Precise Geometry Simulation of Interferometric SAR Signal for Air- and Spaceborne Sensors

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Abstract: A complete interferometric Synthetic Aperture Radar (SAR) simulator has been developed. It achieves precise results by using geodetic models to represent the Earth's shape, and considering SAR effects such as range migration, Doppler shifts, or perturbations of movement in the airborne case, which are included via the inverse Extended Chirp Scaling Algorithm (ECSA).

INTRODUCTION

SAR raw signal simulation, its problems and its advantages in regard to the optimization of SAR system parameters and the development and validation of new processing and interferometric algorithms have been widely discussed in the literature (e.g., [1]). To sum up, simulation allows the control of a great variety of, not only system configurations, (sensor trajectories, PRFs, squint angles...) but also of scene characteristics (roughness, slope, permittivity...) in a parametric manner. In this paper a complete simulation scheme is presented, which is able to deal with all kind of SAR sensors, not only spaceborne as considered traditionally, but also airborne by means of the inclusion of its own differential characteristics.

GEOMETRICAL AND SURFACE MODEL

Many geometrical models can be selected to simulate a SAR mission. Options with an easy solution, such as flat or spherical Earth, are good enough in several situations in which a higher precision is not required. However, for this simulator a more accurate model has been chosen: the elliptical model. This model allows naturally the use of standard cartographic coordinates systems, and thus the results can be easily related to geodesic coordinates [4].

The main input of a simulator, from the geometrical point of view, should the platform position for every point in the space from where the system has transmitted a pulse. In this simulator some possibilities have been implemented. On the one hand, for the spaceborne case it is possible to provide the algorithm with orbit information given by five state vectors (as the Precise Orbit files of the ERS-1/2 satellites), which include position and velocity components at equally spaced mission times. Starting from these state vectors, position data at every azimuth time is obtained by means of interpolation.

On the other hand, in the airborne case the procedure accepts two values as an input: a constant altitude over the ellipsoid and the heading with respect to the north, since these two values are enough to represent a nominal trajectory. One important remark is the following: an airborne simulator must be designed to include the coordinates of a true flight, with possible deviations of position and attitude from the nominal straight track. In our implementation this has been done during the inverse SAR processing (see next section), by means of the inclusion of several steps to distort the nominal impulse response. Therefore, the airborne slant-range reflectivity will simulate a correctly focused image, while the effect of platform deviations has been included in the second part of the algorithm. Indeed, this solution can be considered the most accurate one, since the real airborne raw data are not distorted in the image domain but in the signal domain.

Regarding the information to characterize the terrain itself, the required data is the digital elevation map (DEM), as well as the electromagnetic characteristics of the terrain which is being simulated (permittivity ϵ or conductivity σ).

Once the Earth's shape and the SAR location are modeled, an important stage is to calculate each facet's vertex position. This can be done for every position of the trajectory by defining a plane in the looking direction, perpendicular to the forward axis (zero-Doppler geometry). Its intersection with the Earth is an ellipse that contains all facets' vertexes in the range direction.

Fig. 1 Vertex location within the UTM grid

The next point to consider is the electromagnetic characterization of the individual facets, which has been based on a surface model assuming a backscatter far-field solution using physical optics. Finally, the simulator also includes the effect of the speckle noise, which has been considered by adding a Gaussian distribution to the height values of the scene, so that its summation results in a Rayleigh distribution on the intensity image [1].

point in the observed scene. The analytical development of the coherence results in the following expression for its absolute value:

$$|\gamma| = \frac{1}{1 + SNR^{-1}} \cdot \left(1 - \frac{p}{\lambda} \frac{B_n}{r} \frac{\delta_r}{\tan \theta_L} \right) \cdot \left(1 - \frac{\Delta f_c}{B_{az}} \right) \cdot \text{sinc} \left(\frac{\Delta x}{\delta_x} \left(1 - \frac{\Delta f_c}{B_{az}} \right) \right) \cdot \text{sinc} \left[\frac{\Delta y}{\delta_y} \left(1 - \frac{p}{\lambda} \frac{B_n}{r} \frac{\delta_r}{\tan \theta_L} \right) \right] \quad (4)$$

where the most important noise sources have been taken into account: the signal-to-noise ratio SNR , the azimuth and ground-range mis-registration (Δx and Δy), the azimuth and ground-range resolution (δ_x and δ_y), the normal baseline B_n , the baseline mode p , the slant-range resolution δ_r , the Doppler centroid difference between channels Δf_c and the azimuth bandwidth B_{az} . The local terrain slope is included in θ_L .

Equation (4) can be employed to simulate the noise for every pixel in order to obtain an interferogram with the same decorrelation statistics as a real one.

RESULTS

To evaluate the simulator performance some SAR images have been generated. The image in Fig. 3 is obtained with our simulator from a real DEM corresponding to an area of 7 km x 7 km near Ascó (Tarragona, Spain). The vertical direction corresponds to the azimuth coordinate, whereas the horizontal axis is the range one. The permittivity map has been also considered constant except for the Ebre river, where low values have been assigned. Geometrical distortions produced by the relief such as foreshortening and layover can be appreciated as well as the effect of speckle.

This image has been compared to an ERS-1 processed SLC, acquired on September 12, 1991. Radiometric values are basically the same, and differences are mainly caused by the use of a constant permittivity map in Fig. 3. Displacements between the two images have been also evaluated, obtaining a range precision better than 2 pixels, which gives an idea of the adopted Earth model precision. In azimuth both images match by adjusting the ERS-1 mission times.

Precision in the second simulation phase has been evaluated by comparing the impulse response phase generated via the inverse ECSA and the phase map obtained from the use of the analytical SAR impulse response equation. Errors have resulted to be under 0.02 rad if zero Doppler deviation is assumed, and for a Doppler centroid of 125 Hz it maintains under 0.04 rad, what validates the use of this simulator as an impulse response generator.

With respect to the interferogram simulator, it has been evaluated by means of airborne data acquired by the DLR's E-SAR system [6]. After geocoding X-band data to a UTM grid, a DEM of the test site of Oberfaffenhofen (Germany) is available as an input for the simulator. The result is a realistic interferogram, comparable to the real one, whose fringes contain the major sources of noise.

Fig. 3. Simulated SAR image of the zone of Ascó

CONCLUSIONS

A complete SAR signal simulator frame has been presented. It can be applied in the frame of satellite missions as well as airborne sensors, with the correct geometric and electric features for each case. Moreover, it is devoted not only to generate information with respect to reflectivity, but also to compute realistic interferograms including the main factors, what makes the simulator a powerful tool to design the parameters for topographic reconstruction.

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