Radar Echo Simulation of Large Scale Environments Including Complex Targets

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Abstract— Guidance of weapon systems relies on sensors to analyze targets signature. Defense weapon systems also need to detect and then identify threats also using sensors. One important class of sensors is millimeter waves radar systems that are very efficient for all weather detection. But such sensors systems are so complex that they need simulation to be tested in a large variety of operational conditions. And the synthetic environment, which means physical target and its background (terrains, buildings, vegetation and other entities) rather than just the target itself, is very import for such sensors system simulation.

This paper presents a state of the art of millimeter waves radar simulation. A short presentation of asymptotic methods shows that physical optics support is mandatory to reach realistic results.

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

Finally, examples of results using SE-Workbench-RF are showed and commented.

1. BASIS OF SE-WORKBENCH-RF

1.1. Asymptotic Methods

The physically exact way to compute EM field are the "full wave" methods that are strictly based on the resolution of Maxwell equations.

Full wave methods often use finite element solvers since they apply the four Maxwell equations for each finite element, assuming the fields remain constant within each finite element. Due to this approximation, it is clear that the size of a finite element must be smaller than the wavelength due to the phase rotation of a plane wave. Classically, in electromagnetism, a tenth of the wavelength is a correct first order approximation. So it comes that the amount of finite elements i.e. the time of computation and the memory allocation is all the more important as the wavelength decreases (i.e., the frequency grows) and as the size of objects increases. That is the main reason why full wave methods are not applicable to millimeter waves and large 3D scenes.

In order to bypass this impediment, SE-Workbench-RF uses asymptotic methods coupled to ray tracing [1] to compute scattered electromagnetic fields at high frequency (the size of the objects is supposed to be large compared to the wavelength). In the case of complex targets, the results are very similar to the "exact" method for a much lower computation time. In Fig. 1 the theoretical response of a metallic plate is compared with the value given by SE-Workbench-RF.

Where a few GHz is a high limit for "exact" solutions used on this type of objects, it is almost a low limit in terms of physical validity for asymptotic methods. The standard computation range addressed by this method is roughly between 1 to 100 GHz on far more complex scenes (natural terrain of several kilometers wide with several complex targets inside).

1.2. Ray-tracing

SE-RAY-EM software is the EM kernel of SE-Workbench-RF product line.

Ray-tracing is done through the Shooting and Bouncing Rays (SBR) technique that has been further optimized to calculate efficiently the intersections between rays from the transmitter towards the 3D database and back to a receiving point

Rays are traced from transmitters through a grid (pixels). The intersections of theses beams are computed. There are two types of interactions that are based on two formulations:

- Geometrical Optics (GO) when the beam is reflected by a metallic or dielectric surface.
- Physical Optics (PO) towards the reception points at each interaction.

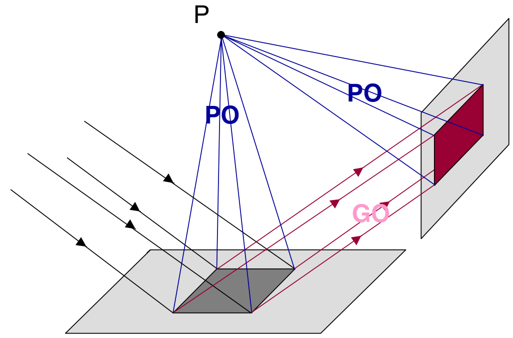

Figure 1: Principle of beam interactions.

To save computation time an adaptive anti-aliasing mechanism is implemented in SE-RAY-EM. Adaptive anti-aliasing is very interesting for EM computations as:

- The size of the primary grid can be coarse as the result of computation is a signal and not an image. The only constraint is that the grid is thin enough to detect important elements of the scene.
- The accuracy needed for EM computation is linked to the wavelength and object boundaries must be sampled at a fraction of the wavelength. Without adaptive anti-aliasing, the computation should use a $100,000 \times 100,000$ pixel grid!
- Adaptive anti-aliasing enables to reduce the number of contributors for which EM models are applied. These complex computations have a cost that cannot be neglected and can be done for a lot of wavelengths. Reducing the number of contributors is then inevitable to reduce computing times.

2. GPU COMPUTATION

During the last years, several technical improvements have been made, especially concerning the SE-RAY-EM ray tracing kernel. The main improvement concerns the performance of computation, both by using parallel computing and simplifying the mode. This approach is very promising, the main reason being that it exists a reference model which is the standard SE RAY-EM software since everything is compatible with this reference version.

