Multi Sensors simulation for missile applications

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ABSTRACT

Guidance of missiles relies on sensors which performance is very dependent on environments and atmospheric conditions. Visible cameras are very efficient for diurnal fine weather conditions, long wave infrared sensors for night vision and radar systems for seeing through atmosphere and foliage. Besides, multi sensors systems combining several collocated sensors provide better efficiency. But such sophisticated systems are all the more difficult to design and qualify. So multi sensors simulation is highly required as illustrated in this paper.

A first part gives a state of the Art of such simulation tools with a special focus on SE Workbench. This is described with regards to infrared/EO, millimetre waves, active EO and GNSS sensors. Then a general overview of simulation of targets and backgrounds signature is presented, considering different types of simulation: parametric studies, open loop or closed loop, hybridisation of SW simulation and HW. Finally, the paper presents some basic requirements for simulation implementation such as the deterministic behaviour mandatory for parametric studies.

Several technical topics are also discussed, such as the rendering technique (ray tracing vs. rasterization), the implementation (CPU vs. GP GPU) and the compromise between physical accuracy and performance.

Keywords: Infrared simulation, Real-time simulation, Target and background modelling, SE-WORKBENCH, HWIL, multi sensors, millimetre waves, procedural methods, parametric studies

1. INTRODUCTION TO OKTAL-SE

OKTAL-SE has some 25 years of experience in the field of sensor simulation. Recently, hardware capabilities for image rendering and heavy computation on a simple

PC have drastically increased which widens the field of application of Physics based simulation. This is now time for these simulations to be operational and provide efficient services in the frame of defence and civilian application involving sensors. The following paragraphs intend to show this type of simulation evolution, based on OKTAL-SE unique experience.

2. MULTI SENSORS SIGNATURE PREDICTION TOOLS

Signature prediction is very important in the defence field in order to detect and identify potential threats but for self-protection. Counter measures and camouflage strategies are very dependent on signature prediction. The signature simulation is all the more difficult as the variety of sensors increases. Now, thanks to data fusion, it is very difficult to reduce target signature for every wavelength. In the optical spectrum, visible, Short Wave Infrared, Middle Wave Infrared, Long Wave Infrared sensors produce quite different images. Beyond that, radar images, in L, S, C, X and K millimetre bands also produces strongly different images. Besides, optical images and radar images are intrinsically different. Typically, the sensitivity to material characteristics is completely different. Optronic sensors are sensitive to temperature, emissivity of materials when radio frequencies sensors are sensitive to electrical conductivity. Finally, the EO/IR signature is sensitive to surface state details at the scale of the wavelength, typically 1 to 10 microns, when RF/EM signature typically from 1 millimetre to 1 meter. Radar sensors also provides some complementary information such as the distance.

Beyond the complexity due to the wavelength variation, a target signature is also very influenced both by its close environment and by the atmosphere propagation from the sensor to the target. In the EO domain, the close environment has a strong influence on masking, shadowing and heating. In RF domain, it also has a strong influence such has multi path to the target by ground reflection and dihedral effects. The atmosphere is also very influent. In the EO domain, it both attenuates and diffuses energy on the path from the sensor to the target. In RF domain, the atmosphere clutter effect can be important. Refraction effect is also due to atmosphere in the long range for RF domain.

Of course, a target is more often a vehicle. But it can also be something much more complex, such as a building or a part of a town. In that case, the simulation complexity also increases a lot.

Many tools exist on the market that aim at simulating signatures [3]. The goal of this paragraph is to give a typology of the tools that can be currently found in the market and can be used in the frame of signature prediction.

In that paper, we focus on imagery tools rather than on classical analytical tools such as NVTherm or TRM4 that are more focused on probability of detection assessment than signature evaluation itself. Besides, these old generation tools cannot address target with strong coupling to terrain and atmosphere nor large targets such as pieces of terrain.

We focus on workbenches based on Synthetic Environment modelling then rendering. The Synthetic Environment is a virtual description of the real world. It is like a CAD file for a manufactured object but it concerns a whole piece of the real environment i.e. the terrain, the infra and super structures, the atmosphere...

In the frame of this challenging technical domain, many tools are necessary to perform such a modelling and simulation of the real word with regards to sensor signature.

A generic definition of Synthetic Environment workbenches distinguishes one part for the modelling and one part for the rendering through a given sensor:

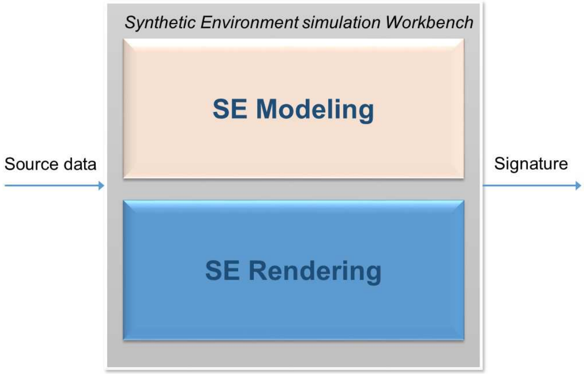


Figure 1. Basic decomposition of a generic SE workbench.

