A derivation of optimum coherent Digital Elevation Models from interferometric SAR data

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Abstract

In this paper we propose a new method for speckle filtering and derivation of an optimum interferogram from fully Polarimetric Interferometric SAR data. This method is based on the phase maps derived from the high resolution ESPRIT algorithm. The cross composite covariance matrix elements are filtered using a supervised edge aligned Lee filter. In this way the cross polarisation interference is minimised, preserving the information held in the Polarimetric phase elements. The results of the application of this method to the Glenaffric radar data are presented and show an improved phase response.

Introduction

Radar Polarimetry interferometry is a new technique extensively applied to parameter estimation of the land cover models. It is particularly important technique for vegetation characterisation and DEM generation, and tree height estimation. SAR interferometry is sensitive to topography and vertical structure of the land cover, whereas Polarimetric parameters are sensitive to texture and orientation of the target. In their work Cloude and Papathanassiou [2] proposed an optimised coherence inversion model for structure over the vegetated area. The optimisation is an important stage in the model due to presence of additive and multiplicative noise. Speckle noise is formed by the coherence interference of waves reflected from many primary scatters. Since the parameters estimation in Polarimetric interferometry is dependant on the phase information, speckle is a problem, and requires considerable attention.

One of the recent works on speckle reduction techniques in the Polarimetry SAR is the Edge enhanced Lee-filter. it has received a great attention due to its localised information preservation and global noise reduction ability.[3] Lee has further proposed application of enhanced edge aligned filter to individual groups of scatteres for a classified image. [4] In this way the cross scattering interference is prevented and cross polarisation interference is minimised.

In this paper we introduce a new method of speckle filtering of the Polarimetric interferometric coherent matrix. The proposed model is based on the TLS ESPRIT algorithm which is known for its high resolution parameter estimation capability.[5] The schematic presentation of the scattering response is given in figure (1). The Pol-In coherent matrix applied to ESPRIT algorithm is filtered for speckle and the optimum interferogram is obtained.

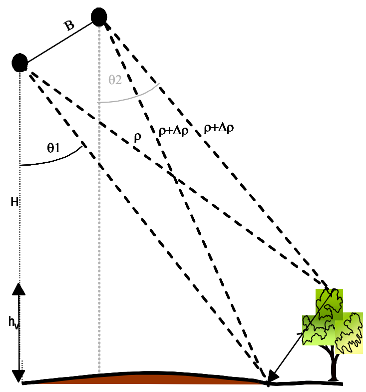


Fig (1), Schematic presentation of the scattering phase centres

The de-speckled interferogram is used to generate the digital elevation model of the given image.

The effectiveness of the method is illustrated using airborne Glenaffric fully Polarimetric interferometric SAR data. The Glenaffric data is L-band with wavelength 0.23m, fully Polarimetric, with repeat pass of 10 m baseline.[1]

Pol-In SAR formulation

The dominant back scatter received at the antenna as a result of repeat pass interferometry can be formulated as:

$$E_1=\sum_{i=1}^{d}\sigma_{1i}.S_{1i}^{kl}.e^{(j.\frac{4\pi}{\lambda}).\rho}+n_1^{kl} \qquad \text{Eq (1)}$$

$$E_2=\sum_{i=1}^{d}\sigma_{2i}.S_{2i}^{kl}.e^{(j.\frac{4\pi}{\lambda}).(\rho+\Delta\rho)}+n_2^{kl} \qquad \text{Eq (2)}$$

Where '*k*' and '*l*' denote the polarisation combination (ie. *HH, VV, HV, VV*), '**n**' is the white additive noise, 'ρ' is the slant range,'$\Delta\rho$' is the path difference the two receiving location related to the base line, and 'σ ' is the power of the polarised signal. The polarisation channelas are assumed to be normalised.

