Imaging Radar Simulation in Realistic Environment Using Shooting and Bouncing Rays Technique

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ABSTRACT

A three dimensional (3-D) realistic radar simulation package including imaging radar simulation concept applied to multisensor scenarios is under development as a project between the Electromagnetism and Radar Department of ONERA and the OKTAL SE Company. Taking advantage of various studies in the domain, this partnership associates the expertise of ONERA in radar phenomenology, wave interaction with targets and clutter, with that of OKTAL SE in the generation and management of realistic scene databases in the infrared and optical domains using advanced Shooting and Bouncing Rays (SBR) techniques [1, 2, 3]. The objective of this program is to develop simulation tools capable of predicting the behaviour of sensors in a realistic environment. This is achieved by coupling a terrain database completed by radar and optical features and a fast SBR algorithm. This paper is focused on the specification of the radar (i.e. electromagnetic wave interaction) principles. Outputs from the simulations illustrate the effectiveness of the tool in respectively, Synthetic Aperture Radar (SAR) simulations; and in the multisensor evaluation context in airborne applications such as enhanced vision in airport application context.

1 PURPOSE

Multiple applications could be created from the basic principles investigated in this project. This paper deals with the possibility of calculating multiple radar interactions in a realistic database. Applications include development and evaluation of new detection and signal processing algorithms to carry out ergonomic study. Simulation parameters take into account equipment potentialities, the sensitivity to meteorological effects and moving or non-moving target discrimination. This paper sets out a specification of the radar principles and examines the results of the first simulations in a realistic environment. Operational simulation of the millimetre wave sensor enables us to specify, evaluate, qualify and test the performances and limits of such future systems. To illustrate the effectiveness of the tool for performing research in this field, a variety of imagery output from the simulations is shown.

2 TECHNICAL FEATURES

2.1 Geometrical realistic database

For the principal airborne application presented in this paper, simulations are achieved using geometrical database which represents a numerical model of terrain, relatively undulating, rich in woodlands vegetation, and isolated trees. The database is composed of a very accurate high-resolution central area and a surrounding area at a lower resolution. The database is automatically generated using a terrain modelling tool (OKTAL SE product) from geographical data and paper maps.

This central area represents a 5 km x 7 km rectangular terrain, containing plane surfaces (crop fields, meadows, forests, lake), linear elements (roads, river) and punctual items (trees, man-made constructions, bridge, pylons with electrical wires). It is described by 200,000 polygons.

The central area is enclosed by a 20 km x 20 km surrounding domain, which is made up of fields, a lake and a river. This environment is described by 7,000 polygons.

Interesting facetted targets, fixed or in motion, land or airborne could be positioned in this scene.

2.2 Optical and infrared features

On figure 1, a part of a scene from the database is shown.

Other databases have been developed for specific application such as enhanced vision in the airport of the future project.

For global application such as multisensor scenarios, specific features and textures related to infrared, optics and radar are provided for each polygon of the scene database and for each polygon of the targets.

Figure 1: Part of a scene from the database

2.3 **Radar features**

More particularly, for radar analysis, two classes of materials have been defined: the metallic materials and the environmental clutter with a predominance of specular and scattering effects. Each category of clutter is characterised by its backscattering coefficient average σ_0, which depends on the incidence angle and polarisation components (HH, VV, VH, and HV). Metallic materials (steel, aluminium) follow the Fresnel reflection coefficients $R_\perp$ and $R_{//}$ (respectively equal to –1 and + 1 for the electric field). The plane wave and clutter or target (composed essentially of metallic structure) interaction is specified below.

3 SHOOTING AND BOUNCING RAYS TECHNIQUE

3.1 In optical and infrared domains

Each polygon of the 3D scene is characterised by :

- physical attributes such as : spectral emissivity, spectral diffuse and specular BRDF; and spectral transmission (for non opaque materials),
- thermal attributes such as : conductivity, density, specific heat, thickness, convection coefficient, which allow computing the temperature of each polygon using thermal software.

