

Using SEDRIS for Representation and Interchange of Environmental Data in Signature Prediction and Sensor Simulation Applications

Mr. Long Nguyen

Naval Air Warfare Center, Training Systems Division
Orlando FL

NguyenLK@navair.navy.mil

Mr. Russ Moulton, Jr.

JRM Technical and Defense Services, Inc.
Suite 1A 1 Hemlock Ct.

Fredericksburg, VA

russ.jrm@eosoft.com

Keywords:

sensor simulation, SEDRIS, IR, thermal, signature

Abstract: *The SEDRIS Program has advanced a much-needed standard environmental data representation and interchange mechanism for the M&S community. Several significant "out-the-window" native environmental database formats have already been successfully translated into other native formats via the SEDRIS data model and API. Release 2.0 of SEDRIS substantially extended its capability in accommodating military-relevant sensor representations. Among these extensions include multi-dimensional data-tables, reference vectors, and the SEDRIS Environmental Data Coding Standard (SDCS), which provides for the necessary sensor-related classification and property attribution of the environmental data. These surface-optical, thermo-physical and electro-magnetic properties, and other data representation extensions support common end-user signature synthesis models to simulate FLIRs, NVGs, radars and other sensors through which the combatant views his environment. Herein the authors present some common technical issues surrounding the capture of environmental data for sensor representations in SEDRIS. By manner of illustration of these issues and the aforementioned extensions in the SEDRIS data representation model, a mapping of the NVESD's Paint-the-Night (PTN) thermal IR database format to SEDRIS 2.0 is also presented.*

1. Introduction

Sensors are the means by which we perceive and interact with our world, or in military parlance, the battle-space. Whether we rely on our unaided eyes, contact lenses, glasses, our ears, night vision goggles (NVGs), a FLIR, a laser, a radar, or a sonar, the mechanism is the same: the energy emitted or returned defines our environment. Passive sensors like our eyes, a FLIR, or a passive transducer collect energy emitted from objects in the environment or the environment itself; while active sensors like a laser, a radar and or an active sonar transducer capture reflected energy they projected through the environment. In either case, the results are used to evaluate these objects and the environment.

Synthetic environments (SE) are no different in this regard. All simulated representations of the natural environment happen with some form of sensor model. Whether these models take the form of an "out-the-window" viewing frustum through the unaided eye, direct view optics (DVO), FLIR, radar

or computer-generated forces (CGF) line-of-sight (LOS) calculation, all of these sensor models involve some determination of the energy collected from the SE by the viewer. These models attempt to capture the appropriate representation of the synthetic environment by approximating some known physical phenomenon. RGB texture is an example of a sensor model toward the unaided eye out-the-window view. A CGF LOS calculation is an example of a sensor model describing whether or not there is direct propagation of energy between two points.

A sensor model is the translation of the SE into an entity's perception of that SE. In general, a sensor model can be thought of in 3 phases: (1) an SE signature, source signature or quantity synthesis portion, (2) an SE propagation portion, and (3) a sensor processing portion. SE databases attempt to capture to some level of fidelity of the environmental characteristics that support the environmental data needs for Phase (1) and (2) models. Polygons, textures, colors, features, materials, and electro-magnetic (EM) properties are examples of SE

quantities that drive Phase (1) models. Aerosol distributions, smoke cloud spectral transmissivity, water salinity, density, temperature, and roughness are examples of SE quantities that drive Phase 2 models. Optical transfer functions, array gain, detector noise profiles, electronic filters and display characteristics are examples of quantities that drive Phase 3 models. This final phase typically leads to some ambiguity in the M&S community, as the R&D sub-community refers to this portion as the “sensor model”. It is therefore important to draw a distinction between sensor-related SE quantities involved in Phases 1 and 2, and the quantities describing the sensor itself in Phase 3.

Every native SE database has some typically unique approach to capturing sensor-related quantities that support some form of run-time Phase 1 and Phase 2 models. Frequently, there is great commonality among native models, and similarities in the associated types of SE sensor-related quantities. Perhaps no-where is this more apparent than in visible spectrum modeling, where the consistent use of textures, polygon RGB colors, and light sources has become ubiquitous thanks to industry standards such as OpenGL. The SEDRIS program has successfully demonstrated a standard SE data representation model that captures these visible quantities. With SEDRIS 2.0, support has been added to now better represent SE quantities in support of other military-relevant sensors, like FLIRs, NVGs, radars and sonars. SEDRIS concerns itself exclusively with Phase 1 and 2 SE quantity representation and data modeling; Phase 3 modeling is left to the native IG implementation.

The SEDRIS Associates Technical Team has pioneered the effort to extend the SEDRIS data model to support sensor-related environmental databases (i.e. environmental databases used by the sensor simulation community). A list of environmental properties uniquely significant to sensor simulations has been developed and has now been incorporated into the SEDRIS data model as part of the SEDRIS Data Coding Scheme (SDCS) [1]. This list borrowed extensively from the SISO (Simulation Interoperability and Standards Organization) EO/IR Data Dictionary [2] and other sources for the necessary thermophysical and surface optical properties needed to capture environmental IR database information, such as that in PTN databases. This approach leads to a highly flexible approach towards supporting the addition of needed environmental properties without impacting the SEDRIS Data Model. Below we afford some background on the SEDRIS Data Representation

Model support for sensors, and a detailed example of how it is being used to capture high-resolution PTN thermal sensor SE databases for M&S community interchange.

2. Difficulties in Sensor Database Exchange

Historically, databases used by electromagnetic (EM) sensor simulations in the training community contain what the environment looks like rather than the intrinsic characteristics that define the natural environment itself. These databases and the tools from which they are developed are generally packaged to provide sensor displays for specific purposes instead of providing basic environmental characteristics that affects all EM sensors. Some tools are turnkey systems and offer displays for a specific weapon system type. An example of a database produced from this would be an image for a PVD (plan view display) for radar. Other tools are tailored for specific trainers or vehicle platforms. Data captured in these systems would be useful for multiple sensors but only on a tank trainer, for example. Still others provide more realism by highlighting effects from a limited number of specific features in the environments. An example would be the effects of shore brightening on an airborne radar display. Each of these databases contains data representing the effects of the environment tailored for particular displays instead of the environment’s natural characteristics which is independent of the sensor display types or specific feature types.

