SIREEL – Simulated InfraRed Earth Environment Lab

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ABSTRACT

The National Ground Intelligence Center (NGIC) has the mission to produce and disseminate all-source integrated intelligence of foreign ground forces and equipment to ensure that U.S. forces have a decisive edge on any battlefield. The NGIC provides the best signatures available on foreign ground force systems within requested wavebands and defined scenarios through field measurements, predictive codes, or scaled models. The Simulated InfraRed Earth Environment Lab (SIREEL) leverages this expertise to make geometric models and real and simulated IR signatures available in a variety of formats to a wide range of customers from acquisition and material developers to operational forces, including those involved in Homeland Defense and Operations Enduring Freedom and Iraqi Freedom.

The key feature of SIREEL is a process in which infrared measurements and predictive models are used to produce infrared signatures of threat vehicles and scenes. Through simulations and field collections the NGIC can generate the infrared signature of any system, at any time, in any operating condition, at any location. SIREEL has available dozens of high fidelity signature models that are accessible through Internet, SIPRNET, and JWICS websites. Current simulation efforts include continued modeling of basic weapon chassis as well as systems under netting, coated with IR reflective paints, and with modifications such as skirting and reactive armor. Future areas of development involve simulated gun flash to enable identification of the firing weapon system, interactive plume modeling, and higher fidelity system-scene integration. This paper will discuss the process and tools developed for the program. These include CAD model development tools and techniques; mesh application, IR codes, and dissemination methodologies.

ABOUT THE AUTHOR

Dan Rinald was born and raised in Pittsburgh, PA. He graduated from Allegheny College in Meadville, PA with a BS in Physics. He earned a Master's of Engineering Physics degree from the University of Virginia in 1990. Mr. Rinald is a 12-year employee of the National Ground Intelligence Center, formerly Foreign Science and Technology Center. Principal jobs have included computational Infrared analyst, 3D CAD modeler, MASINT website developer, and Unix system administrator. In 1999, he was selected for the Exceptional Intelligence Analyst Program completing a study entitled, "3-D Computer Target Models: a Policy Statement Regarding the Adoption of a Methodology for the Production and Analytical Use of 3-D Computer Target Models within the Intelligence Community." In 2002, he completed the Leadership Education and Development Course.

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INTRODUCTION

The Measurement and Signatures Intelligence (MASINT) Division of the National Ground Intelligence Center (NGIC) has the mission to collect, process, exploit, and disseminate MASINT signatures on foreign ground forces' equipment and facilities responding to Army, DoD, and other Departments' requirements for system-specific signatures. The Simulated InfraRed Earth Environment Lab (SIREEL) was developed to augment the field collection efforts on infrared (IR) signatures. The initial strength of the SIREEL program was developed around the dissemination of signature data to the warfighter via an unclassified, password-protected website. Since this beginning stage the SIREEL program has built a cost-effective, time-efficient assembly line process for producing computational infrared signature models.

For background, here is a little information on infrared signatures. All objects with a temperature above absolute zero emit electromagnetic energy. Therefore, all objects in our environment emit energy. Some of this energy is emitted in the region of the spectrum known as the thermal (or infrared) region, wavelengths of roughly 0.7 to 1000 µm. Our eyes cannot see this infrared energy, but we have designed sensors that can. The following descriptions breakdown the regions most often encountered for target descriptions. The portion from 0.7 to 1.1 µm (called Near IR) is dominated by reflected and not emitted energy - similar to the visible region that we can sense with our eyes. Since it measures reflected energy, it requires an active source, such as the sun, to illuminate it. The short wave IR (SWIR) waveband is roughly 1.1 to 3.0 µm. The emissions dominated portion begins around 3 µm. Midwave IR (MWIR) is from 3 to 5 µm and long wave IR (LWIR) is from 8.0 to 14.0 µm. The majority of the energy emitted from 5.0 to 8.0 µm is absorbed by the atmosphere and is not useful for detection and identification purposes. Given appropriate surface property parameters, i.e. waveband specific emissivity, and the temperature of the object, the radiant intensity can be calculated for the given wavebands. The surface temperature is the data point being generated when running infrared simulation codes. From this data the waveband radiant intensities can be determined.

