

Simulation of active and passive infrared images using the SE-WORKBENCH

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ABSTRACT

The SE-WORKBENCH workshop, also called CHORALE (“simulated Optronic Acoustic Radar battlefield”), is used by the French MoD/DGA to perform multi-sensors simulations by creating virtual realistic multi spectral 3D scenes and then generating the signal received by a sensor.

Taking advantage of developments made in the frame of Radar simulation, CHORALE is currently enhanced with new functionalities in order to tackle the “active” problem, involving new generation of infrared sensors such as laser radars.

This article aims at presenting the challenges for simulating simultaneously passive IR imagery of a full terrain and active imagery especially on targets. We insist on duality and differences concerning in particular monochromatic/coherent waves versus incoherent waves, BRDF modeling taking into account surface roughness, polarization effects, Doppler effects.

The SE-WORKBENCH implements the “Photon Map” method that enables to treat the “global illumination” paradigm, consisting of multiple reflections ray tracing effects combined with Monte-Carlo ray scattering. This approach is assessed in the frame of coherent illumination by laser. The constraint of the atmosphere propagation accurate dependence on wavelength is also studied. Special requirements for advanced systems such as flash laser systems or heterodyne infrared detectors are analyzed. Finally, modeling issues of the degradations introduced by atmospheric turbulence are discussed.

Keywords: Infrared simulation, Active imagery, Passive imagery, multi spectral, Ray tracing, Open GL, BRDF, MTF, LASER, Radar simulation

1. INTRODUCTION

1.1 What is the SE-WORKBENCH

The SE-WORKBENCH, also called CHORALE, is a multi-sensor battlefield modeling workbench mainly used by French DGA, German BWB and by South Korea MoD, in order to achieve the synthesis of 3D scene observed by a sensor, this in two steps:

- The physical characterization of the 3D scene behavior
- The Computation of the physical signal received by a sensor

The SE-WORKBENCH is entirely based on software products developed by OKTAL-SE and realize the multi-spectral unification of optronics, electromagnetism and acoustics, using a common kernel & physical extensions affectation both aimed at a unique 3D scene and a common technology.

The SE-WORKBENCH is a winning initiative for sharing R&D efforts and federating a user group community that intends to exchange experience and knowledge.

The first development was in 1994 and has been strongly boosted by the French SCALP missile program and the qualification of the IR tracking system. At the beginning, the SE-WORKBENCH was focused on the IR domain. In 2003, an acoustic version already described in previous SPIE conferences, has been developed. In 2001, an electromagnetic version of the workshop was initiated, with the help of ONERA French research center, mainly focused on millimeter waves and wide scenes, typically for SAR applications.

The 3D scenes processed by the SE-WORKBENCH are very precise and realist, using textures in order to accurately define the material geo mapping, as illustrated in synthetic image given on the right.



Fig. 1: Airport synthetic image

The control of the SE-WORKBENCH validity domain is based on both a theoretical validation approach (development of physical models, general modeling and simulation knowledge, elementary tests and validity assessment) and a validation process based on comparisons with experiments (SCALP/EG missile [FR], Storm Shadow missile [UK], AASM missile [FR]).

The SE-WORKBENCH architecture can be declined in 3 functional architectures for infrared (IR), electromagnetic (EM) and acoustic (AC) domains sharing the same following organization:

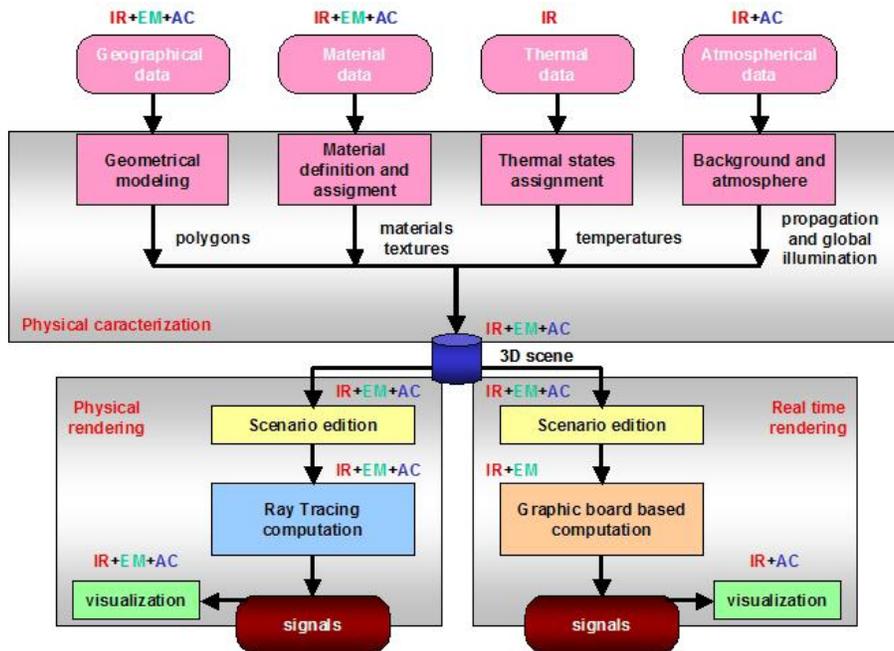


Fig. 2: SE-WORKBENCH architecture

1.2 The Multispectral approach

This multi sensor capability is one of the key features of our simulation workbench.

A unified IR+EM+AC approach of physical material management enables to combine different sensors of different domains on the same scene. To perform it, the SE-WORKBENCH new release includes a new multi domain material format and an associated API.

Two basic difficulties have driven this strategy:

- the number of material combinations grows exponentially with the number of domains. So does the number of duplicated data. For example, the material “red painting on wood” has the same optronic features as “red painting on concrete”. It is useless to duplicate the spectral BRDF and emissivity of “red painting” on all the materials that are painted in red. On the other hand, for thermal computations, it is important to know if the material under the “red painting” is “wood” or “concrete”.

