Temporal IR Energy Maps for Synthetic Virtual Training

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ABSTRACT

State-of-the-art Command, Control, Computers, Communications, Intelligence, Surveillance and Reconnaissance (C4ISR) requires affordable and timely generation of imagery to enable training that responds to requirements of the future flight. This capability needs to render realistic visible and infrared (IR) representations, in real-time, accurately mimicking real sensor capabilities and limitations, and generate plausible run-time, views that accurately simulate the intel sensor models used for analysis during mission training scenarios. Accomplishing this requires both synthetic terrain and material mapped data plus the ability to alter that data to develop new, what-if scenarios. This work describes a synthetic terrain generation and runtime process which can rapidly create many, variable, realistic, sensor-enabled environments tailored to specific training objectives of operators and analysts. We mimic a physics-based sensors model to accurately simulate the data and environments intelligence officers will use to analyze and exploit synthetic imagery in real-time. This simulation process allows for more robust training than only reviewing pre-recorded past scenarios. We describe our work to demonstrate the feasibility of creating plausible visible and IR "artifact free" temporal energy maps using procedurally generated techniques. We pre-bake visible and IR lighting, and simulate the sensor in real-time using a commercial-off-the-shelf game engine (Unreal4). This capability allows production of such maps to be performed without the need for fly-over imagery. This allows for better training and mission planning since trainees train on simulated situations instead of merely watching prerecorded videos.

ABOUT THE AUTHORS

Dr. Joseph T. Kider Jr. is an Assistant Professor at the Institute for Simulation and Training (IST) at the University of Central Florida (UCF) in Orlando, Florida. Dr. Kider has over ten years research and numerical simulation experience spanning light transport problems, such as physical-based illumination and material appearance.

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INTRODUCTION

The Air Force needs physics-based sensor models to accurately simulate the physical and environmental data to train intelligence officers for analysis and future flight planning in real-time. These simulated environments should deal with dynamic multispectral lighting (visible and infrared (IR)) and multispectral material interactions. Current runtime solutions either require significant and expensive hardware resources or provide simplified and reduced fidelity results. State-of-the art game engines allow realistic and dynamic global visible spectrum illumination using a variety of physically-based techniques (Kajiya, J. T. 1986) from lightmaps (Abrash, Michael 1997), virtual point lights (Keller, Alexander 1997), light cuts (Walter, B., Fernandez , et al., 2005),(Walter, Bruce, et al, 2006), cone tracing (Crassin, Cyril, et al, 2011), instant radiosity (Keller, Alexander, 1997), and lightfield probes (Morgan McGuire, et. Al,.,2017). They provide dynamic computation of lights which change shadows and reflections based on material properties. Game engines primarily focus only on three visible light wavelengths (red, green, and blue), ignoring or greatly simplifying IR and other non-visible spectrum. Light mapping was introduced for the Quake game engine by Carmack, Abrash, and Zelsnack (Abrash, Michael, 1997) and has since been extended (Walter, Bruce, et al , 2006)(Christensen P., Batali D, 2004) (Morgan McGuire, et al,2017) for usage in modern engines. Light mapping pre-calculates the global illumination lighting of surfaces in a scene to accelerate run time performance by utilizing maps and texture lookups.

Additionally, the availability of supporting data for material-based sensor simulation has lagged. Material encoded imagery and video is limited to available real-world collected geographic areas, resolution, and currency. Training capability for Intelligence officers is limited to reviewing existing pre-recorded video imagery or using simulation that lacks image fidelity and user-driven variability. This limits flexibility in what type of scenarios can be trained (i.e. users can only view what is available on video). Creating what-if training scenarios is limited to basic simulator techniques such as the runtime placement of 3D models.

We addressed these challenges under an Air Force Small Business Technology Transfer (STTR) to 1) demonstrate the feasibility of creating plausible visible and IR “artifact free” material mapped imagery, leveraging the experience from the U.S. Army SE Core program and 2) demonstrate the feasibility of leveraging and extending physically-based game-engine visible lighting techniques, such as lightmaps, to produce realistic multispectral lighting in both visible and IR wavelengths. Our extension of lightmap techniques into the IR spectrum also addresses time variant changes through the diurnal cycle to include sensor critical phenomena such as thermal crossover and are referred to as Temporal Energy Maps (TEM). This paper describes our approach to these challenges and our initial results.

Overview of the Technical Approach

Our STTR Phase I prototype pre-computes synthetic imagery with mapped materials and utilizes 3D models to pre-calculate the illumination in multiple spectra. This allows common sensor models to view visible and various IR views seamlessly in real-time. This work confirmed the feasibility of our approach to use synthetically generated imagery, pre-baked IR TEMs, and a common game engine to generate high quality IR sensor views to support Intelligence Analysis training and training research**Error! Reference source not found.**Figure 1 off-line, pre-exercise synthetic imagery and TEM processing to reduce runtime hardware performance requirements. A key customer need, is the ability to modify terrain, create new scenarios, and adjust sensor model parameters without vendor support. The game engine-based runtime approach also provides a user-friendly, efficient and effective approach to setting up training scenarios by users. Our approach strives to maximize reuse from U.S Government, open source communities, and widely used, low or no cost industry products.

Figure 1 provides a pictorial representation of the High Level Technical Architecture of our prototype. In Figure 1 upper left, Geospatial data, such as typically provided by the National Geospatial Intelligence Agency (NGA) or OpenStreetMap (OSM) public data, feeds into the Synthetic Imagery Processing Toolkit (SIPT) to procedurally generate imagery with mapped materials by taking geo-typical ground textures, guided by the geo-specific Geographic Information System (GIS) feature data (points, lines, and polygons) This provides plausible aerial imagery suitable for training use cases.