Simulated (computational) infrared signatures are used to meet the exacting demands of a diverse group of customers. The intended customer of the SIREEL website is the pilot, gunner, or mission planner (warfighter) who views the world through a thermal sight. SIREEL provides to the warfighter measured and computational 2D and 3D infrared images, movies, and scenes. The IR team at NGIC also has customers in the acquisition and decision making communities. The acquisition community is comprised of the smart weapon developers and research and development scientists. Whereas the warfighter needs image-based information for training or deployment decision-making, the acquisition community desires waveband specific radiant intensities, temperatures from regions of interests, average/minimum/maximum target temperatures, or target-to-background delta Ts from numerous look angles to help program their algorithms. As opposed to images, these customers use tabular data forms, i.e., quantitative data versus qualitative data. Figure 1 shows an example of the simulated radiant intensities of a T-62 tank in static and moving operating conditions in a cold, snowy background at various look-angles. The decision maker community needs the intelligence community's (IC) best assessment on a particular requirement. The IC will use a combination of data forms from warfighter (images) to acquisition community (data tables) to make these assessments. Using the same assembly line process developed for the SIREEL program, data can be produced to satisfy the varying requirements of all these customers.

Day		Cold/Snow Background (Day)	T-62, Cold Environment, Static (Day)	T-62, Cold Environment, Moving, (Day)
Azimuth	Elevation	Wsr	Wsr	Wsr
0	10	3.63	4.95	5.13
30	10	5.64	8.40	8.04
60	10	6.66	10.37	10.12
90	10	6.45	10.40	10.46
120	10	6.36	11.18	12.00
150	10	5.47	11.32	12.97
180	10	3.64	8.63	14.63
210	10	5.41	10.78	20.32
240	10	6.28	10.27	24.80
270	10	6.40	9.50	23.92
300	10	6.68	9.64	20.27
330	10	5.69	8.07	15.14
360	10	3.63	4.95	5.13

Figure 1. Tabular Data: Azimuth/Elevation angles vs. Radiant Intensity of T-62 in various Operational Conditions

There is no one infrared signature of a particular system. Extremely conservative estimates say it takes over 18000 images to define a target signature. A more rigorous methodology, includes surface treatments, ranges, sensor types, etc leads to nearly 180,000,000 T. Gonda (*Signature Management for FCS*. Presentation by the Tank Automotive Command, 2001). Key variables that affect the signature of a system are season, climate, time of day, location, background, operational condition, countermeasures or add-ons, and azimuth/elevation angle. Because of these variations field collection of data would be cost and time prohibitive if not impossible. Through simulated signatures the NGIC is capable of providing data on any target in any condition and the data can be tailored to a particular deployment or use. The SIREEL program is capable of providing necessary data to a diverse customer base in a timely and effective manner. Figure 2 shows a description of the assembly line process and tools.

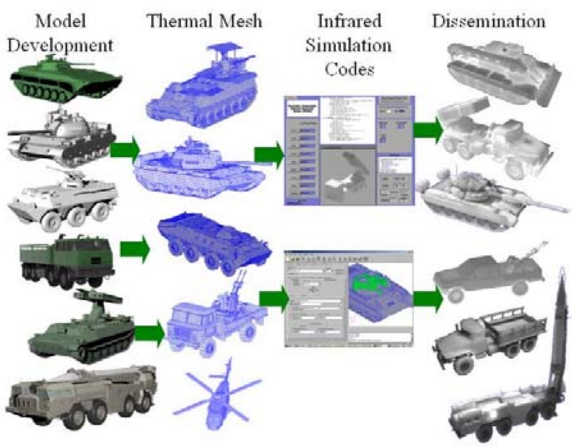

Figure 2. The Assembly Line Process for IR Signature Models

MODEL DEVELOPMENT

The desired result of the ground vehicle IR signature modeling process is a 3D model that is sufficient in detail to provide an accurate thermal signature of a target for any particular application. The model must be able to convey important information such as vehicle shape from different aspects and location of thermal features. The process for creating an IR model of a vehicle consists of four major steps: creating a geometric representation of the vehicle, deriving a thermal mesh from the geometric reference, attributing the thermal mesh and creating a predictive signature model, and interrogating or preparing the output data from the predictive code for dissemination to the customer. Figure 2 showed these steps and examples of models at each stage of the development process.