An optronic (visible and infrared) model is implemented in our SBR algorithm. For each intersection between the 3D scene and each ray cast, it takes into account thermal emission, diffuse and specular reflection of the sun and diffuse reflection of the sky; and effects of atmospheric propagation.

3.2 In radar applications

The shooting ray technique is well adapted to this purpose. A set of rays representing the incident plane wave is shot toward the observed area composed by target and/or clutter (see figure 2). 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 their intersection with the target (respectively the environmental clutter) constitutes a planar surface (respectively the same category of clutter). When a dense grid of uniform geometrical optics rays (10 rays per wavelength) is shot [4], an efficient algorithm of antialiasing [1], implemented in our SBR technique, drastically decreases the shooting ray number. A fast Radar Cross Section (RCS) analysis of complex 3-D perfectly conducting targets was carried out using this approach [5].

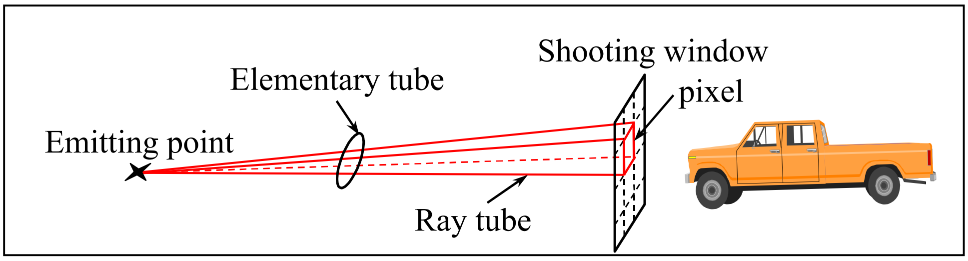

Figure 2: Shooting and bouncing rays technique

4 RADAR INTERACTION

4.1 Plane wave and clutter interaction

Each category of clutter is characterised by its backscattering coefficient average σ_0, which depends on the incidence angle and polarisation components (HH, VV, VH, and HV). But, real simulation values for σ are obtained by including statistical fluctuations (for speckle effects) using an exponential probability density function coupled with an uniform probability density function for the phase of backscattered field. This fluctuation is stored in each polygon as a texture pattern. Data on backscattering coefficients are extracted from (sparse) measurement campaigns published in literatures and F.T. Ulaby and M.C. Dobson‘s works [6]. An important synthesis task was performed in order to take into account frequency bands diversity and polarisation information. Contributions from all rays are summed up at a far-field observation point to obtain the final backscattered field from a definite area**.**

4.2 Plane wave and target interaction

High frequency asymptotic techniques and shooting rays technique were coupled in order to predict the backscattering field from complex targets [5]. To evaluate the multiple interactions, each ray is followed from one part of the target to another one. For large targets (according to the wavelength), the main contributions come from specular points at surfaces or edges. Thus, the RCS of complex targets can be predicted using the high frequency asymptotic approximations. Now, for facetted targets, two principal methods are applied: Physical Optics (PO) for surface scattering [4, 5, 7] and Geometrical Optics (GO) coupled with previous method to take into account multiple interactions. The shooting and bouncing rays technique performs very well in processing these interactions which can not be neglected because of their high return in wide aspect angle. Again, contributions from all rays are summed up at a far-field observation point to calculate the final backscattered field, eventually leading to the RCS of the target. This method is tested using examples of complex vehicles such as jeep or tank and then, illustrate the necessity to take into account the multi-bounce effects in backscattering prediction.

Prospective work is ongoing in order to include edge diffraction [5, 8] using Physical Theory of Diffraction (PTD) or/and Uniform Theory of diffraction (UTD) and the coupling between such methods and GO. Thus, the scattering of intercepted surfaces throughout the multiple bounces, edge diffraction, reflection(s)-diffraction and/or diffraction-reflection(s) coupling could be considered.