Extremely cost effective for their intended purposes, these databases and tools have fast editing capabilities and are closely intertwined with their sensor models. These tools are generally off-the-shelf, licensed in large quantities and reasonably priced. Widely used raw databases such as DTED and DFAD [Notes 1,2] can be imported and edited quickly to produce the final results observed by the sensor operator. The effects of adding to or altering the environment can quickly appear on the synthetic sensor displays. These databases have been providing the perfect solution for the stand-a-lone simulation system in a procurement environment that demands full functionality with limited cost and development time.

Reuse and interchange among different systems is another story, however. With the efficiency of fast editing and the close link with sensor models comes the price of limited editing and expansion capabilities. Only a few canned built-in effects are

available for editing. Often times, it is faster to use another tool that accommodates the new feature and develop the new database. This problem is compounded for database interchange among different sensor simulations or vehicle platforms. In order to share the data with other sensor types, the database would have to be stripped of its built-in sensor parameters before it has meaning to a different sensor. This is nearly impossible since the data has no meaning without the context of the sensor types or vehicle platform parameters from which it is built.

3. Standardized EM Representations in SEDRIS

SEDRIS is tasked to standardize SE database interchange including databases for Electromagnetic (EM) sensor simulations. In doing so, SEDRIS matured in four stages. It first looked at EM standards or pseudo-standards in the industry and carved out intrinsic characteristic of the environment that are relevant to sensor simulations. In parallel, the SEDRIS Associates [Note 3] developed the SEDRIS Data Representation Model (SDRM) to accommodate conventional databases described in the previous section. This is accomplished through the creation the Color, Light, and Image classes [Note 4]. As described in [1], the SDRM is then improved to include the relevant intrinsic EM terms in the Data Table family of classes and the SDCS. Finally, the SDRM is polished to accommodate a variety of database producers by adding a Qualified Property Description Class. Each stage is explained below.

In an effort to standardize EM interchange SEDRIS referenced journals published in the simulation community, widely used references and handbooks, and military standard and specifications. One effort to standardize EM terms was presented by the IR Posse group at a previous SIW conference [2]. In this paper, a comprehensive data dictionary was provided for EM terms. Part of this data dictionary contained environment characteristics that can be grouped into five categories of properties– temporal variation, surface optical, thermal fluid dynamics, geometric, and meteorological. From the commercial industry, the Photonics Dictionary and different versions of EO/IR/RADAR handbooks provided the widely used definitions. From the military industry, mil-std-141, DIGEST Part IV, DFAD specification, and mil-hdbk-850 were referenced extensively.

As early as Fall of 97, the SDRM was robust enough to capture the conventional databases used in sensor

simulations. Back then, version 1.04d, the SDRM included the Color, Light, and Image family of classes. These covered one band in the EM spectrum and accommodated the visual database interchange adequately. Included in these are the Emissive, Specular, Diffuse, and Alpha Classes, the Candela field, and the Presentation Domain enumerations. These classes and fields parallel the first order characteristics of the environment that affect all EM sensors – emissivity, specular and diffused components of reflectivity, transmissivity, and radiance, respectively. They fully accommodate the range of sensors that are based on the visual band, including direct view optics (DVO). These characteristics could also be used to derive or approximate the same parameters for use in EM sensor simulations of any other bands. The Presentation Domain enumeration provides the list of sensor types to which the above classes and fields could apply.

Also apparent early in the process of developing the SDRM for sensor simulation was the need for a large number of terms and to qualify these terms with each other, i.e., defining dependent and independent variables in a multi-dimensional graph, table, or function. To illustrate the explosion of terms one can describe the basic reflection characteristics with a number of types of reflectivity including spectral, directional, diffused, specular, band-integrated, long-wave-IR-, etc., or some combination of these. The reflectivity characteristics, or signature element, is also often a function of many other terms or axes, including incidence angle, reflection angle, polarization, wavelength, or type of material, to name a few. To accommodate for the large number of characteristic terms that describe the environment, SEDRIS created the SDCS for version 2.0. In addition, to capture the dependency relationships of these attributes, the Data Table family of classes in SDRM is used. Multiple tables and sub-tables, i.e., tables within tables or tables referencing tables, are also accommodated for the most complex environment representations.

SEDRIS's most recent change in progress involving EM sensors addresses the need to accommodate sensor-related environment characteristics without the use of the classes mentioned above. This necessity arose from SEDRIS users that require associations of dependent and independent EM terms with only one or a very few number of data points for each term. Instantiating Data Table classes for such purposes would be needlessly extravagant. Instead, the Qualified Property Description Class was created

to simply express dependency of one EM term with another.

4. SEDRIS Approach to Sensor-related SE Representation and Interchange

It is important to recognize that sensor-related SE data can often be isolated from geometry and feature data and thus be represented and interchanged via a separate SEDRIS transmittal. PTN thermal sensor-related SE attribution, for example, can be isolated from the terrain skin and associated features, and mapped directly to SEDRIS data tables. In this manner, sensor models can be exported to other native environments without impractical geometry and feature adjustments in the native format or IG hardware. This approach is recommended, as it fosters greater M&S interoperability and re-use. For example, it is conceivable that a SIMNET simulator, deriving its run-time database from a SEDRIS transmittal, could also use a PTN SEDRIS thermal model transmittal to upgrade its thermal sensor modeling; however, it would be impractical for a SIMNET application – using an S1000 TIN'd terrain skin construction – to utilize the regular, T-meshed grid terrain characteristic of an entire PTN SEDRIS transmittal.