The ground vehicle IR signature modeling process begins with the creation of a three dimensional geometric reference model of a vehicle. This has historically been a difficult task, but the speed and capabilities of personal computers, and the capabilities of modeling software have increased to the point where this stage of the development can be accomplished with commonly available tools. The most difficult challenge typically faced by a geometry modeler is building a model that is sufficiently accurate for a given application. Creating models for target-training applications often involves vehicles about which very little is known. In some cases assumptions must be made concerning the shape and size of components of the vehicle because the best information available may be photographs. In other cases, accurate line drawings or examples of the actual vehicle may be available and the accuracy of the model can be very high.

Fortunately, IR signature models have less stringent spatial detail requirements than other types of signature models and IR signature models can be created with sufficient detail from relatively limited information. The typical spatial resolution of the SIREEL predictive signature models ranges from three to five inches and non-critical features smaller than this are not modeled. Figure 3 shows a completed geometry model.

Figure 3. Geometry Model

Since the NGIC is the DoD authority on foreign ground systems, the validation of the geometry is completed concurrently with the model development. The NGIC system experts provide the data to the geometry modelers or concur with the methods and dimensions used to build the model.

As the SIREEL model inventory grows so do the available parts for reuse in other models. Of late the prevailing approach by many countries is to improve current inventory to meet existing needs. Well-established, well-proliferated base chassis such as the Russian MTLB have been modified to carry different payloads and munitions. China is also known for creating a variety of armored–class vehicles from one common chassis. This reuse of chassis and parts plays to the strengths of modeling and simulated signatures. Figure 4 shows four configurations for the Chinese WZ-531 base chassis.

Figure 4. Common Chassis, Four Different Systems

Thermal Mesh

After the geometric reference has been created it is used as the primary input for the creation of a thermal mesh. The thermal mesh is simply another representation of the geometry of a vehicle but with very specific requirements. The thermal mesh must be created with low aspect ratio quadrilateral polygons in order to properly model the flow of heat across a vehicle component. In the final thermal solution, each polygon is assigned a calculated temperature over time based on a number of heat inputs over time, and each polygon is referred to as an isothermal node. The thermal signature codes have a finite limitation on the number of node temperatures that can be calculated at one time and this limitation drives the final resolution limits of the signature model. Figure 5 shows a typical thermal mesh created in the SIREEL process. The mesh shown in figure 5 is comprised of approximately 45,000 quadrilateral or triangular polygons.

Figure 5. Typical Ground Vehicle Thermal Mesh

The creation of the thermal mesh model is a critical part of the assembly line process. Misaligned or poorly constructed meshes will affect the accuracy of the first principle physics codes. For example, if nodes that are intended to connect do not, proper conduction will not take place. Comparable heat transfer issues arise for convection and radiation between nodes as well if parts are omitted or misplaced.

INFRARED SIGNATURE SIMULATION CODES

After the thermal mesh has been generated and segmented into appropriate groups, the mesh is used as the primary input to a signature prediction code. Currently the NGIC uses the Physically Reasonable Infrared Signature Model (PRISM), and the Multi-Service Electro-optic Signature (MuSES) code. PRISM is a code that has been the historical standard for ground vehicle signature prediction and MuSES is the recent intended replacement for PRISM. MuSES is the more modern code with a user-friendlier interface but it is a proprietary code and the user does not have access to the source code. This lack of access to source code makes it difficult for the user to model complex heat transfer processes such as the ones occurring in vehicle engines. PRISM source code is available and this allows the PRISM user to create whatever functions and subroutines necessary to model whatever is required. However, due to its more modern software architecture MuSES can accommodate models with higher numbers of thermal nodes and this allows for higher spatial resolution models. The approach used for the SIREEL infrared signature models is a hybrid process that takes advantage of the strengths of both codes. A custom version of PRISM was created that can accommodate more nodes than the standard release version of PRISM, and for relatively low node count models, PRISM is used to generate the IR signature. For models with higher node counts, PRISM is used to calculate the temperatures of engine components and temperature curve files are written out for importing into MuSES. MuSES calculates environmental interactions, node-to-node conduction and node-to-node radiation exchange. These fundamental heat transfer calculations combined with the engine component temperature curves from PRISM represents a highly flexible hybrid approach to ground target IR signature generation.