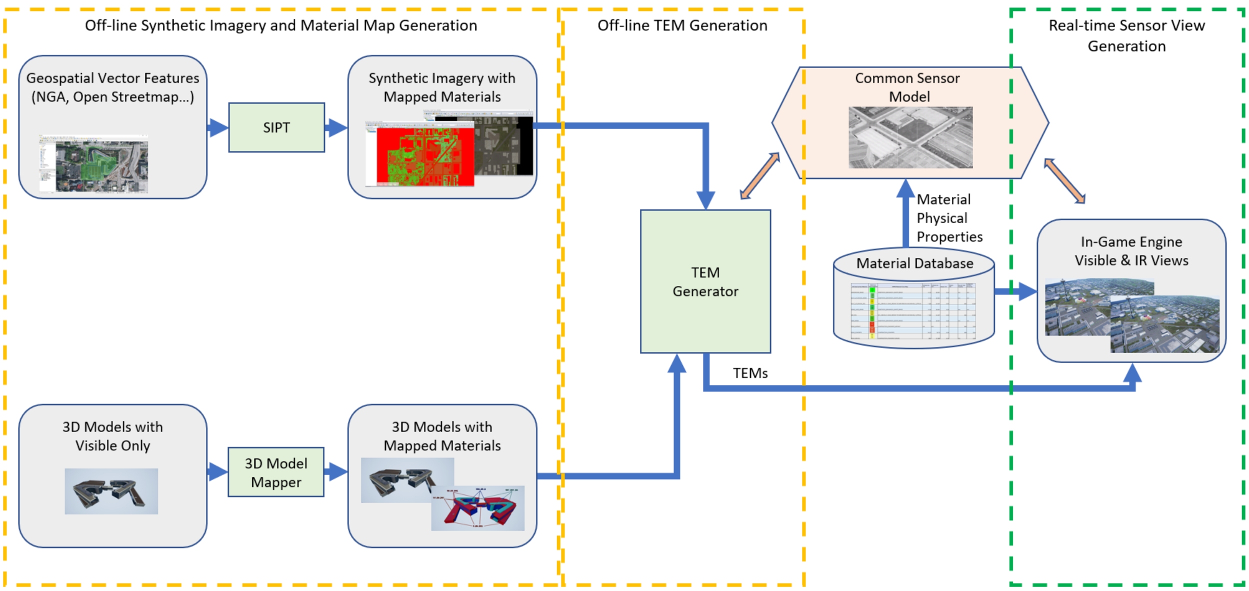

Figure 1. High Level Technical Architecture

As shown in the Figure 1 lower left, standard format 3D visual models are mapped to materials based on the visible model textures (e.g. red brick mapped to a building model wall). Our initial prototype mapped these materials using typical modeling tools for this 3D model material mapping, which could be automated or semi-automated in future revisions.

As shown in Figure 1**Error! Reference source not found.** center, the material mapped imagery and 3D models are ingested by the TEM Generator software. Material physical properties are processed using our IR sensor model to generate TEMs for varying times of day, with a TEM - time distribution driven by the diurnal cycle and related IR phenomena, such as thermal crossover points occurring around the dawn and dusk transitions. A higher concentration of TEMs are generated for these more variable IR viewing time periods.

Figure 1**Error! Reference source not found.** right shows our runtime visible and IR rendering based on the Unreal® Engine 4 (UE4) commercial product, available at no cost for game development. All concepts and the general architecture are applicable to other game engines, such as the Unity® Engine or Quake Engine®. We implemented basic flight and view controls, which may be mapped to a specific training system control device or driven by a common commercial hand-held game controller.

SYNTHETIC (PROCEDURALLY GENERATED) AERIAL IMAGERY

The SIPT was developed by the U.S. Army SE Core program to generate imagery from GIS vector feature and elevation data (Toth, R , et al, 2015)(Toth, R, et al, 2016). It essentially takes attributed lines and polygons representing the geographic features, such as roads, bridges, grasslands, forests, water, etc. and automatically "paints" imagery with texture brushes to create color or black & white imagery. It can also "paint" a correlated material map, similar to the output from image material classification. Figure 2**Error! Reference source not found.** provides an overview of this process.