5. A SEDRIS Thermal Sensor SE Example

To illustrate the SEDRIS support for sensors, let us consider the example of capturing NVESD's PTN thermal IR database in SEDRIS Transmittal Format (STF). PTN was selected as a candidate IR database model to “prove out” the SEDRIS 2.0 data representation model utility in capturing IR environment information. The first step in this process was to map PTN model objects and classes to those in the new SEDRIS data model, and to recommend any changes via SEDRIS Change Requests (SCRs) that might be required to complete this mapping. This mapping and SEDRIS sensor data model improvement activity was partially funded under a contract with Naval Air Warfare Center Training Systems Division (NAWCTSD), and completed with additional investment by JRM Enterprises.

A PTN-SEDRIS import utility is presently under development. We begin by describing the PTN thermal SE and associated sensor-related attributes. Next, we present the proposed PTN SE mapping to SEDRIS 2.0 to illustrate how thermal sensor-related attributes are captured for interchange.

5.1 NVESD “Paint the Night” Thermal SE

PTN version 2.0 uses a fast signature model called SigSim to calculate long-wave and mid-wave IR thermal signature energy from the SE to the viewer. These signatures are synthesized dynamically from four PTN SE database files:

- (1) SGI (Silicon Graphics Inc) Performer Fast Binary (*.pfb)
- (2) EO/IR Texture files (*.int)
- (3) EO/IR material system files (*.ir)
- (4) Meteorological Data files (*.met)

Each of these files can be mapped separately into SEDRIS and are described briefly below.

5.2 PTN SGI Performer Fast Binary Files (*.pfb) and IR Texture Files (*.int)

PTN uses the Silicon Graphics Performer Fast Binary (PFB) format to capture the basic natural environment geometric primitives, sensor-band attributes, textures, and relationships. As its name implies, PTN PFB's are SGI Unix-IRIX binary files which are compiled from raw environment data. They consist of basic scene objects that are hierarchically organized into a Scene Graph. These basic objects include pfLODs, pfGroups, pfGeodes, pfGeoSets, pfGeoStates, and pfMaterials.

The *.pfb files include three classes of model objects: terrain surfaces, tree structures, road networks, rocks and buildings. The geometries for these model objects are comprised of sets of attributed vertices, normally grouped into tri-meshes for optimized run-time rendering on OpenGL graphics platforms. Texture information is captured in the typical fashion of file pointers and associated geometric texture mapping coordinates.

PTN natural environmental sensor databases are offered either as a completely integrated PFB file, or separately as terrain skin, forest, and road network PFBs. Often, vertices from objects like terrain surfaces, trees and road networks are grouped together into higher-level objects called tri-meshes, or collections of contiguously stripped vertices. These tri-meshes then comprise a complete terrain, forest of trees, or road network.

5.3 PTN EO/IR Material System files (*.ir)

The EO/IR material system file describes all the materials, material configurations, material properties, and other parameters used in the PTN SE

for simulating electro-optic and infrared sensor-band signatures. These sensor-band signatures include thermal (i.e. long-wave and mid-wave FLIR), near-IR (i.e. image intensifiers/NVGs), and visible (Direct View Optics-DVO, black and white day TV, and low-light TV-LLTV).

The EO/IR material system file is an ASCII file, and is space-delimited (space or tab), with each row defining a material system, and each column defining appropriate parameters. These parameters include the surface optical, thermophysical, dimensional and boundary condition properties of the material thermal

system, and are completely described in Table 1 below.

5.4 PTN Meteorological File (*.met)

The *.met files contain the relevant meteorological inputs to drive the SigSim signature model. The file is in simple tab-delimited ASCII format. It includes time-dependent influences such as ambient air temperature and pressure, relative humidity, direct and diffuse solar insolation, and down-welling (long-wave) irradiance. A typical two-day cycle *.met file for Fort-Hunter Liggett is shown in Table 2 below.

Table 1
EO/IR Material System File Properties

<i>EO/IR material system parameter</i>	<i>Header descriptor</i>	<i>Datatype</i>	<i>Units</i>	<i>Value Range</i>	<i>Definition</i>
index	index	long	Enum	0-max-long	index for pfMaterial reference
material system name	material	string	Char	0-50 characters	Name of the material system
altitude (optional)	alt	double	Meter	Meters	Altitude above mean sea level
boundary condition 1 (bc 1 "top surface")	bc1	integer	enum	0-5	0=surface fixed at temperature T1 1=surface convective cooled by air at Tair and Vair 2=surface forced convective cooled at T1 and V1 3=surface forced convective cooled at Tair and V1 4=surface aerodynamically heated 5=surface fixed to air temperature
boundary condition 2 (bc 2 "bottom" surface)	bc2	integer	enum	0-5	0=underlying surface in contact with infinite heat capacity material at T2 1=underlying surface ambient air convective cooled at Tair and Vair 2=underlying surface forced convective cooled/heated at T2 and V2 3=underlying surface forced convective cooled/heated at Tair and V2 4=underlying surface aerodynamically heated 5= underlying surface in contact with infinite heat capacity material at Tair
bc 1 temperature	T1	double	deg C	-273.15 – max double	temperature referenced at the "top" surface of the material system
bc 2 flow velocity	V1	double	meter s/second	0.0 – max double	velocity referenced at the "top" surface of the material system
bc 2 temperature	T2	double	deg C	-273.15 – max double	temperature referenced at the underlying surface of the material system

