GROUND TOPOGRAPHY ESTIMATION OVER FORESTS CONSIDERING POLARIMETRIC SAR INTERFEROMETRY

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1. INTRODUCTION

Forest areas cover approximately 30% of the Earth's solid surface, with a mean tree height of about 20 m. Any attempt to provide global surface mapping based on SAR Interferometry (InSAR) is affected by the presence of the vegetation cover, in such a way, that the interferometric phase due to the surface scattering presents a bias, respect to the actual value, due to vegetation. The magnitude of this bias error depends on the systems parameters, mainly the used frequency, and on the forest characteristics, mainly the extinction coefficient. From a quantitative point of view, this error and may range up to the mean tree height. The evaluation of volume decorrelation effects in multi-baseline InSAR data has demonstrated that there is no conventional frequency (from P- up to X-band) able to be sensitive only the ground under a vegetation layer without being affected by any volume, i.e., vegetation scattering contribution. In consequence, all Digital Elevation Models (DEM's) generated by means of conventional InSAR are affected by a more or less significant vegetation bias. The correction of this inherent vegetation bias, always present in conventional interferometric data, and the estimation of the underlying ground topography is an essential improvement of the topographic information provided by SAR interferometry, with great ecological as well as commercial impact.

In this work, we will propose an alternative implementation of the Random Volume over Ground (RVoG) scattering model inversion to estimate underlying ground topography from Polarimetric Interferometric SAR data (PolInSAR) [1]. This new processing technique presents several advantages respect the conventional use of the RVoG model, namely, the proposed approach presents a more robust (by means of parameter estimation) implementation and an unambiguous estimation of the ground topography.

The first section of this work will with present the theoretical foundations of the proposed technique, as well as the present limitations. Of special importance will be the determination of the effects of the speckle noise component on the estimation of the ground topography. Accordingly, a special emphasis will be paid to the statistical characterization of the information retrieved by the proposed technique. This study will make possible to determine the minimum number of independent samples necessary for a correct estimation of the ground topography. The second part of the present work will focus on the quantitative evaluation of the proposed technique. In a first stage, an evaluation considering simulated PolInSAR data, based on the RVoG model, shall be conducted. On a second stage, this evaluation shall be extended to a variety of forest conditions using repeat-pass Pol-InSAR data acquired by DLR's airborne E-SAR system. The obtained results shall be validated against available ground-truth. Critical issues shall be presented and analyzed. Finally, optimized system and acquisition scenarios shall be presented based on the conclusions of this work.

2. POLARIMETRIC SAR INTERFEROMETRY

A PolInSAR acquisition scheme to collect SAR data works on the basis of acquiring two fully polarimetric data sets from slightly different positions in space. Separately, both data sets are characterized in the same way as a classical PolSAR data set [2]. In terms of information content, nevertheless both may present differences as a consequence of the baseline existing between them. Collectively, the characterization of the higher dimensional PolInSAR data set is performed by a natural extension of the characterization of the lower dimensional PolSAR data set. However, respect to the information content, the PolInSAR data set contains: both polarimetric sources of information, the interferometric information and the data necessary to obtain interferometric information as a function of polarization. The individual polarimetric datasets, in the monostatic case, may be expressed vectorially by means of the equivalent target vectors [2]

$$\mathbf{k}_{l,i} = [S_{hh}^i, \sqrt{2}S_{hv}^i, S_{vv}^i]^T \tag{1}$$

$$\mathbf{k}_{p,i} = \frac{1}{\sqrt{2}}[S_{hh}^i + S_{vv^i}, S_{hh}^i - S_{vv}^i, 2S_{hv}^i]^T \tag{2}$$

where ^{T} represents the vector transposition and $\{h, v\}$ denotes the orthogonal linear polarization basis, where h stands for the horizontal polarization whereas v stands for the vertical polarization. Finally, $i = 1, 2$ refers to each one of the interferometric data sets. The vector $\mathbf{k}_{l,i}$ represents a vectorization of the polarimetric information in the lexicographic basis whereas $\mathbf{k}_{p,i}$ is a vectorization in the Pauli basis. The analytical analysis that follows will be based on the lexicographic formulation.