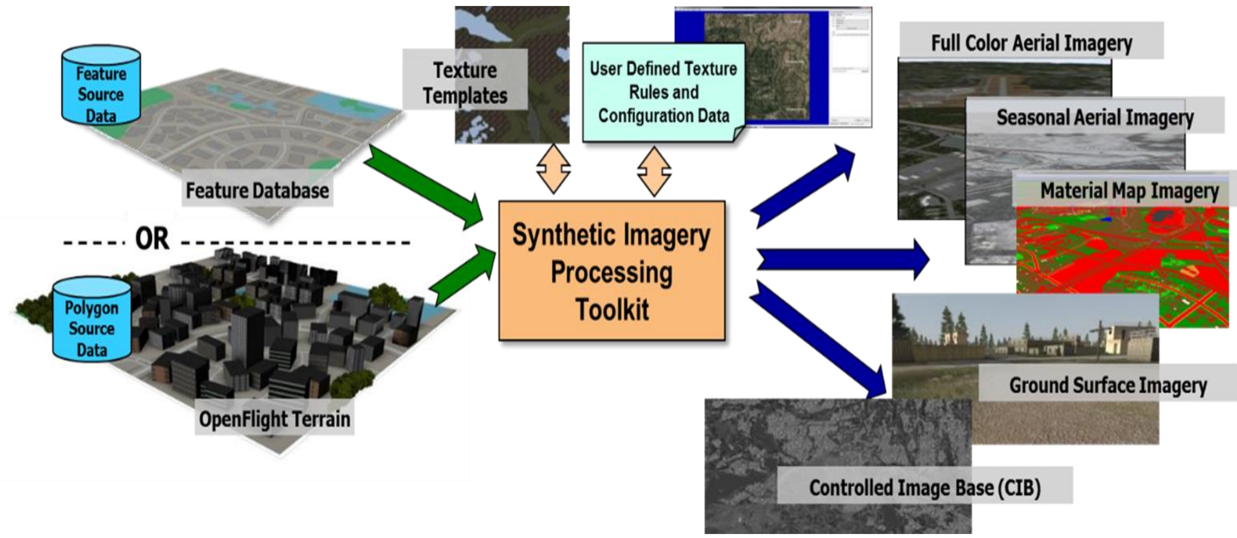

Figure 2. Synthetic Imagery Generation Processing Flow

For our prototype, we utilize the SIPT to generate the aerial imagery and a correlated material map. End user advantages to incorporating SIPT include:

- High quality, per-pixel material mapped imagery with no dependency on pre-flying the area and collecting imagery.
- Capability to generate image resolutions to match training needs. Ultra-high resolution to support sensor zoom may be generated throughout or for specific high value training areas.
- Generated imagery is free of artifacts such as clouds, time of day shadows, and vehicles, leaving the runtime free to generate these as desired for the training exercise.
- The end user team can modify the GIS data, such as adding a new building based on new intel and "what-if" scenario training and re-generate a specific patch of the imagery.

Modifications to the input GIS data can be accomplished using most common GIS tools to include no-cost tools such as QGIS. An example of using SIPT to generate and edit terrains with the appropriate material mappings is shown in Figure 3 Figure 3. Original Synthetic imagery (visible)and Figure 5 original imagery and corresponding material maps (Figure 4 and Figure 6) for the same area regenerated with some buildings removed.

Figure 3. Original Synthetic imagery (visible)

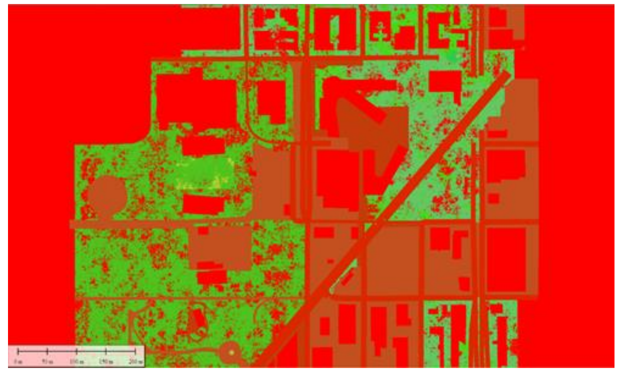

Figure 4. Material View of imagery (visible)

Figure 5. Buildings removed Synthetic imagery (visible)

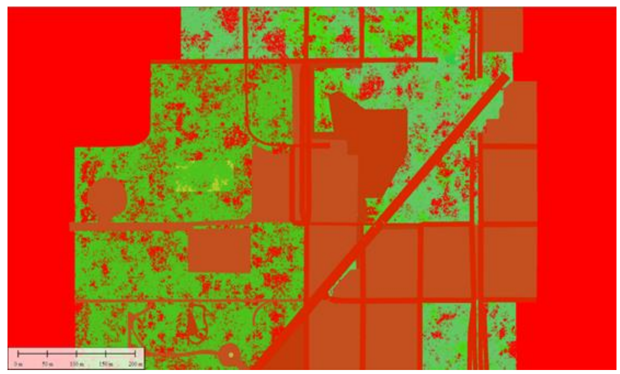

Figure 6. Buildings Removed Material View (visible)

MATERIAL DICTIONARY AND MATERIAL PROPERTIES

To support material mapping to the imagery and 3D model textures and the subsequent physics-based sensor modeling, we require a dictionary (list of materials) and a corresponding set of material physical properties. This initial prototype utilized a small number of materials, starting from the 33 materials utilized in the Army's Emerald City, a section of the Seattle WA area developed for the I/ITSEC 2017 Operation Blended Warrior (ModernMilitaryTraining.com, 2017). We expanded that 33 to 43 total used materials to provided sufficient variation for the proof of concept while keeping the data products simplified for debugging purposes. This is not the recommended end state material set but avoided the need to use proprietary datasets and allowed us to concentrate limited program time on the key objectives. Table 1 shows a section of the SE Core draft material list (Nguyen, P, et al, 2016), in hierarchical form.

Table 1. Preliminary SE Core material hierarchy (snippet only)

