A FULL ELECTROMAGNETIC SAR IMAGE SIMULATOR FOR URBAN STRUCTURES

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ABSTRACT

The purpose of this work is, starting from a close tracking of the basic electromagnetic processes, to propose a simulator enabling a better understanding of the radar images of urban areas. An improved understanding of the radar images formation processes in this case should lead to a better knowledge of the potentialities and the limits of the SAR imagery and interferometry of urban areas.

We argue that finite-difference time domain method (FDTD) is a quite new and promising approach for the propagation in urban areas. As a first example, we consider canonical scenes, e.g. parallelepipedic buildings on flat backgrounds, without roughness. The backscattered field is carefully studied and interpreted as a function of the optogeometry of the scene and the structure of the electromagnetic pulse.

This opens the way to more complicated urban structures, a study in progress.

1. INTRODUCTION

Analysis and evaluation of high resolution SAR systems needs a modelisation of the whole imaging system. A major scientific problem, in this respect, is the generation of SAR raw data with high numerical and modeling accuracy, and restricted computer time and space. Such data will be provided by the future Earthobservation system Orfeo, with metric resolution, thus better than the ERS, RadarSat, or EnviSat resolutions. Even if this evolution opens the way to many applications like Digital Model of Elevation reconstruction, it is of poor help, as far as urban areas are concerned, for a good understanding of radar signal formation with high and very high resolutions.

Interactions of Radio Frequency radiation with urban environment, with complex surfaces, are still badly controlled. A far as we know, all attempts to understand high resolution radar signals have failed, due to the lack of proper knowledge and proper quantitative models [1].

For example, canonical scenes consisting in a single dielectric building and a flat dielectric background are still open problems. Quantitative explanations of the link between building properties, sensor characteristics and the corresponding SAR image are not available. So far,SAR images of urban areas are continuously acquired by the available SAR sensors, but, in practise, users are not able to extract from those images all the useful information.

The main effort to apply SAR images to urban areas monitoring has been devoted to detection, exploiting the fact that the urban areas appear as brighter pixels in a SAR image; the complexity of the electromagnetic phenomena that occur in urban scenes imposes a severe limit to any further investigation.

Over the last years, there has been extensive work on the simulation of wave propagation in urban area, but these studies have been mainly devoted to mobile radio propagation characteristics and energetic balances, rarely to image construction. Most of these works use approximate methods and backscattering models depending on the Uniform Theory of Diffraction [2, 3]. The present work proposes a new method to simulate SAR raw data : the finite-difference time domain method (FDTD), an exact method in the numerical sense. Very few studies deal with this kind of method to compute backscaterred electromagnetic field from urban structures and when they do, so they are often of limited context ; as an exemple, Boulands work [4] is restricted to two-dimensional world. The advantages of FDTD include : rigorous algorithm, possibility to handle dispersive materials including metals, time-domain simulation and modularity. The main disadvantage is that for many three-dimensional structures of interest to the radar community, FDTD simulation with high accuracy requires a computer memory rapidly increasing with the scene dimensions and the models meshing parameters ; the time needed to run increase consequently, in an unsustainable fahion. Todays advanced computing power enable to apply this method for SAR imagery. The simulator presented here is developed with the EADS tools.

2. FDTD SIMULATIONS

2.1. FDTD algorithm

The FDTD algorithm, based on the Yee scheme, discretizes with appropriate, interlaced, meshings Maxwells equations in both time and space coordinates [5].

Equations solver quality is guaranteed by the principles described in [6]. The FDTD computing area is obviously limited in space : the waves inside this area are reflected instead of leaving the FDTD domain, as if the latter was surrounded by perfect conductors. Absorbing boundary condition for truncating three-dimensional FDTD meshes is the Berengers perfectly matched layer (PML) technique [7].

2.2. Acquisition modelisation

The first step is the CAD construction and the meshing. The three-dimensional domain is described by its size and the spatial step. Then urban scene is created by determining its dimensions, its features and its electromagnetic parameters. Each created object is defined by its geometry (due care is given, of course to sampling theorems) and its electromagnetic parameters (relative permability μ_r, relative permittivity ε_r and conductivity σ). The complexity of its geometry is illimited. An object can be metallic, anisotrop or even dispersive.