4.3 Radar propagation

Attenuation due to vegetation and meteorological parameters has been taken into account. Both effects are predicted by applying the recommendations in 1986 and 1992 of the CCIR (Comité Consultatif International des Radiotélécommunications) in Geneva respectively. The vegetation model was improved after a comparison with a database of measurements for the cases of vegetation with and without leaves [10]. The atmospheric effects cover oxygen and water vapour absorption; clouds, haze, fog, and different intensities of rain attenuation.

4.4 Radar parameters

The principles used in the radar sensor modelling are flexible and thus preserve the evolutionary concept. This modelling transforms the field in front of the antenna into parameters such as range, radial velocity and angles. Then, this domain is processed according to specific procedures and operating modes. The performed simulation is developed from the matched filter theory and the associated ambiguity function. This approach based on energetic concepts (maximising signal-to-noise ratio for a known signal) is applied on all standard radar systems.

4.5 Antenna

Various antenna models are under consideration according to specific objectives, practical applications and aspect angle coverage requirements.

5 EXPLOITATION – UTILISATION

5.1 Radar cross section calculations

Radar Cross Section (RCS) calculations were achieved using the principles previously presented. Multi-bounce contributions are taken into account in this case.

An example of millimetre wave modelling facilities on a 25000 facetted armoured repair and recovery vehicle has been performed. Time calculation is around 6 minutes for each range profile (obtained from 200 synthesised frequencies) on a standard workstation. Measurements were performed concerning this target. Very satisfying agreements between calculations and experimental results were observed in terms of RCS and Inverse Synthetic Aperture Radar (ISAR) imagery.

5.2 SAR simulation

Generally, imagery sequences generated by the radar transfer function are displayed using 2-D or 3-D visualisation tools. The visualised output data are voxels, which contain information about backscattering strength, angles information, distance and velocity.
In this particular case of SAR simulation, the illustrated calculations on figure 4 have been conducted using the following parameters:
- flight altitude of the carrier: 2 000 m
- image area: around 2 km x 2 km
- synthetic antenna beamwidth: 0.032°
- elevation beamwidth: 13°
- incidence angle: 63°

1024 range gates of 2 m (i.e. range resolution) were used to calculate the image on figure 3

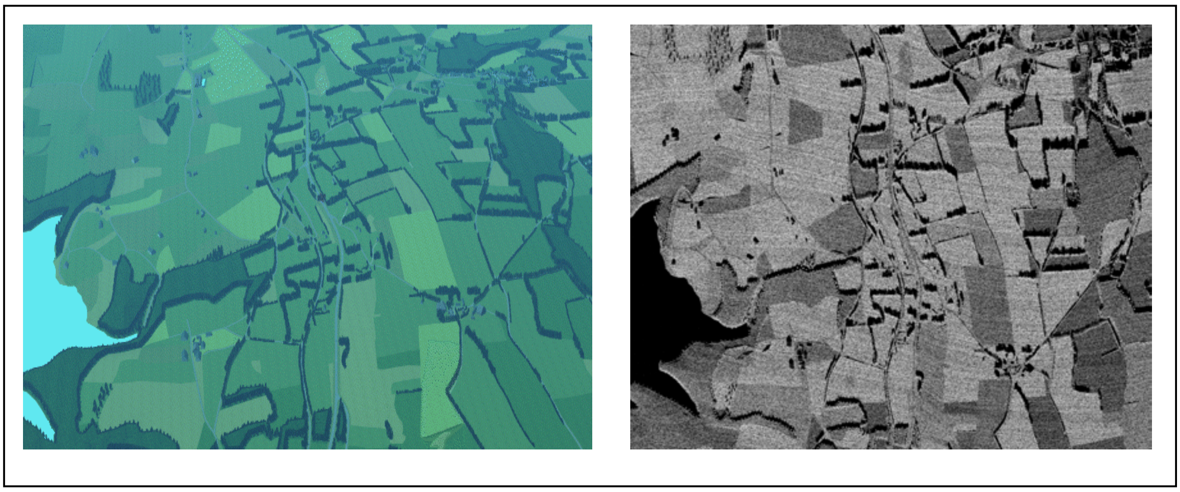

Figure 3: Specific area from database in optical domain and its SAR image simulation

5.3 Enhanced vision in airport context

The global project includes, among other subjects, enhanced vision using millimetre wave radar and infrared sensors imagery principally in poor weather conditions (haze, fog, rain). In order to evaluate the contribution of high resolution multisensor system in the airport context, simulations have been conducted on virtual airport database (ie Toulouse Blagnac airport area).