Natural							Natural	
							Vegetation	
Rock							Vascular	
Mineral	Igneous	Sedimentary	Soil	Bark	Leaf			Fl
Anhydrite	Andersite	Chalk	Ash_Fire	DouglasFir	Acacia	Lakegrass	PinePinon	C
Biotite	Anorthosite	Coal	AshVolcanic	ElmAmerican	AshMountain	Lambsear	PineSierraLodgepole	Clo
GypsumSand	Aplite	Coke	Clay	HawthorneWashington	AspenQuaking	LarchEuropean	PineVirginia	I
Halite	Basalt	Coquina	Granite_Gravel	Oak	Barley	Maize	PlaintreeLondon	Da
Lime	Basalticandersite	Dolomite	GypsumSand	PineMonterey	BeechAmerican	MaplePlanetree	PoplarYellow	Euc
Mica	Diabase	Flysh	Loess		Birch_Sweet	MaplePlanetree_Autumn	PoplarYellow_Autumn	Ho
Quartz	Diorite	Limestone	Marble_Gravel		Blackbrush	MapleRed	RedwoodEastern	Me
Salt	Dunite	LimestoneCalcite	Marl		Bluegrass	MapleRed_Autumn	Rice	M
Trona	Gabbro	LimestoneChalk	Organic		CedarAtlanticWhite	MapleRockyMountain	Ricegrass	Per
	Granite	LimestoneClay	Quartz_Gravel		CedarEasternRed	MapleSugar	Rosebay	P
	Granodiorite	LimestoneDolomite	Sand		Cheatgrass	MapleSugar_Autumn	RubberRabbitbrush	Ro
	Ijolite	LimestoneFossil	Scorched Earth		Clover	Marshgrass	Rye	Rubber
	Lamprophyre	LimestoneOolitic	Shale		Cloverweed	Mesquite	Sagebush	Sa
	Lava	LimestoneSilica	Shells		Crabgrass	Moorgrass	SmoothBrome	Stra
	Monzonite	LimestoneTravertine	Silt		CreosoteShrub	Oak_Autumn	Strawberry	Su
	Norite	Phosphorite	Stone		Cucumber_Tree	OakArkansas	Sweetgum	Wo
	Obsidian	Sandstone			CypressBald	OakEnglish	Tundragrass	
	ObsidianRhyolitic	Shale			CypressMonterey	OakPin	Weedpepper	
	Picrite	Siltstone			Daisy	OakWhite	Wheat	
	Porphyry	Tufa			Dandelion	OakWhite_Autumn	Winterfat	
	Pumice				Eucalyptus	Oat	Woodsorrel	
	Rhyolite				Fern	Olive		

As an initial basis for our material properties, we acquired the NAVAIR Portable Source Initiative (NPSI) Standard for Material Properties Reference Database (MPRD) material database and performed a best-mapping of data coverage. An architectural objective is to allow for easy substitution with Air Force or other material property data as required.

To support this and other development efforts, we would recommend a no-fee public or government owned attribution definition and matching material property database to accompany a common material dictionary. To maximize benefit, this should be unclassified with a well-defined format allowing easy injection of classified version, when needed. Consolidating data available from existing sources may provide sufficient data to populate the dataset. Sources such as, the NPSI MPRD, the U.S. Geological Survey (USGS) Spectral Library, the University of Central Florida (UCF) hosted National Center for Forensic Science (NCFS), each provide a subset of the needed data. For our future needs, a limited subset of materials will suffice for simulation and training needs, which would greatly limit the effort to populate material properties. An example of a reduced working set, under development by the SE Core team, is shown in Figure 7.

	A	B	C	D
1	SECORE_MATERIAL_NAME	RGB_PIXEL_VALUES	RGB_COLOR	DESCRIPTION
2	B-Aggregate-Asphalt-Pavement	220,40,0		A mixture of dark bituminous pitch with sand or gravel, used for surfacing roads and flooring.
3	B-Aggregate-Asphalt-Shingle	160,80,0		A mixture of dark bituminous pitch with sand or gravel, used for roofing.
4	B-Aggregate-Brick-Masonry	250,70,70		A small rectangular block typically made of fired or sun-dried clay, used in building.
5	B-Aggregate-Cement	120,140,160		Powdery substance made with calcined lime and clay. Included here as a component to other
6	B-Aggregate-Concrete-Masonry	200,200,0		A composite material composed of coarse aggregate bonded together with a fluid cement
7	B-Aggregate-Concrete-Pavement	255,200,40		A composite material composed of coarse aggregate bonded together with a fluid cement that hardens over time. Used as a building material in construction for sidewalks, driveways,
8	B-Aggregate-Stone	30,30,250		Coarse to medium grained stonel used in construction
9	B-Fabric-Cotton	200,50,80		The fabric that is made from the fiber of the cotton plant.
10	B-Fabric-Nylon	230,100,200		Fabric made out of sythetic polymers of the same name that is used in clothing and packaging.
11	B-Glass-Window	100,80,60		Glass used in most windows in housing or vehicles.
12	B-Metal-Aluminum	140,140,140		Metal made primarily of the element Aluminium used commonly in transportation,
13	B-Metal-Copper	220,150,70		Any metal that is primarily composed of copper. Commonly used in piping, wiring and cables,
14	B-Metal-Iron	70,70,70		Commonly used in construction as a high strength low cost metal, and also used in alloying.
15	B-Metal-Steel	190,40,80		Commonly used as reinforcing of structures or tools and in others uses such as steel wool for
16	B-Oil-Crude	100,0,100		Also known as petroleum, a naturally occuring yellow-to-black liquid found beneath the
17	B-Plastic-Fiberglass	50,30,90		Commonly used in making storage units or as a structural component in housing and piping.
18	B-Plastic-PolyvinylChloride-PVC	40,80,100		Better known as PVC, used in construction as insulation and lightweight structuring and in
19	B-RockMineral-Quartz	220,220,220		Silicon dioxide arranged in a tetrahedral shape, and the second most common mineral in the
20	B-Rubber	160,160,250		Used to mainly represent vulcanized rubber which is common in vehicle tires.
21	B-Soil-Clay	150,50,0		The upper layer of earth in which plants grow, a black or dark brown material typically
22	B-Soil-Sand	200,100,150		Sediment or soil containing granules of finely divided rocks or mineral particles.
23	B-VegetationBark-DouglasFir	200,170,80		Bark of the Douglas Fir. (Includes other firs and spruces)
24	B-VegetationBark-Oak	240,200,40		Bark of the Oak. (Includes most oaks)
25	B-VegetationBark-PineMonterey	150,100,50		Bark of the Monterey Pine. (Includes other pines)
26	B-VegetationLeaf-AspenQuaking	90,200,150		Leaf of the Quaking Aspen native to Canada, the northeastern United States and the Rocky
27	B-VegetationLeaf-Clover	40,150,120		The leaf of the clover plant, any member of Trifolium genus, native to the entire world.
28	B-VegetationLeaf-FirBalsam	130,200,130		Leaf of the Balsam Fir native to Eastern Canada and the northeastern United States.
29	B-VegetationLeaf-FirDouglas	100,200,80		The leaf of the Douglas Fir native to British Columbia and the western United States.