Attribute Assignment by Parts

Figure 6 shows the color-coded parts of a model. Each part is comprised of a set of nodes. Common characteristics that define whether or not nodes can be joined within the same part are whether or not the nodes have the same material, thickness, surface properties/condition, and convective fluid interaction (e.g., exhaust stream or ambient air).

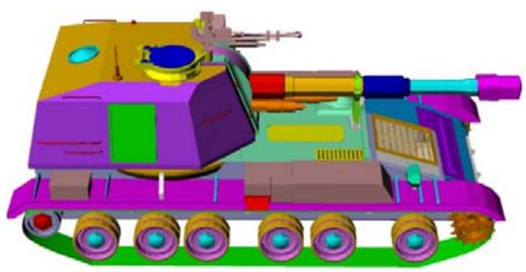

Figure 6. Different Parts on a System

Engine Modeling

Beyond a well-developed thermal mesh, the attention to detail in modeling and simulation of the key heat sources is the next critical step. The engine, drive train, and running gear of a ground vehicle are the dominant contributors to a vehicle's IR signature in most tactical scenarios. The heat generated by the engine and drive train propagates from these active components to other parts of the vehicle by complex radiation, conduction, and convection paths. The temperatures of the components of the running gear (wheels and tracks) of a ground vehicle are driven by parameters such as the speed of the vehicle, mass of the vehicle, terrain type, and bearing friction. All of these complex heat transfer mechanisms must be addressed in order to accurately calculate the IR signature of an active ground vehicle. Figure 7 demonstrates the general process for the incorporation of detailed engine models into ground vehicle signature models.

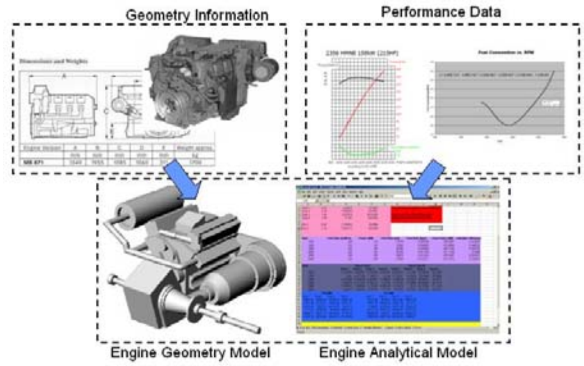

Figure 7. Engine Modeling for Ground Vehicle IR Signature Calculations

The engine modeling process begins with the collection of whatever data is available on the engine and drive train of the vehicle to be modeled. The first step is to create a three-dimensional model of the engine, generate a thermal mesh of the engine geometry, and incorporate the engine mesh into the vehicle thermal mesh. Analytical forms of the heat generation and heat transfer processes of the engine components must then be generated to create the software functions necessary to calculate the temperatures of the engine components. The code generation process begins with the collection of manufacturer-supplied automotive performance data or the derivation of these performance curves if they are not available. This data is then assembled and curve fitted in spreadsheets to create the equations necessary to generate code. These equations are used to modify the PRISM source code, which is then re-compiled and executed to generate either the vehicle IR signature, or the necessary heat curves to drive MuSES. Some of the parameters that are incorporated into the spreadsheet analysis are the engine bulk properties, such as weight and material, the power vs. RPM curves, fuel consumption, gear ratios, exhaust flow, cooling air in/out duct area, and exhaust area.

Once the relatively difficult task of engine modeling is complete, the mesh is attributed in either PRISM or MuSES, simulation scenario parameters are set, and a thermal signature calculation is performed. It is important to note that the IR signature of a vehicle is a strong function of its environmental and operational history; therefore the temperatures of vehicle components must typically be calculated over an entire day in order to obtain the signature of a vehicle at a single time during that day. Figure 8 shows six example IR signatures of a BM-21. The signatures down the left-hand side of the figure represent a solar loaded daytime

(1300) signature in the three operational states of cold, idling, and exercised.

The three signatures down the right side of the figure represent the same operational states for a nighttime (0200) signature. All six of these signatures were generated with three PRISM or MuSES runs with signature models being output for two discreet times during each simulation.

