

Coherence Based Polarimetric SAR Tomography

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Abstract: Synthetic Aperture Radar (SAR) three dimensional image provides the scene reflectivity along azimuth, range and elevation coordinates. This 3-D image is formed from acquisition of multiple signals from different orbits. Tomographic reconstruction of this image gives the vertical information of the object present in the data. Polarization Coherence Tomography (PCT) is used for estimation of vertical profile from multibaseline E-SAR L-band data of oberpfaffenhofen, Germany. In this paper, an approach is proposed for ground phase and temporal decorrelation estimation. This is done with respect to Random Volume over Ground inversion procedures. The value of this ground phase and temporal decorrelation is given as the additional input to PCT for accurate height Estimation. Height estimated from PCT approach is validated with height estimated from ASTER DEM data.

Keywords: Coherence, Polarization, Interferogram, Vertical Structures, Flat Earth Removal, SAR Tomography

1. INTRODUCTION

Synthetic Aperture Radar(SAR) Tomography is the latest tool for the investigation of forest areas for multibaseline observations. The availability of multibaseline data for SAR Tomography help to resolve the estimation of vertical structure of the targets. Nowadays remote sensing instruments gives better solution for forest application. Multibaseline data allows the formation of synthetic aperture not only along range and azimuth direction but also in elevation direction.

SAR Tomography is the extension of conventional two dimensional image to three dimensional image due to additional synthetic aperture in elevation direction. Due to its penetrating capability, SAR tomography gives access to vertical distribution of backscattered power from the ground to canopy layer. The Random Volume over Ground (RVoG) model is the basis for vegetation mapping method. Inversion of this model for fully polarimetric interferometric data has been used to estimate height. The shape of the scattering function inside the canopy is partly based on RVoG model. Polarization coherence Tomography approximates vertical structure of the canopy by Fourier-Legendre polynomial series. The accuracy is based on available number of measurements. The RVoG model is used to extract forest height, ground phase and temporal decorrelation. The result of this inversion procedures is given as input to Polarization Coherence Tomography. The performance of this work is evaluated by using ASTER DEM data and then the relative error is calculated.

This paper is organized as follows: Section II gives the information about related work, Section III provides information about proposed method and describes the methodologies for SAR tomography, Section IV gives the implementation of the proposed work and Section V provides the results of proposed work, finally Section VI describes conclusion and future work.

2. RELATED WORK

TomoSAR techniques have been more and more employed in the last years to investigate vegetated areas, as witnessed by the number of papers recently published in this field [1]–[6]. Polarization coherence

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Tomography (PCT) [7] is a new approach in which a small number of baselines or interferogram is used. However, it need priori information, they are vegetation top height and topographic phase. This can be calculated by variety of methods, such as field measurements, LIDAR method or by using POL-InSAR[8] algorithms. The performance analysis of the vertical profile via PCT is by using LIDAR DEM and also simulated data. Then the relative error is calculated [9]. The discussion is largely based on estimation of vertical profile corresponding to different volume solutions, which are solved through tomographic imaging.

3. METHODOLOGIES

The PCT method allows to calculate vertical scattering function inside the volume when volume height, ground phase and coherences are known. For retrieving volume height and ground phase Random Volume over Ground inversion method is used. In this paper these values are obtained from high accuracy Digital Elevation Model and digital canopy height model to compare vertical structure profile with PCT.

This methodology involves the following steps.

- Noise Removal
- Flat Earth removal
- coherence estimation
- Interferogram generation
- Polarization Coherence Tomography

The First step is the speckle noise removal. This is done by using Lee filter. The filtered image is given as the input to Flat Earth Removal and is discussed in 3.1.

3.1. Flat Earth Removal:

The baseline is the important parameter to choose the interferometric pair image. Here is the procedure to estimate the baseline value. At first we interpolated the two orbits corresponding to the two images using Lagrange interpolation. The baseline is calculated by this equation:

$$B = \sqrt{(X_s - X_m)^2 + (Y_s - Y_m)^2 (Z_s - Z_m)^2} \quad (1)$$

The two radar positions, first radar points (X_m, Y_m, Z_m) and second radar points (X_s, Y_s, Z_s) correspond to the same point in both images.