Figure 7. Notional Recommended Material Working Set - Partial View

3D Model Material Mapping

TEM generation requires materials mapped to both aerial imagery and 3D models. The SIPT processing automates material mapping to the imagery. This system mapped the 3D model materials, such as red brick to a wall, using typical modeling tools, as shown in Figure 8. The goal is to have a system that automatically procedurally generates 3D buildings with material maps. These materials will have different spectral properties based on the range of a particular sensor. So a building or vehicle would appear differently in visible and various IR bands.

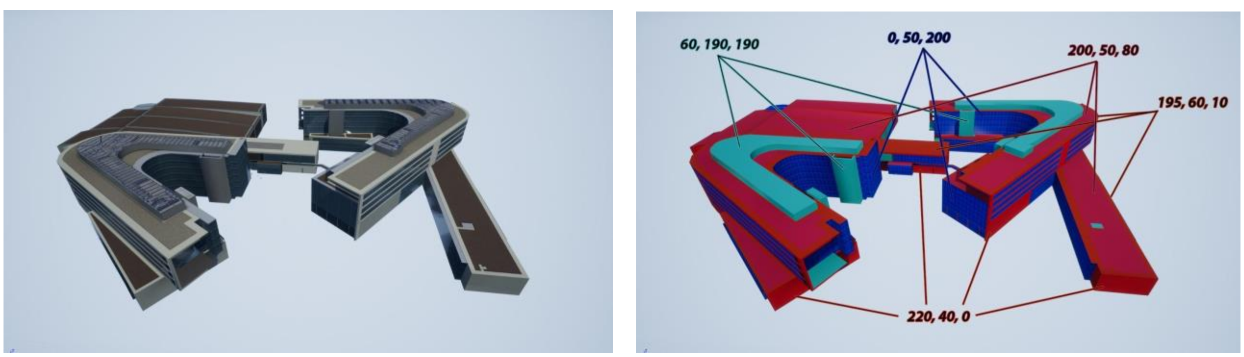

Figure 8. (Left) 3D model of the Gates Foundation building in Seattle, and (Right) corresponding material mapping corresponding to the different material on the building's geometry.

USER SCENARIO GENERATION AND SENSOR CONTROL

Our development approach has two critical phases: Pre-processing (off-line) and Real-time processing (during execution). Figure 9 provides a system view of what will be preprocessed (which includes imagery generation, baking daylight spectral maps, and baking terrain spectral maps), and what will occur in real-time (dynamic spectral sources, and material reflections).

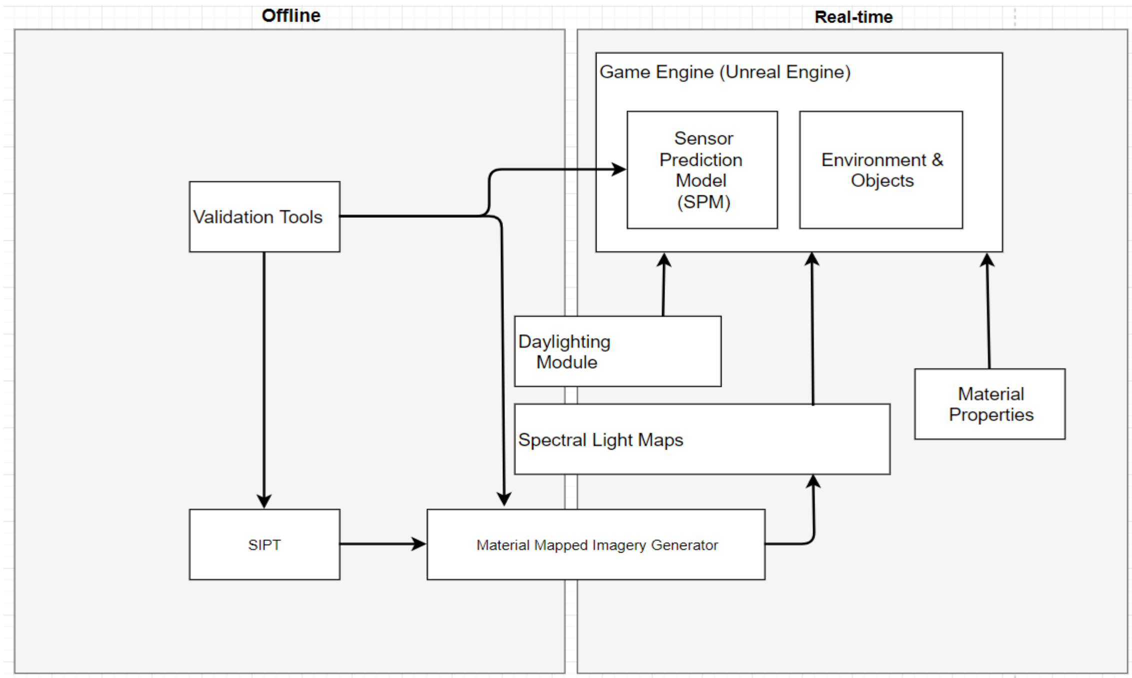

Figure 9. System Diagram of Proposed Rapid Generation of Synthetic Virtual Training Tool

Procedurally generating imagery with material maps from GIS vector features, is the initial preprocessing offline step. This material mapped imagery then is fed into our spectral map generator which will produce maps daylighting and ground based spectral light maps at specified time intervals and store the textures for real-time interaction in the Unreal Engine.