- for a given material, due to the lack of data (measurements) for a specific spectral band, the user may select a replacement material with similar features. As a consequence, for another spectral band, the features of the substitutive material and the original material are not necessarily coherent.

To share this new type of multi domain materials, some tools of the SE-WORKBENCH have been updated, especially SE-PHYSICAL-MODELER that enables to create the physical materials and to assign them to 3D objects or templates for terrain generation (for profiling and elevating features).

The figure below shows the same 3D synthetic environment rendered in visible and in the IR domain.



Fig. 3: Illustration of the multi spectral capacities of the SE-WORKBENCH.

1.3 Motivation for extending the SE-WORKBENCH to the active domain

The current version of the SE-Workbench addresses the passive IR systems (see the description of the SE-WORKBENCH-IR hereafter) and the active RADAR systems (see the description of the SE-WORKBENCH-EM hereafter).

But, the use of advanced active systems such as flash laser systems or heterodyne infrared detectors is considered as they have interesting capacities with regard to range determination, fine resolution achievement, Doppler discrimination (by filtering of the clutter) or target recognition.

So one of the main future challenges for the SE-WORKBENCH is to be able to deal with the active domain especially in the infrared spectrum.

Thus for OKTAL-SE the challenge for the future is to produce what we can call the SE-WORKBENCH-AD (“AD” for Active Domain) which has to be the most coherent as possible with the SE-WORKBENCH to guarantee the multi spectral approach adopted up to now. The purpose of this paper is to show how the SE-WORKBENCH-AD can be derived from both the IR and EM workbenches by the reuse of existing components or functionalities already developed in the IR or in the EM domain.

2. THE SE-WORKBENCH-IR

The SE-WORKBENCH-IR is made of different components, as described hereafter, corresponding to the successive steps of a IR sensor simulation that are the modeling, the scenario edition, the rendering without the sensor effects and finally the sensor transfer function simulation.

Furthermore, the user can do software integration in order to control the generated scenario execution from a remote or custom application. This can be achieved with the help of the SE-TOOLKIT consisting of a set of libraries and application programming interfaces (API) to help the complex application design and integration.

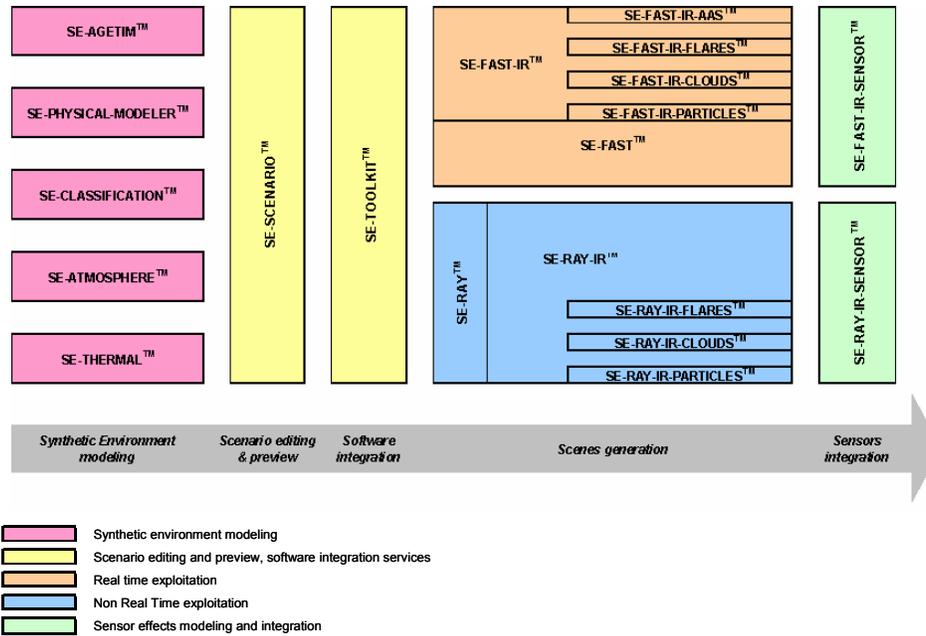


Fig. 4: The SE-WORKBENCH-IR components.

2.1 SE-AGETIM

The SE-AGETIM (*Synthetic Environment Multisensor Terrain Generation Tool*) product is an integrated software that enables the generation of 3D synthetic environment with a user specified resolution and realism. It provides the user with a unique way of integrating heterogeneous geographical data to produce a coherent 3D database. Corrections and enhancements can be applied on source data. The SE-AGETIM product is based on a reference of the market Geographical Information System (GIS) for its user interface.



Fig. 5: Example of a 3D virtual mock-up generated using SE-AGETIM.

2.2 SE-PHYSICAL-MODELER

The SE-PHYSICAL-MODELER (*Synthetic Environment Physical Modeler*) product enables the 3D synthetic environment developer to easily characterize the elements of the scene in terms of their physical properties. It gets state-of-the-art display capabilities, including interactive 3D visualization window based on Open-Inventor. The visualization windows are updated when modifying mapping or material. All the material used can be shown with a palette editing, with spectral and thermal characteristics graphic display.

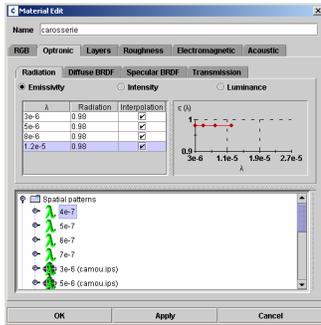


Fig. 6: Infrared material physical properties edition.