Flat Earth removal is calculated by using Fast Fourier Transform. This method relies on the detection of the orbital frequency of the fringes which are regularly repeated, by detecting the maximum amplitude in the spectral plane. After deduction of its position along both horizontal and vertical axes. The ratio of the horizontal and vertical position calculated from the maximum image size respectively. It gives both horizontal and vertical frequency of the orbital fringes, and this allows the generation of these fringes and their subtraction directly from the raw interferogram.

3.2. Coherence and Interferogram estimation

Coherence is estimated for individual polarization components and then interferogram generated individual and the combinational polarization components such as HH, VV, HV, HH+VV, HH-VV respectively. The interferogram is calculated by using equation (2).

$$S_1 \times S_2 = A_1 \cdot A_2 \cdot \exp\{\Delta \varphi\} \quad (2)$$

where S_1 and S_2 are the complex images and A_1 and A_2 are the amplitude of the complex images.

The phase difference of the image $\Delta \varphi$ is given by

$$\Delta \varphi = -\frac{4\pi}{\lambda}(R1 - R2) + \Delta \varphi_{error} \quad (3)$$

where $\Delta \varphi_{error}$ is the phase signal error or signal delay. It is due to atmospheric disturbances, mode of acquisition etc.

The similarity of the two radar signals can be measured by calculating the interferometric coherence, which is the normalized complex correlation

$$\gamma = \frac{\langle S_1 S_2 \rangle}{\sqrt{\langle |S_1|^2 \rangle \langle |S_2|^2 \rangle}} \quad (4)$$

γ Varies between zero in the case of decorrelation, and one if the two signals are perfectly correlated. The phase of this expression is the phase difference of two signals backscattered by targets; it is given by an image called interferogram. This phase is given modulo 2π and represented in the image by fringes.

3.3. Polarization Coherence Tomography

The PCT for a penetrable volume scattering is the complex interferometric coherence $\tilde{\gamma}$. This coherence can be formulated from the scatterers and is given by

$$\tilde{\gamma} = e^{ik_z Z_0} \frac{\int_0^{hv} f(z) e^{ik_z z} dz}{\int_0^{hv} f(z) dz} \quad (5)$$

The equation (5) can be simplified as

$$\tilde{\gamma} = e^{i\phi} \frac{\int_0^{hv} f(z) e^{ik_z z} dz}{\int_0^{hv} f(z) dz} \quad (6)$$

where ϕ_0 is the ground phase, Z_0 is the position of the bottom of the scattering layer and $f(z)$ is the vertical structure function and kz is the vertical wave number, related to the baseline of the considered interferometric pair. The reconstruction of the function $f(z)$ from at each point in the image is then termed polarization coherence tomography. The function $f(z)$ is bounded and so can be expanded efficiently in terms of the Fourier-Legendre series. If we approximate $f(z)$ with a finite number n of series terms, then the unknowns of our problem (1) are the n Legendre coefficients, and tomography reduces to estimation of this set of coefficients from data. Of course, to retrieve the n coefficients we need n image pairs, so that a system of n equations of the kind of (6) in n unknowns can be obtained and solved. Hence the problem is the solution of a set of (complex) linear equations which can be reformulated in a compact form as shown in (7):

$$[F]a = b \Rightarrow \hat{a} = [F]^{-1}b \quad (7)$$

The evaluation of this coefficients can be related to matrix inversion problem. After that wave number has been estimated. Finally reconstruction of vertical profile is estimated.