Each of these 2 parts can also be decomposed in several modules:

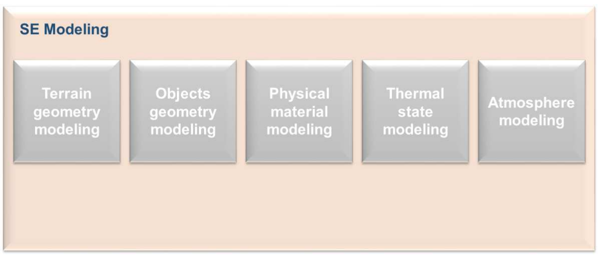


Figure 2. Basic decomposition of the modelling part of a generic SE workbench

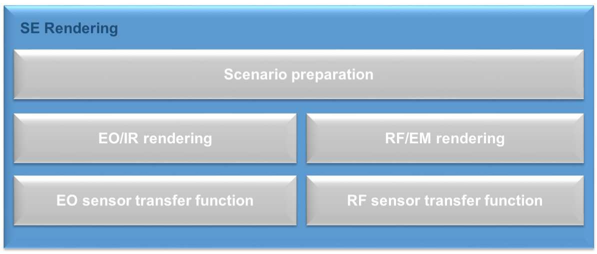


Figure 3. Basic decomposition of the rendering part of a generic SE workbench

3. RENDERING TECHNIQUES

Concerning the rendering part, several techniques are in competition. We can focus on the two main approaches:

- rasterization
- ray tracing.

Rasterization is typically the technique used in OpenGL, the software layer that enables to take advantage of the 3D capabilities of Graphical Process Unit boards, especially on PCs. This is the current technique used in the frame of video games. The basic idea is to consider the 3D scene as a complex collection of triangles, characterized with 3 coordinates and mapped using texture that create a surface modulation of colour, transparency and roughness. Except for large field of observation, Thales theorem is easily applicable to projection of the 3D triangles onto a 2D virtual screen, assuming that a 3D triangle becomes a 2D triangle. Rasterization technique then consists in "painting" the triangle inner surface with colour and texture.

Ray tracing technique produces nearly the same image. But the approach is quite different. It consists in tracing rays from the observer through the virtual 2D screen and finally in the 3D scene also made of many triangles and textures. Each ray, for each pixel of the virtual 2D screen, encounters a 3D point then bounces and also take into consideration shadowing rays systematically traced to every light source of the scene. The final colour is then attributed to the pixel. Actually, a given triangle is paint pixel after pixel in such an approach.

The basic advantage of rasterization technique is to take advantage of the hardware capabilities of GPUs.

Ray tracing technique covers a lot of advantage. More sophisticated shapes than simple triangles can be easily taken into account. It is possible to work wavelength by wavelength. Reflection and shadowing effects are automatically simulated. For each ray, we can calculate the distance, which is very important in case of coherent computation, typically for radar since the phase is directly linked to the distance of each propagation segment.

4. STATE OF THE ART

In order to qualify synthetic environment workbenches, and establish a sort of cartography of multi sensors signature prediction tools, it is interesting to decompose the analyse into several components:

- the waveband, typically "EO" against "RF"
- the domain of application, for instance: "real time Simulation with Man In the Loop (MIL)", "real time Simulation with Hardware In the Loop (HWIL)", "studies & research simulation (R&D)"
- the technology, typically "rasterization (GPU)" against "ray-tracing (RAY)"

- the technical level, typically "low cost (LOW)" against "professional (PRO)".

Waveband	Domain	Class	Techno
EO	MIL	LOW	GPU
RF	HWIL	PRO	RAY
	R&D		

Figure 4. Multi sensors signature prediction tools cartography components

Following this classification, and according to OKTAL-SE 25 years of experience in that field, we have tried to estimate the number of technical solution (commercial & from research centres) available on the market, currently and internationally.

The last column "Dispo" indicates the number of products in the respective category:

A: 1 to 3 products in the world

B: 5 to 10 products in the world

C: 10 to 100 products in the world

Waveband	Domain	Class	Techno	Dispo
EO	MIL	LOW	GPU	C
EO	MIL	PRO	GPU	B
EO	HWIL	PRO	GPU	A
EO	R&D	PRO	GPU	A
EO	R&D	PRO	RAY	A
RF	MIL	LOW	GPU	B
RF	MIL	PRO	GPU	A
RF	MIL	PRO	RAY	A
RF	HWIL	PRO	GPU	A
RF	R&D	PRO	RAY	A

Figure 5. Multi sensors signature prediction tools cartography components availability

Several indications can be deduced. First, there are more Electro-Optics tools available than Radio Frequencies tools. Man In the Loop simulation tools are very popular on the market. In the professional class, there are no so many tools available. For Man In the Loop simulation and Hardware In the Loop simulation, only GPU/rasterization technique is used. In priority, RAY/ray-tracing technique is used for radar.

