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PolInSAR Coherence Based Decomposition for Scattering Characterization Of Urban Area

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Abstract: Polarimetric SAR data based scattering retrieval has been widely used to characterize manmade and natural features. It has been found that PolSAR data has the capability to retrieve scattering information contributed by different features within a small area or single resolution cell. Generally, it has been found that the urban structures are contributing the high double-bounce scattering, but due to closely spaced urban structure, multiple reflections of the SAR waves from the walls of the buildings give the appearance of the volume scattering. The overestimation of volume scattering from urban structure could be reduced by the adoption of interferometric coherence in decomposition modeling. The urban buildings are considered as permanent scatterers which is usually not affected by the temporal and volume decorrelation. Therefore, they show high coherence magnitudes. The prime focus of this research was the implementation of PolInSAR coherence in the decomposition modeling to minimize the overestimation of volume scattering from the urban structure. This study has used the CoSSC product of the TanDEM-X mission. The results obtained from PolInSAR coherence based decomposition modeling had shown the dominance of double bounce scattering in the urban area for closely spaced structures also.

Keywords: Polarimetric SAR; PolInSAR; CoSSC, TanDEM-X, Urban structure

1. Introduction

A radar remote sensing technique, polarimetric interferometry when used with an imaging synthetic aperture radar system is generally termed as Polarimetric SAR Interferometry i.e. PolInSAR [1]. It is an advanced technique of radar remote sensing that integrates the advantages of both polarimetry and interferometry and constitutes the full collection of polarimetric and interferometric information. PolInSAR has number of applications such as forest-stand /tree height retrieval, agricultural height estimation, crop parameter estimation, building parameter and building height estimation, forest biomass estimation, forest parameter estimation and ground topography estimation etc. [2]. Polarimetry associates with the switching of the polarisation state of transmit and receive channels to measure differences in backscatter due to orientation, shape and material composition[3]. This leads ultimately to measurement of the 2x2 complex scattering matrix [S], from which we can incorporate the response of the image pixel to arbitrary polarisation combinations. Such radars are termed S-matrix or Quadpol systems (since four channels are measured by the radar, usually all possible combinations of horizontal and vertical linear polarisations HH, HV, VH and VV respectively) [3]. The latter describes radar interferometry which involves in coherently combining signals from two separated spatial positions (so called baseline of the interferometer) to extract a phase difference or interferogram [3]. The combination of polarimetric and interoferometry leads to the separation of scattering mechanisms within a resolution cell. PolInSAR is different from standard interferometry in which it allows the generation of interferograms for random transmit or receive of the polarisation pairs[3]. We will be able to see that in this, therefore, the combination of interferometry with polarimetry is greater than the sum of its parts and that PolInSAR allows us to overcome severe limitations of both techniques when taken alone [3]. The coherence in the urban spaced structure which contains more permanent scattering is usually not affected by the temporal and volume decorrelation. Therefore, they show high coherence magnitudes. However, vegetation areas heavily experience both the temporal and volume decorrelation originated by the wind or the changes in the wind direction and the distribution of scatterers in vertical dimension. Therefore, they show lower coherence. This means that the natural features and the man made features can be distinguished by using the PolInSAR coherence. To illustrate, different interferometric characters between forest and urban structures. In urban structures, it is distinct that they will show highest coherence that is concentrated in a narrow region because of the closely spaced structure. The orientation angle affects the decomposition results because it increases the HV components which cause the overestimation of volume scattering , even when this effect is corrected some urban areas still behave like vegetation area. Recently, Polarimetric SAR Interferometry (PolInSAR) is used to overcome this problem, since it is difficult to discriminate between vegetation and urban using PolSAR [3].

2. Experiments

The work was carried out on the Dehradun region which is capital city of the Uttarakhand state of India. FRI (Forest Research Institute) campus was selected as the region of study. It is located in the doon valley in the foothills of Himalaya settled between the river Ganges in the east and river Yamuna in the west.

