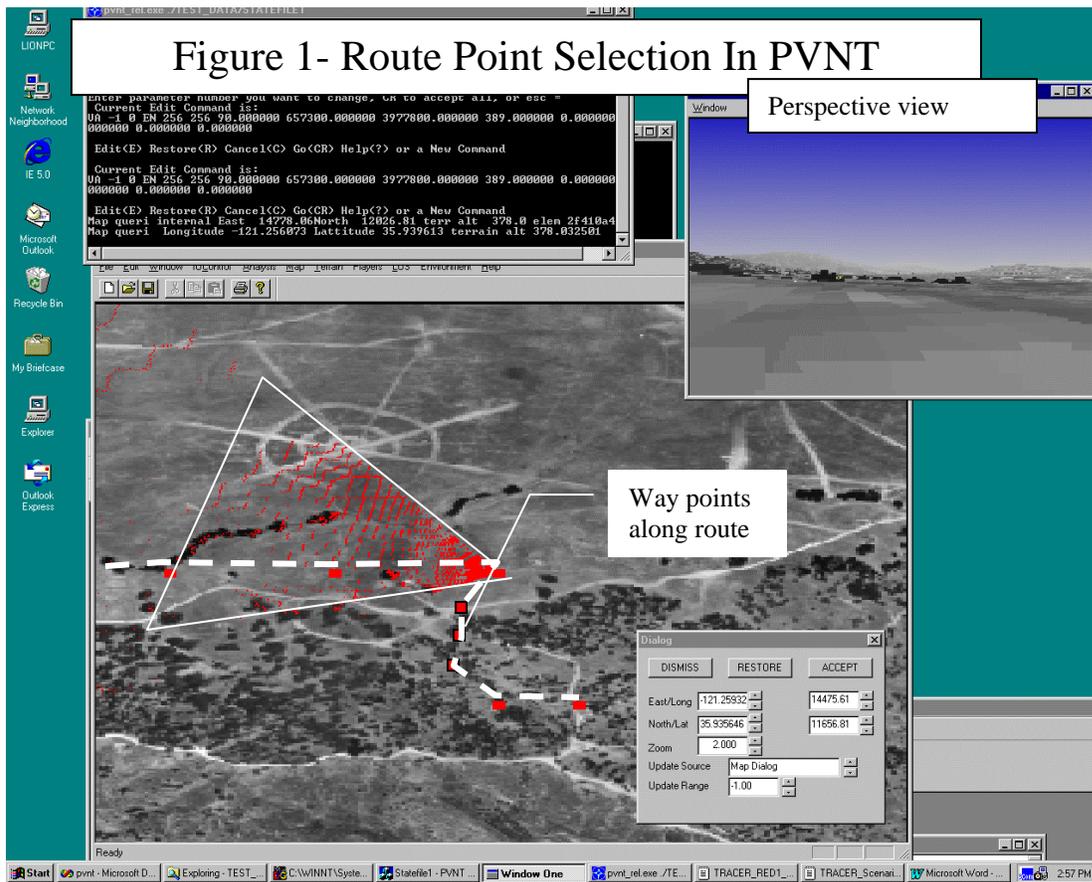
PVNT LOS Algorithm

The line-of-sight calculation is performed as follows:

- Enter parameters defining a target template aspect as seen from the viewer;
- Enter view and target position;
- PVNT generates a perspective view from the viewer to the target;

- PVNT inserts the target template into the perspective view using a Z-buffer algorithm; and
- PVNT processes the view with the target and performs a pixel count of the target in view.

Figure 2 below shows the perspective view with a template of a vehicle. Note that the target, colored red in the white circle, is partially obscured by the bushes and only the left side of

the body is shown along with the mast and the sensor pod on top of it.

The ability to generate full perspective views rapidly allows PVNT to perform such more sophisticated LOS calculations then those using a direct geometric line paring approach. Advantages of this method are:

- Partial visibility handled;
- Viewer can be hidden and only the sensor exposed; and
- Foreground background contrast available for detection calculations

In our study the primary output of this calculation was the fractional visibility of a target and its slant range. If a target had a fractional visibility of 50%, half of the possible pixels were exposed to the viewer.