Fig. 7: Polygon edition for structure modification, material association, texture assignment.

2.3 SE-CLASSIFICATION

The SE-CLASSIFICATION (Synthetic Environment Classification) product is used to classify texture of physical materials. The picture to be classified is decomposed in layers. For example, for a wall picture, one “roughcast” layer, one “window” layer and one “shutter” layer are created. For each layer, a material modulation is computed. For the “window” layer, brown pixels are associated with the “wood” material, and the others ones with the “glass” material.

The classification panel, taking advantage of photo-interpretation, enables to select a color by picking on the picture and then to associate it to a physical material. To check the spectral behavior of materials in use, and to get an idea of the result, a visualization panel enables the pre-view of the physical classification effect.

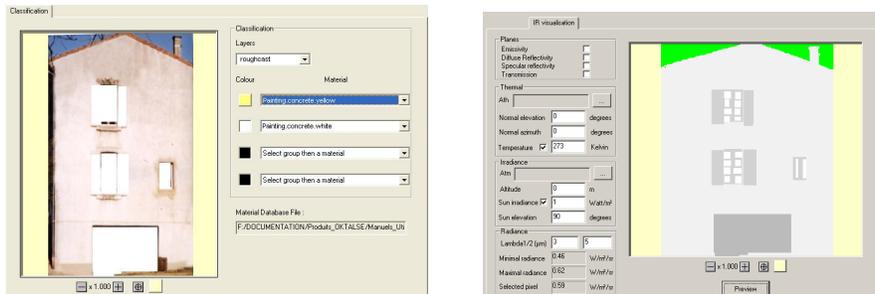


Fig. 8: Textures classification panel as function of a material library and pre visualization window.

2.4 SE-ATMOSPHERE

The SE-ATMOSPHERE software allows the user to characterize the atmosphere. It can be used to parameterize the LOWTRAN and MODTRAN kernels as well as a generic atmospheric model whose physical model has been developed by OKTAL-SE in cooperation with CELAR. It can ease the edition of the configuration files with the help of a JAVA based user interface that avoids parameterization errors.

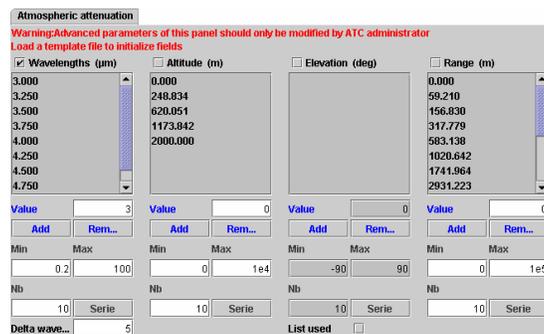


Fig. 9: Atmospheric model parameterization window.

The SE-ATMOSPHERE software computes:

- A table of spectral data of sun/moon irradiance for a list of altitude h_j and a list of wavelength λ_i
- A table of atmospheric transmission for a list of wavelengths, altitudes, and Lines of Sight (LOS)
- A table of sky radiance for a list of wavelengths, altitudes, and LOS.

These data are stored in a file and used by:

- The scene generation software (SE-RAY-IR and SE-FAST-IR) for the computation of atmospheric transmission, sun/moon irradiance and sky radiance,
- The thermal software (SE-THERMAL) for the computation of incident fluxes.

2.5 SE-THERMAL

The thermal software (SE-THERMAL) enables the pre-calculation of all the possible temperature states of a scene at a given time of the day for a given atmosphere (SE-ATMOSPHERE). It also contains a module that enables the thermal shadow calculation (SE-THERMAL-TSC).

The thermal software takes into account:

- The history of atmospheric conditions
- A decomposition in layers of the polygons and, for each layer, the thermal attributes (conductivity, specific heat, thickness, convection coefficients, ...)
- Two kinds of polygons: “terrain polygons” and “wall polygons” (for which an inner temperature or an inner heat flux can be defined by the user)
- The wind and its direction.

2.6 SE-SCENARIO

The scenario construction & preview stands between the modeling phase and the scene generation process, the user can build scenarios that will be helpful for the scene specification. Static scene generation can be expensive in terms of calculation time.

The advantage of the scenario is the ability for the user to place the sensors, to fine-tune their positions and the overall control (SE-SCENARIO). Trajectories can be assigned to sensors through the same user interface.

The SE-SCENARIO tool is an interactive 3D database analysis and scenario preparation tool. It also contains preparation, logger and playback functions. It can be used to edit SE-Advanced-Scene and SE-Fast-Scene scenarios for visible, infrared, electromagnetic and acoustic simulations. It offers the possibility to control position, orientation and behavior of sensors and objects, even to edit the trajectory of a moving element.

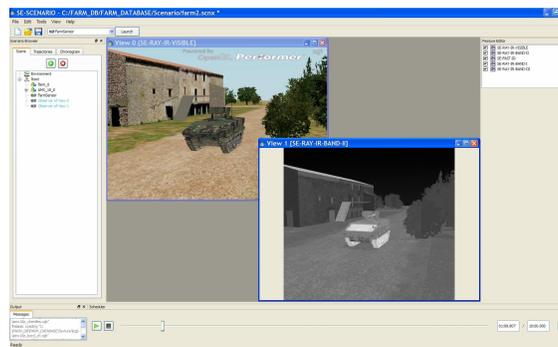


Fig. 10: SE-SCENARIO GUI.

2.7 SE-RAY-IR

SE-RAY is the ray tracing kernel developed by OKTAL-SE which enables to compute high realism images in several spectral domains. SE-RAY-IR is dedicated to the rendering of synthetic environments in the IR domain and is based on SE-RAY ray tracing kernel.

The great originality of SE-RAY comes from the model based on physics. SE-RAY uses elementary pyramids defined by four adjacent rays (one basic pixel) which allows one to compute elementary surfaces and solid angles.