Nowadays, Graphic Processors Unit (GPU) have proven to be very efficient for optimizing General Purpose (GP) computations, and particularly ray tracing applications [2] as SE-RAY-EM. However, the transition to GPU is not straightforward and several issues have to be taken into account [2].

2.1. Issues

Since GPU are very efficient for single precision floating point (float) computation, the implementation has then been designed to only uses double when it is absolutely necessary, mostly in the computations that involve the phase of the electromagnetic signal.

For CUDA version of SE-RAY-EM, OKTAL-SE has developed an alternative based on BVH (Bounding Volume Hierarchy) method. The BVH is a tree structure applied to the terrain tiles and to the objects.

In the new CUDA version of SE-RAY-EM, instead of tracing individual rays, we use "cones" to trace beams.

If the electromagnetic computations depend on the working frequency, the geometric computations are common to all frequencies. In this new CUDA version of SE-RAY-EM, we postpone the frequency computations for as long as possible by generating all geometrical contributors first.

2.2. Results

The first test (Fig. 2) consists in comparing qualitatively the radar cross section obtained between the GPU implementation (red) and both the standard version of SE-RAY-EM (blue) and the reference from the ONERA MAXWELL3D software (green), which is based on Integral Equation EM approach and Moment Method numerical implementation.

The target is an aircraft, 1000 m away, at a frequency of 600 MHz. Results computed by the three codes are very similar.

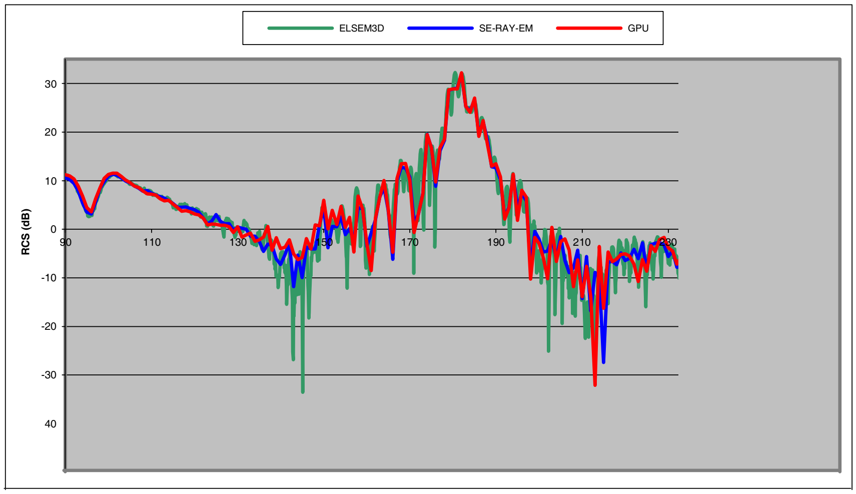

Figure 2: RCS of an aircraft computed with ELSEM3D (green), SE-RAY-EM (blue) and GPU version (red).