Figure 2- LOS View with vehicle template
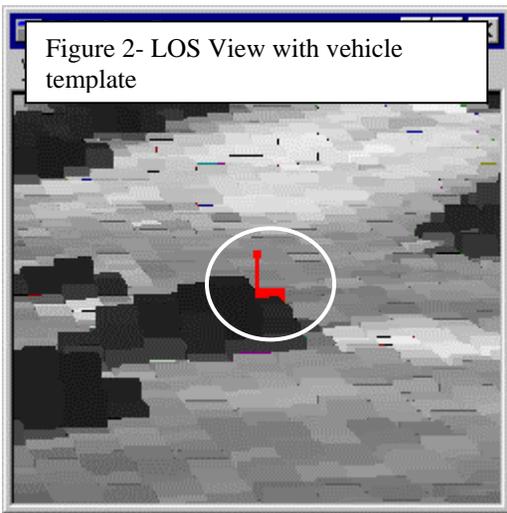
SCOUT VEHICLE CASE STUDY

The objective of the study was to determine the impact of a mast-mounted sensor on a battlefield system with respect to target acquisition opportunities and susceptibility to detection. The measures of performance are, given a tactical scout mission, which vehicle type has more inter-visibility to the enemy while remaining less exposed to those enemy targets. The tactical scout mission required each vehicle to move through a suspected enemy position. LOS result comparisons between the vehicle-target pairings regarding the presented area of the target were done. This included both presented area of the enemy targets and

presented area of the friendly vehicles while moving through the terrain.

Several methodologies are available for analysis. The generation of weapons effectiveness potential (KEM96) generates terrain maps from stationary players. Routes can be drawn on these maps and compared for effectiveness. This novel method shows great promise in that a single map can provide significant insight into the effectiveness of a weapon over a large geographic region. More traditionally, this simulation generates a large number of LOS data, which is then analyzed. We employed this methodology to generate and analyze different vehicle scenarios in high-resolution terrain. Details of the methodology are described in the next section.

Methodology

Step 1 : A subject matter expert using high resolution terrain knowledge from PVNT interactively chooses defensive positions which maximized visibility and minimized exposure. Step 2 : A second subject matter expert selects route way points for two scout vehicles also using PVNT. This includes travel points and stop points at which sensing takes place. The routes are chosen without knowledge of the opposing player positions.

Figure 3 shows a diagram of the player positions and two planned routes. Vertical boxes indicate stop points. Vehicle 1 selected a 18.2 km. route defined by 310 points and 7 halt points. Vehicle 2 selected a 17.2 km route defined by 283 points and 6 halt points.

Fig.3 Zone Recon Vignette
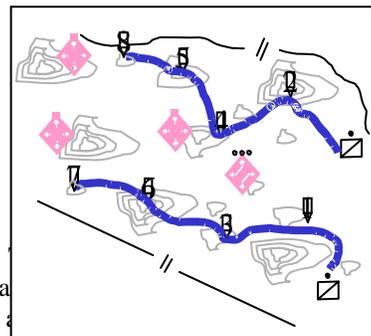
Step 3: [...] points a [...] ol (DAT) a [...] he route using its mobility model by inserting time stamps and PVNT LOS generation commands. A 56 MB file containing over 7000 route

waypoints for each vehicle is created. This is for a mission lasting two hours and five minutes in real time.

Step 4: The scenario command file was sent to PVNT, which performed over 749,000 PVNT commands to include position updates and LOS calculations using a 64x64 pixel view template. Run time was 5.5 hours and 778,000 lines of ASCII output were generated. Each output line indicated the red and blue player pair for which LOS was calculated as well as the range, target size, and fractional visibility of the target.

Step 5: The Data Analysis Tool converted The PVNT output file with the LOS results into a Microsoft ACCESS database. Using Structured Query Language (SQL) statements on the database, performance measures were evaluated and graphs were generated through automation.
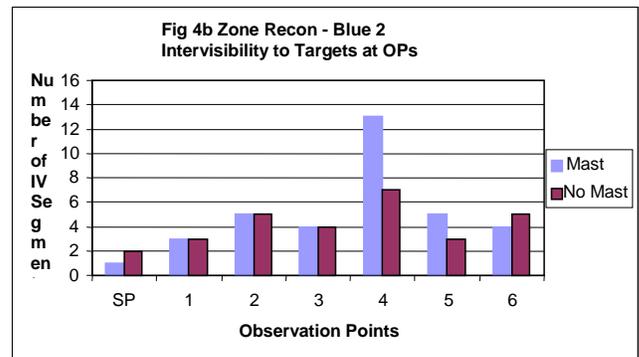
Study Results

Two vignettes were defined and run through the methodology described in the last section. The first, called the Infiltration vignette, involved two blue vehicles on routes attempting to minimize exposure. The second, called Zone Reconnaissance, included two vehicles attempting to maximize their knowledge of enemy force locations. Two different vehicle types were given the same mission. Yet, through the use of the Subject Matter Expert, each vehicle was employed using it's capabilities. On the whole, the difference between the vehicle with the mast and the vehicle without the mast visibility during travel was insignificant. This was expected since both vehicles were of similar size and moving along similar routes at the same speed.