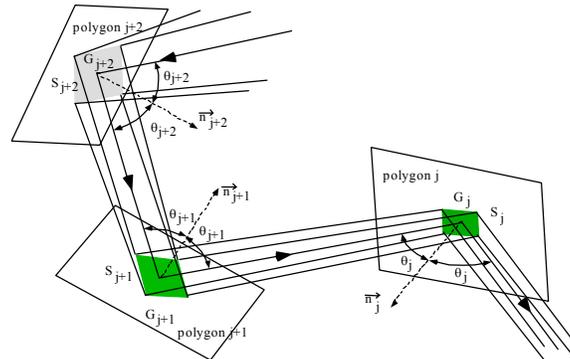


Fig. 11: Management of ray tubes in SE-RAY-IR.

Besides SE-RAY-IR takes into account the wavelength sampling. Actually SE-RAY-IR works wavelength by wavelength.

Time consumption is very optimized using SE-RAY. Actually performances are nearly independent on scene complexity. To do this SE-RAY uses a spatial subdivision method that enables to get a perfect knowledge of the scene topology before computing the first image. The scene space is decomposed in a hierarchy of volume elements (voxels) and then turned into a recursive space of voxels that improves efficiently the intersection computations.

The solution to improve image quality mainly consists in over sampling by tracing more rays. The method adopted for SE-RAY-IR is the adaptative one. The most important antialiasing criteria are the following: number of different polygons in the pixel, number of different materials, normal vector variation within the pixel.

Based on generalization of texture definition to any physical data, SE-RAY-IR can simulate the variation of specular reflectivity with the observation angles.

Concerning the physical IR model, SE-RAY-IR can take the following contributions into account:

- The thermal emission: The self emission due to temperature is fundamental in the IR domain. It can be characterized differently, using temperature T and emissivity ϵ , using radiance L , using irradiance law (diffuse sources) or using intensity law (light sources). The main characterization is expressed by the Black Body Law or Planck's law.
- Diffuse and specular reflections: Artificially a diffuse part and a specular part can be distinguished. The diffuse component can be characterized by $BRDF_d(\lambda, \theta_i, \phi_i)$ and the specular component can be characterized by $BRDF_s(\lambda, \theta_i, \phi_i, \alpha)$ in which α is the angle between the ideal specular direction and the observation direction. The physical reflection model is based on an automatic function for factorization $BRDF(\lambda, \theta_i, \phi_i, \theta_r, \phi_r)$ into $BRDF_d(\lambda, \theta_i, \phi_i)$ and $BRDF_s(\lambda, \theta_i, \phi_i, \alpha)$ terms.
- Direct Sun lighting: Direct sun or moon lighting takes into account the atmospheric attenuation and diffusion between the astral source and any point in the 3D scene. An external data file (typically based on LOWTRAN or MODTRAN) contains attenuation and diffusion values for discrete values of the wavelength and of the altitude.

- Diffuse Sun lighting and sky/ground illumination: Sky and ground are considered as a global entity providing energy in any space direction. When loading the database, the canopy is tessellated in discrete solid angles defined using elevation and azimuth angles.
- Self emission of the atmosphere: An external data file (typically based on LOWTRAN or MODTRAN) contains atmospheric radiance data for discrete values of wavelength, altitude, elevation, azimuth and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric radiance is determined using linear interpolation
- Atmospheric attenuation: An external data file (typically based on LOWTRAN or MODTRAN) contains atmospheric attenuation for discrete values of wavelength, altitude, elevation and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric attenuation is determined using linear interpolation
- Sky, horizon and cloud cover: Sky and horizon is a pure analytic model.

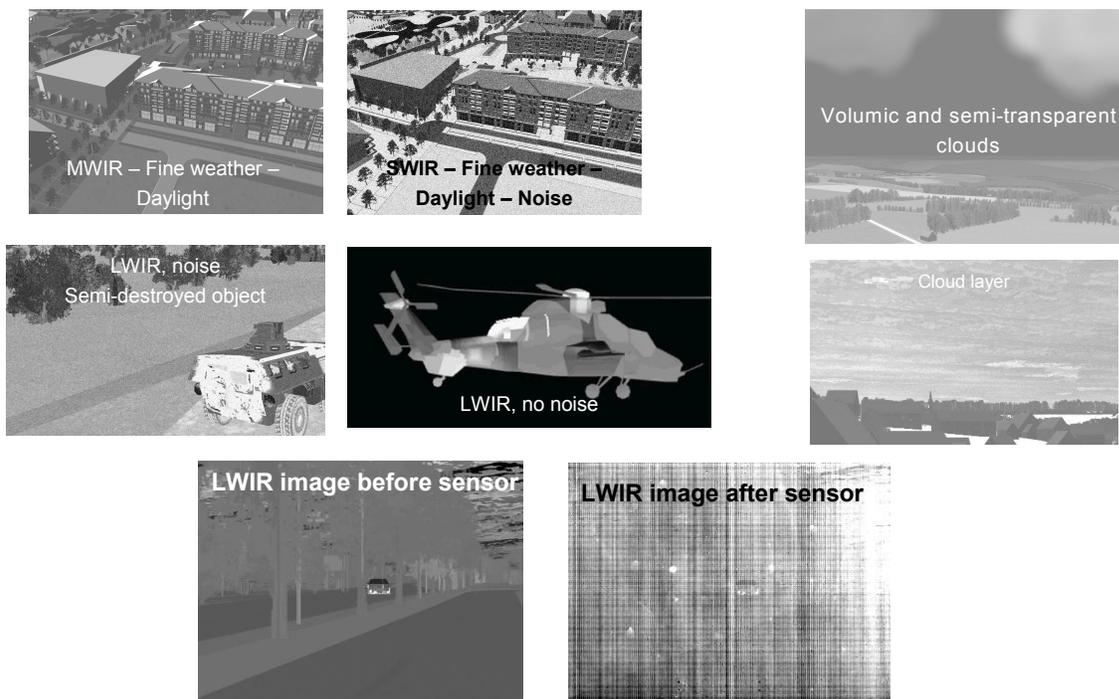


Fig. 12: Examples of IR images generated using SE-RAY-IR.