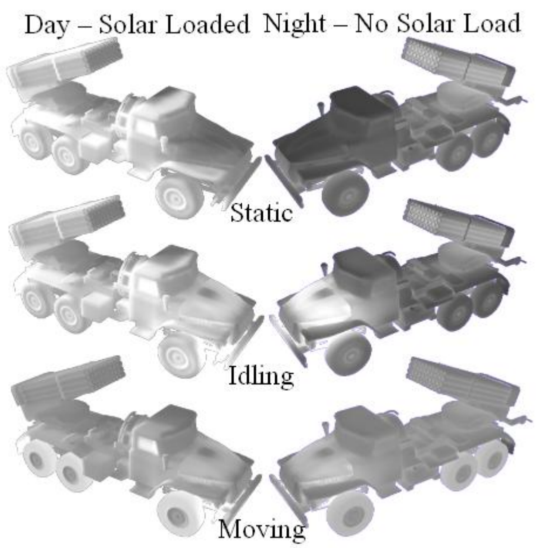

Figure 8. Example Ground Vehicle IR Signature Models

The different signatures shown in figure 8 demonstrate the power and flexibility of high-resolution predictive IR signature modeling. For example, the nighttime cold signature in the upper left demonstrates passive radiative exchange between the vehicle model and the natural environment and between different sections of the vehicle itself. The flat surfaces that are exposed to the night sky appear colder and this is due to a net radiative heat loss to the sky from these components. Other sections of the vehicle that are shielded from the night sky, such as the area under the missile tubes, exchange thermal radiation with each other and stay relatively warm. The idling signature in the middle shows the effect of the engine heating on the hood and other front sections of the vehicle, and the moving signature model in the bottom of the figure demonstrates wheel heating and the effects of forced convection on the vehicle. Forced, ambient air convection causes the hood of the vehicle to cool off and the relative thermal contrast between other parts of the vehicle is reduced as the forced convection heat rate becomes relatively dominant and attempts to force the temperatures of many components to the ambient air temperature. In addition, the solar-loaded signature on the left-hand side of figure 8 demonstrates self-shadowing as the thermal shadow of the rocket tubes can be seen on the bed of the vehicle and the roof of the cab.

Validation

The simulated signature is validated by comparing it against measured data when available. This comparison may be with a system that is identical to the modeled system or one that is reasonably similar, for example, one that has comparable armor thickness, material, and surface properties. Key regions of interest are identified and compared as part of the validation process. These areas may be engine decks, exhaust ports, air intake grills, turret tops and hatches, front glacis or hoods.

The validity of the comparison will be enhanced if detailed meteorological data is collected. Typical parameters are air temperature, solar radiance (direct and indirect), wind (speed and direction), humidity, and cloud cover. Entering this data into the simulated run helps reduce the number of unknown affects on the calculated signature.

DISSEMINATION

Dissemination methods vary depending upon customer data requests. All data are entered into the National Signatures Program/National Threat/Target Signature Database System (NSP/NTSDS). This site is currently only accessible on classified networks, but an unclassified site is pending. The Program is a joint, multi-community program to implement an authoritative measurement and signature data system to provide users seamless online access to U.S. Government signature data. It leverages and links multiple signature data centers into a complementary distributed system through which users can electronically locate and retrieve high quality data.

SIREEL has developed a tool called Primus for viewing the output signature data from PRISM and MuSES and calculating or reformatting that data to meet all our customer requirements. Primus can read in single time outputs or time sequences. It provides statistics on the data, such as minimum/maximum temperatures, background temperature, minimum/ maximum dimensions, temperature of selected pixel and radiometric mean of a chosen view. The main window allows for the selection and viewing of available and rendered system parts – parts can be toggled on and off

from the viewing window. Output from Primus includes radiant intensity within a given waveband, mean temperature, delta T of target and background, and minimum/maximum temperatures. For a given point in time, Primus can save all this data for a selected set of angles by clicking one "calculate metrics" button.
This data satisfies current requirements from the acquisition community. Image (JPEG) and movie (AVI) files can also be generated from Primus using the same "calculate metrics" button. With the addition of future work to include sensor degradation of the image, SIREEL will fully meet the requirements of the warfighter community as well. Currently the SIREEL process only provides simulated data based upon temperatures calculated at the target surface. Figure 9 shows the Primus tool main window with metrics area and viewing window.