Using the vector notation, a multi-track repeat pass interferometric scatter vector at the antenna can be written as:

$$\mathbf{E}_i=\left[S_i^{HH} \quad S_i^{HV} \quad S_i^{VV} \quad S_i^{VH}\right]^* \quad i = 1,2 \qquad \text{Eq (3)}$$

The Interferometric target vector is defined as the augmented vectors of the repeated tracks (in this case 2) given by:

$$\mathbf{E}=\left[E_1 \quad E_2\right]^* \text{ where } \mathbf{E}_2=\Phi.\mathbf{E}_1 \qquad \text{Eq (4)}$$

The square matrix 'Φ' is the transformation matrix that relates the scatter vector from the repeated tracks.

The transformation matrix holds the related amplitude and phase differences between the received signals from the two tracks.

It is assumed that the amplitude variation between the two signals is minimum and can be ignored therefore the difference between the received multi-track data is directly related to the phase difference which itself is a function of direction of arrival, transmitted frequency, and the baseline between the two tracks.

The phase difference of arrival between the received signals with respect to the incident angle and the baseline is given by

$$\phi = e^{\left(j.2.\pi/_{\lambda}B.\sin(\theta)\right)} \qquad \text{Eq (5)}$$

Given 'λ' is the wavelength, 'B' is the baseline and 'θ' is the incident angle.

The interferometric target Coherence matrix is defined by the second order ensemble of the target vector:

$$\mathbf{C} = <\begin{bmatrix}E_1\\E_2\end{bmatrix}[\mathbf{E}^*_1,\mathbf{E}^*_2]> \qquad \text{Eq (6)}$$

The Coherence matrix **'C'** is a Hermition matrix and can be expressed in terms of its principle components as:

$$\mathbf{C} = <\mathbf{F}.\Lambda.\mathbf{F}^*> \qquad \text{Eq (7)}$$

Where **F** is the Modal matrix and **'Λ'** is the diagonal Spectral matrix of **'C'**.

The Modal matrix spans both Signal and noise subspaces of the augmented target vector, and can be modelled as:

$$\mathbf{F} = [\mathbf{F}_s,\mathbf{F}_n], \qquad \text{Eq (8)}$$

$$\mathbf{F}_s=\begin{bmatrix}F_1\\F_2\end{bmatrix} \qquad \text{Eq (9)}$$

$$\text{and } \mathbf{F}_2=\Phi.\mathbf{F}_1 \qquad \text{Eq (10)}$$

(Note: notations '$_n$' and '$_s$' refer to the noise and signal subspaces respectively.)

In [10] and *et al*, it is shown to minimise the influence of noise from the signal eigen vectors F1 and F2, spanning the same subspace as 'C', the total least sqaure method is employed.

The Total Least Square (TLS) solution is an unbiased results and is based on the eigen decomposition of the modal matrix **F** and estimation of the rotational invariance matrix Φ.

Defining signal space covariance matrix $\mathbf{F}_{12}$, obtained from dominant eigen vectors of **F**:

$$\mathbf{F}_{12}=\begin{bmatrix} F_1^* \\ F_2^* \end{bmatrix}.\begin{bmatrix} F_1 & F_2 \end{bmatrix}= \mathbf{G}.\Lambda_G.\mathbf{G}^*$$ Eq (11)

And $$\mathbf{G}=[\mathbf{G}_s,\mathbf{G}_n] \text{ and } \mathbf{G}_n=\begin{bmatrix} G_{n1} \\ G_{n2} \end{bmatrix}$$ Eq (12)

The eigen decomposition of the variance matrix (**G**) at minimum noise subspace is achieved by projection of the F1 to Moorw-Penrose pseudoinverse of F2 given by:

$$\Phi= -\mathbf{G}_{1n}.(\mathbf{G}_{2n})^{-1}$$ Eq (13)

The eigen values of the optimised TLS solution provide the phase differences related to the scattering centres. That is the phase of eigen values of Φ are scatter centres and contain the topographical information.