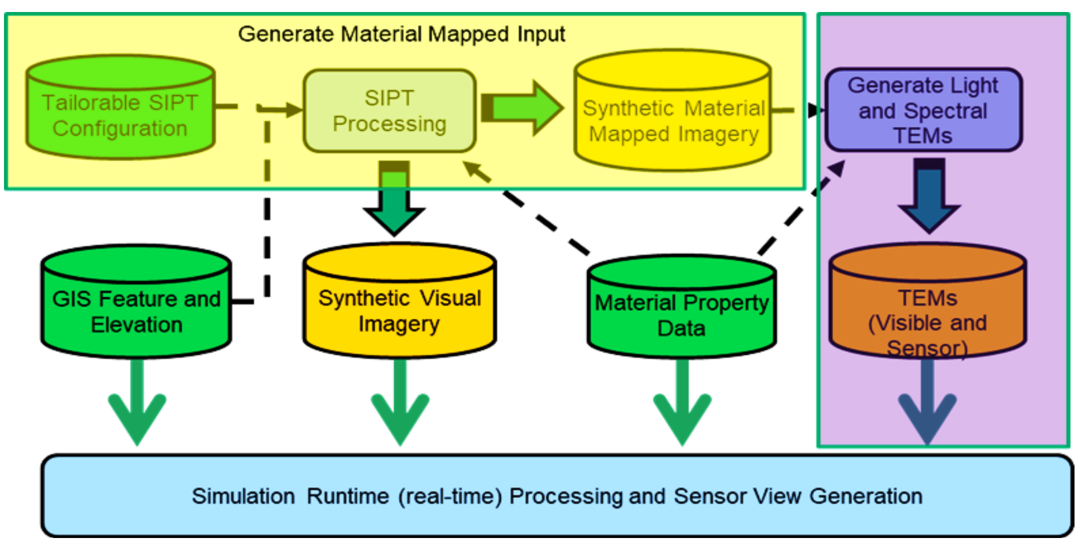

Figure 10. General Pipeline Overview of our Proposed System.

The TEM content is generated in the context of two processing stages shown in the top row processing in Figure 10; (1) Generate Material Mapped Input (highlighted yellow in the Figure) and (2) Generate the Light and Spectral TEMs (highlighted purple). To define content and format for the final TEM (output of the second processing step Generate the Light and Spectral TEMs), we are currently leveraging game engine light map techniques and formats.

Pre-processing (Temporal Energy Maps)

The system begins with configuring and procedurally generating the synthetic material mapped imagery by the SIPT. The procedural imagery is then used to generate spectral light maps and sensor views. This information is then passed to the real-time engine. To facilitate the simulation runtime processing of IR sensor views, we process, and pass material encoded textures for both terrain imagery and 3D model textures in addition to the pre-baked TEMs. This data is generated per-terrain and per-model. The material property thermal data remains a persistent data store accessed both during TEM generation and by the runtime for dynamic IR changes. This process is similar to the popular Light Mapping approach which is common in many standard game engines already. The actual pre-baked TEM consist of two textures per time step which captures the luminance information rather than the material description. Each element of the textures is called a "lumel" since it represents elements of luminosity for the environment. The two lightmap textures are pre-computed offline and hold most of the luminance information for the environment to speed up the program in UE4.

The first luminance texture computes a standard luminance map for normal visible range textures (~380nm – 720nm). The second luminance texture hold information for the near-IR range of luminance (~720nm – 1500nm). The first step is to calculate the UV coordinates to properly texture map objects in the environment. This happens during the model creation stage but is essential to the lightmap step. The lightmap UV coordinates are converted to 2D texture space to hold the luminal information. This is then blended for smooth transitions using a Lambertian formulation. Static lights from the environment such as the sun, skylight, streetlights, and building lights are considered in this phase.

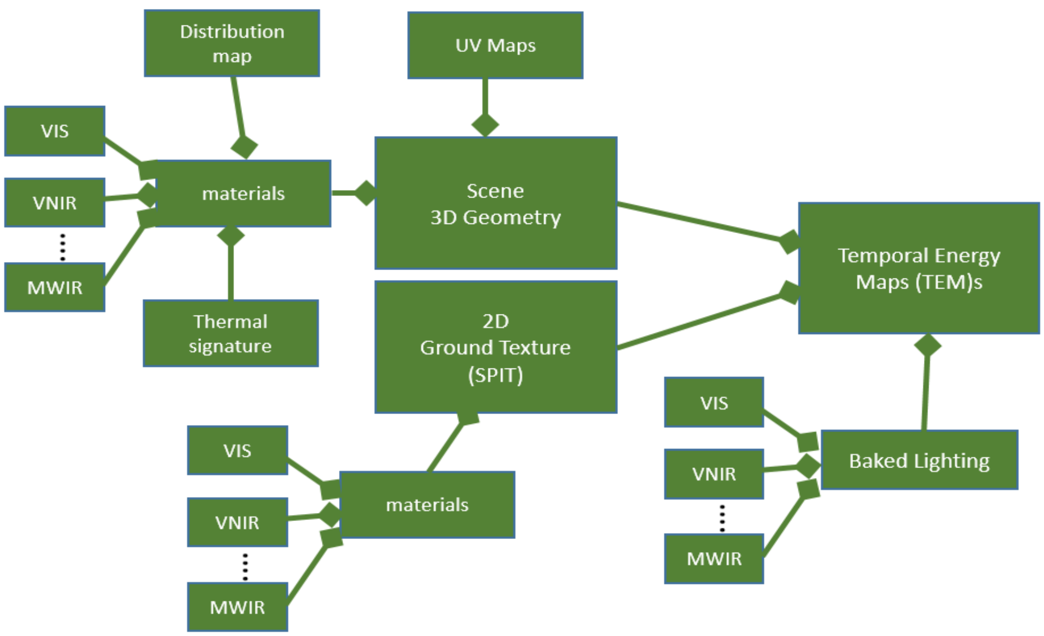

Figure 11. TEM Modular System Architecture of major components and features of underlying scenario geometry and material configuration. Here we show where we prebake out lighting for runtime training.