Table 1 (con't)
EO/IR Material System File Properties

<i>EO/IR material system parameter</i>	<i>Header descriptor</i>	<i>Datatype</i>	<i>Units</i>	<i>Value Range</i>	<i>Definition</i>
bc 2 flow velocity	V2	double	meter s/second	0.0 – max double	velocity referenced at the underlying surface of the material system
solar absorptivity	aS	double	unit-less	0.0-1.0	scalar governing the fraction of solar flux (0-3 um) absorbed vs that of a blackbody
longwave emissivity (3-inf um)	eL	double	unit-less	0.0-1.0	scalar governing the fraction of flux emitted in the 3-inf um band vs that of blackbody
longwave-IR emissivity (8-12 um)	eLWIR	double	unit-less	0.0-1.0	scalar governing the fraction of flux emitted in the 8-12 um band vs that of blackbody
midwave-IR emissivity (3-5 um)	eMWIR	double	unit-less	0.0-1.0	scalar governing the fraction of flux emitted in the 3-5 um band vs. that of blackbody
near-IR (.7-1.3 um) reflectivity (diffuse)	rNIR	double	unit-less	0.0-1.0	near-IR band reflectivity
reflectivity visible red (diffuse)	rVISr	double	unit-less	0.0-1.0	red visible spectrum reflectivity
reflectivity visible green (diffuse)	rVISg	double	unit-less	0.0-1.0	green visible spectrum reflectivity
reflectivity visible blue (diffuse)	rVISb	double	unit-less	0.0-1.0	blue visible spectrum reflectivity
specularity	spec	double	unit-less	0.0-1.0	fraction of reflectivity that is directional versus diffuse
convection coefficient	hc	double	unit-less	0.0-max double	scalar governing rate of convective heat transfer
thermal conductivity	k	double	W/m-K	0.0-max double	the rate of heat flux conductance through a material
specific heat	ch	double	J/kg-K	0.0-max double	amount of heat it takes to raise the temperature of one kilogram of the material one degree K (C)
density	p	double	kg/m ³	0.0-max double	kilograms per cubic meter
depth	d	double	m	0.0-max double	thickness of the material thermal system
shininess	shine	double	unit-less	0 – 128	integer governing the width of the lobe of the specular reflectance
Reynolds number	rtype	double	unit-less	0.0-1.0	scalar governing degree of turbulence of flow across air-foil
Stanton number	S#	double	unit-less	0.0-1.0	scalar governing the coefficient of aerodynamic heating
shadow flag	shad	enum	enum	0,1	0=not shaded from sun 1=shaded from sun

Table 2
Sample PTN Met File
Fort_HL_261_89.met

YR	Day	Hr	Sec	Atm	Air	RH	Wind	Wind	Tot	Direct	Diff	Down
				Press	Temp	(%)	Spd	Dir	Sol	Sol	Sol	Well
				(mb)	(C)		m/s)	(deg)	(W/ cm2)	(W/ cm2)	(W/ cm2)	IR W/cm2)
89	262	0	0	969	10.8	89	0.3	128	0	0	0	276.8
89	262	1	0	968.8	10.6	89	0.31	128	0	0	0	275.8
89	262	2	0	969.2	10.5	90	0.67	76	0	0	0	275.5
89	262	3	0	969.2	9.4	90	0.05	76	0	0	0	269.9
89	262	4	0	969.4	9.5	91	0.21	91	0	0	0	270.7
89	262	5	0	969	8.9	89	0.01	160	0	0	0	267.1
89	262	6	0	969	8.3	92	0.01	160	13.4	6.6	6.8	264.9
89	262	7	0	969	10.6	89	0.01	160	189.7	135.9	53.8	275.8
89	262	8	0	969	13.3	77	0.01	160	416.9	346.3	70.5	286
89	262	9	0	969	16.7	61	0.01	160	626.6	547.7	79	297.6
89	262	10	0	969	17.2	58	3	160	780.3	690.4	90	298.9
89	262	11	0	969	18.9	45	1	190	869.7	769.8	99.9	301.1
89	262	12	0	969	20.6	44	2	240	862.3	719.3	143	319.3
89	262	13	0	969	22.8	41	1	140	829.9	689	140.9	329.5
89	262	14	0	969	23.3	39	2	170	734.4	599.8	134.7	330.8
89	262	15	0	969	23.9	40	1	160	576.9	452.2	124.7	335
89	262	16	0	969	24.3	41	0.92	156.5	407.6	337.4	70.2	328.2
89	262	17	0	969	22.8	44	0.84	152.9	181	128.5	52.5	321.8
89	262	18	0	969	20.6	48	0.76	149.4	8.3	4	4.3	312.1
89	262	19	0	969	18.9	53	0.68	145.8	0	0	0	305.6
89	262	20	0	969	17.5	59	0.6	142.3	0	0	0	301
89	262	21	0	969	16	65	0.52	138.7	0	0	0	295.6
89	262	22	0	969	13	70	0.44	135.2	0	0	0	281.8
89	262	23	0	969	11.5	80	0.37	131.6	0	0	0	277.6

Every PTN vertex in a *.pfb file is associated with a material system from the EO/IR material system file. At run-time, SigSim predicts the sensor-band dynamic radiant emittance and reflection at the surface of each material system as a function of surface normal, time-of-day, time-of-year, meteorological condition and weather condition. The model includes a real-time 1-D thermal model which is used to predict the surface temperature of the material system in the emittance calculation. Materials are modeled as one-dimensional structures with boundary conditions at the both ends of the 1D structure. SigSim then maps these quantities into OpenGL emission, ambient, diffuse and specular r,g,b attributes for the associated vertices in a rendering callback routine.

Sample SigSim run-time signature data, and corresponding FLIR sensor views from the Fort Hunter-Liggett PTN SE are depicted graphically below in Figures 1 and 2. For the signature modeling enthusiast, Appendix A offers a technical presentation of the SigSim analytical forms and OpenGL mapping.

It's convenient at this point to interject a key benefit of PTN for synthetic environment database reuse and exchange. The four images in Figure 2 could have been easily approximated, captured as snap shots, and accessed as images during run-time. This is typically done for lower fidelity simulations. However, there would be little value in exchanging these IR snap shots with simulations of other weapon system types such as radar or millimeter wave that

use different display types. PTN databases, on the other hand, contain intrinsic material properties that are more useful. The images rendered, whether IR

from PTN, or Radar from another consumer of PTN databases, would be highly correlated and consistent since it is based on the same physical properties.