ϕ **=** eigen values of Φ

$$\arg(\phi) = \mathbf{Sin}(\theta).(2\pi B/\lambda)$$ Eq (14)

The time difference between the scatter centre on the ground for E_1 and E_2 is directly relate to the topographical phase parameters. This is the key point in derivation of the interferogram from ϕ**.**

The eigen vectors that correspond to the dominant scatter centres are related to the largest eigen values of coherence matrix. In presence of signal there is at least one dominant back scatter, related to the centre on the ground level. This indicates that this model always provide a solution even in the lowland regions or bare grounds where there is no second scattering centre due to absence of tall woody vegetation structure.

Although the TLS ESPRIT algorithm minimises the influence of the additive white noise in the coherence matrix, however it is unable to eradicate the multiplicative speckle noise inherent in the phase information. The common solution to reduce the speckle effect is an average filter, such as a box filter. However, such filters, average the local information indiscriminately, destroying useful phase information in the areas of high variance. Therefore other methods of noise cancellation such as enhance edge lee filter is required to eliminate the speckle without reducing the phase information.

In several literatures Lee has proposed variation of his filter and its application. In particular in [3,4] he has referred to the edge aligned filtering in a classified scattering domain.

This method is evolved to preserve the Polarimteric properties avoiding the cross talk between polarisation channels without indiscriminately averaging important phase information due to the neighbouring noise.

A basic Lee filter formulation is given by:

$$\hat{C} = \overline{C} + b.(C - \overline{C})$$ Eq (15)

where $\hat{C}$ is the filtered coherence matrix and $\overline{C}$ is the mean coherence matrix. The scalar coefficient b is the coeffiencient of variance (CoV) and holds a value between 0 to 1. 'b' is nearly 1 in areas of high variance and almost 0 in homogeneous areas.

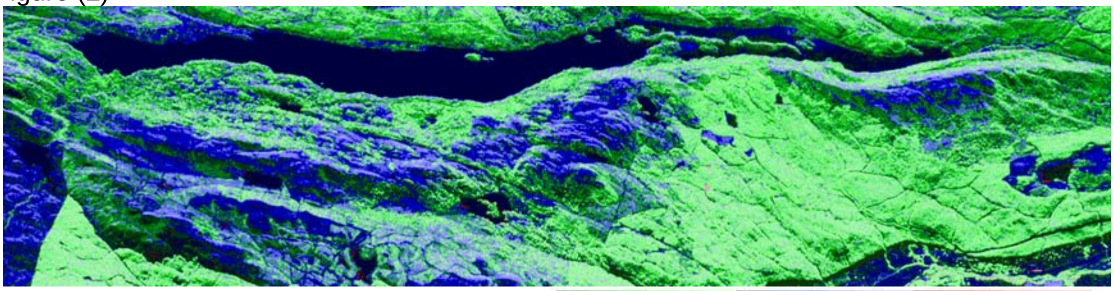
As is described in [4], the same CoV must be applied to the elements of Covariance matrix.

To minimise the cross talk between the polarised channels of different scattering mechanisms the Enhanced Lee filter is applied to the elements of scattering mechanisms independently. In here to classify the image into different scattering mechanism, the 3 component Freeman Durden classification methods is used. The initial scattering groups are further classified by complex Wishart maximum likelihood classifier. As shown by Freeman in [6] and Cloude in [7], the second order coherence matrix of the three back scatter components under assumptions of un-correlated cross polarised components and un-correlated cross scattering mechanisms and cross polarised reciprocity yields to the total back scatter model of:

$$\mathbf{C}=\mathbf{C}_v+\mathbf{C}_s+\mathbf{C}_d$$ Eq (16)

Where **C**v, **C**s and $\mathbf{C}_d$ are the covariance matrices for volume, surface and dihedral backscatter components respectively. The 3 component decomposition and classification of the fully coherent Polarimetric Glenaffric data is described in [8]. The result of this classification provides an insight in the land cover and its biophysical structures.