Based on the RVoG scattering model for forested areas, the interferometric complex correlation coefficient defined as

$$\rho = |\rho|e^{j\phi_x} = \frac{E\{S_1 S_2^*\}}{\sqrt{E\{|S_1|^2\}E\{|S_2|^2\}}} \tag{3}$$

where S_1 and S_2 represent any pair of interferometric SAR images may be modeled as follows

$$\rho_{Vol}(\mathbf{w}) = e^{j\phi_0}\frac{\rho_v + \mu(\mathbf{w})}{1 + \mu(\mathbf{w})}. \tag{4}$$

As one may observe in the previous equation, the value of the complex correlation coefficient depends on the polarization state $\mathbf{w}$. The coefficient ρ_v represents the volumetric contribution to the final complex correlation coefficient, whereas $\mu(\mathbf{w})$ is the ground-to-volume amplitude ratio. This ratio determines, according to the system properties and the characteristics of the forest, the influence of the ground contribution, as a function of the polarization state $\mathbf{w}$. Finally, the complex term $e^{j\phi_0}$ accounts for the ground phase.

In a complete absence of the volumetric component, the polarimetric interferometric complex correlation coefficient equals

$$\rho_{Vol}(\mathbf{w}) = e^{j\phi_0} \tag{5}$$

and as observed the phase component is only determined by topography. In a presence of a volume, the complex correlation coefficient is also affected by the volume, producing the phase of ρ_{Vol} to contain both: topographic and volume contributions. Consequently, the phase term $e^{j\phi_x}$ is biased due to the presence of the volume.

2.1. Topographic Phase Estimation

Based on the dependence of (4) on the polarization state $\mathbf{w}$, an inversion technique [3] was developed for the retrieval of diverse forest parameters, namely, the forest height and the topographic phase. Due to the fact that the volumetric contribution can not be eliminated in ρ_{Vol} as a function of the polarization state $\mathbf{w}$, a direct access to the topographic component is not possible. In the algorithm proposed in [3], the retrieval of the phase component is based on a fitting process, where the linear behavior of ρ_{Vol} respect to **w** is fitted to the actual data. This process presents two main drawbacks. On the one hand, the estimation of the ground or topographic phase component is based on the robustness of the fitting process, that can be compromised if data are ill conditioned. On the other hand, the algorithm, as a concsequence of the fitting process, provides two solutions for the ground phase that need to be regularized based on physical assumptions.

The objective of the work to be presented in this paper is to detail a new algorithm for the retrieval of the ground phase component overcoming the drawbacks of the technique proposed in [3]. Based on the RVoG scattering model, one may analyze the effects of the volume component on the individual elements of the polarimetric interferometric covariance matrix. In this study, which shall be detailed in the final version of this work, mathematical expressions supporting the previous statement will be provided. As it shall be demonstrated by the first time, a particular selection of the polarization state **w** makes it possible a direct access to the ground phase term $e^{j\phi_0}$. Consequently, this direct access assures that the estimation of the ground phase component presents one solution, overcoming the necessity of the regularization needed in [3]. The straightforward consequence of the direct access to $e^{j\phi_0}$ is that the elimination of the regularization process benefits the robustness of the estimation of the ground phase component. The mathematical foundations and the details of the technique shall be presented.

Important attention shall be paid to the statistical characterization of the topographic phase component in case of forested areas, as this characterization is different from the one of the classical interferometric phase in case of bare areas. This statistical study will help to propose new system configuration aiming to retrieve the topographic phase in forested areas.

3. RESULTS

The algorithm that shall be presented in this paper, and whose foundations have been detailed in Section 2.1 shall be tested and validated on simulated, as well as on experimental PolInSAR data. Since the presence of speckle noise prevents the actual access to the real topographic phase component, a quantitative evaluation of the algorithm properties can be only performed on the basis of simulated data.