5. SE-WORKBENCH

OKTAL-SE simulation software products constitute a « simulation chain » from the 3D complex synthetic environment generation to the sensor rendering and via the scenario edition.

This process can be pictured as in figure 6.

Two groups of software products can be distinguished: edition software tools that are dedicated to the generation of the 3D synthetic environment and rendering tools that are used to simulate the signal received by the sensor in AEO (Active Electro Optics – Physical Sensor Rendering with laser illumination), EO (Electro Optics – "Real-Time EO Sensor rendering" et "Physical EO Sensor rendering"), RF (Radio Frequency - "Physical EO Sensor rendering" et "Real-Time RF Sensor rendering") and GNSS (Global Navigation Satellite System) - GNSS Sensor rendering).

Two groups of rendering tools can be distinguished: in one hand rendering tools in the EO domain for visible and infrared spectra and for both passive (natural illumination) and active (illumination by a laser source) systems simulation, in the other hand rendering tools in the Radio Frequency (RF) domain that address radar and GNSS (Global Navigation Satellite System) applications.

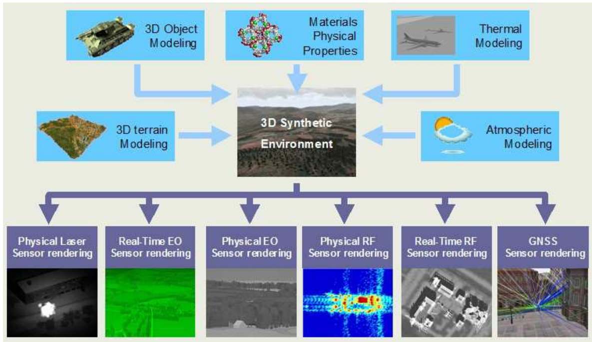


Figure 6. Global architecture of OKTAL-SE SE-Workbench

In both groups, both non-real time and real time rendering solutions are available.

Full SE-Workbench is decomposed in four editions:

- SE-Workbench-EO for passive visible and infrared rendering [1]
- SE-Workbench-RF for radar and electromagnetic
- SE-Workbench-AEO for infrared active imagery and laser
- SE-Workbench-GNSS for GNSS application.

In the frame of this paper, we focus on SE-Workbench-EO and SE-Workbench-RF.

SE-Workbench-EO

SE-Workbench-EO [1] has been designed for the creation of synthetic models of complex environments that have to be as realistic as possible in order to stimulate systems using sensors in the EO domain. For achieving that issue, SE-Workbench-EO is organized in four main parts as described hereafter:

- **Physical modelling of the environment**: an entity of the environment (terrain, vehicle, atmosphere flare…) is considered through a geometrical model (e.g. external surface of a vehicle) and the aim is to assign physical properties to this geometrical model

- **Scenario edition**: entities of the environment are gathered to compose a virtual scene, shooting conditions are defined, trajectories of mobile entities are created, temporal behaviours and events are handled and the scenario edition tool also enables to interactively visualize the scenario while running
- **Scene generation**: computation of the physical signal received by sensors observing the scene at a given date or over a time period, considering either non-real-time rendering (focus put on physical realism) or real-time rendering (focus put on performance)
- **Sensor integration**: optional step that can be included as a final step of the simulation chain to simulate sensor effects that disturb the physical signal received by the sensor (e.g. adding Gaussian noise on the image), as formerly either in real time or non-real-time modes.

Physical modelling of the environment

The physical modelling of the environment can be split into several groups of functions:

- The **geographical modelling** that consists in importing mapping data and then in generating a 3D terrain with the physics on it based on physically characterized materials and templates
- The **geometrical modelling** that consists in importing a 3D model of an object and then to modify this model or to create a new geometrical representation
- The **material characterization** that consists in defining the physical behaviour of a material in the several spectral domains considered in the simulation, typically from 0.4 to 20 microns
- The **physical characterization** of a 3D object that consists in assigning radiative and thermal properties to the geometrical primitives of the object based on the 3D model of the object and a physical material database
- The **atmospheric modelling** that consists in defining the meteorological conditions and to compute the behaviour of the atmosphere in such conditions [4]
- The **thermal modelling** that consists in predicting the equilibrium temperatures of a material, an object or a terrain from a physical material characterization, or a physically characterized object or a physically characterized terrain
- The **special effects** that consists in handling the special behaviour of entities such as dynamic surfaces or volumes, light sources or particle systems. Some dedicated tools also deal with aircraft and missile plumes [2].

Scenario edition

The scenario edition in SE-Workbench-EO can be split into several groups of functions:

- The **edition** of the **virtual scene** that consists in gathering several entities of the environment that have been previously physically modelled and that can be physically characterized 3D objects or a terrain, an atmospheric model, pre-computed thermal files and special effects
- The **sensor definition** that consists in positioning and pointing observers in the virtual scene and in defining the observation parameters that are needed for the scene rendering
- The **scenario animation** that consists in defining trajectories, in assigning them to mobile entities (objects of the virtual environment and/or sensors) and in creating temporal actions or events (e.g. explosion at the end of a missile trajectory)
- The **interactive observation** that consists in flying over the virtual scene and observing it, in running a scenario as seen by a sensor and in checking if the scenario is ready to be exploited.