2.1 Materials

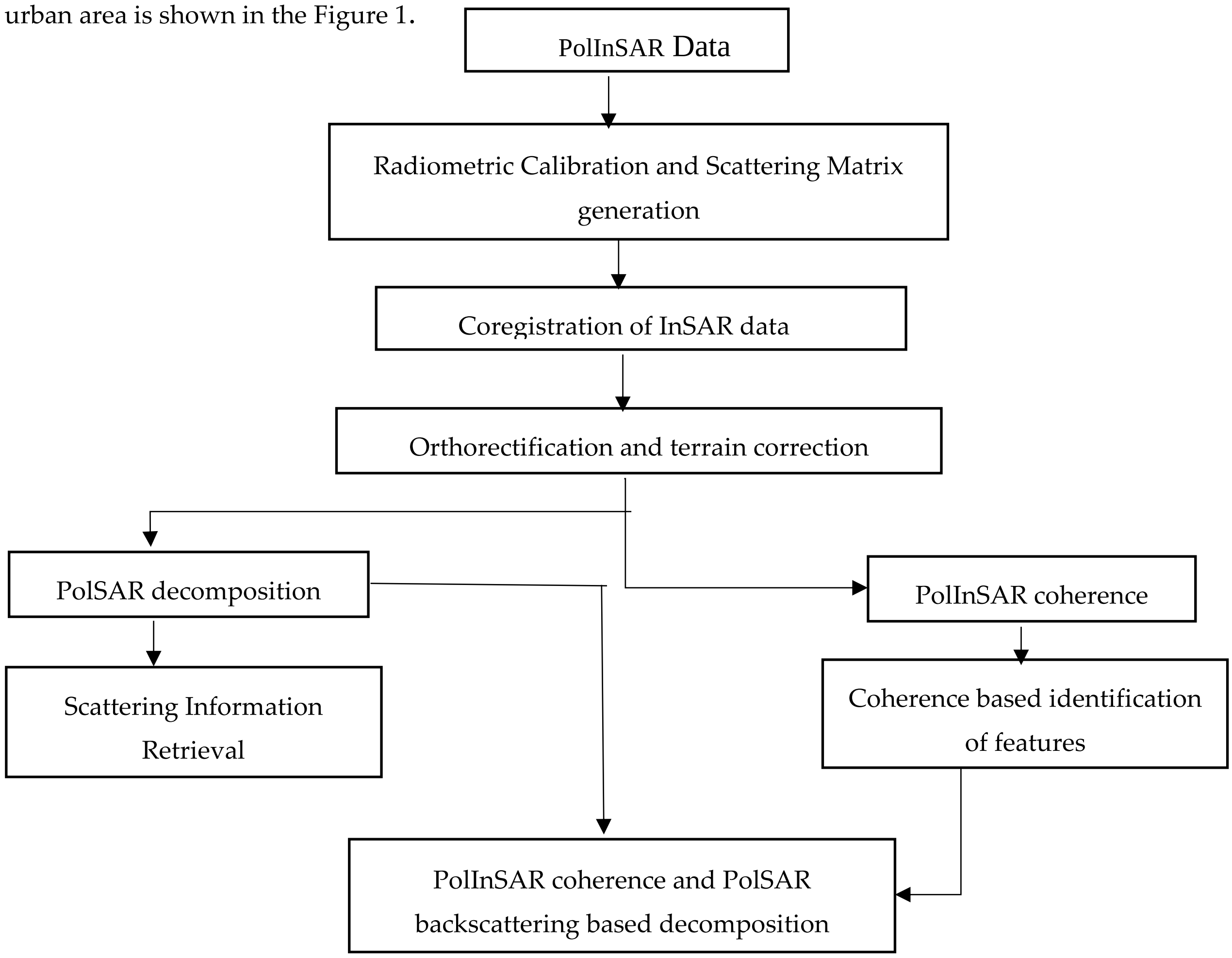
This section provides the detailed information about the fully polarimetric bistatic mode X- band TDM data that was acquired by TerraSAR-X and TanDEM-X. The PolInSAR data over Dehradun, India were acquired in bistatic mode. Fully polarimetric and interferometric products of TerraSAR-X and TanDEM-X were used in this study as the urban structures are permanent scatterers and are not usually affected by the temporal and volume decorrelation so, zero temporal baseline is used in this study to minimize the error [4]. The TDM data was provided by DLR (German Space Agency) in CoSSC format i.e co-registered single look slant range complex. The detailed description of SAR data is given in Table 1. As the TDM CoSSC experimental products were acquired over the Dehradun area in quad-pol interferometric mode. Both the satellites TerraSAR-X and TanDEM-X were operated in bistatic mode with the baseline of 218.89 m. All the four polarimetric channels HH, HV, VH and VV in interferometric acquisition are there in both the datasets. This model was generated with the incorporation of both the channels i.e. co- polarised channels and cross polarized channels. As the cross polarized channels gives the depiction of volume scattering component because of the forest vegetation whereas, in urban structures considering the double bounce scattering which is generally acquired from the interaction of SAR waves with the stable structures or ground stem interaction from forest trees.

Table 1-Description of SAR data

Acquisition	Master	Slave
Satellite	TSX-1	TDX-1
Date of Acquisition	February 2,2015	
Polarization	Quad-pol	
Wavelength	X-Band	
Azimuth Resolution(m)	2.41	
Absolute orbit	42,349	
Angle of incidence near	36.02	
Angle of incidence far	37.56	
Product	TDM –CoSSC experimental	
Effective baseline	-	218.89

2.2 Methods

The steps involved in PolInSAR coherence based decomposition for scattering characterization of urban area is shown in the Figure 1.