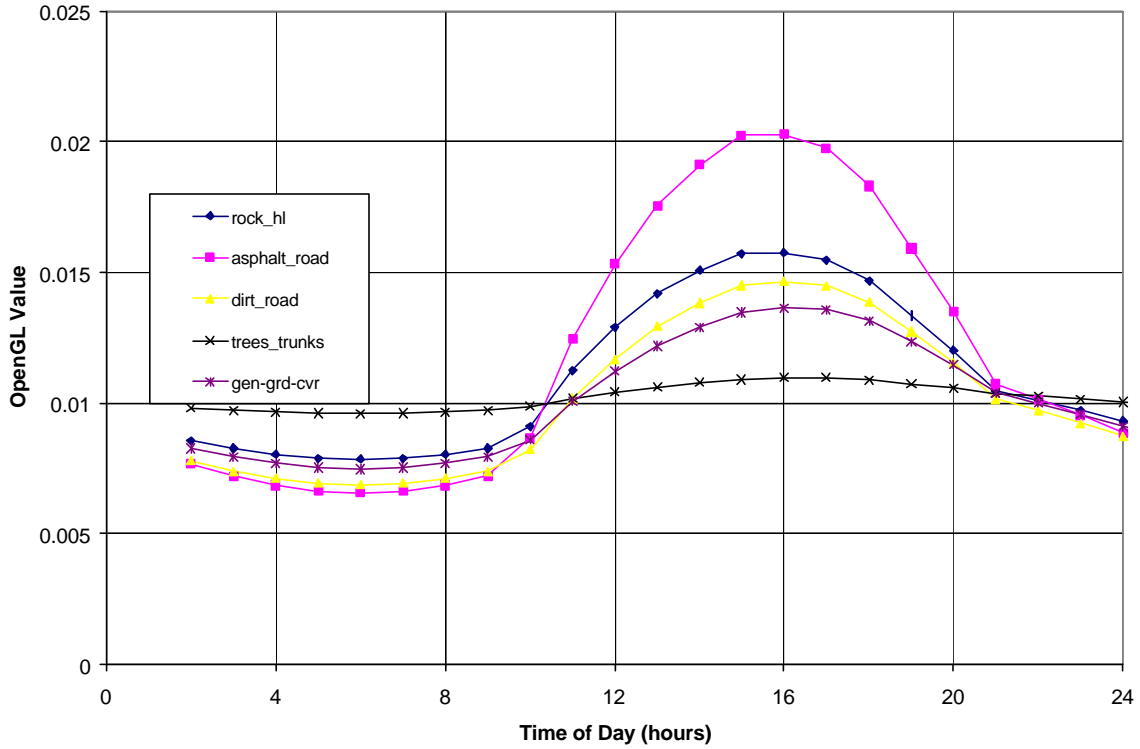


Figure 1. SigSim Diurnal Cycle 8-12 um Thermal Emission August 89 Fort Hunter-Liggett PTN SE

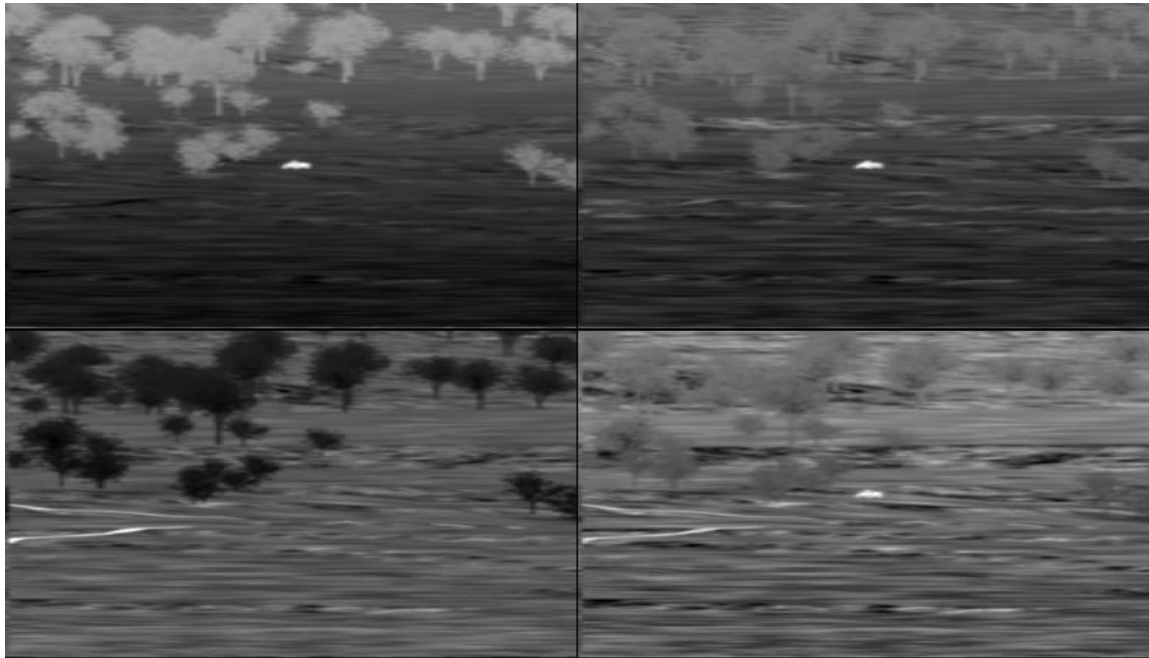


Figure 2. August 89 Fort Hunter-Liggett PTN SE – 4 Times of Day

6. PTN Thermal SE – SEDRIS 2.0 Mapping

Table 3 below details a partial mapping of PTN IR database classes and objects to SEDRIS v2.0 classes, fields, enumerations and codes. Due to space limitations of this paper, the meteorological mapping is not included in the table. This mapping is presently being used to develop a PTN-SEDRIS import utility based on the SEDRIS version 2.5 Write API.