Scene rendering

Scene rendering in SE-Workbench-EO can be split into two different functional groups:

- Realistic rendering based on **ray tracing** (interactions between the rays and the polygons are computed). This approach can be completed by the “photons maps” technique that allows one to simulate soft shadows created by extended sources, coupled radiations (e.g. hot cavities with caustics or radiative coupling between a vertical wall and the horizontal ground). The implementation is based on C++ and makes use of the CPU of the computer. In open loop simulation videos showing real time rendering can be registered. But in closed loop simulation real time rendering cannot be achieved using ray tracing.
- Fast rendering based on **rasterization** method (polygons projection) and on OpenGL technology implement on the graphic board. More precisely the technique that is used is Open Scene Graph (Open source overlay of OpenGL) and “shaders” for the implementation of physics (source code that is

integrated in the "graphic pipe" in order to enhance the OpenGL functions spectrum).

Sensor integration

Sensor integration is SE-Workbench-EO can be split into two functional groups:

- Post-processing of realistic rendering images using generic functions for convolution, noise and gain simulation. The technique used is C++ implemented on the CPU
- Post-processing of fast rendering images using generic functions for convolution, noise and gain simulation. The technique used is CUDA implemented on the GP GPU (General Purpose Graphical Process Unit).

SE-Workbench-RF

The aim of SE-Workbench-RF is to create synthetic models of complex environments that are as realistic as possible in order to simulate systems with EM sources and sensors, typically radar systems. For achieving that issue, SE-Workbench-RF is organized in three main parts as described hereafter:

- **Physical modelling of the environment**
- **Scenario edition**
- **Scene rendering**: for each sensor defined in the scenario the physical signal received by the sensor is computed at a given data or over a time interval using either realistic rendering (priority put on the precision of the computed signal) or fast rendering (priority put on the time performance). The scene rendering can produce different kinds of results: at the lowest level EM contributors are produced (a contributor is a small portion of the scene characterized by its position, the amplitude and phase of the EM field radiated by the contributor and if needed the Doppler and the polarization related to the contributor). At intermediate level the scene rendering consists in computing the EM signal in range gates or as a function of angle of arrival or speed (Doppler shift). At highest level the scene rendering consists in producing images such as ISAR images, RBGM (PPI) images or SAR images considering a simple and generic sensor model.

Physical modelling of the environment

The physical modelling of the environment can be split into several groups of functions:

- The **geographical modelling** that consists in importing mapping data and then in generating a 3D terrain, with the physics on it, based on physically characterized materials and templates
- The **geometrical modelling** that consists in importing a 3D model of an object and then to modify this model in order to adapt it for rendering in the RF domain
- The **material characterization** that consists in defining the physical behaviour of a material in the several spectral domains considered in the simulation, typically from 100 MHz to 100 GHz
- The **physical characterization** of a 3D object that consists in assigning physical properties to the geometrical primitives of the object based on the 3D model of the object and a physical material database
- The **atmospheric modelling** that consists in defining the meteorological conditions and to compute the behaviour of the atmosphere in such conditions, more precisely to compute its atmospheric influence on the propagation of the EM signals and particularly to compute the clutter created by rain.

Scenario edition

The scenario edition in SE-Workbench-RF can be split into several groups of functions:

- The **edition** of the **virtual scene** that consists in gathering several entities of the environment that have been previously physically modelled and that can be physically characterized, such as 3D objects or a terrain, an atmospheric propagation model and special effects
- The **sensor definition** that consists in positioning and pointing transmitters and receivers in the virtual scene, either co-localized or in a bistatic configuration, and in defining the computation parameters that are needed for the scene rendering
- The **scenario animation** that consists in defining trajectories, in assigning them to mobile entities and in creating temporal actions or events (e.g. chaff to deceive a missile)
- The **interactive observation** that consists in flying over the virtual scene and observing it, in running a scenario as seen by a sensor and in checking if the scenario is ready to be exploited.

Scene rendering

The scene rendering of SE-Workbench-RF can be split into two functional groups:

- Realistic rendering based on ray tracing (computation of the interactions between rays and polygons and their edges) and on Geometrical Optics, completed by Physical Optics for computation of scattering of surfaces and edges excited by the incident wave. The implementation on the CPU is based on C++. Using this approach, it is not possible to reach real time computation. Several packagings are available depending on the simulation level considered:

- ✓ Computation of contributors to stimulate accurate radar models
- ✓ Computation of raw data to stimulate generic radar models
- ✓ RCS (Radar Cross Section) computation
- ✓ Computation of radio wave propagation
- ✓ Computation of RBGM (PPI) signals
- ✓ Computation of SAR like images.

