FERMAT a new radar simulation approach

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Abstract: 3D virtual databases are more and more realistic and any kind of terrain and objects can be easily modelled. A new approach in radar simulation is now possible thanks to efficiency in geometrical description and in ray tracing performance. FERMAT code is based on an ElectroMagnetic asymptotic modelling which takes advantage of these improvements for radar simulation.

Keywords: Radar simulation, ElectroMagnetic asymptotic formulation, virtual prototyping, databases modelling, virtual reality, 3D mock up, Physical Optics, Geometrical Optics.

1 - Introduction

FERMAT is a joint development of ONERA/DEMR French research centre and OKTAL SYNTHETIC ENVIRONMENT SME Company specialised in both research and training simulation particularly in the defence markets. FERMAT (Fonctionnalités pour l'Electromagnétisme et le Radar par des Méthodes AsympTotiques) is being developed in the framework of the ONERA PAME project. PAME is a collection of ONERA available electromagnetic software tools. FERMAT federates and takes advantage of several ONERA research works and theses concerning high frequency EM asymptotic methods and EM field computation. FERMAT enables to share a unique computation kernel for multiple applications e.g. radar simulation, antenna emission on structure, EMC and propagation modelling.

2 - Database generation

3D databases modelling and virtual reality techniques have been recently boosted first of all by the video game market expansion, then by training simulation market especially in the scope of military applications needing sensor simulation in the IR and EM domain.

The improvement in geometrical complexity in the construction of databases and in their exploration with ray tracing technique are due to correlated progress of 3D hardware graphic boards, CPU, and advanced simulation software tools.

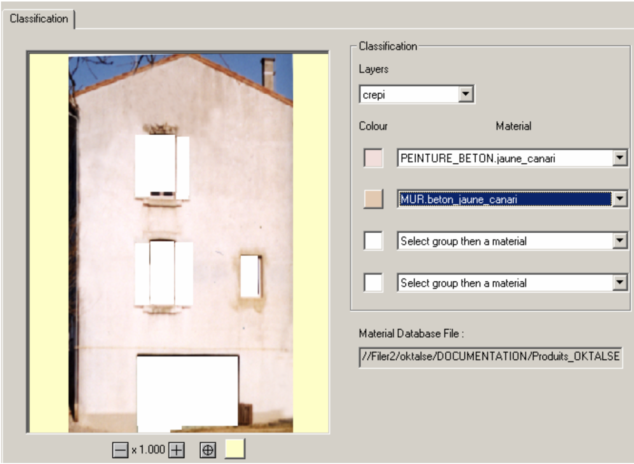
The main advantage of using so complex 3D databases in radar simulation is that the real direct interaction of the incident EM wave and the 3D scene can be simply taken into account. This enables one to treat in the same run the target and the background, which is very interesting to naturally deal with the complex interaction of the target with its background. FERMAT uses an optimised "forward ray tracing" technique that allows very efficiently to trace the propagation, the specular reflections, and the scattering of the incident radar waves and so, to estimate the "radar response of the scene".

OKTAL SYNTHETIC ENVIRONMENT AGETIM™, GAIA EM™, PTT EM™, terrain modelling tool enables to automatically generate 3D virtual mock-ups, very detailed at geometrical level, and natively enhanced with physical attributes, especially in the EM spectral domain. These 3D databases associate terrain meshing, vegetation infrastructures, building superstructures and moving objects considered as targets for the assessed radar.

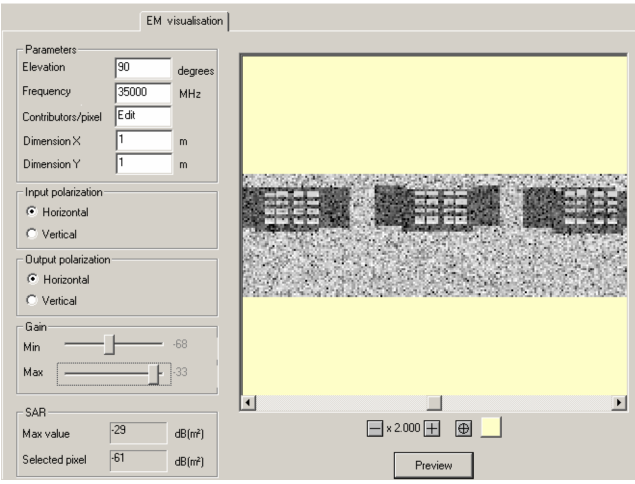
For databases generation, FERMAT relies on different tools:

- 3D geometrical databases enhanced with specific physical attributes related to electromagnetic scattering and depending on the type of materials. These databases include a huge amount of objects such as terrain, vegetation, buildings, vehicles … modelled by thousands of polygons.