3.1. Simulated PolINSAR Data

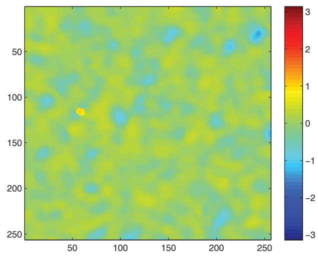
In order to generate simulated PolInSAR data, a simulator able to generate PolInSAR data according to the RVoG model has been implemented. The exact simulation of the RVoG scattering model considers both, a volume contribution, and a ground contribution based on the X-Bragg scattering model [4].

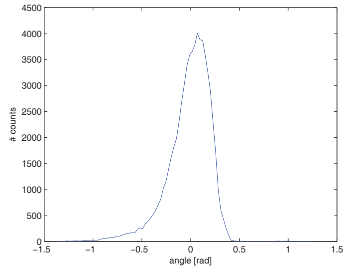
Three sets of simulated data have been considered to test the algorithm descried in Section 2.1. The three simulations consider the following scenario: a ground-to-volume ratio of -5 dB, a ground component considering a relative permittivity $\varepsilon_r = 3.5$, a forest with a constant height of $20m$ and a geometry corresponding to the E-SAR system with a flight height of 3000 m and a horizontal baseline of 5 m. The difference among the three simulations consists of the topographic component $e^{j\phi_0}$, that are equal to 0 rad, $\pi/4$ rad and $3\pi/8$ rad. The 6×6 PolInSAR matrix is estimated considering a 11×11 boxcar filter. The retrieved topographic phases and the corresponding histograms are presented in Fig. 1. This figure also contains the mean value of the retrieved phases, that as observed, corresponds to the actual value of this component.

As it may be observed from the previous results, the topographic phase is correctly retrieved without the bias introduced by the volume component.

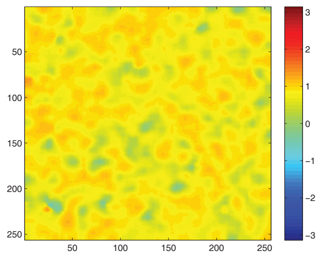
3.2. Experimental PolINSAR Data

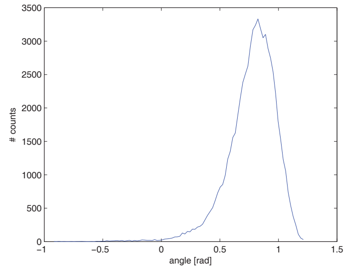
The final version of the paper will contain an evaluation of the proposed algorithm considering experimental PolInSAR data acquired by DLR's airborne E-SAR system.



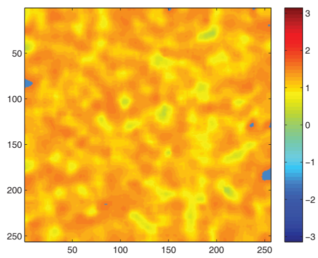


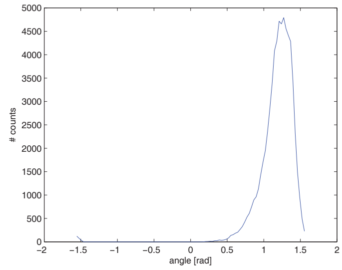
(a) Ground topography $\phi_0 = 0$ rad (b) Mean value equal to -0.060 rad.





(c) Ground topography $\phi_0 = \pi/4$ rad (d) Mean value equal to 0.7929 rad.





(e) Ground topography $\phi_0 = 3\pi/8$ rad (f) Mean value equal to 1.1806 rad.

Fig. 1. Retrieved topographic phases, and the corresponding interferograms, considering the technique proposed in this work.

4. CONCLUSIONS

The paper present a new technique for the retrieval of the topographic phase component in forested areas. The main principles of the retrieval algorithm have been presented and shall be detailed in the final version of the paper. Preliminary results based on simulated PolInSAR data demonstrate the capability of the algorithm to retrieve the topographic phase without the effect of the volume component.

5. REFERENCES

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