- Fast rendering also based on ray tracing and Geometrical Optics completed by Physical Optics. The technique used is CUDA implemented on the GP GPU. Using such technique, it is possible to achieve real time rendering of radar signals. Two levels of representation of the results are available:
  - computation of RBGM (PPI) signals
  - computation of SAR like images.

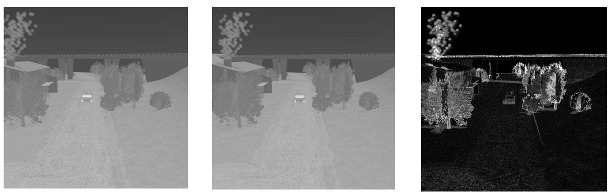
6. SIMULATION REQUIREMENTS AND BASIC RULES

The first requirement comes from the multi sensors feature. Nowadays, most of guidance systems, alert systems, Enhanced Vision Systems, use several sensors at the same time to improve the detection. For that reason, it is important that the simulation tool shares exactly the same synthetic environment and the same input data. Besides, it is important to share exactly the same scenarios. Every simulation obviously admits some simplification. It is important that these simplifications be the same for all the spectral domains, typically for both electro optics and radio frequencies.

SE-Workbench respects this constraint of "**optronic and radiofrequency duality**". In SE-Workbench it is possible to consider the same synthetic environment for passive optronic sensors, active optronic systems, RF systems and GNSS receivers. The same virtual mock-up is used for all these kinds of sensors thanks to inheritance and polymorphism which concern the geometrical aspects but also the material aspects. This enables to make savings in terms of resources but also to ensure coherency between the various spectral domains for multi domain simulation. This unified approach is of course particularly relevant for data fusion studies.

The second requirement concerns the validity control of the simulation. It is important to **quantify the simulation error**. In Physics, the challenge is not to find the perfect truth (which is also impossible using experimentation) but to quantify the approximations. Actually, the multi sensors signature simulation can be considered as correct, with regards to a dedicated system that uses this signature model, as long as the simulation does not introduce any bias into the behaviour of this system, for a given set of usage scenarios. In that case, we can consider the simulation as accredited for a given system and for a given usage. That is the important point. All the challenge is to reach the minimum level of simulation that meets this requirement. No use to do a more sophisticated simulation. For example, in the case of a low-cost infrared camera for far field application, due to poor resolution and strong MTFs of the optics and detectors, it is no use to compute very high-resolution simulation of the scene nor make any intensive modelling of 3D details in the scene, which would be drastically filtered by the sensor anyway.

SE-Workbench respects this constraint in a special way. The basic idea is to compute the same signature using two approaches, one very physical but complex, one simpler but more efficient. Using SE-Workbench it is possible to play the same scenario in both real time and non-real time rendering modes. In the case of non-real time rendering no approximation is made in terms of Physics. This is why non-real-time rendering is considered most of the time for the validation of the SE-Workbench. In the case of fast rendering, several simplifications have to be considered. SE-Workbench enables to analyse image per image the differences between the fast rendering image and the non-real time rendering image that can be thus considered as the reference image.



SE-RAY-IR Image in MWIR *SE-FAST-IR Image in MWIR* *Difference*

Figure 7. Error assessment

OKTAL-SE provides its customer with both rendering approaches. The customer measures the difference between the simplified rendering and more sophisticate rendering affordable, on its own private scenario, and so qualify the validity of each simulation run based on the "fast" rendering.

The third requirement is very important for R&D simulation context and more especially for parametric studies. The parametric study aims at assessing the influence of one parameter, all other parameters being frozen. This approach is fundamental in order to understand a system of treatment of signature. This approach is possible using simulation and quite impossible for experimentation in real world. Typically, in experimentation, it is quite impossible to freeze thee meteorological conditions. Considering simulation, it is simple. But to take advantage of this feature using simulation, the simulation must be **deterministic**. It means that, if you run several times the same scenario, you get exactly the same results.

It is not so simple to be deterministic. In SE-Workbench, for instance, many features look random. Typically, particle systems are globally controlled, but the position of each particle is stochastic. The same approach for clutter material in the frame of radar. In SE-Workbench, many mechanisms have been developed with regards to time scheduling in order to take advantage of stochastic features without any drawback.

7. CURRENT RENDERING TECHNIQUES MIXED IN SE-WORKBENCH

In SE-Workbench, many techniques are used for the rendering process, depending on the spectral domain, IR vs. EM, and on the application.

The first technique is rasterization. In the frame of rasterization Open GL is used for standard real-time rendering. Besides, shaders have been developed for more specific features. A shader is a piece of code that is directly loaded on the NVidia family GPUs and that bypass OpenGL. For example, OKTAL-SE has developed a special shader to code the Black Body law. For example, a shader has been written to code a sixteen-bit radiance pixel in the Red and Green components of the DVI output of the GPU.

The second technique is ray tracing. In OKTAL-SE's, ray tracing is implemented according to three ways. The standard way with an implementation on CPU. The "fast" way using a CUDA language implementation, available on the NVidia family GPUs. The medium way based on an Open CL implementation.