The left side of the table shows the PTN quantities and the right side the corresponding SEDRIS classes or codes. The second row denotes the object hierarchy relationship which in this case is a “one-to-many” relationship. An asterisk denotes a pending SEDRIS Change Request (SCR) to resolve a mapping difficulty.

The hierarchy is important as it details the relationship and level of aggregation of PTN objects that obviously must be preserved in the STF. In the write API, objects and associated fields are added to a SEDRIS transmittal through successive calls to SE_CreateObject(), SE_PutFields(), and SE_AddToTransmittal(). Same level and lower level objects are added by calls to SE_AddAssociate() and SE_AddComponent().

Note that there are two objects assigned at the level one hierarchy, one for the PFB scene graph which is predominantly geometry, and one for the EO/IR material system file. This mapping was selected to separate out the sensor-related PTN SE quantities for ease in creating sensor-only SEDRIS transmittals, in keeping with the aforementioned approach.

The PTN T-meshes (regular gridded terrain skin), are nicely accommodated by the SEDRIS Finite_Element_Mesh data class. Color characteristics are captured in a conventional way by the family of color classes. Property Tables with SDCS SEDRIS Attribute Codes (SACs) provide the primary mechanism for capture of sensor-related SE attributes. The aforementioned work in incorporating the EO/IR Data Dictionary terms into SDCS and the existing families of color and data table classes in the SDRM made mapping the sensor-related PTN terms to SEDRIS relatively straightforward.[6]

The requested changes to SEDRIS to accommodate additional PTN IR terms involve only SAC codes in the SDCS. These changes do not affect the SDRM, STF or API, and will be reflected in a future SDCS

release. A benefit of this SEDRIS design approach is that attributes may be easily added to accommodate native database conversions without new releases of the STF, SDRM or API.

Table 3. PTN to SEDRIS Mapping

Paint-the-Night SE					SEDRIS 2.0 DRM
1	2	3	4	5	
Scene Graph					Synthetic_Environment <> Environment_Root
	pf LOD, Group, Geode				Union_of_Primitive_Geometry, Level_of_Detail_Geometry, Classification_Related_Geometry
		pf GeoSet			Finite_Element_Mesh
			vertex i, j, k		Vertex_With_Component_Indices
			normal i, j, k		Reference_Vector SE_RENDERING_NORMAL
			texture s,t		Image
			pfGeoState Material		Property_Table_Reference, Property_Table
				material index	Regular_Axis, SE_SAC_Index
				emission r,g,b	Emissive_Color, RGB_Color
				ambient r,g,b	Ambient_Color, RGB_Color
				diffuse r,g,b	Diffuse_Color, RGB_Color
				specular r,g,b	Specular_Color, RGB_Color
EO/IR Material System File					Synthetic_Environment <> Environment_Root
	material system name				Property_Table<> SE_SCC_MATERIAL_CHARACTERISTICS SE_SAC_INDEX
	altitude (optional)				Table_Property_Description
	boundary condition (BC 1)				SE_SAC_SUPPORT_TEMPERATURE_CODE_T OP_SURFACE *
	boundary condition (BC 2)				SE_SAC_SUPPORT_TEMPERATURE_CODE_B OTTOM_SURFACE*
	BC1 temp				SE_SAC_TEMPERATURE_SURFACE
	BC1 flow velocity				SE_SAC_WIND_SPEED_TOP_SURFACE*

Table 3. PTN to SEDRIS Mapping (con't)

Paint-the-Night SE		SEDRIS 2.0 DRM
1	2	
EO/IR Material System File		Synthetic_Environment <> Environment_Root
	BC2 temp	SE_SAC_TEMPERATURE_TOP_SURFACE*
	BC2 flow velocity	SE_SAC_AIR_FLOW_BOTTOM_SURFACE*
	solar absorp	SE_SAC_SURFACE_ABSORPTIVITY_SOLAR or SE_SAC_ABSORBTIVITY with SE_SAC_WAVELENGTH
	longwave emissivity (3-inf um)	SE_SAC_EMISSIVITY & SE_SAC_ELECTROMAGNETIC_BAND or SE_SAC_WAVELENGTH
	longwave-IR emissivity (8-12 um)	SE_SAC_EMISSIVITY & SE_SAC_ELECTROMAGNETIC_BAND or SE_SAC_WAVELENGTH
	midwave-IR emissivity (3-5 um)	SE_SAC_EMISSIVITY & SE_SAC_ELECTROMAGNETIC_BAND or SE_SAC_WAVELENGTH
	near-IR (.7-1.3 um) reflectivity (diffuse)	SE_SAC_SURFACE_REFLECTIVITY_DIFFUSED & SE_SAC_ELECTROMAGNETIC_BAND or SE_SAC_WAVELENGTH
	reflectivity visible red (diffuse)	SE_SAC_SURFACE_REFLECTIVITY_DIFFUSED & SE_SAC_ELECTROMAGNETIC_BAND or SE_SAC_WAVELENGTH
	reflectivity visible green (diffuse)	SE_SAC_SURFACE_REFLECTIVITY_DIFFUSED & SE_SAC_ELECTROMAGNETIC_BAND or SE_SAC_WAVELENGTH
	reflectivity visible blue (diffuse)	SE_SAC_SURFACE_REFLECTIVITY_DIFFUSED & SE_SAC_ELECTROMAGNETIC_BAND or SE_SAC_WAVELENGTH
	specularity	SE_SAC_SURFACE_REFLECTIVITY_SPECULAR
	convection coefficient	SE_SAC_CONVECTION_COEFFICIENT
	thermal conduct	SE_SAC_THERMAL_CONDUCTIVITY
	specific heat	SE_SAC_SPECIFIC_HEAT
	density	SE_SAC_MATERIAL_DENSITY
	depth	SE_SAC_THICKNESS
	shininess	SE_SAC_SHININESS*
	reynolds number	SE_SAC_REYNOLD'S NUMBER*
	Stanton number	SE_SAC_STANTON_NUMBER*
	shadow flag	SE_SAC_SHADOW_FLAG*