The classification process enables to use pictures and textures in order to affect physical materials at pixel level. As a consequence, a simple polygon is turned in a combination of different materials, clutter materials, dielectric materials or metallic materials. Classically, the picture to be classified is decomposed in layers. For example, one « grass field » layer, one « road network » layer and one « forest » layer are created for a ground picture, in the case of terrain. For example, one « wall » layer, one « window » layer and one « door » layer are created for a façade picture, in the case of buildings as shown below:

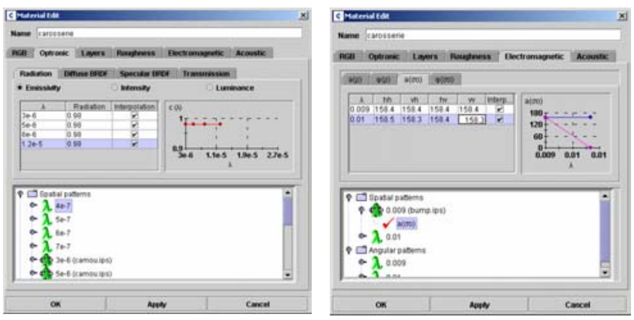


For each layer, a material modulation is computed, and a EM pre visualisation enable to check the EM consistency of the physical material allocation, as shown hereafter:

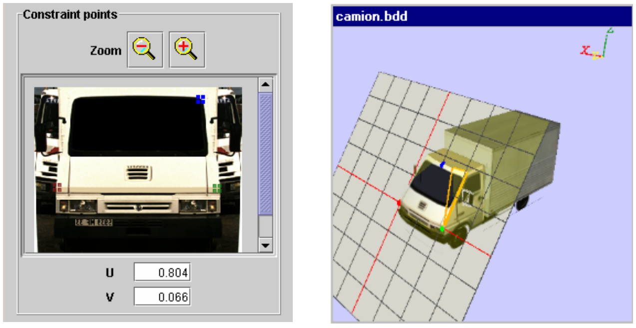


➢ Modelling tools useful to manipulate the geometry and the physical attributes assignment.

This set of tool is very important and enables both to check the physical values of the materials, for instance the spectral and angular dependency of Fresnel reflection coefficients, as shown below:

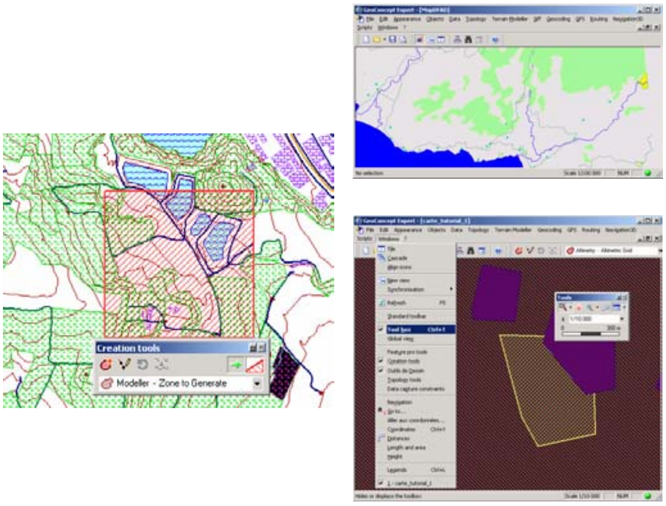


But also to affect the physical data on the geometry, very efficiently, using specific automatic texture mapping mode that enables to respect for instance continuity on several neighbouring polygons.



➢ Terrain modelling tools that automatically generates the first draft of the database including the physical attributes, with the possibility to detail this draft using the previous modelling tools.

Terrain modelling is based on the AGETIM OKTAL SYNTHETIC ENVIRONMENT product. This product is currently used by DGA in CELAR, LRBA, ETBS and ETAS to create 3D virtual mock up for defence applications. AGETIM 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 are applied on source data.



A very useful feature consists in profiling "templates" (see picture below), in order to transform simple cartographic 2D features into full 3D geometry, automatically enhanced with the physical attributes.