The advantage of the CPU way is the simplicity. Simplicity for debugging but also for profiling.

The CUDA implementation takes advantage of the GPU performance. The GPU is seen has several "small" CPUs with their own memory and a reduced set of instructions. Current Titan Black NVidia GPUs have several thousands of CUDA core available for computation. The drawback of CUDA is portability and difficulty to be debugged or profiled.

The Open CL approach is a good intermediate. It is good for portability. It takes advantage of multithreading, like CUDA, but basically for the CPU cores, which is a good compromise.

Concerning the application, OKTAL-SE strategy is different for EO and for RF. The difference comes from the "FAST" branch of SE-Workbench. As already explained, EM domain implies a computation in vector space, not a simple scalar computation, meaning amplitude but also phase computation, which makes ray tracing mandatory for EM.

Besides, time computation constraint is quite different depending on the application:

For pure research simulation, CPU based ray tracing is perfect.

For some R&D simulations, typically parametric studies, a great amount of run and trials is to be done. In that case OKTAL-SE proposes several solutions. For IR domain, either a GPU based ray tracing or a GPU based slowed down rasterization is available. For EM domain, GPU based ray tracing is convenient

For Man In the Loop simulation, in IR domain, GPU based standard rasterization and, in EM domain, simplified GPU based ray tracing are convenient.

For Hardware In the Loop simulation, in IR domain, GPU based optimized rasterization and, in EM domain, simplified and optimized GPU based ray tracing are convenient.

Waveband	Domain	Technique
EO	R&D	CPU ray tracing
EO	Monte Carlo	GPU ray tracing
EO	Monte Carlo	GPU rasterisation
EO	MIL	GPU rasterisation
EO	HWIL	GPU rasterisation
RF	R&D	CPU ray tracing
RF	Monte Carlo	GPU ray tracing
RF	MIL	CPU ray tracing
RF	HWIL	GPU ray tracing

Figure 8: Rendering methods function to application and spectral domain

8. NEW GENERATION RENDERING TECHNIQUES

One basic limitation of simulation comes from the Synthetic Environment modelling. SE modelling is first long, then expensive and finally risky. The main risk is due to human intervention. If the 3D scene geometry and radiometry (associated physical materials) is not correct, the rendering is obviously not good as well.

The SE modelling is all the more complex as the scene area is wider. Besides, get exact representation of geometries and materials is quite an impossible challenge for large databases. Happily, the correlation to the ground truth is not mandatory in the whole scene. If we take the example of a civilian aeronautical application, the ground truth is mandatory in the vicinity of the airport, but less important for high altitude flight. We speak of "geospecific" modelling for high correlation to the ground truth and of "geotypical" modelling for weak correlation to the ground truth.

Classical approach

Concerning the rendering, in the classical approach, as described from the beginning of this article, the Synthetic Environment is stored as a collection of files on disk. These files basically contain the geometry as a collection of triangles, the classified textures and associated physical materials. Everything is static, even if some dynamic features are also stored in dedicated scenario files (particle systems, trajectories...). The rendering engine in that case, for ray tracing as for rasterization, simply displays the static content of these files.

Procedural approach

In the procedural approach, many features are generated on fly, during the rendering stage, meaning that, for instance, lots of triangles are created in real time. In that case, the Synthetic Environment files does not contain the triangles but the rules to generate those triangles in real-time.

For instance, in the image hereafter, the contour and trees seed is stored in the SE, but the 3D trees (with 3D leaves) are generated on fly by the rendering engine. In this SE-Workbench image, the rendering is based on rasterization and uses dedicated shaders. This approach is also compatible to ray tracing rendering.

Figure 9: Procedural generation of 3D trees

Comparison of static & procedural approach

Advantages of classical method with regards to SE modelling

- Very adapted to geospecific constraints
- Portable

Drawbacks of classical method with regards to SE modelling

- Modelling costs can be huge (depending on the database resolution a size)
- Disk space can be huge

Advantages of classical method with regards to SE rendering

- Rendering is deterministic (repeatable)
- Commutation of Level Of Detail for important objects is fully controlled

Drawbacks of classical method with regards to SE rendering

- For real time application, the frame rate is not regulated
- Distance of visibility is more limited
- For near distance observation, the SE is not detailed enough which convey blurring effects

Advantages of procedural method with regards to SE modelling

- Cost effective SE modelling
- Well fitted to special feature as micro vegetation
- Very adapted to geotypical modelling

Drawbacks of procedural method with regards to SE modelling

- Poor control in details of the SE modelling
- Not fitted to geospecific representation

Advantages of procedural method with regards to SE rendering

- Portability
- For real time application, the frame rate is regulated (image fluidity)
- Generalized, automatic and continuous representation of Levels Of Detail
- Animation of all procedural objects (for instance helicopters rotor wash influence on grass undulation)

Drawbacks of procedural method with regards to SE rendering

- Difficult to control the deterministic constraint on rendering

As a conclusion, OKTAL-SE technical strategy approach consists in to mixing these classical and procedural approaches, keeping advantage of both.