Results at 500 m from the touch down zone in front of the runway is shown on figure 4 for a simulated 94 GHz radar. Images have been calculated on a field of 30º (azimuth) by 10º (elevation). The antenna beamwidth is 0.15º in azimuth and 10º in elevation. The range gates are summed up in each 0.15º in elevation to obtain square pixels on such figure. This is chosen in order to achieve the same resolution both in cross range and along range. For each resolution cell or pixel, coherent summation of the different contributions from clutter and targets were performed according to the principles described above. To limit speckle fluctuations , average of 10 uncorrelated images are calculated and displayed.

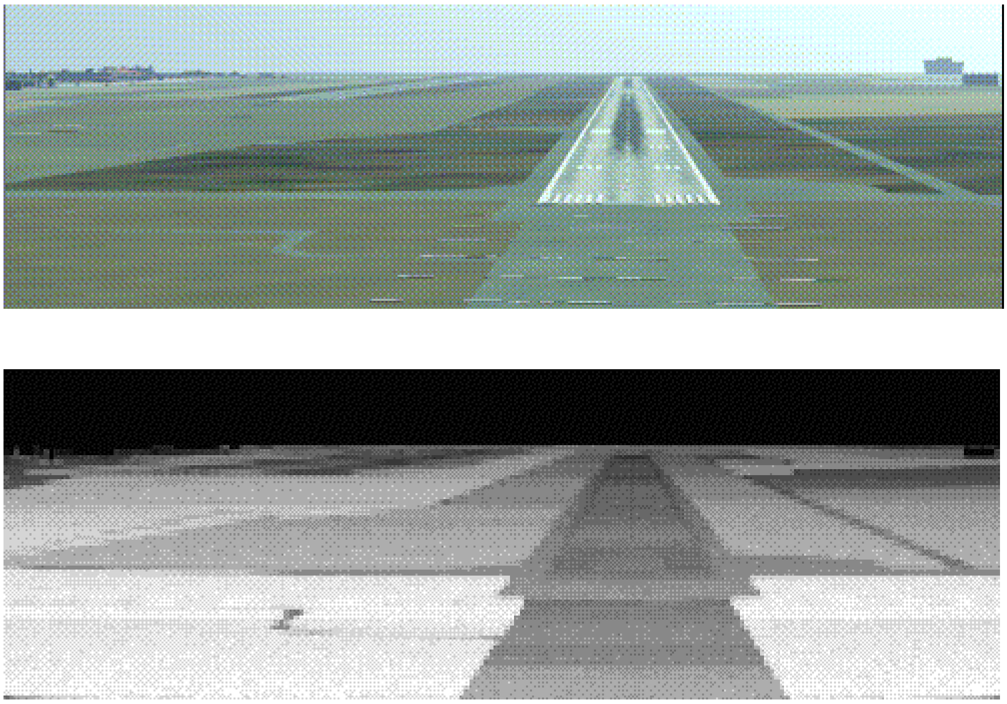

Figure 5: Visible and 94 GHz radar image simulation – 500 m from touch down zone

6 SUMMARY AND PROSPECTS

Plane wave and target (or clutter in realistic database) interaction using SBR technique and high frequency asymptotic formulations have been presented in this paper. Taking the opportunity of various studies in this domain, a radar simulation package is under development. The simulation tool provides realistic calculations (RCS, 2-D SAR image, …) for complex geometry or database coupled with realistic scenarios. Future prospects intend to take into account target description by parametric surfaces, dielectric layers on or material loading in the targets and roughness of the target surfaces. Moreover research is ongoing on strong coupling between target and its immediate environment for other potential applications on radar imagery.

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