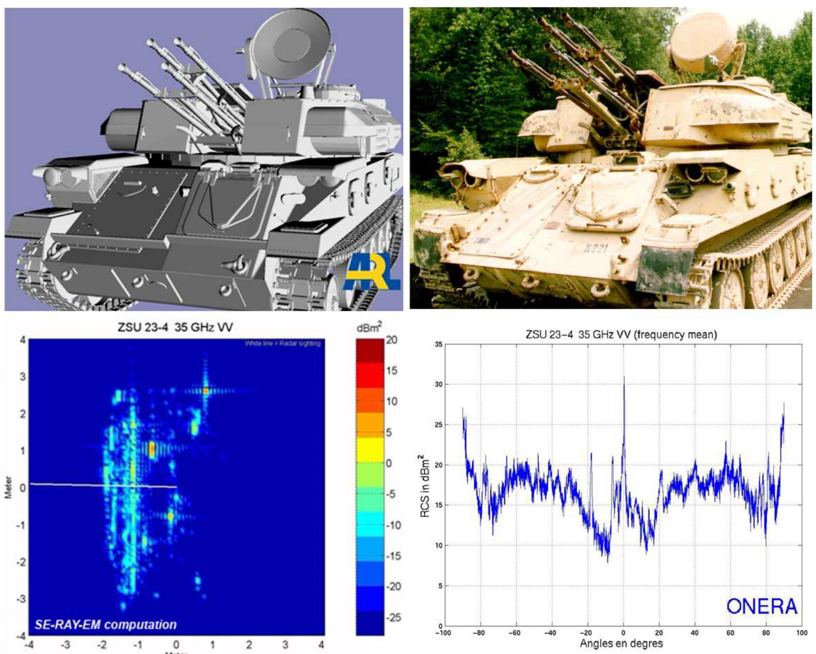

Figure 3: Comparison of SE-Workbench-RF, with real operational complex measurements.

The second test set up consists in the computation of the RCS at 10000 m of a tank with one or 151 frequencies from 8 to 11 GHz.

To compare the performances, the computations have been performed using the standard version of SE-RAY-EM and using the new parallel implementation with both a CPU and a GPU version on a desktop PC win: Intel Core I5 3470 and Nvidia GeForce GTX Titan.

Table 1: Computation times.

	Standard Core I5	**CPU Core I5**	**GPU GeForce Titan**
Mono-frequency	12.17	5.60	0.111
151 frequencies	80.40	70.4	0.735

The GPU implementation is 10 to 100 times faster depending on the performance of the graphic board. This approach is definitely very promising. GPU power increases very rapidly. The amount of CUDA cores grows exponentially. This opens wide the field of application of radar simulation.

3. SOME EXAMPLES OF RESULTS

3.1. ISAR Simulation

In this example, in the frame of a NATO group and in cooperation with ONERA and ARL, SE-Workbench-RF has been validated through the comparison of ISAR images simulated using SE-Workbench-RF with a set of measurements provided by ARL on a test military vehicle:

3.2. SAR Simulation

Examples of SAR images computed using SE-Workbench-RF are shown here after.

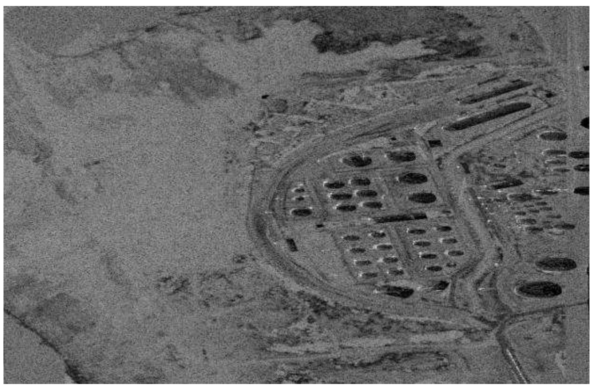

Figure 4: SAR image generated using SE-RAY-EM CPU version.

Figure 5: SAR simplified image for Man In the Loop real time simulation generated using SE-RAY-EM GPU version.

3.3. RBGM (Real Beam Ground Mapping) Simulation

An example of RBGM image computed using SE-Workbench-RF is shown here after.

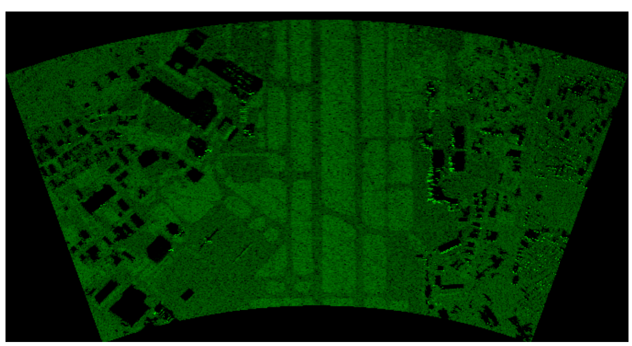

Figure 6: RBGM image generated using SE-RAY-EM GPU version.

REFERENCES

1. Mametsa, H. J., S. Laybros, T. Volpert, P. F. Combes, P. N. N'Guyen, and P. Pitot, "FERMAT: A high frequency EM scattering code from complex scenes including objects and environment," *PIERS Proceedings*, 28–31, Pisa, Italy, March 2004.
2. Boudet, A., N. Douchin, and P. Pitot, "GP GPU acceleration of a po based RF simulation software dedicated to radar simulation in large scale and complex environments," *PIERS Proceedings*, 657–661, Stockholm, August 12–15, 2013.