If we come back to the civilian aeronautical application example, the following figure gives a good example of mixing that is currently being developed in SE-Workbench:

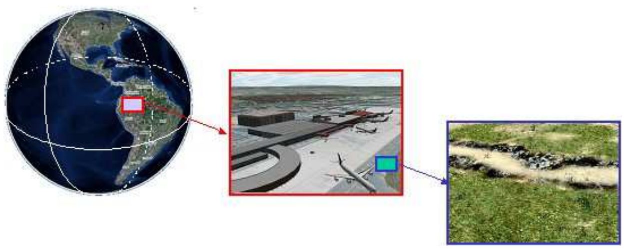


Figure 10: Mixing classical and procedural approaches

The first idea is to be able to model and render the whole globe. In that frame, procedural is mandatory. Some worldwide free low-resolution satellite images (e.g. Landsat) and Digital Elevation Models (e.g. DTED) are used for that. Many details are then automatically invented by the procedural engine. The second idea is to be able to incrust in the geotypical representation of Earth, a dedicated geospecific punch. In that application, for instance, punches are airports. Of course, in that case, the runway and its marks and lights must be accurate as in the real world. Anyway, the idea is to add geotypical invented details in the geospecific punch, for example some grass on the intermediate surfaces and some roughness on the taxiways.

Another advantage of the procedural method, in the frame of this mixed approach, concern Physics. Actually, the main difficulty is the physical data acquisition. Typically, in EO domain, outdoor BRDF measurement costs are prohibitive. It is worse in the case of reflectivity measurement for radars. Of course, attribution of physical attributes at globe scale does not make any sense. **Procedural is so a good alternative to invent physical attributes that make sense**. OKTAL-SE has made several studies in that field with support of European research centres both for EO and RF. It is particularly promising in RF, especially in the millimetre waves since, at these frequencies, there is not a lot of real data available.

9. SIMULATION OF SKYDOME

Modelling/simulation approach

In case of a scenario where the sensor is scanned to the sky, for example when considering a surveillance system, the radiations generated by the skydome (stars) have to be considered in both the visible and the infrared domains. Indeed, the stars may induce spurious signals that may prevent the detection of the target.

So, the skydome modelling and rendering capacities were added to SE-Workbench-EO based on the Hipparcos catalogue that contains roughly 200,000 stars.

Concerning the absolute magnitude of the stars, the following three bands are available:

- 0.75 to 1 µm
- 1 to 1.5 µm
- 1.5 to 2 µm.

The catalogue also provides the distance from the Earth and the location of each star.

The global skydome simulation rendering is illustrated on the figure here after:

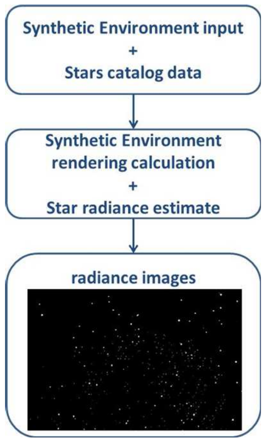


Figure 11: skydome simulation process

For computing the radiance emitted by a star, we have to compute its radius, its distance to the Earth and its surface temperature. And finally, the star is considered as a Black Body, which allows to consider the integration of the Black Body law to estimate the emitted radiance of the star as follows:

$$L_{star} = \int_{\lambda_1}^{\lambda_2} L_{CN}(T_{star}, \lambda) \cdot d\lambda$$

For rendering of the skydome, the stars are represented by “light source” type of objects in SE-SCENARIO and the stars are placed in the Earth reference frame (ECEF) according to the date and time of the simulation. So, the sensor sees the skydome with the real position of the stars along its trajectory.

Validation approach

The validation approach for both the location and the radiance of the stars is illustrated by the two schemes here after:

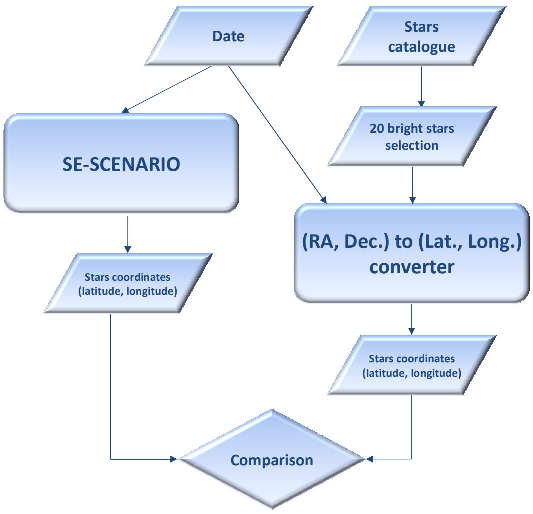


Figure 12: Validation process for star location

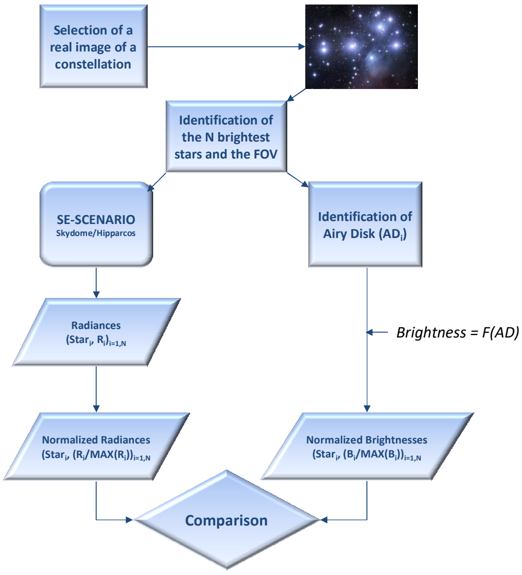
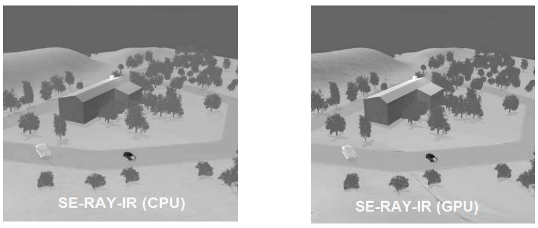


Figure 13: Validation process for star radiance

10. EXAMPLES OF SIMULTION RESULTS

Some results concerning GPU version of SE-RAY-IR



Sofware / Hardware	Computation time (s)	Speed up compared to SE-RAY-IR
SE-RAY-IR	20.5	
SE-RAY-IR-GP GPU/ Laptop	2.06	x 9.95
SE-RAY-IR-GP GPU/ High-end	0.23	x 89.13

Figure 14: GPU version of SE-RAY-IR assessment

SE-RAY-IR GPU version was recently developed and assessments have been made in terms of comparison of image quality and computation time performance. The image hereafter uses a small test database delivered with SE-Workbench, which is optimized for GPU computing, SE-RAY-IR CPU standard version runs on a high-end Intel Core i7-4770K at 3.50GHz, when SE-RAY-IR-GPU runs on a laptop NVidia GeForce GT555M GPU, and also on a high-end NVidia GTX Titan Black. It shows that we can expect an acceleration factor of about 100 with new powerful GPU boards.

Some results concerning procedural rendering in SE-FAST-IR

The images hereafter are real time infrared procedural images computed using procedural new feature of SE-FAST-IR. The image geometric and radiometric resolution is some centimetres for a total surface of 60 x 80 km.

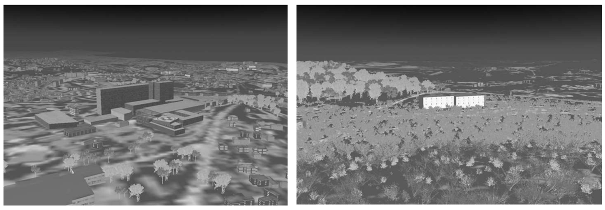
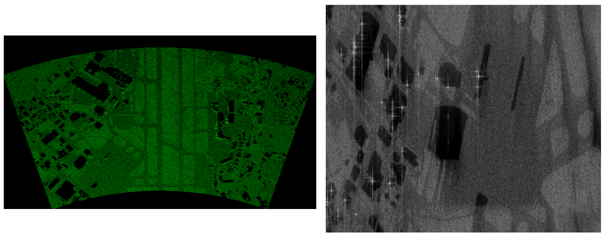


Figure 15: new procedural SE-FAST-IR rendering

Examples of synthetic radar images

The radar images hereafter are pure synthetic images, meaning that they are generated considering ray tracing and asymptotic formulations for computing EM interactions for the rendering of the 3D synthetic environment (here the 3D mock-up of Toulouse Airport developed by OKTAL-SE).



Real Beam Ground Mapping (RBGM) mode   *Synthetic Aperture (SAR) mode*

Figure 16: Synthetic radar images in both modes

REFERENCES

[1] Thierry Cathala, Jean Latger, "Improvements of SE-Workbench-EO for the infrared real time rendering of outdoor scenes", OECD Conference Center, Paris, France / 28–30 January 2014.

[2] Alain Le Goff, Thierry Cathala., "Analysis tools of IR signature in SE-Workbench-EO", OECD Conference Center, Paris, France / 28–30 January 2014.

[3] Thierry Cathala, Nicolas Douchin, André Joly, Sven PERZON, "The use of SE-WORKBENCH for aircraft infrared signature, taken into account body, engine, and plume contributions", Proc. SPIE 7662-30 (2010).

[4] Thierry Cathala, Nicolas Douchin, Jean Latger, Karine Caillault, Sandrine Fauqueux, Thierry Huet, Luc Labarre, Claire Malherbe, Bernard Rosier and Pierre Simoneau, " The coupling of MATISSE and the SE-WORKBENCH: a new solution for simulating efficiently the atmospheric radiative transfer and the sea surface radiation " Proc. SPIE 7300-21 (2009).