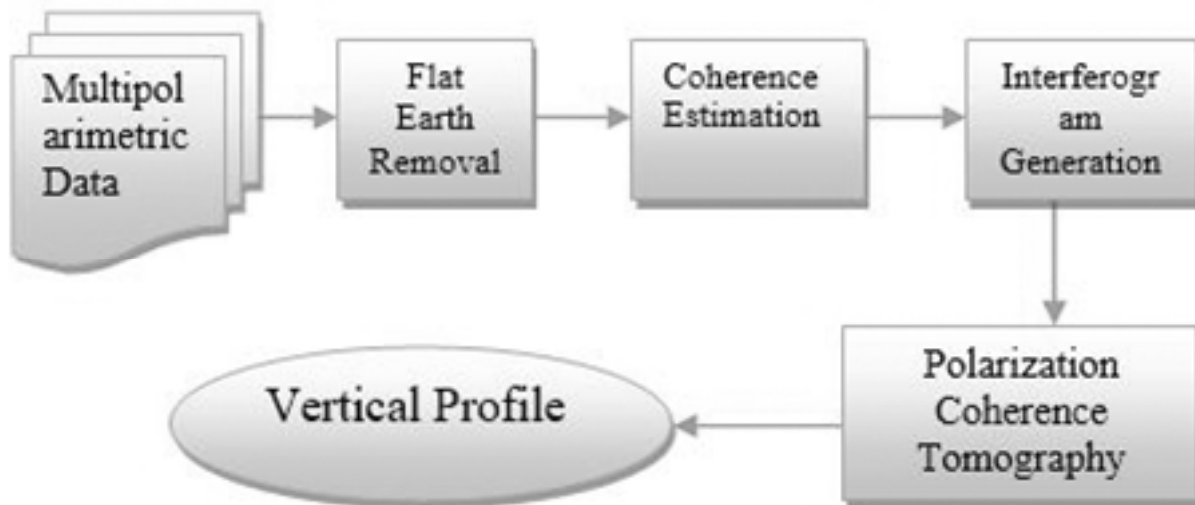


Figure 1: Diagram of the proposed method.

4. IMPLEMENTATION

The multi Polarimetric data is given as the input to speckle noise removal process, which is shown in Figure 1.

Noise Removal:

Lee filter is used to remove the speckle noise in SAR images.

lee filter is defined by

$$Y_{ij} = K + W * (C - K) \quad (8)$$

where Y_{ij} is the output despeckled image

K is the mean of kernel or window

W is the weighing function

C is the center element of the kernel.

$$\text{Calculation of } W = \frac{\sigma_k^2}{(\sigma_k^2 + \sigma^2)} \quad (9)$$

where σ_k^2 is the variance of the reference image.

σ^2 is the variance of the pixel in the kernel or window.

This output of Lee filter is given as the input to Flat earth removal.

Flat Earth Removal

Flat earth phase is removed based on the fast Fourier transformation after that critical baseline is calculated. This is explained in 3.1. This output of Flat earth removal is given as the input to the coherence estimation.

Coherence Estimation and interferogram generation

coherence is estimated based on the equation (4) mentioned above. It will give how much given coefficients are correlated. After that interferogram is calculated for each and individual polarization components and also for the combinational components and it is explained in equation (2).

Polarization Coherence Tomography

Isolation of Two Reference Polarization Channels :candidates for the two volume and surface dominated polarization channels w_1 and w_2 is isolated separately and also isolated for the channels $w_1 + w_2$. The corresponding interferometric complex coherences $\tilde{\gamma}$ are calculated.

The RVOG model can be expressed as

$$\gamma(w) = e^{i\phi_0} \frac{\gamma_1 \gamma_v + \mu(w)}{1 + \mu(w)} \quad (10)$$

where $\gamma(w)$ is complex interferometric coherence. w is the unitary scattering mechanism. ϕ_0 is the ground phase and it is the known real number. γ_1 is the temporal decorrelation this is a real number and is not depend on polarization. γ_v is volume only coherence and is polarization independent $\mu(w)$ is the effective ground to volume amplitude ratio.

Phase Bias Removal and ϕ_0 estimation

These two coherences is used in the appropriate order to estimate ϕ_0 ground phase from the RVoG model (10). Phase is estimated directly from equation (10) for the particular Polarimetric channel. The resultant phase is used for the reconstruction of particular structures for all polarization channels. There is a problem while choose polarization vector w , for this phase bias removal method is used. This is used to improve the accuracy of surface topography estimation. Then the wave number k_v is estimated, with compensation for any temporal decorrelation and then identify a volume polarization channel w_v and calculate Wave number k_v .

$$\phi_0 = \arg(\tilde{\gamma}_{w,S}) \quad 0 \leq \phi_0 < 2\pi \quad (11)$$

Height estimation: Height k_z value is calculated from baseline geometry. It is shown as

$$\tilde{h}_v = \frac{2k^v}{k_z} \quad (12)$$

Coherence calculation for arbitrary user selected polarization w

An arbitrary polarization scattering mechanism w is selected for imaging. For each pixel of the image the complex coherence is calculated for the polarization channel and then Legendre Spectrum for polarization w is also calculated.

After that the two Legendre coefficients a_{10} , a_{20} is calculated for Polarimetric channel w . This will give the non zero regions in the vegetation.

Finally the normalized vertical profile is reconstructed. Two Legendre coefficients and knowledge of the height is used for each pixel to reconstruct a normalized vertical profile of scattering.

For validation the resultant vertical profile is compared with the ASTER DEM data and then the relative error is calculated.