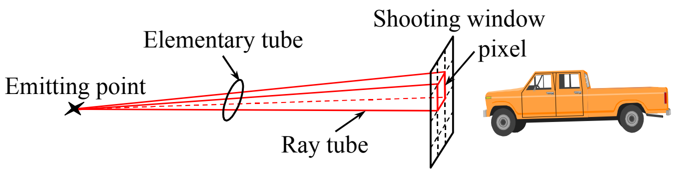
3 - Electromagnetic computation

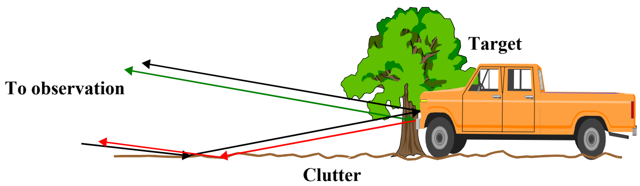
For EM computation FERMAT associates different techniques:

➢ A very optimised ray tracing technique which consists in managing the intersection and the path tracing, first from the emitting sources then to the receiving points. Computation time does not strongly depend on scene complexity thanks to an advanced scene topology pre computation, based on voxelisation.

The main requirement for FERMAT is to be sure of not forgetting any possible path on EM energy propagation. Four neighbouring rays constitute a pyramid. Combination of all pyramids covers all the free space supposed to contain EM energy.

The "shooting ray" technique, or "forward ray tracing" technique, is well adapted to the high frequency electromagnetic purpose. A set of rays representing the incident plane wave is shot toward the observed area composed by objects tessellated with triangles. More specifically, from an emission point, this area is included in a cone in which elementary tubes of four rays are launched. Every tube is defined so that its intersection with the object constitutes a planar surface. When a dense grid of uniform geometrical optics rays is shot, the efficient ray tracing algorithm for antialiasing, implemented in the Shooting & Bouncing Rays technique, drastically decreases the shooting ray number.





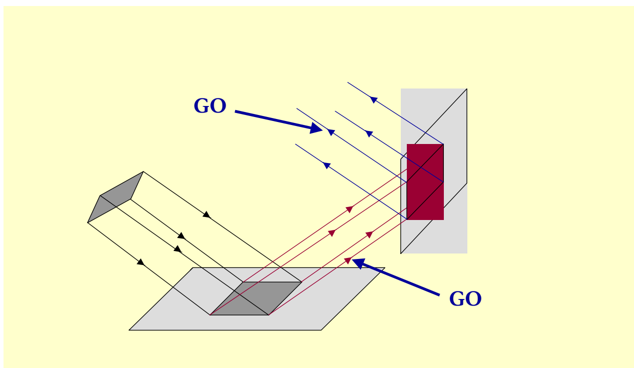
Currently, performances are nearly independent on scene complexity. To do this, the ray tracer uses a spatial subdivision method, which enables to get a perfect knowledge of the scene topology before computing. Except for moving objects, which possess a special treatment, this topology is static and available till the database does not change. Scene space is decomposed in a hierarchy of volume elements (voxels) which both contain the list of inner objects and topological relations with the other voxels. Space scene is so turned into a recursive space of voxels, which improves efficiently the intersection computations.

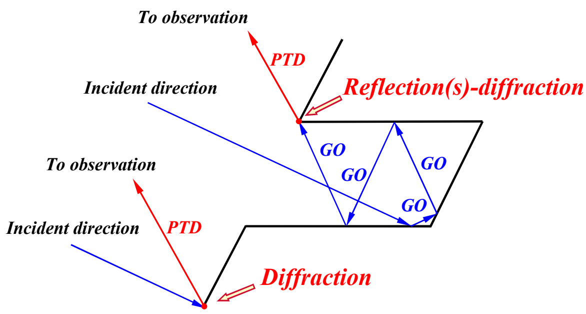
Moreover, this family of ray tracing implements a very original method for "sparing rays" called "antialiasing". Antialiasing acceptation is different in EM physics than in imagery. The aliasing artefact classically occurs when a polygon becomes smaller than the ray spot, for instance due to the distance. This is the most important artefact concerning the physical aspects. In any case, the solution to improve quality mainly consists in over sampling by tracing more rays. The FERMAT method, with regard to physical requirements, is the adaptive one. The idea is that the density of rays is proportional to the local 3D complexity. For instance, a few rays are traced to a uniform huge polygon when many rays are traced to a very complex small target.

The most important antialiasing criteria are the number of different polygons in the ray spot, the number of different materials, and the normal vector variation within the ray spot.

Finally, the ray tracing method is based on CORBA multi threading which enables to take advantage of parallelism computing. So a heterogeneous computer network can be used to accelerate the process.

- Complete electromagnetic models, which includes propagation, reflection, scattering, diffraction and a unified strategy merging near field and far field formulation. Computation time does not strongly depend on scene complexity thanks to an advanced scene topology pre computation, based on voxelisation. The management of surface roughness enables to extend the physical model up to millimetre domain. The models advisedly use the formulations of Geometrical Optics (GO), Physical Optics (PO), Uniform Theory of Diffraction (UTD) and Physical Theory of Diffraction (PTD).

