A SIMULATOR PROTOTYPE OF DELAY-DOPPLER MAPS FOR GNSS REFLECTIONS FROM BARE AND VEGETATED SOILS

Marco Brogioni[1] *, Alejandro Egido*[2]*, Nicolas Floury*[3]*,Roberto Giusto*[5]*,*
Leila Guerriero[4]*, Nazzareno Pierdicca*[5]

[1]IFAC-CNR, Florence, Italy, [2]STARLAB,Barcelona, Spain, [3]ESA/ESTEC, Noordwijk, Netherlands, [4]University of Tor Vergata, Rome Italy, [5]Sapienza University, Rome, Italy

1. INTRODUCTION

The first theoretical description of the GPS reflected waveform measured by a receiver appeared in Zavorotny and Voronovich [1]. This model was applied by authors to ocean surfaces, introducing the probability distribution function of ocean slopes into the scattering coefficient that was modeled by means of the Geometrical Optics approximation. Subsequently, the same authors extended their work concerning GPS scatterometry over ocean to the case of a bare soil rough surface [2]. Due to its simple form, only the GO has been considered in the GNSS-R theoretical works developed up to now. This representation, excluding all Bragg effects, assumes that only incoherent scattering takes place. However, as described in the literature [3, 4, 5], the bistatic signal consists of both a coherent and an incoherent component. According to recent studies [6], the coherent scattering focused in the specular direction can largely overpass incoherent scattering when the observed surface is characterized by small scale roughness with respect to wavelength, like in the case of bare soil or lightly vegetated fields. Experimental evidence of this can be found in [7], where a simplified coherent scattering model was used to relate GNSS-R measurements to soil moisture volumetric content obtaining high correlation values.

This means that theoretical models able to reproduce the power amplitude measured over land by a GNSS-R receiver need still to be validated. In particular, the concept of a glistening area associated to the scattering from a large number of tilted facets fails, and the reflection comes mainly from the first Fresnel zone. A more complex situation can occur when the land surface is characterized by complex topography, which can originate more specular reflections, a situation which may resemble, but still not identical, to the one originated by a sea surface.

In this paper, the simulator which has been developed in the framework of the LEIMON Project, supported by ESA, will be described. First, some considerations about the signal characteristics of the particular LEIMON configuration will be presented, with particular attention to resolution and to the correlation time of the signal. Then, the GNSS'R cross-correlation process between the reflected signal and the direct signal will be simulated implementing a software which takes as input both the system and observation parameters. The incoherent soil scattering properties will be modeled through the Advanced Integral Equation Model, the coherent component simulation assumes a spherical shape of the wave front impinging on the surface, and the attenuation and scattering properties of the vegetation cover will be modeled by means of the electromagnetic model developed at Tor Vergata University. The output is represented in the form of Delay Doppler Maps produced by a GPS receiver looking down at the land surfaces onboard a platform at different height steady or flying at different speeds. Various examples as a function of geophysical and system parameters will be shown. The LEIMON data will be used to validate the simulator in the specific condition of the experiment, that is a receiver placed on a crane arm, about 25 meters above the surface. The simulator can be also used to predict the signal, both incoherent and coherent components, received from other types of platforms, thus allowing to design the right strategy for what concerns coherent and incoherent (e.g., look summation) processing of the data. The outcomes of this parametric study can also be translated into simplified relationships, which can be useful as a basis to train retrieval algorithms.

2. THE ELECTROMAGNETIC MODELS

The mean power of the reflected signal received by a GNSS'R system can be modeled by the integral bistatic radar equation which includes terms that represent delay filtering by the PRN code modulation and Doppler filtering. The geophysical properties of the scattering surface affects the magnitude of GPS signals through the bistatic scattering coefficient which, in case of signal scattered from land surfaces, is a function of the soil dielectric properties, surface roughness and vegetation cover.