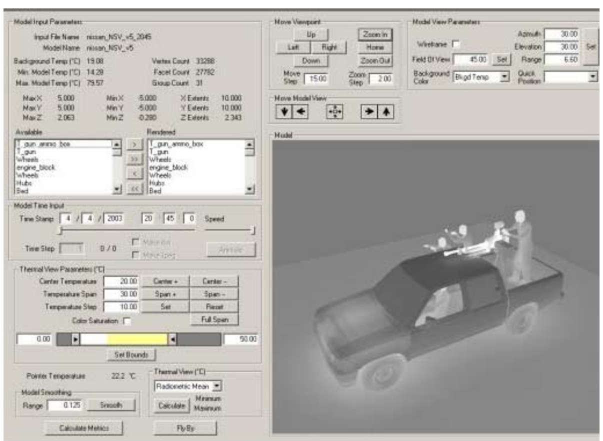

Figure 9. Primus Tool for Simulated IR Signature Analysis

As stated in the Introduction, the SIREEL website tailors the data to the thermal site users to aid them in training and deployment for detection, tracking, targeting, identifying friend or foe, and battlefield awareness.

ON-GOING EFFORTS

Gun flash

Total weapon firing signature consists of the weapon system signature, muzzle flash, munition ejecta (spent casings, munition links) and near-muzzle effects. Furthermore, these signatures vary widely with changes in weapon munition (type of powder and projectile used), firing rate (single shot, semi-automatic and automatic fire) and environmental conditions. Since it is unfeasible to collect measured data for weapons firing signature data across all spectra under all expected environmental conditions, a means to predict the signatures using modeling and simulation is highly desirable. A modeling methodology and tool set is being developed to predict the multi-spectral (ultraviolet through infrared and acoustic) signature of a weapon based on the weapon design and operating parameters, munitions characteristics, and environment. The modeling methodology uses computational fluid dynamics (CFD) modeling with chemical kinetic reaction to predict the muzzle flash effects. Computer-assisted design (CAD) tools are used to develop weapon and munitions geometries for the CFD code. Standard military thermal models (PRISM and MuSES) are used to predict the effects of firing on the weapon signature itself, as well as near-muzzle effects and ejecta signatures. Figure 10 shows a simulated signature of the gun barrel and the muzzle flash. Initial efforts focused on small arms; however, the methodology is scalable to any weapon, given weapon design information and munitions characteristics. Current efforts focus on determining the thermal infrared signature; future efforts include ultraviolet, visual and acoustic signatures (Haase, R., Janicki, P., and Rinald, D., 2003).

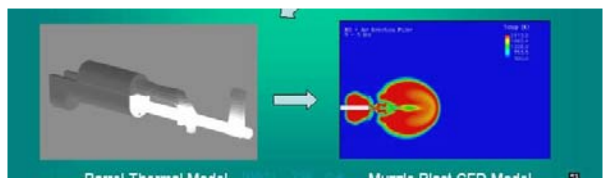

Figure 10. IR modeling of gun barrel and muzzle blast

Plumes

A significant contributor to the infrared signature of a target is the plume created by exhaust or hot air from the engine compartment. These hot airflows exiting the vehicle are especially important in the lower wavebands, e.g. 3-5µm. As with the gun flash effort, existing codes are being evaluated for the CFD portion of the effort. The next phase will investigate adding the CFD output with the thermodynamics of the hardbody signature codes, i.e., PRISM and MuSES. Helicopter downwash will be a particular case of interest for this work. Figures 11 and 12 show some of the outputs from our plume simulation efforts.