V. RESULTS AND DISCUSSION

Experimental results are based on ESAR oberpfaffenhofen Germany city dataset from ESA campaign. The description about the dataset is described in the Table 1. Each dataset consist of three fully Polarimetric SLC images. The input SAR image is shown in Figure 2.

The isolation of polarization channel with respect to amplitude and phase is shown in Figure 3.



Figure 2: Input SAR Image.



Figure 3:

Table 1
System parameters about the test data site

Campaign	ESAR Oberpfaffenhofen data
System	E-SAR -DLR
Site	Oberpfaffenhofen, Germany
Scene	Mixed forest and urban are A
Topography	Flat
Tomographic Tracks	3- Polarimetric data
Carrier Frequency	L-Band
Slant range resolution	2.532 m
Azimuth resolution	1.2 m
Vertical resolution (L-Band)	10 m

The interferogram of the individual Polarimetric channel HH and VV is shown in Figure 4(a) and Figure 4(b).

Then after that topographic phase and DEM difference height is shown in Figure 5 (a) and Figure 5(b).

Figure 6(a) and Figure 6(b) gives the ground phase height and PCT height of the proposed method.

Then the three Dimensional image of the proposed method is is shown in Figure 7.

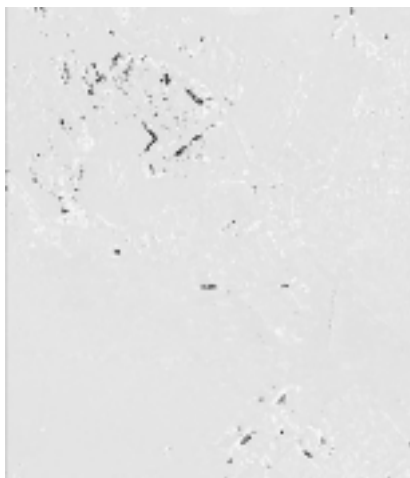


Figure 4(a):

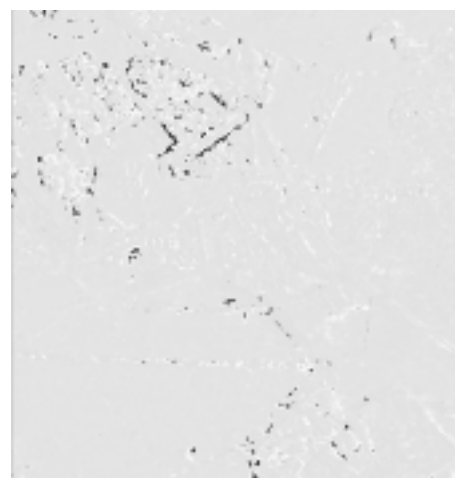


Figure 4(b):

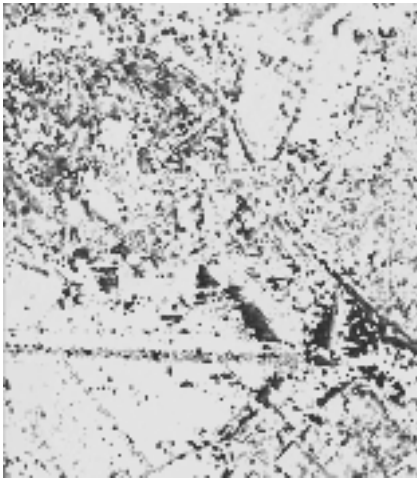


Figure 5(a):

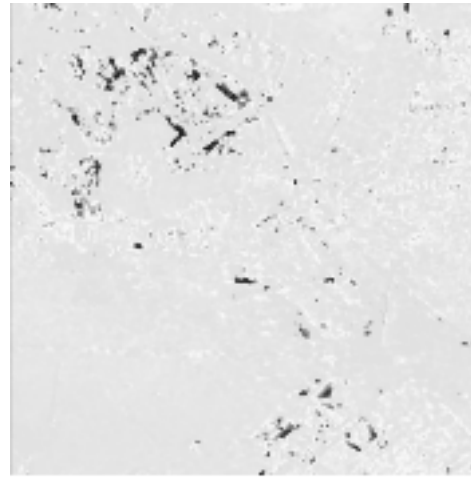


Figure 5(b):



Figure 6(a) :



Figure 6(b):