Simulating the incoherent contribution requires analytical models of bistatic scattering. It is generally accepted that at L band, natural soil surfaces fall in the region of application of SPM and IEM. The latter in particular will be considered in this study in its Advanced formulation [8] and considering its polarimetric extension in order to account for circular polarization of both transmitting and receiving antennas, as in the case of GPS signals.

Two approaches are essentially reported in the literature for the computation of the coherent component produced by scattering from a rough surface. Both of them are valid for surfaces with small surface height standard deviations and small surface slopes. The first one considers the incident plane as a plane wave [4], whilst the other [9] considers the sphericity of the incident wave front. Here, the formulation of the coherent scattering coefficient proposed by [9] has been selected, since it correctly takes into consideration the spherical shape of the wave front impinging on the surface when produced by a real antenna.

Land surfaces are often covered by vegetation which interacts with the L-band electromagnetic wave of the impinging GNSS signal. This calls for an appropriate representation of the dielectric and morphological properties of vegetation in order to allow a correct reproduction of the its attenuation and scattering properties. Scattering from vegetation is mostly described by means of the discrete approach, which represents vegetation elements as dielectric objects of simple canonical shapes. The model which has been selected in this paper is the Tor Vergata model which includes multiple scattering of any order (between vegetation elements and vegetation and the soil) applying the Matrix Doubling algorithm. Furthermore, it is polarimetric [10], thus allowing a correct simulation of the polarization properties of vegetation scattering.

3. THE SIMULATOR

First of all, the configuration adopted in our experimental study will be considered, in order to test the simulator with data collected in the experimental LEIMON campaign. The simulator will be subsequently used to carry out a parametric study. Other GNSS-R configurations, such as airborne and spaceborne scenarios, will be considered in order to investigate the sensitivity of the processor output to geophysical. Realistic ranges of soil and vegetation variables will be given as input.

Among the simulator functions, the capability to identify the point of specular reflection above the Earth surface associated to reception of the reflected signal is a first step of the processing chain. In case of the LEIMON real situation, the identification of the transmitting satellite is performed as in common GPS receivers, using the up-looking antenna capturing the direct signal. Once the transmitter is identified, at a certain time one can compute satellite position (typically in ECEF coordinates) from satellite ephemerid. By knowing the receiver position and the surface geodetic height (provided as user input in latitude, longitude and geodetic height), the specular point can be computed in latitude and longitude. In case a simulation exercise has to be performed, the satellite can be postulated as user input, and its orbit is propagated until its reflection can be seen by the receiver within a suitable range of incidence angles (again supplied as user input). In both cases (a real measure or a simulated one), a local reference frame is assumed for further analysis, with the z axes coincident with the surface geodetic vertical at the specular point and the x axes tangent to the surface and laying in the plane of incidence. The transformations between the local and the absolute ECEF frames are then derived to compute the positions and velocities of both transmitter and receiver in the local frame. Once everything is projected in the local frame, the software computes for each point $x'y'$ of a two dimensional grid defined on the horizontal xy plane (i.e., the mean local plane tangent to the surface) the scattering direction (zenith θ and azimuth ϕ angles), the ranges from receiver to the point, and the Doppler shift (based on transmitter and receiver speed and Earth rotation). It is therefore assumed that the mean surface is locally coincident with its tangent plane z=0. Note that the range from transmitter to receiver and the incidence direction are assumed equal for all the surface grid points thanks to the large distance of the GPS satellites from the surface. The above quantities allow the program to compute the bistatic scattering coefficients associated to both the coherent and incoherent components and for RR (circular right-right) and LR (circular left-right) received-transmitted polarization combinations. Then the scattering coefficients are combined by the bistatic radar equation within regular intervals of time delay (proportional to the range) and Doppler shift in order to build the Delay-Doppler map. The receiver antenna gain is inserted into the radar equation as function of the point looking angle assuming a cosinusoidal pattern (being the antenna beamwidth provided by the user).

11. REFERENCES

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