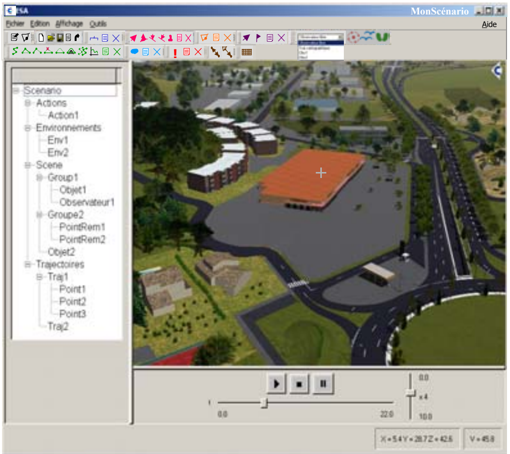




Thus, the scattering of intercepted surfaces throughout the multiple bounces, edge diffraction, reflection(s)-diffraction and/or diffraction-reflection(s) coupling could be considered.
Attenuation due and meteorological parameters have been taken into account. Both effects are predicted by applying the recommendations from the CCIR in Geneva. The atmospheric effects cover oxygen and water vapour absorption, clouds, haze, fog, and different intensities of rain attenuation.

- ➢ Ergonomic tools dedicated to scenario definition (objects positioning, 2D/3D paths edition, moving objects paths assignment, radar paths assignment, radar parameters definition…).

Interactive tools enable to modify objects and sensors positions, create trajectories using 3D defined control points, interpolate and smooth paths, add objects in the 3D scene, play and replay scenarios…



- ➢ Special radar sensor templates, for SAR for instance

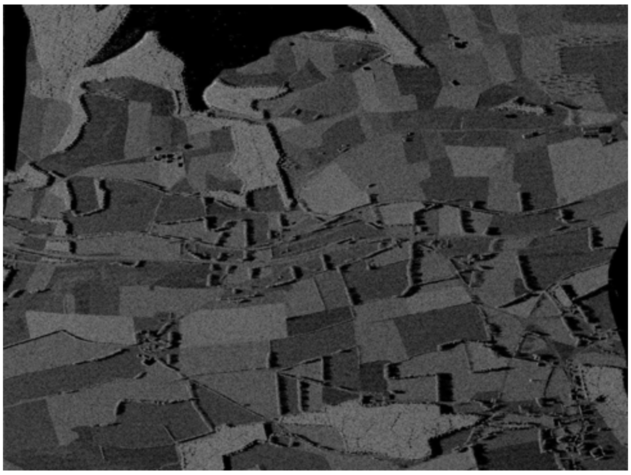
Interactive tools, specially aimed at SAR simulation enable to prepare SAR scenario i.e. to define: objects, radar position and orientation and to create their own trajectories.

FERMAT carries out direct computation of the EM waves interactions with involved targets and the 3D environment. Targets are defined using real CAD files so FERMAT evaluates target and clutter contributions in the same process. FERMAT naturally takes into account geometrical effects of theses interactions: masking and shadowing, « speckle», dihedrals configuration (from terrain, vegetation and superstructures respectively such as cliffs, wood edges, buildings, target/clutter coupling), multiple paths phenomena including transmission.

The radar instrument is simulated by an observation transfer function depending on angles, range and speed, defined by the "radar ambiguity function".

The first applications of FERMAT concerned enhanced vision systems based on millimetre Doppler radar, for military and civil applications. In the case of civil airport context, for very critical atmospheric situations, these enhanced vision systems have been assessed both for landing and ground management.

Current applications concern SAR modelling, as illustrated below. FERMAT computes SAR images of targets within natural background, parameterised by the radar resolution, which can be a very interesting means to simulate image-processing algorithms for automatic recognition. For instance, with a Monte Carlo approach, in the frame of a parametric study, to assess algorithm sensibility to one parameter, all parameters are frozen except one.



FERMAT validation exploits the fact that the same computing process is performed on the targets and the environment or background, which makes possible to validate radar calculation by RCS computations on objects of reference. Thus, the validation is based on comparison with other EM tools and model in the scope of asymptotic methods, in the context of national and international specialised « workshops » and also on comparison with other reference methods, in simplest cases, for canonical EM situations.

4 - Prospects

A lot of FERMAT complementary tools evolutions are already planned. The main items of the FERMAT roadmap are:

- ✓ Improving the curvature modelling and the divergence management due to curved objects
- ✓ Interoperability of FERMAT using the SEDRIS and HLA standards
- ✓ Special packaging for target detection studies
- ✓ Special packaging for ground-target interaction modelling
- ✓ Special packaging for SAR and bistatic configuration.
- ✓ Wall penetrating radar simulations capabilities
- ✓ Automatic indoor modelling using AGETIM

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