Interferometric SAR Space-Varying Filtering of X-Band SRTM Data

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Abstract: Interferometric SAR data should be filtered in order to remove the geometrical decorrelation caused by the presence in the signal pair of “incoherent” components not illuminated in both the passes. This operation is generally carried out, via common band filters, by assuming a planar topography whereas in the real, non-planar topography case, the problem becomes space variant. We discuss the application of recently derived optimal, Minimum Mean Square Error, space-varying filters for the coherence optimization to the SAR data of the X-Band SRTM mission. We also discuss the extension of the analysis in the azimuth direction to the problem of optimally filter the Doppler Centroid decorrelation.

1. INTRODUCTION

Synthetic Aperture Radar Interferometry (IFSAR) is based on imaging, in at least two passes, the same scene from different look angles. Angular diversity results in a phase modulation that is dependent upon the scene topography and causes the presence of independent components in the acquired data pair: this effect is known as geometrical or spatial decorrelation. With reference to the X-Band SRTM system, fig.1 shows the plot of expected coherence degree versus the terrain slope in absence of any other decorrelation source. We note how a variation of the topography can induce a coherence change larger than 0.1.

![Coherence vs Terrain Slope](image)

Fig.1: Coherence degree versus the terrain slope (in degs)

Accordingly, IFSAR data should be pre-filtered in the range direction in order to remove the geometrical decorrelation by canceling those uncommon components. Commonly this filtering is carried out in the spectral domain by assuming a planar topography and therefore the spatial stationarity of the wavenumber spectra [1]. It is usually referred to as Common Band (CB) filtering.

The spatial decorrelation filtering has been recently revisited by addressing the problem in a signal estimation framework...
This allowed deriving an optimal, in the MMSE sense, processing algorithms, capable to handle the problem in its space-varying nature. This filtering procedure has been also extended to the azimuth direction to account for possible differences in the Doppler Centroid in the two interferometric channels during the acquisition. With reference to the SRTM data, here we investigate the performances of this space-varying filtering on the SRTM data.

2. SIGNAL FILTERING

We start by considering the problem of filtering the geometrical decorrelation. Accordingly, referring to the range direction following the focusing and the registration steps, the IFSAR signal pair can be expressed in the discrete-time case as follows [2,3]:

\[ h_1 = F_1 \gamma + n_1 \]
\[ h_2 = F_2 \Phi \gamma + n_2 \]

where \( h_1 \) and \( h_2 \) are the vectors containing the data at the two channels, \( \gamma \) is the vector that describes the scene backscattering coefficient, \( F_1 \) and \( F_2 \) are the post-focusing impulse response function matrix associated the imaging system (the onboard filter), \( \Phi \) is the diagonal matrix describing the phase change contribution associated to the terrain profile and \( n_1 \) and \( n_2 \) are the thermal noise component.

Assuming both the scene and the thermal noise to be stationary white processes and resolving the problem of the joint estimation of one signal with respect to the other as shown in we have [2,3]:

\[ \hat{h}_1 = F_1 \Phi^* \left( F_2 F_2^* + \lambda_2 I \right)^{-1} h_2 \]
\[ \hat{h}_2 = F_2 \Phi \left( F_1 F_1^* + \lambda_1 I \right)^{-1} h_1 \]

The filtering procedure for the data at the second (first) channel in (3) and (4) is extremely simple: the data should be first pre-whitened, then a counter phase-modulation by the phase factors \( \Phi^* \) (\( \Phi \)) associated to the cross-channel phase change is implemented and then a final filtering with the first (second) channel IRF provides the filtered signal that is best correlated to the first (second) channel data. Note that the pre-whitening filter is controlled by the signal-to-noise ratio through the factors \( \lambda_1 \) and \( \lambda_2 \). Anyway, this processing step is generally avoidable because of the flatness property of the range post-focusing system transfer function.

The range filtering technique so far discussed can be extended to filter-out the uncorrelated contribution in azimuth due to the presence of different acquisition Doppler-Centroid [4]. Let us refer to the model in (1) and (2). This model can be extended to the azimuth direction, by properly changing the modulation term, responsible of the slope-induced spectral shift, and the impulse response function filter. In particular we have:

\[ h_1 = \Phi_1 F_1 \gamma + n_1 \]
\[ h_2 = \Phi_2 F_2 \gamma + n_2 \]

where

\[ \Phi_1 = \text{diag}[0, \exp(-jf_1M\Delta x'), \ldots, \exp(-jf_1M\Delta x')] \]
\[ \Phi_2 = \text{diag}[0, \exp(-jf_2M\Delta x'), \ldots, \exp(-jf_2M\Delta x')] \]

are the phase factor associated to the Doppler Centroid \( f_1 \) and \( f_2 \) at the first and second antenna, respectively [2,3], \( \Delta x' \) is the azimuth spacing and \( M \) is the number of samples. Note that both \( f_1 \) and \( f_2 \) can be azimuth and range dependent and they induce decorrelation whenever \( f_1 \neq f_2 \). Note also that the matrices \( F_1 \) and \( F_2 \) are associated to the Azimuth Antenna Pattern (AAP) that here plays the role of the on-board filter, e.g. it shapes the bandwidth of the acquired reflectivity. However, unlike the on-board filter transfer function, the AAP is not at all flat.
The design of the optimal MMSE filter then follows closely the arguments in the range direction. In particular we have:

\[ \hat{h}_1 = \Phi_1^* \Phi_1 \Sigma_1^{-1} \left( \Phi_2^* \Phi_2 + \Sigma_2 \right)^{-1} \Phi_2^* \Phi_1 \Sigma_1 \hat{h}_2 \]

\[ \hat{h}_2 = \Phi_2^* \Phi_2 \Sigma_2^{-1} \left( \Phi_1^* \Phi_1 + \Sigma_1 \right)^{-1} \Phi_1^* \Phi_2 \Sigma_2 \hat{h}_1 \]

Unlike the range case, in (9) and (10) whitening component cannot be neglected since the AAP is not white. The gain in the image quality is then due to two independent reasons:

(A) in the case of a different Doppler Centroid Frequency in the two acquisitions, the filtering cancels out the decorrelated contributions;
(B) the filter compensates the different AAP weighting of the common component thus resulting in an additional noise contribution elimination.

The actual noise power should then be dimensioned according to thermal and quantization noise.

3. EXPERIMENTAL RESULTS

The proposed filtering procedure has been tested on simulated data relative to the Vesuvius area. The parameters are those peculiar to the X-Band SRTM system. Both received signals have been oversampled by a factor of two in the range direction. The results are shown in fig.2. In particular fig.2.a shows the unfiltered signal while fig.2b shows the improvement obtained by the applying the azimuth Wiener filtering for the reduction of the Doppler Centroid decorrelation. Fig.2.c presents the result of the space-varying range and azimuth Wiener. Here we note the further improvements related to the reduction of the geometrical decorrelation.

REFERENCES

Fig.1: Simulation on the Vesuvio volcano area. (a) initial interferogram, (b) azimuth Wiener filtering, (c) azimuth and range Wiener filtering