7. References

- [1] Birkel, P. “SEDRIS Data Coding Standard (SDCS)”, Proceedings of the Spring Simulation Interoperability Workshop, 1999 (on CD-ROM)
- [2] Moulton, R. et al. “Towards Standards for Interoperability and Reuse in IR Simulation”, Proceedings of the Fall Simulation Interoperability Workshop, 1998 (on CD-ROM)
- [3] Laurin, T. et al. The Photonics Dictionary, 34th edition, Laurin Publishing Company, Inc, 1988.
- [4] US Department of Defense, MIL-STD-1241 - Military Standard, Optical Terms and Definition, US Government Printing Office, 1967
- [5] Digital Geographic Information Working Group, The Digital Geographic Information Exchange Standard (DIGEST) Part 4, Edition 2.0, 1997
- [6] Connors, P. “Extending The Synthetic Environment Data Representation and Interchange Specification (SEDRIS) for the Representation of Sensors in the Synthetic Environment”, University of Central Florida, Spring 1999

8. Notes

1. DFAD (Digital Feature Analysis Data) is a database consisting of selected natural and cultural planimetric features, type classified as point, line, or area features as a function of their composition and size.

2. DTED (Digital Terrain Elevation Data) is a uniform matrix of terrain elevation values produced by NIMA (National Imagery and Mapping Agency).

3. SEDRIS Associates are members of private companies, educational institutions, research laboratories, or government agencies who participate in the development of SEDRIS.

4. Color, Light Source, and Image are three families of classes within the SEDRIS Data Representation Model (SDRM) that are germane to visual synthetic environment databases. The Color classes define the object’s color; Light Source classes affect the brightness and the color; and Image classes provide textures.

Author Biographies

LONG NGUYEN is an Electronics Engineer at the Naval Air Warfare Center Training Systems Division, Modeling and Simulation Development Branch. He holds an M.S. Degree from the University of Central Florida and has contributed to various major Modeling and Simulation Research projects including SEDRIS, STOW, JSIMS, and ASTT as an acquisition or simulation engineer.

RUSS MOULTON is President of JRM Enterprises, Inc. He specializes in military sensor modeling and simulation, and has developed many related simulation products for government and industry.

Appendix A – SigSim Thermal Model Description

SigSim, the Paint-the-Night real-time thermal model, is a 1D solution to the heat diffusion equation, utilizing inputs from the EO/IR material system file (Table 1) and meteorological data file (Table 2). It runs as a background process on the PTN IG and translates its output to OpenGL constructs for real-time IR visualization.

Equations 1-14 below afford a technical development of the SigSim analytical forms for spectral thermal signature synthesis, driven by the PTN SE data. Equations 10-20 detail how these dynamically calculated signature quantities are then mapped to OpenGL constructs.

SigSim starts with a steady-state temperature solution for the Table 1 material system, based on a quadratic approximation for thermal emission:

$$T_{surf} = q + \sqrt{\frac{r + 4a\alpha E_{sun_dir} \cos \mathbf{q}}{2a}} \quad (1)$$

where T_{surf} is the surface temperature of the EO/IR material system at boundary surface 1. The scalars q , r , and a are functions of the boundary temperatures and coefficients and the surface and bulk material properties from Table 1, and the meteorological SE data from Table 2. The solar absorptivity is given by α and θ is the angle between the direct solar insolation (E_{sun_dir}) and the material surface normal. Substituting

$$s = 4a\alpha E_{sun_dir} \quad (2)$$

in equation (1) yields

$$T_{surf} = q + \sqrt{\frac{r + s \cos \mathbf{q}}{2a}} \quad (3)$$

Expanding the numerator under the radical in a Taylor series expansion in θ about 2π , the cosine term can be isolated from the scalars yielding

$$T_{surf} = T_{base} + T_{\Delta} \quad (4)$$

where

$$= + \frac{+ -}{\sqrt{\quad}}$$

and

$$T_{\Delta} = \frac{s \cos \mathbf{q}}{4a\sqrt{r + s}} \quad (6)$$

T_{base} represents the “base” surface temperature of the material and T_{Δ} represents “additional” surface temperature contribution due to surface normal dependent thermal loading. These quantities must be converted to radiant emittance in the sensor spectral band. The radiant exitance within a given band is related to the temperature by the integral of the Plank function or

$$M(T, \mathbf{I}_1, \mathbf{I}_2) = \int_{\mathbf{I}_1}^{\mathbf{I}_2} \frac{c_1}{T^5} (e^{c_2/IT} - 1)^{-1} d\mathbf{I} \quad (\text{W/m}^2) \quad (7)$$

where λ_1 and λ_2 are the wavelengths defining the band and T is the temperature. The constants c_1 and c_2 are such that the units are watts per meter squared. A fast Taylor-series expansion of the Planck function is used to compute the integrated in-band blackbody emittance and the integrated thermal derivative (ITD) which is given by

$$M'(T, \mathbf{I}_1, \mathbf{I}_2) = \left. \frac{dM(\mathbf{t}, \mathbf{I}_1, \mathbf{I}_2)}{d\mathbf{t}} \right|_{\mathbf{t}=T}. \quad (8)$$

The ITD is critical because T_Δ is a differential that must be referenced to an absolute temperature; its contribution is an additional radiant emittance that adds to the contribution from T_{base} . For a given FLIR sensor spectral band $[\lambda_1, \lambda_2]$, the total possible thermal emission is in two terms as follows:

$$M_{\text{emission}} = M(T_{\text{base}}, \mathbf{I}_1, \mathbf{I}_2) + M'(T_\Delta, \mathbf{I}_1, \mathbf{I}_2) \quad (9)$$