As the PolInSAR dataset of TerraSAR-X and TanDEM-X was provided by DLR, the radiometric calibration was performed on both the datasets and scattering matrix was generated. The radiometric calibration corrects the SAR image so the pixel values show the backscattering of the reflected surface[5]. Two sets of scattering matrix is generated in which the diagonal elements represent the co-polarised information i.e HH and VV channels and the off diagonal elements i.e HV and VH channels represent cross polarized information. S1 and S2 of Eq. (1) are denoted by the scattering matrices of master and slave images respectively. Symmetric backscattering matrix obtained by the reciprocity theorem is

$$S_1 = \begin{bmatrix} S_{1_{HH}} & S_{1_{HV}} \\ S_{1_{VH}} & S_{1_{VV}} \end{bmatrix} \qquad S_2 = \begin{bmatrix} S_{2_{HH}} & S_{2_{HV}} \\ S_{2_{VH}} & S_{2_{VV}} \end{bmatrix} \quad (1)$$

Then the coregistration of the InSAR data, for coregistration two or more images must be coregistered into a stack. As there are two images master and slave, the pixels in slave image are moved to align with the master image to sub-pixel accuracy. The main focus of coregistration was that it ensured that all the ground targets contribute to the same pixel in both the master and slave image [6]. The next step was of orthorectification and terrain correction, as in orthorectification the effects of image perspective and relief effects were removed for the purpose of creating a planimetrically correct image whereas, in terrain correction the SAR geometric distortions were corrected by digital elevation model and map oriented product was produced with the help of geocoding [7]. Once the dataset was orthorectified and terrain corrected the dataset was ready for PolInSAR processing. First there was PolSAR decomposition, which was done by Freeman-Durden decomposition model for both of the images i.e. master and slave by this scattering information was retrieved for all the scattering i.e. volume scattering for forest vegetation, odd bounce scattering for smooth surface and double bounce scattering for urban structures. Whereas, for PolInSAR coherence the identification of features was done on the basis of coherence. Two PolSAR acquisitions were carried out using the exact same geometric configuration viz. Beam mode, Incidence angle, and Polarization mode. The scattering matrix for each pixel can be derived for both the acquisitions. [S1] and [S2] are the scattering matrices for the two acquisitions and the vectorized form can be represented by the scattering vectors $k1$ and $k2$ respectively. The 6x6 coherence matrix [T6] is the main observable in PolInSAR.

$$[T_6] = \begin{matrix} k_1 \\ k_2 \end{matrix} [k_1{}^{*T} \quad k_2{}^{*T}] >= \begin{bmatrix} [T_{11}] & [\Omega_{12}] \\ [\Omega_{12}]^{*T} & [T_{22}] \end{bmatrix}$$

$$k_1 = [S^1{}_{HH} + S^1{}_{VV} \;\; S^1{}_{HH} - S^1{}_{VV} \;\; 2S^*{}_{HV}\,]^T$$

$$k_2 = [S^2{}_{HH} + S^2{}_{VV} \;\; S^2{}_{HH} - S^2{}_{VV} \;\; 2S^*{}_{HV}]^T$$

Where, the superscripts ^{1} and ^{2} represent the acquisitions from two ends of the baseline.

$$[T_6] = \begin{bmatrix} S^1{}_{HH} + S^1{}_{VV} \\ S^1{}_{HH} - S^1{}_{VV} \\ 2S^1{}_{HV} \\ S^2{}_{HH} + S^2{}_{VV} \\ S^2{}_{HH} - S^2{}_{VV} \\ 2S^2{}_{HV} \end{bmatrix} [S^{1*}{}_{HH} + S^{1*}{}_{VV} \;\; S^{1*}{}_{HH} - S^{1*}{}_{VV} \;\; 2S^{1*}{}_{HV} \;\; S^{2*}{}_{HH} + S^{2*}{}_{VV} \;\; S^{2*}{}_{HH} - S^{2*}{}_{VV} \;\; 2S^*{}_{HV}\;]$$

$$T_6 = \begin{bmatrix} [T_{11}] & [\Omega_{12}] \\ [\Omega_{12}]^{*T} & [T_{22}] \end{bmatrix}$$

Where, $[T_{11}]$ and $[T_{22}]$ are the Hermitian coherence matrices for the two acquisitions and they explain the polarimetric properties of each acquisition while $[\Omega_{12}]$ is a non-hermitian complex matrix which constitutes of both polarimetric and interferometric information. [2]