In here we have used results of the classification process achieved from Freeman Durden with Complex Wishart after 6 iteration cycle, for total 18 classes, 6 per scattering mechanisms, volume, surface and Dihedrals. The classified image of Glenaffric is shown in Figure (2)



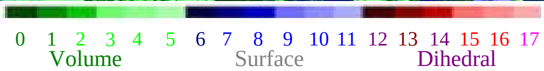


Figure 2 , The Freeman-Durden classified image of Glenaffric

Fig(2) The Freeman classified image of Glenaffric radar data

The Lee filter algorithm follows these basic steps:

-1) for each pixel the dominant scattering mechanism is identified,
-2) for each scattering type, all cross scattering elements within the filtering window are masked out,
-3) an edge aligned mask is formed,
-4) a common Lee filter coefficient of covariance is calculated,
-5) and finally the filtering process is applied to all unmasked elements within the window.
-6) the process is repeated from step 3 for all scattering types.

In here it is assumed that Pol-In ESPRIT algorithm two dominant phase scatters are result of the scatter centers on the ground and on the surface or about the centre of land cover the canopy. It is also assumed that the dominant scatter centre is the one from the ground level and directly related to the topographic information required for Digital Elevation model estimation.

Samples of interferogram formed from application of the ESPRIT algorithm without filter, with box filter (5X5) and with Lee-Edge aligned and classified filtering is given in figure 3:

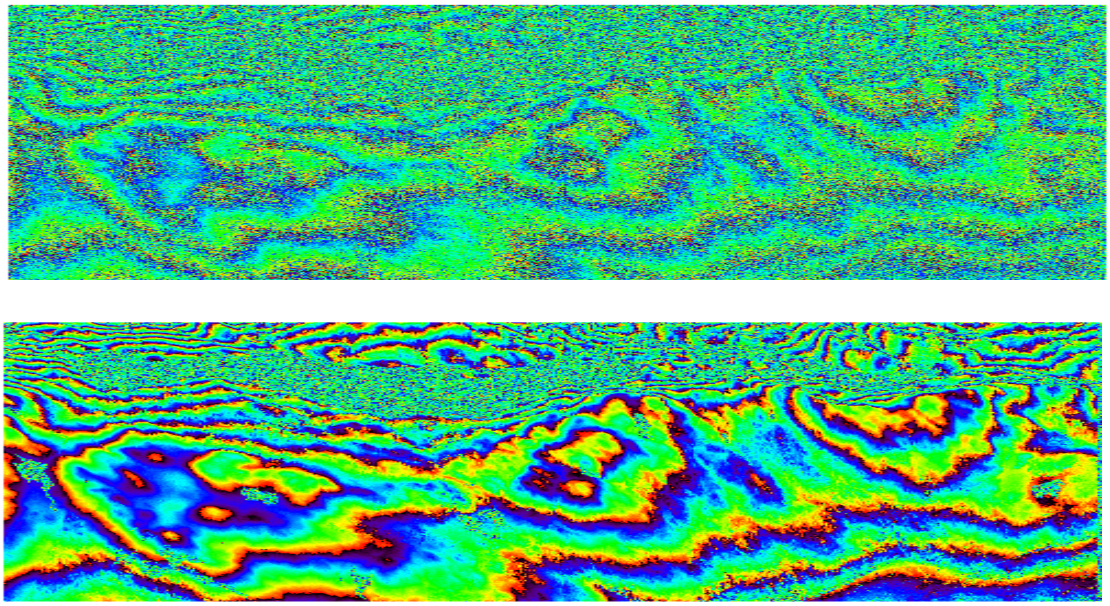


Figure 3 Interferograms for Glenaffric radar data, before and after application of filter

It can be seen that the residual noise is significantly reduced from the interferogram after the application of the filter. From the Optimum de-speckled interferogram the optimum DEM is derived. In here to form the Digital Elevation Model an iterative 'localised region grow' model is used. In each step of iteration a coherence mask is applied to the image with a relaxing threshold limited by average local coherence. The pixels within the unmasked regions of the interferogram are unwrapped until there is no more elements left. This is a variation to the

Xu-Cumming region grow model described in [9]. The particulars of this method are subject of another paper.