2.8 SE-FAST-IR package

The SE-FAST-IR package is made of a major product (SE-FAST-IR) and additional modules depending on the considered application.

With the help of some pre-calculation steps, real time images are computed with the SE-FAST-IR solution. It is dedicated to the computation of image sequences for near infrared sensors (light intensifying) and thermal infrared systems with short, medium or long waves (SWIR, MWIR, LWIR). The products make use of the results of the SE-CLASSIFICATION tool, the SE-PHYSICAL-MODELER modeler and the SE-ATMOSPHERE atmospheric files computation product. The thermal pre-calculations are based on SE-THERMAL code.

The previous version of SE-FAST-IR was based on a pre computation of the whole 3D scene with specific radiance texture adapted to a given waveband for a given spectral response. The real time process only consisted in using Open GL laws basically for non-static parts of the scene (for instance the specular parts, or the moving objects) and for the atmosphere propagation modeling depending on elevation, azimuth and range.

The new release of SE-FAST-IR brings a technological rupture by using OpenGL pixel shaders enabling direct calculation on 3D graphic cards. A shader is a procedure written in a special purpose high-level language that replaces a part of the graphic pipeline of a 3D graphic board.

3. THE SE-WORKBENCH-EM

As illustrated on the figure below, the SE-WORKBENCH-EM shares common components with the optronic simulation chain: the only difference lies in the rendering part of the simulation chain as the EM formulations are different from the IR ones. But it is very important to notice that the ray tracing kernel is exactly the same for both spectral domains.

The fact that the geometrical modeling is exactly the same for both the EM and IR domains is a key point in our multi spectral approach.

The synthetic environment modeling part is the same in EM and in IR, although the materials characteristics are different from one spectral domain to the other. But the way to assign physical attributes to the materials that are present in a 3D scene are identical in both spectral domains, especially the classification of the visible textures that relies on the same approach in EM and in IR.

3.1 The EM workbench architecture

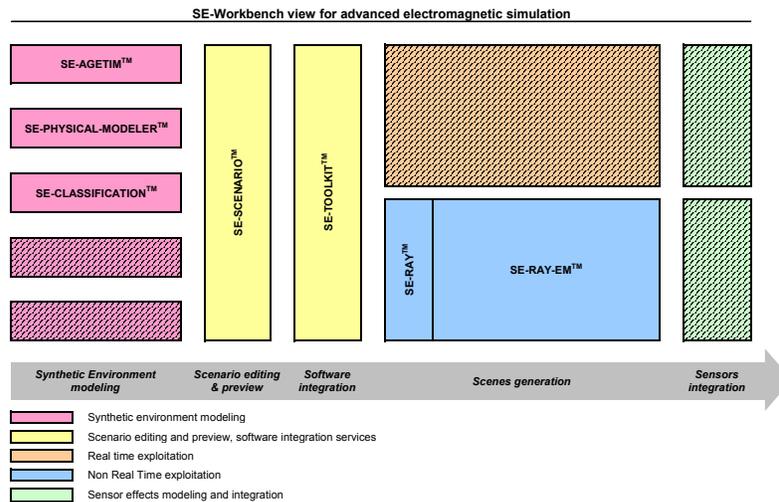


Fig. 13: The SE-WORKBENCH-EM components.

3.2 The specificities of the EM domain

The SE-RAY-EM/FERMAT kernel input is a meshed database made of triangles in order to accelerate the intersections computation.

The so called "voxelisation" algorithm that is implemented in order to be less sensitive to the amount of polygons in the 3D scene. This optimization is compulsory in SAR case, because of the size of the scene we have to deal with and because of the accuracy of representation we need in order to be physically realistic.

The second step concerns all the basic mechanisms enabling to cast rays in the 3D space from the radar. These mechanisms are very sophisticated and self adapt to the local scene complexity. This adaptation is generally called "antialiasing". To perform this antialiasing, adaptatively and lazily (only if necessary), the general physical model has to be taken into consideration for each interaction.

This is a key point of the technical approach and the only way to spare rays and so be able to analyze a whole radar scene. This approach is radically different from classical asymptotic methods where a first computation of all the possible geometrical paths within the scene is made and then a physical model is applied.

In the frame of SE-RAY-EM/FERMAT, a geometrical Shooting and Bouncing Rays (SBR) technique has been optimized in order to calculate the intersections between rays from the transmitter towards the database and back to a receiving point. EM models of propagation, reflection, diffraction and an operating strategy (thanks to SBR) that enables a unified calculation for the near or far EM scattered fields from the scenes. These models are the formulations of Geometrical Optics (GO), Physical Optics (PO) and Equivalent Current Method (ECM). Again, these models, judiciously coupled with the SBR technique make the computation time slightly independent on the complexity of the treated virtual scene.