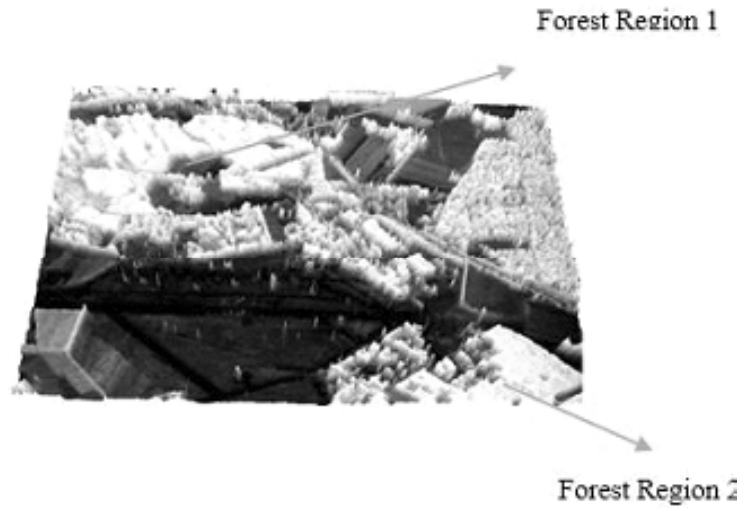


Figure 7:

The ground phase and temporal correlation is calculated from Random Ground over Volume. This parameter are the additional information to calculate PCT of the image.

For the typical forest the height of the scatterer is assumed to be 20 m. Thus the threshold is set between 0.05 to 0.15.

The wave number bigger than this limit can introduce the ambiguity in the ground phase detection in RVoG inversion and smaller k_z area are too noisy and they are not useful to calculate forest height.

To obtain the height of the vertical structure of the forest, all the profiles are re-interpolated to the value zero for ground.

To validate the results, height of the ASTER DEM and the resultant vertical profile are compared with respective to observed relative error.

The relative error is calculated as

$$\text{Error} = \frac{\text{Height from SAR data} - \text{Height from ASTER DEM}}{\text{Height from ASTER DEM}}$$

Height from SAR data is nothing but the height obtained from the resultant vertical profile.

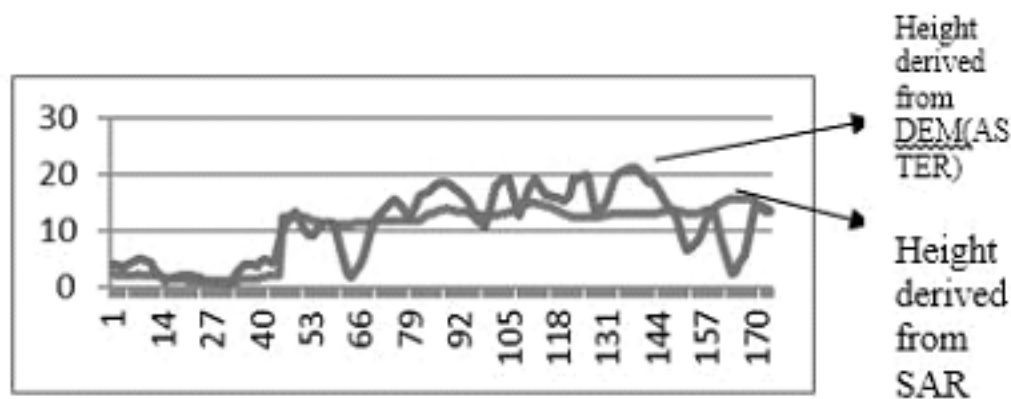


Figure 8:

Figure 8 shows that the results from ASTER DEM and Height obtained from proposed method. Red line denotes height from ASTER DEM and the Blue lines denotes height from SAR data. From the Figure 8 our proposed method is relative to with ASTER DEM and the observed relative error is 4.209.

6. CONCLUSION

In this paper a method for identification of vertical structures in the forest is developed based on the ground and volume scatterers with Multi-Polarimetric data. The obtained filtered image is given as the input for coherence estimation and then interferogram is generated for the data. Then topographic phase and ground volume is estimated using RVoG model. Finally three dimensional reconstruction of vertical profile is calculated. The results of tomographic profile is validated with ASTER DEM and then the observed relative error is 4.209. From the results it can be shown that the vertical profile obtained from the proposed method is relative with ASTER DEM. The relative error can still be reduced by adapting an effective algorithm to estimating vertical profile is considered as the future research.

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