Equation (10) is the total emission from a perfect emissive body. Real materials deviate from this condition and equation (10) must be modified by the emissivity of the material. Using a crude sky model and simple background model to predict the apparent T_{sky} and $T_{\text{background}}$, in-band irradiance from these sources may be predicted as well.

$$M_{\text{sky}} = M(T_{\text{sky}}, \mathbf{I}_1, \mathbf{I}_2) \quad (10)$$

$$M_{\text{background}} = M(T_{\text{background}}, \mathbf{I}_1, \mathbf{I}_2) \quad (11)$$

The integrated sensor band emissivity of a surface is related to the total integrated surface reflectivity by

$$\mathbf{r}_{\mathbf{I}_1, \mathbf{I}_2} = \mathbf{1} - \boldsymbol{\epsilon}_{\mathbf{I}_1, \mathbf{I}_2} \quad (12)$$

where ϵ is the emissivity and the subscripts indicated band integrated quantities. It is while equation (13) describes the total reflectivity, physical realism demands that the spatial distribution of that reflectivity be accounted for. If there is some directional nature to the reflectivity, then a reasonable approximation might be to establish a ‘‘specular’’ percentage of the total integrated surface reflectivity that is directional, such that

$$\mathbf{r}_{\text{diffuse}} = (1 - \mathbf{g}) \mathbf{r}_{\mathbf{I}_1, \mathbf{I}_2} \quad (13)$$

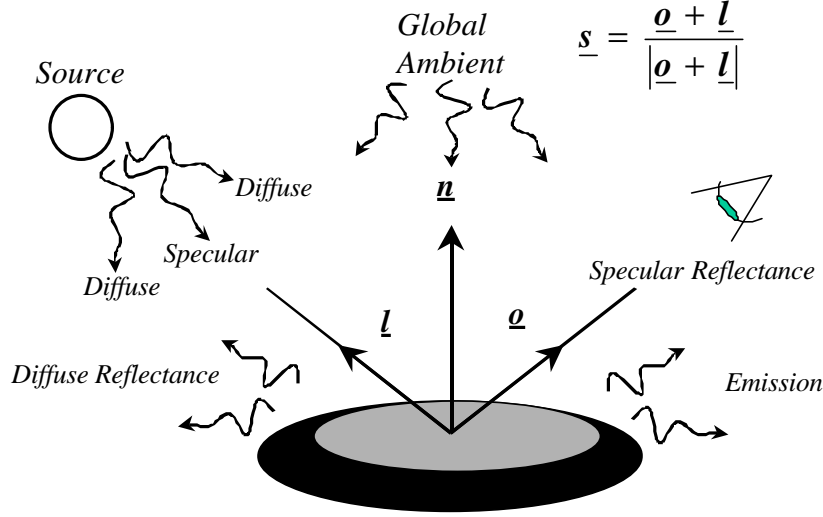
$$\mathbf{r}_{\text{directional}} = \mathbf{g} \mathbf{r}_{\mathbf{I}_1, \mathbf{I}_2} \quad (14)$$

where γ is the fraction of the total integrated surface reflectivity that is specular. This is similar to the Phong model in computer graphics. Equations (1) – (14) comprise a reasonable approximation to the thermal phenomena governing infrared scene formation.

The OpenGL lighting model is a straightforward implementation of a single-lobe BRDF model. Sources having ambient, diffuse, and specular components interact with geometric representations of scene objects. Each object has an attendant set of ambient, diffuse, and specular material parameters that control the intensity of the interaction. The equation governing the interactions is

$$I = T(u, v) \{ \mathbf{m}_a I_a + \mathbf{m}_d + \mathbf{m}_d I_d \max(\underline{l} \cdot \underline{n}, 0) + \mathbf{m}_s I_s [\max(\underline{s} \cdot \underline{n}, 0)]^V \} \quad (15)$$

where $T(u,v)$ is the texture modulation as a function of the texture coordinates u,v . I_a , I_d , and I_s are the ambient, emissive, diffuse and specular light intensities respectively. \mathbf{m}_a , \mathbf{m}_e , \mathbf{m}_d , and \mathbf{m}_s are, respectively, the ambient, emissive, diffuse, and specular materials properties of the object, and V is the shininess. The vectors \underline{l} , \underline{n} , and \underline{s} are as defined in Figure 2.



Geometry of OpenGL rendering equation.

FLIR sensors have a limited dynamic range with respect to temperature. If the temperature range is defined by the interval $[T_{\min}, T_{\max}]$, then the corresponding radiant emittance range is $[M_{\min}, M_{\max}]$. Since the OpenGL parameters must map into the interval $[0,1]$, the values obtained using equations (1)-(11) must be scaled appropriately. Taking the scaling into account, the following mapping of the radiometric quantities from the steady state model into OpenGL is obtained.

$$\mathbf{e}_{I_1, I_2} \frac{M_{base} - M_{mi}}{M_{max} - M_{min}} \rightarrow \mathbf{m}_e \quad (16)$$

$$\mathbf{e}_{I_1, I_2} \frac{M_{\Delta}}{M_{max} - M_{min}} \rightarrow \mathbf{m}_d \quad (17)$$

$$(1 - \mathbf{g}) \mathbf{r}_{I_1, I_2} \rightarrow \mathbf{m}_a \quad (18)$$

$$\mathbf{g} \mathbf{r}_{I_1, I_2} \rightarrow \mathbf{m}_s \quad (19)$$

$$\frac{M_{sky} - M_{background} - M_{min}}{M_{max} - M_{min}} \rightarrow I_a, I_s \quad (20)$$

Note that the diffuse light term I_d is set to unity and that equation (20) defines an identical mapping for the ambient and specular light terms. Shininess is the only OpenGL parameter unmapped at this point. Since OpenGL shininess is in the range [0.0,128.0], mapping the width of the BRDF lobe to an OpenGL shininess value is simply

$$128 \left(1 - \frac{\Omega}{\mathbf{p}^2} \right) \rightarrow \mathbf{V} \quad (21)$$

where Ω is the solid angle of the lobe.