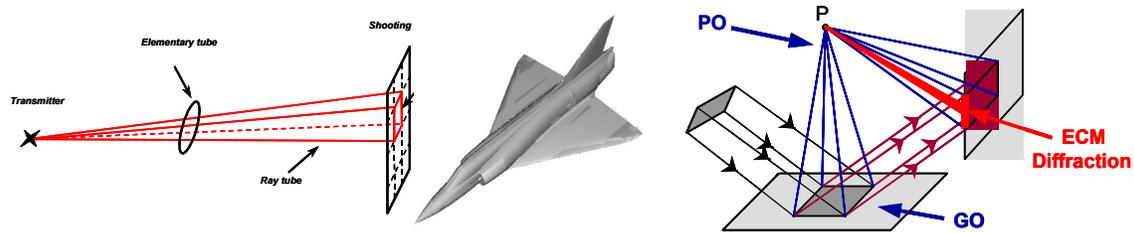


Fig. 14: Coupling of SBR technique and EM asymptotic methods.

The SE-WORKBENCH-EM takes the following features into account:

- Polarization of EM waves: in SE-RAY-EM, any polarization case can be taken into account as a combination of both basic linear polarizations (H and V).
- Amplitude & phase: the EM formulations are totally coherent as in the ray tracing approach that computes the actual path lengths even in the case of multiple bounce reflections.
- Dielectric & “clutter” materials: dielectric materials are characterized by their complex permittivity, their conductivity (and their permeability if necessary), while “clutter” materials correspond to the natural ground materials and are characterized by a backscattering coefficient.
- Surface roughness: the height of the surface is locally modified using a texture that is supposed to be representative of the surface roughness.
- Multiple bounced specular reflection, scattering & edge diffraction, including the polarization effects (cross polarization generation and depolarization) induced by these interactions.
- Divergence factor due to surface curvature: the curvature of a surface is derived from the normal variations at the vertices of the surface using an interpolation scheme such as the Gouraud algorithm.
- Doppler effects: the Doppler spectrum is derived from the phase variations with the simulated time.
- Range gating: the contributors are summed in each range gate taking into account an auto correlation function that can be defined by the user.
- Wave form: the wave form simulation is achieved through the range gate definition along with the auto correlation function of the radar sensor.
- Antenna diagram: both the transmitting and the receiving antenna diagrams can be introduced in the simulation scenario.
- Monostatic as well as bistatic scenarios can be computed.

3.3 Validation of the SE-WORKBENCH-EM

The validation approach adopted for the EM workbench is based on multi level approach involving:

- Calculations on canonical objects, such as a plate, a sphere, a cylinder, a dihedron, a trihedral, ...
- International Workshops: mainly through OKTAL-SE partner in the EM domain, ONERA, who participates to NATO groups
- Calculations on generic objects, such as planes, tanks, ships, ...
- Comparison with measurements, thanks to OKTAL-SE customers such as FOI in Sweden or FGAN in Germany
- Comparison with other EM codes such as ELSEM3D, ONERA software based on Moment Method, and Xpatch, a well known US asymptotic software.

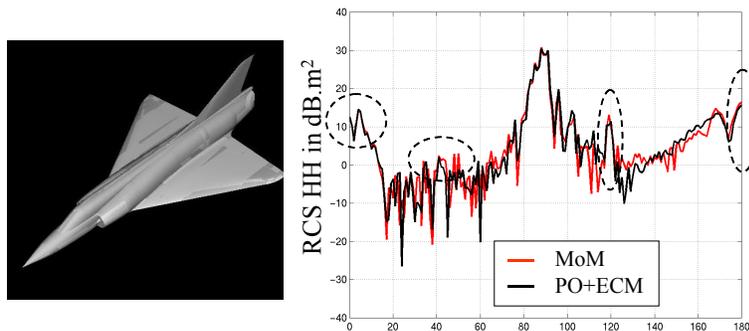


Fig. 15: Example of a validation test case.

4. THE PHOTON MAPS METHOD

4.1 General principles of the Photon Maps method

The Photon Maps is a rendering method used to improve surface rendering and soft shadowing effect.

A lot of work has been done on realistic rendering. For the majority of existing techniques, it is difficult to handle scenes with a huge number of extended light sources. As our goal is to do infrared rendering, we do have to handle all surfaces of the scene as extended light sources. In most of the existing density estimation techniques, a ray tracing pass is used for direct lighting computations and density estimation is only used for indirect illumination computation.

In the case of infrared rendering, the ray tracing pass cannot be handled because it is prohibitive to sample efficiently all the sources (all the surfaces) of the scene. Thus we chose to compute the whole illumination using density estimation. But it appeared that we needed a huge number of particles to handle direct illumination correctly and this number cannot be stored in nowadays computer memory. Our research to solve infrared simulation problems leads us to a multi-pass density estimation method that allows us to render 3D scenes containing a lot of light sources without increasing the memory consumption. Our infrared approach can handle all surfaces and participating media as light sources. The memory consumption of the method is independent of the scene complexity and of the number of particles used to render the final image.

The method used in the SE-WORKBENCH-IR to implement the Photon Maps method is a two-pass algorithm (see figure below).

Firstly, the light is propagated through the participating surface using standard ray tracing techniques. A virtual particle, called photon by analogy with the corpuscular theory of the light, is used to store energy at the interaction points of the light with the surface.

The second pass consists of reconstructing the radiance seen by the observer by throwing a ray from the eye to the participating surface.

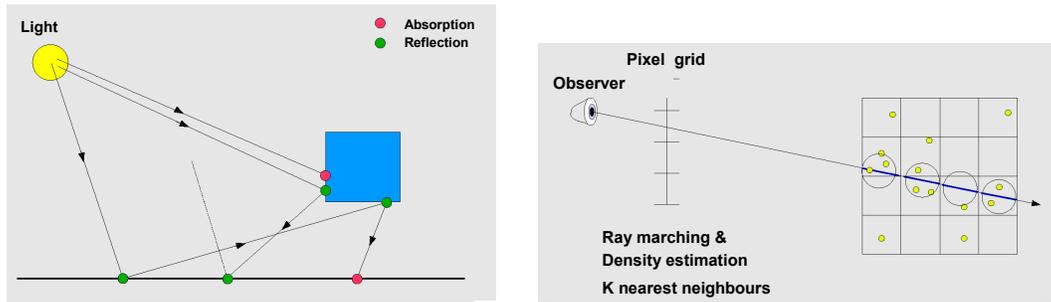


Fig. 16: General principles of Photon Maps applied to surfaces: the two-pass algorithm.