The unraveled phases are in radians and are related to multiples of vertical wave number (K_z). The phase information is converted to the height metric unit by dividing the unwrapped phase by K_z. given:

$$Kz=\frac{4\pi(\theta_1-\theta_2)}{\lambda\sin\theta_1} \qquad \text{Eq (17)}$$

The digital elevation model derived from the unwrapped interfrogram of image 3 is given in figure 4.

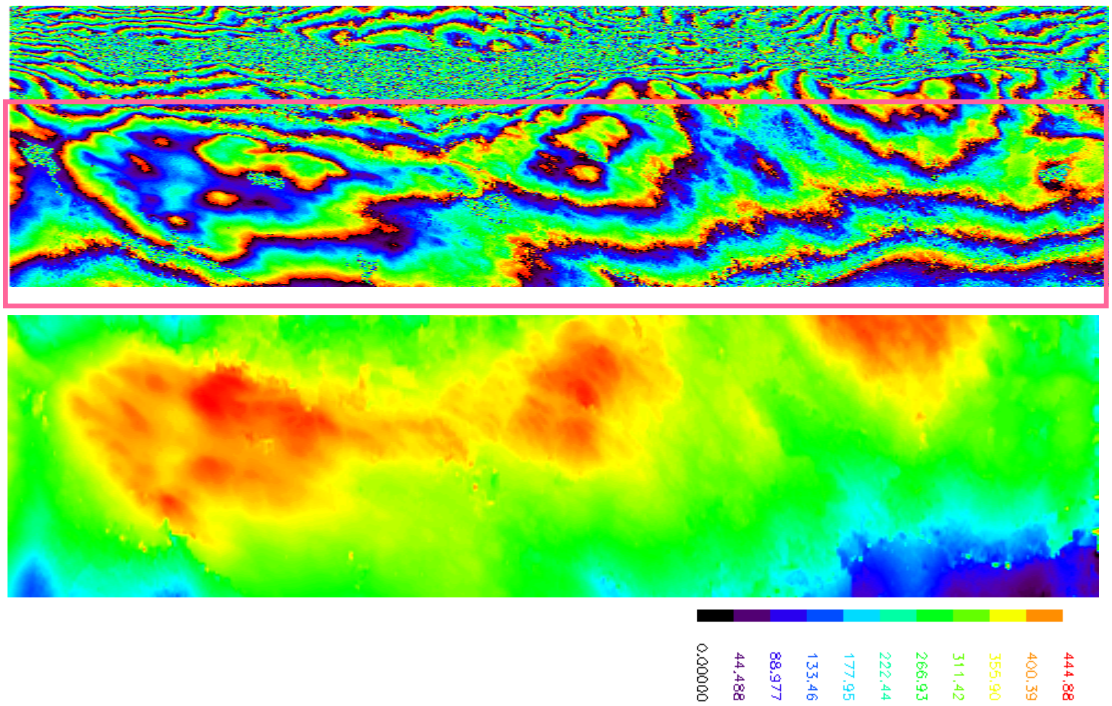


Figure 4 Digital elevationn model for part of the Interferogram for Glenaffric radar data after application of filter.

Conclusion

In this paper we proposed a method of speckle filtering based on Lee enhanced and Edge aligned filter on the coherence matrix formed by ESPRIT algorithm. The filtered covariance has a sharper and reduced residual noise phase parameters. The de-speckled optimum phase parameters are used to derive the topographic information from which the digital elevation model is formed.

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