Real-time Processing (Temporal Energy Maps)

Once the Temporal Energy Maps have been pre-processed, we use them as textures on the majority of the static assets at runtime. A disadvantage of this approach is the lighting is not performed at runtime. Therefore, a series of "hero" assets are separated out and dynamically rendered in the environment. These assets are analyst sensor view use cases of important assets directly related to the scenario. The dynamic assets emit different light and heat depending on the spectral range of the sensor view being run. The dynamic assets still interact different based on the underlying baked lighting. For example, the difference in heat signature varies from morning to later in the afternoon where there is less contrast with the vehicle's thermal properties and thermal shadows. The dynamic asset would generate the same amount of heat and light, but would interact differently based on the current TEM that is loaded for the underlying static assets. The overall architecture of our TEMs is shown in Figure 11.

Real-time Processing (Physically-based Sensor Simulation)

The physically-based camera system consists of a camera object that is modular and controllable by the user. We implemented this system inside UE4. The sensor is controlled by the user or attached to a moving asset. For the purposes of this project we attached the camera objects to a moving Unmanned Aerial Vehicle (UAV) geometry. The sensor itself has a variety of controllable features since it is a Physically-based camera sensor. We specifically looked at aperture size, shutter speed, and sensor effects. Sensor effects include noise, grain and jitter. The overall architecture is shown in Figure 12.

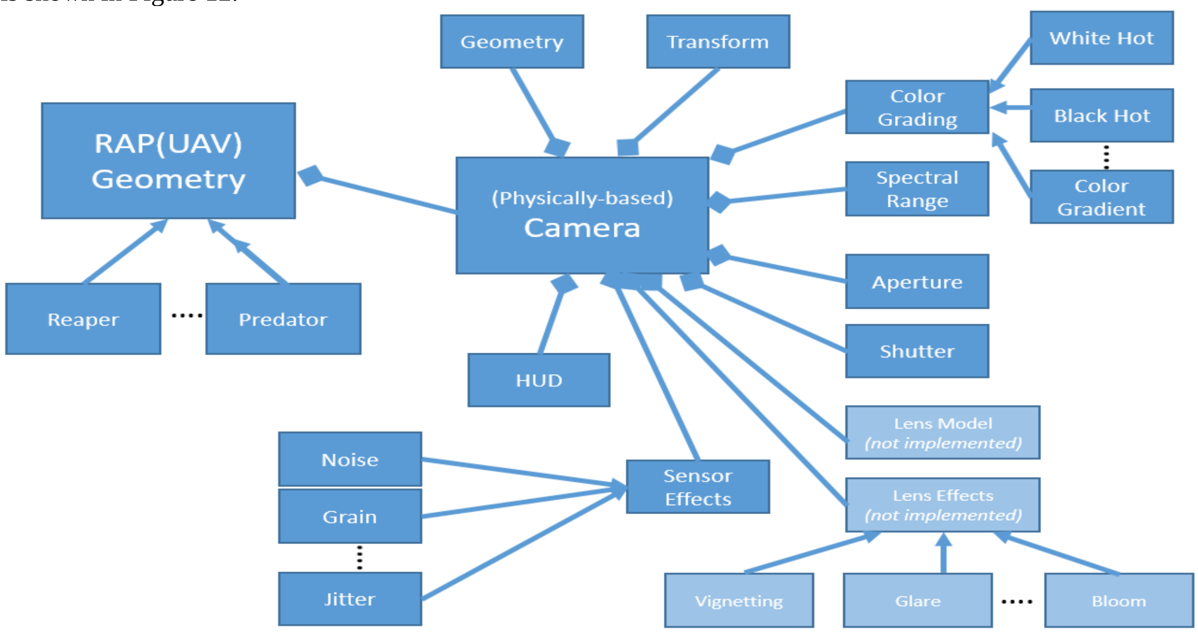

Figure 12. UE4 Modular System Architecture of major components and features of sensor system. The major components are editable and modular allowing for a wider range of training scenarios.

An important feature to training intelligence officers are IR signatures and nuances they would see during a mission. For example, a training scenario looked at important features relevant to training intelligence officers are IR signatures and nuances they might see from motorized vehicles. Figure 13 demonstrates two different sensors calibrated for different spectral ranges. The materials were set to show subtle differences between the views. This modular asset creation system demonstrates the range of possibilities trainers have to create content for actual scenarios they could see on the ground during operational missions. This is better than having outdated video or unrealistic traditional IG scene. Figure 14 shows a change in heat signature for the vehicle.