So far, the Photon Maps method is available only in the IR workbench in both surface and volume versions.

The PM method has been introduced in the SE-WORKBENCH-IR essentially for the resolution of the Radiative Transfer Equation when obscurants or clouds are set in the scene: the aim is to be able to reproduce the diffusion effects due to the scattering volume.

But, the PM approach is also a solution to handle scenes with a huge number of extended light sources. Thus it is one of the methods that can be considered for rendering a scene by taking into account the multiple bounce reflections between the polygons of the 3D database. This point is a key feature with regard to the extension of the SE-WORKBENCH to the active domain.

4.2 Key features of the Photon Maps approach implemented in the SE-WORKBENCH-IR

- Performance nearly independent of the scene complexity.
- All kinds of material can be taken into account through the BRDF.
- Extended light sources can be taken into account.
- The only method for solving the caustics problem.
- The computed data are independent of the observer position.
- Diffusion and focalization modeling using PM method is very important for target surfaces coupling with ground rendering and for target exhaust plume modeling.

4.3 Applications of the Photon Maps



Fig. 17: Application of Photon Maps method to a synthetic scene: improvement of surface rendering.

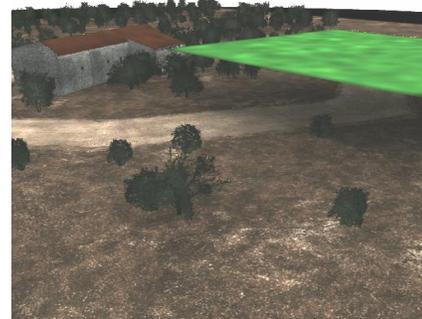


Fig. 18: Application of Photon Maps method to a synthetic scene: soft shadows rendering.

5. DEFINITION OF A SE-WORKBENCH-AD

5.1 The challenge of the Active Domain

The challenge for the SE-WORKBENCH is to compute a synthetic environment that is representative enough for an active IR system, i.e. when the source has a very narrow beam, is polarized, highly coherent and spectrally very pure so that a coherent processing at the receiving sensor can be achieved. The laser source can also be a pulsed one thus offering range gating capacities. With regard to these new potential capacities, the simulation challenge has to face to phenomenon that are specific to the active domain and might have been ignored in the passive domain:

- As the radiated wave is coherent, one has to be able to deal with the phase very precisely.
- In connection with the previous point, the surface state of objects will have a strong influence on the wave that is backscattered to the receiving sensor. So one has to be able to define a connection between the BRDF of a surface and its roughness and to take this into account when computing the Laser Cross Section (LCS) of the object.
- As the source may be polarized, one has to deal with polarization effects: so the formulations should incorporate polarization changes due to 3D interactions along with depolarization effects.
- As the source is coherent, one may be interested by the Doppler filtering capacities that are achievable using a laser illumination. Thus Doppler effects have to be taken into account in the simulation.
- As for the atmospheric radiative transfer, the spectral purity of the source implies that the atmospheric model has a high spectral resolution of the model. This is not the case of MODTRAN, so this has to be replaced by other models such as FASCODE and HITRAN.
- One of the main challenges for computing laser propagation in the atmosphere is to be able to simulate the effects induced by the turbulence since they may affect tremendously the wave at the receiving sensor, both in amplitude and phase.

When dealing with the active domain, the challenge is also in the ability to have simulated data that are representative enough to real scenarios. This implies that one is able to incorporate specific effects in the simulation scenario in order to make it more realistic, such as:

- Dealing with laser illumination, flash laser, heterodyne systems, with some specific capacities such as the range gating that implies to compute the distances very accurately even in a turbulent atmosphere.
- Dealing with both scattering by optical targets and the clutter (to reproduce the speckle effect).
- Dealing with 3D scenes that combine an IR passive image of a large terrain with IR active images on targets.
- Dealing with either monostatic or bistatic scenarios.
- Dealing with very advanced active sensors with high level capacities such as hyperspectral systems.

5.2 Design of the SE-WORKBENCH-AD architecture

The challenge for producing a SE-WORKBENCH that is relevant for the active domain seems to be very high but it is of great importance to notice that a large number of the points listed above have already been implemented in the SE-WORKBENCH-EM since they are necessary for dealing with radar systems. Thus the basic idea is to derive the SE-WORKBENCH-AD from both the IR and the EM workbenches as illustrated hereafter. It is very important to notice that our approach is adequate with our multi spectral philosophy.

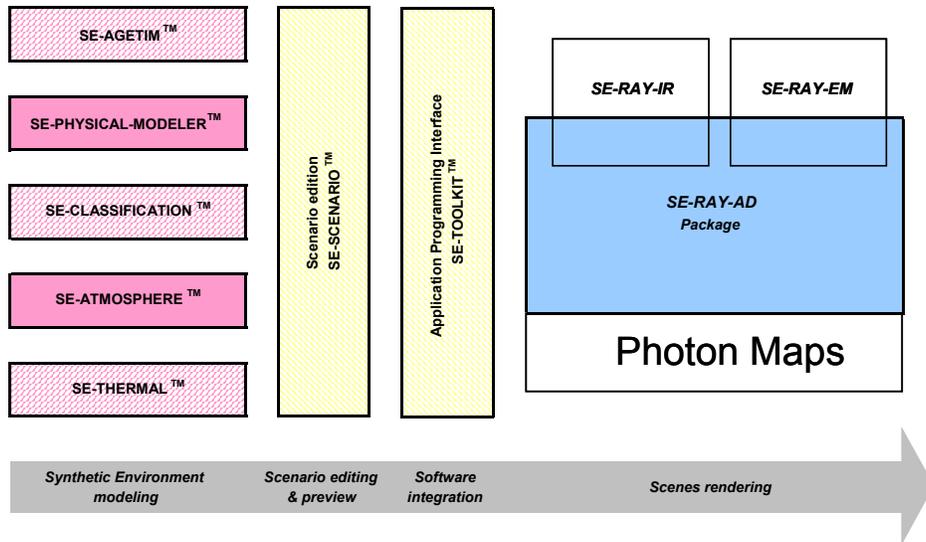


Fig. 19: The SE-WORKBENCH AD architecture preliminary definition.