The simulator presented here is able to simulate monostatic and bistatic SAR acquisitions for a particular position of the radar, as shown in the figure 1.

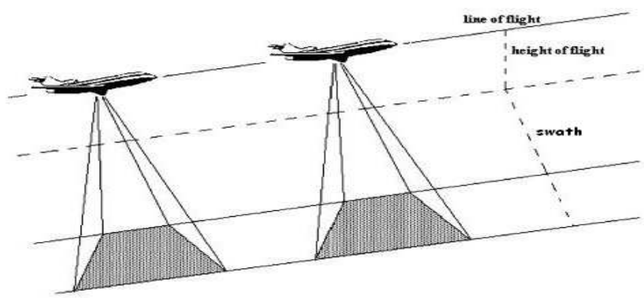

Fig. 1. Acquisition geometry by an airborne radar.

Moreover it is possible to generate SAR image considering a set of simulations relative to many positions of the radar, defined by their angles in the spheric geometry.

2.3. Incident field characteristics

In SAR imagery, airborne or spatial radars are used. Thus the incident field must be initialized outside the discretization domain. This requires the description of the incident field in the FDTD domain and the computation of the backscattered field out of the area. This step is necessary to the computation of the field before the PML are applied. Huygens principle is the basic tool for these two operations ; although the details can be rather subtle, let us just say that a so called Huygens surface is delimited inside the PML to compute the near-field/far-field transformation [8].

Plane wave approximation can be used with reasonable accuracy in some cases. This approximation is guaranteed for space radars. However its validity for airborne radars is restricted to only a small part of the ground swath. Such is the case in our simulations. For exemple, if we consider a building with a characteristic dimension of 100 m, illuminated with a mean incident angle of 60 degree by a radar at 3500 m of altitude (Fig. 2), we find the extension of the incidence angles is around $\Delta\theta = 0,4$ degree ; in this case the maximal distance between the plane and spherical wavefronts is about 17 cm.

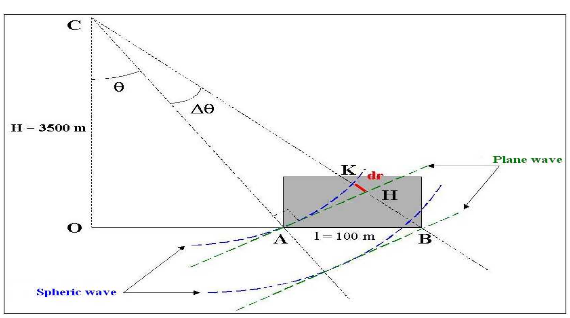

Fig. 2. Airborne radar emitted plane and spheric waves illuminating a scene with a characteristic dimension l.

In the simulations, urban structures modelized have limited dimensions in order to legitimate the use of the plane wave approximation. In this case, only the electric field needs to be computed ; the magnetic field is given by the standatd relation : $\vec{H} = \frac{\vec{u}\times\vec{E}}{\eta}$, where $\vec{u} = \vec{u}(\vec{r},t)$ is the unit propagation vector and $\eta = \sqrt{\frac{\mu}{\varepsilon}}$ is the electromagnetic impedance.

As regards the mathematic formulation of the radar signal, we do not need to simulate a chirp pulse as it is the case in real systems. Indeed, if we can simulate a very short electromagnetic pulse, we dont need to use a frequency ramp anymore to improve the range resolution. The incident electric field is then modelized by $\vec{E}(\vec{r},t) = f(t)\vec{u}(\vec{r},t)$, where $f(t)$ is a gaussian pulse with spectral bandwith as large as required for a good signal resolution.

3. CONCLUSIONS ON STRUCTURE DETECTION AND CHARACTERIZATION IN URBAN AREA

The FDTD computation provides a new approach to simulate radar wave propagation inside urban areas. It is possible to study canonical scenes (for instance a dihedral corner formed by a parallelepipedic building standing on a flat background), from which we can study the backscattered field functions of the dimensions of the building, the ground width, the incidence angle of the electromagnetic pulse or the electromagnetics parameters.

Therefore, even if the roughness phenomenon is not already considered, it is possible to simulate a SAR image of the scene modelized : thus we can study multiple matter/radiation interactions existing in more complicated scenes consisted of several urban structures. This tool provide a promising way to improve our understanding toward the complexity of urban SAR images.

4. REFERENCES

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