3. Results and Discussion

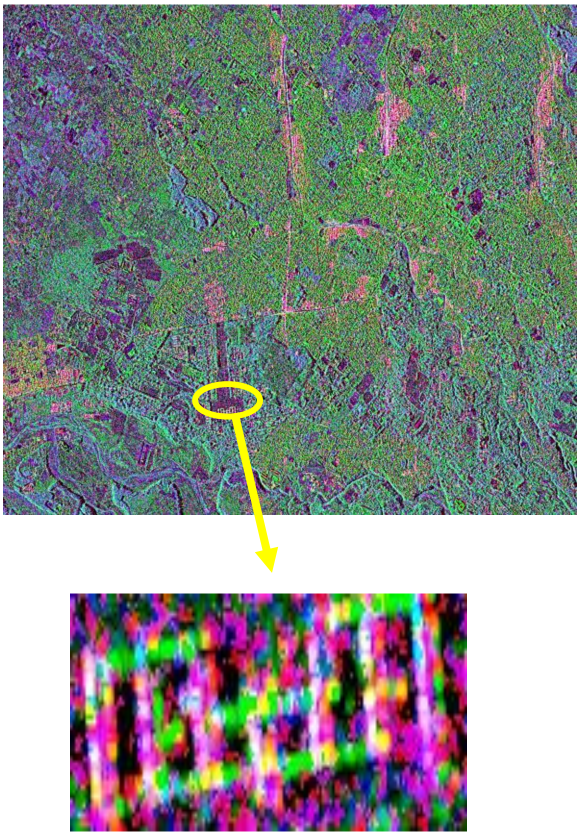


Figure 2 (a) Freeman Durden Decomposition of Study Area, (b) Region of Study in Master Data Set

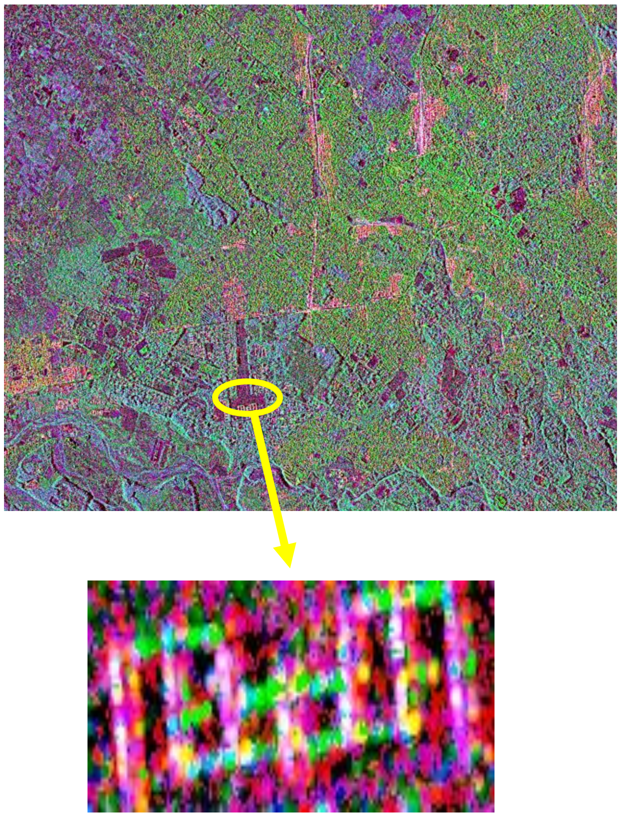


Figure 3 (a) Freeman Durden Decomposition of Study Area, (b) Region of Study in Slave Data Set

Figure 4 PolInSAR Coherence of The study region

As it is clearly visible to us in both of the master Figure 2(a) and slave image Figure 3(a) of PolSAR for Freeman-Durden decomposition model and in PolInSAR, the coherence is high which clearly depicts the urban structures in the region whereas, in PolSAR decomposition there was an overestimation of urban structures. We can see that in the zoomed view of the images Figure 2 (b) and 3 (b),there is the FRI (Forest Research Institute) building in the Dehardun region which is an urban structure, but there are also trees and other stable structures and if we compare both of the images of PolSAR for that building, there are differences in the output. The red colour shows the urban structures the green colour depicts forest vegetation and blue colour for double bounce scattering. Whereas, in PolInSAR, Figure 4, the coherence of that particular region clearly distinguishes between the urban structures and the other stable structures because of the high coherence in that region and it also shows prominent double bounce scattering in the closely spaced structures. The study strongly recommends the use of PolInSAR coherence in the decomposition modelling to minimize the ambiguity in the scattering retrieval from an urban area due to close spaced buildings.

5. Conclusions

The backscatter based techniques has the potential to differentiate stable structures of double bounce scattering and the unstable structures of volume scattering. Finally, the study concludes that the decomposition model based approaches increases the accuracy of the different characteristics that are urban structures and the forest vegetation.

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Conflicts of Interest: All authors declare that they have no conflict of interest.

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