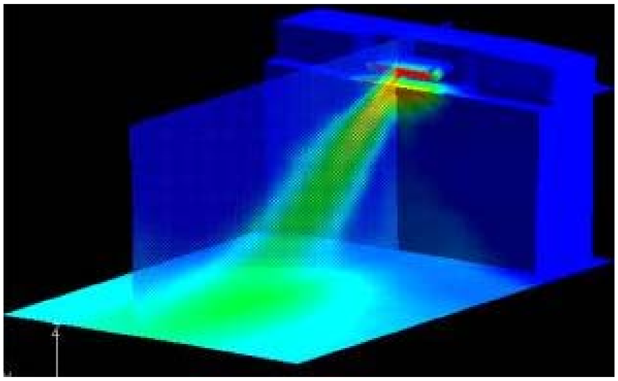

Figure 11. Idling T-72 exhaust plume

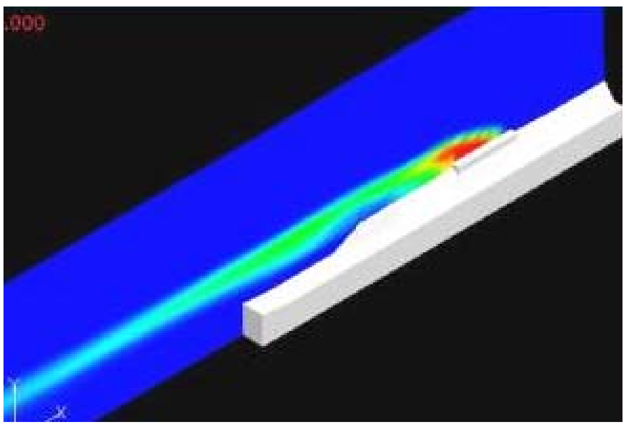

Figure 12. Moving BMP exhaust plume

Camouflage, Concealment, and Deception

How the target is placed in an environment directly impacts the perceived signature of the system. If the target is placed in a berm and/or under a net (see Figure 13) or has a low-emission paint or material applied to its surface, all these aspects need to be incorporated into a simulation to appropriately define the signature of the target that will be seen by a gunner, pilot, or smart weapon sensor. The ability to model decoys and other deception practices will aid in discriminating real threat systems from decoys. SIREEL is in the process of identifying any unique parameters or aspects that may be needed to characterize the signatures of these systems uniquely.

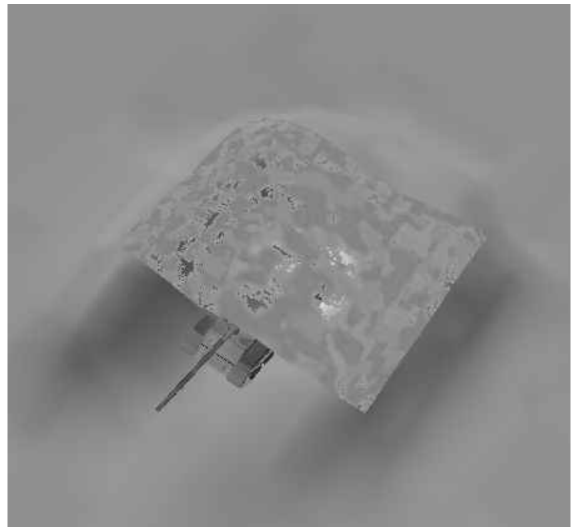

Figure 13. Tank in berm under net

Sensor Integration Effects

To more effectively meet the requirements of the warfighter community, SIREEL is looking to add sensor degradation effects to the simulated infrared images and movies. NGIC is currently reviewing our options for this effort.

SUMMARY

The confluence of faster computers, software enhancements, and improved personal skill sets applied in assembly line fashion has set a new standard in quickly generated, high fidelity thermal signature simulations. An infrared signature simulation can be generated in less than two weeks to a level where it is nearly indistinguishable visually from field measurements. These spatial images are used for ground troop and pilot training as well as targeting. Validation techniques are being worked to aid in defining the temperature variations of a system in terms of boundaries (minimum/maximum), average, or relative variations of the surface temperature of a military system. The data produced from the SIREEL Program have been used to support Operations Iraqi Freedom and Enduring Freedom as well as in the development of future weapon systems, such as Future Combat Systems (FCS).

As funding lines develop, future work will include software modules to simulate the chemical kinetic reactions of a gun flash from UV through Far IR, plumes for exhaust ports, and sensor integration effects. The SIREEL Program has begun looking at how the modeling methodology or data entry may be affected when approaching the problems presented by camouflage, concealment, and deception practices.

ACKNOWLEDGEMENT

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