At stop points (see figures 4a and b) however in the zone recon vignette, the mast mounted vehicles had a total of 67 Inter-visibility (IV) segments (both Blue 1 and Blue 2) versus the 52 IV achieved by the non-mast mounted vehicle type. The most significant differences occurred at Observation Point 2 (OP2) (Blue 1), OP5 (Blue 1), and OP4 (Blue 2). The mast mounted vehicle type had inter-visibility to enemy targets at OP2 and 5 (Blue 1) while the non-mast mounted vehicle types had no IV segments. At OP4 (Blue 2), Vehicle Type 1 had LOS to 6 more targets than Vehicle Type 2. Figures 4a, and 4b show a comparison

of Vehicle Type 1 versus Vehicle Type 2 at the stop points.

Figures 4a Zone Recon - Blue 1 Intervisibility to Targets at OPs
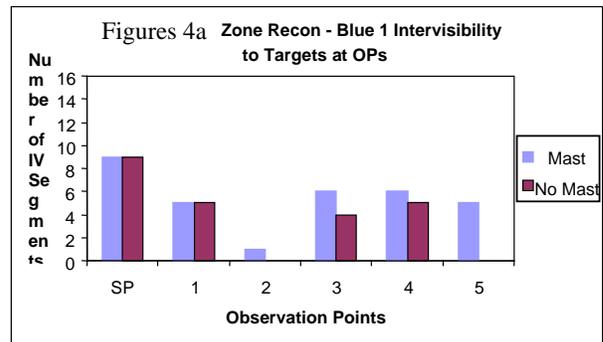
In the infiltration vignette, there was no significant difference in the number of enemy IV segments to the vehicles at the observation points. Enemy targets had a total of 92 IV segments to the mast mounted vehicle type versus 96 IV segments to the non-mast mounted vehicle type.

Fig 4b Zone Recon - Blue 2 Intervisibility to Targets at OPs

From the results of the study, it is unclear whether one vehicle provides a distinct advantage over the other. In both vignettes, the mast mounted vehicle type shows improvement over the non-mast mounted vehicle with respect to the percent of enemy targets to which it achieves line-of-sight (LOS) and the total number of IV segments at the OPs. In both vignettes, the mast mounted vehicle types has more IV segments at greater ranges than the non-mast mounted vehicles. For this paper, however, the methodology is much more significant than the individual results. A few comments are therefore in order.

In high-resolution terrain using partial target inter-visibility calculations, the LOS is not

reciprocal. Some red players could see the blue player when the reverse was not true. This is contrary to our experience with geometric line-of-sight results. We examined several such differences and found for example, a stationary player could be hidden behind a bush, but able to see over the top. Such phenomena make the LOS calculations more realistic although accuracy checks developed with older technologies are not always applicable.

In addition to LOS calculation results, the high- resolution simulator proved to be an effective tool for operational route planning. PVNT visualization allowed the Armor SME to "see" the terrain. The panoramic view from the perspective of the scout observer greatly enhanced route planning and line-of-sight clearance. PVNT "playback" of routes allowed a

basic ability to review the tactical movement of the scout

CONCLUSION

The use of high-resolution terrain simulators has been shown to be a significant aid in analyzing tactical importance of weapon design features, which depend on concealment, cover, and camouflage. In addition to LOS calculations, the impact of mission planning utilizing knowledge of micro terrain features has been demonstrated. Future work will concentrate on the improvement of a user-friendly interface, automation of data paths to other simulators and the expansion of 1-meter databases to cover more areas of the world.

REFERENCES

[Baer91] " Implementation of a Perspective View Generator", Transputing '91, P. Welch et. al., Vol. 2 pp. 643-656, ISOPRESS Amsterdam, 1991

[Baer93] "An Approach for Real-Time Terrain Database Creation from Aerial Imagery", by W. Baer and J. R. Akin, *SPIE Proceedings Vol. 1943-17 OE/Aerospace and Remote Sensing Conference*, 12-16 April 1993.

[Baer95]"Global Terrain Database Design for Realistic Imaging Sensor Simulation", W. Baer and C. Reed, *Proceedings 13'th DIS Workshop on Standards for Interoperability of Distributed Simulations*, Vol I, p. 19 ,Sep 18-22 1995

[Kem96] " Computer Visualization of Battlefield Tenets", Kemple, W.G. and Larson, H. J. , Mathematical Computer Modeling, Vol. 23, No. ½ (1996): pp. 25-37

MAJOR JAMES ILLINGWORTH is an Operations Research Analyst at the TRAC-Monterey office. His interests are in terrain generation, relational databases, and simulation modeling. He specializes in integrating relational databases into simulations, statistical analysis of data, and virtual modeling of military weapon systems.

BARD MANSAGER is a Senior Lecturer of Mathematics at the Naval Postgraduate School specializing in combat modeling, systems engineering and antitank missile analysis.

WILLIAM G KEMPLE is the Associate Director of the Institute for Joint Warfare Analysis. His research concentrates on combat weapons effectiveness models and display methodologies.

BIOGRAPHY
WOLFGANG BAER is a Research Assistant Professor of Computer Science at the Naval Postgraduate School specializing in data capture, high-speed algorithms, and parallel computers for real-time battlefield application.