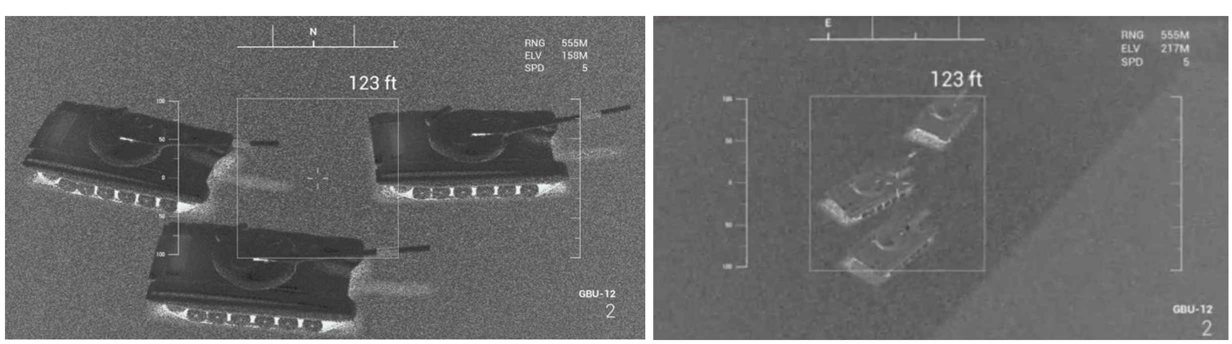

Figure 13. Example IR signatures from vehicles on the ground. The left and right represent two possible spectral ranges and materials that vary their signatures across these ranges to produce slightly different signatures.

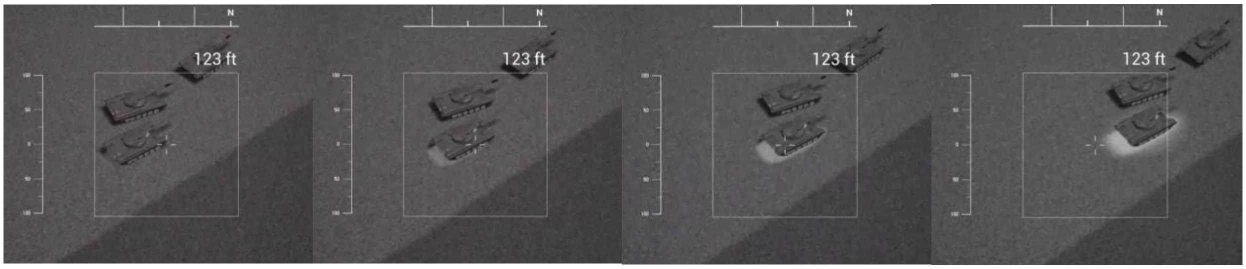

Figure 14. Demonstration of IR Heat up and cool down fading heat signatures on a UAV circling a tank. The heat exchange between the tank and ground increases as the thermal signature changes.

CONCLUSIONS AND FUTURE WORK

Our Phase I research confirmed the feasibility of our approach to use synthetically generated imagery, pre-baked IR TEMs, and a common game engine to generate high quality IR sensor views while reducing the runtime rendering load. This proof of concept was limited to simple scenarios confined to a specific urban terrain set of buildings. Significant follow on opportunities exist to further refine the TEMs. We recommend the following key areas for further investigation and testing

Extending to additional, example training scenarios:
As with traditional lightmaps, pre-baked TEMs address the static, background IR view only. Most training scenarios will be centered around dynamic IR changes, either pre-set for the scenario, such as placement of a portable power generator, or moving objects, such as vehicles and humans. Our prototype incorporated a limited set of moving model interactions and only simple scenarios. To optimize TEMs for use in actual training, we recommend expanding the test and evaluation scenarios. We have identified several next-step focus areas based on subject matter expert (SME) identified, training need-driven specific scenarios to support key teaching points. Example high priority scenarios include:

- Thermal signatures to support detecting vehicle use and movement. Both environmental and self-generated heating and cooling of surface, major engine, drive train, and wheels and tracks.
- A variety of diurnal conditions with emphasis on thermal crossover and IR contrast, and supporting sensor selection training points.
- Effects of dynamic objects on the static terrain, such as thermal shadows with realistic degradation over time.
- Moved and disturbed dirt, such as from an Improvised explosive device (IED) placement, with sufficient realism to train sensor and bandwidth selection across weather and diurnal cycle conditions.
- Effects of explosions and residual fires on sensor views.

Application of High-performance computing (HPC) to the off-line generation of synthetic imagery and TEMs
Two processing stages show potential to benefit from HPC processing, the synthetic imagery generation and the TEM generation. Supporting sensor zoom levels across wide areas will require adequate resolution imagery, likely in the 0.1m resolution range, for target areas of interest and potentially the entire terrain extents, requiring significantly more processing from our proof of concept 1m imagery generation. The procedural imagery software is designed for distributed and parallel processing to support processing large extent terrain, making it a low risk candidate for adapting to true HPC processing. The second candidate processing area is the actual TEM generation. Further analysis during Phase I and Phase II will determine the optimum number of TEMs to generate to support an acceptable level of observed temporal changes, when blended in the runtime. As the terrain area and detail increases, we again will utilize HPC cores to generate the TEMs for particular sub-grids, times of day, and potentially differing seasonal and weather conditions.

Refining the user-accessible sensor tuning parameters and controls
One area for future sensor simulation refinement would be to model and computer ray-optic interactions to produce truly realistic lens effects on sensors. By providing basic lens types and their ray-optic interactions will provide even

more realistic sensor effects. The second would be to more realistic model the noise, grain, and thermal effects. Allowing operators control to tune all these parameters will allow them to train officers under a variety of mission critical conditions.

Lessons Learned

Real-time interaction and sensor simulation in modern game engines provide better training tools to C4ISR officers. This allows for more realistic mission training than watching video or interacting with unrealistic image generators. Allowing full control of sensor tuning parameters allows trainers the ability to simulate a wide variety of possible sensor hardware configurations for missions.

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