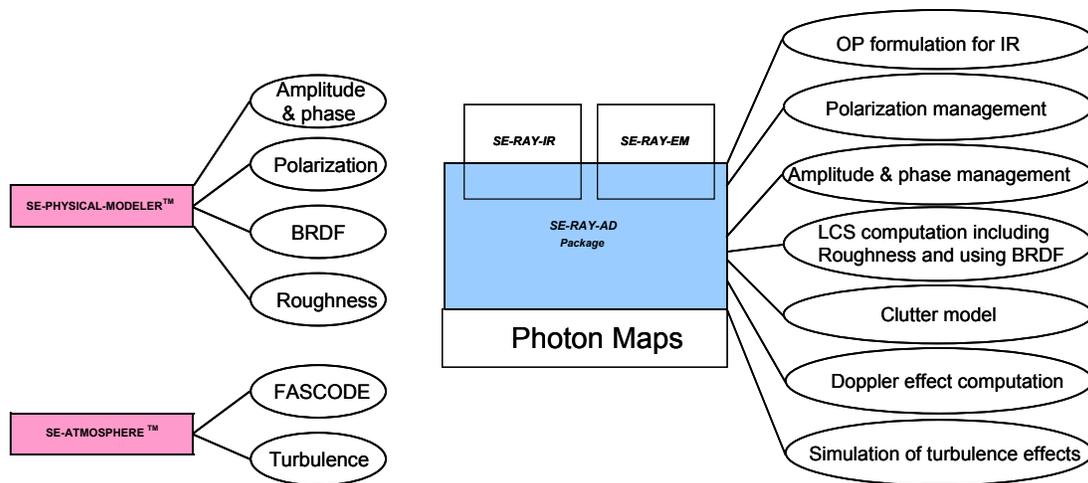


Fig. 20: Evolutions needed for producing a SE-WORKBENCH-AD.

Figure 20 above shows schematically what are the new functions needed for dealing with active IR sensors along with the components of the SE-WORKBENCH that one has to improve for producing the SE-WORKBENCH-AD.

5.3 Focus on some new functions of the SE-WORKBENCH-AD

The BRDF

The basic idea is to characterize a material by its physical parameters, i.e. the dielectric complex permittivity ϵ , the electric conductivity σ and if necessary the magnetic permeability μ . This way for characterizing a material in the IR domain is the one already adopted in the EM domain; so it is another step towards to coherency between both spectral domains.

The improvement currently under development should also allow the user to define the roughness of a surface by two parameters that are the RMS height of roughness, σ_h , and the correlation length, l . The challenge is then to deduce a model for the BRDF from the materials and roughness parameters described above.

The multiple bounce reflections

The Photon Maps method is considered as a good solution for computing the multiple bounce reflections onto objects and also between the objects and the ground for simulating the coupling between the targets and the ground that is of great importance for realism.

The turbulence effects

The effects due to the atmospheric turbulence are induced first along the propagation path between the laser source and the scene: they result in beam deviation and enlargement and in spatial fluctuation of the irradiance, so they may have a strong influence on the effective Laser Cross Section of a target. The turbulence induced also effects on the return path to the sensor where they result in beam enlargement, defocusing effects and amplitude and phase scintillation. So the image generated at the focal plane of the sensor may be strongly disturbed.

For computing these effects, three main approaches can be considered:

- One possible method consists in first simulating the turbulent atmosphere itself and then modifying the ray tracing algorithm to be able to compute the ray paths in this non-homogeneous atmospheric model.
- Another approach is based on the so-called “phase screen” algorithm that allows one to compute the wave amplitude and phase after propagating through a turbulent atmospheric layer. But this approach seems far away from the basic principle adopted in the SE-WORKBENCH for non real time rendering that is ray tracing.
- The simplest way to take the turbulence into account is to globally render the effects it induces using a atmospheric 2D Modulation Transfer Function as a post-processing on the synthetic image.

Concerning turbulence, one has to have in mind that it should be necessary to introduce in the simulation a local atmospheric transfer model taking into account 3D modeling: indeed the local surface state (roughness, convection coefficient, ...), the local geometry (e.g. cavities) and the local atmosphere correlated to the surface temperature, create local refraction effects that could be accurately modeled using 3D ray tracing functions.

5.4 Conclusion on the future development SE-WORKBENCH-AD

After a first investigation step, we can conclude that the development of the SE-WORKBENCH-AD can take benefit of both the IR and EM existing workbenches, which is of great importance because it will allow us to guarantee the coherency between the various sensor applications of the SE-WORKBENCH. Among others, several aspects like polarization, phase coherency, surface roughness, and so on, have already a solution in the radar domain that can be quite easily extended to the IR active domain. Other aspects, like the multiple bounce reflections, should be treated using methods already implemented in the IR passive domain such as the Photon Maps that seem to be very promising for that.

But we have also highlighted some specific aspects that need further investigation and certainly new developments such as the simulation of the atmospheric turbulence.

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