REFLECTIVITY AND DEM ESTIMATION FROM MULTI-BASELINE COMPLEX SAR SIGNALS

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1. INTRODUCTION

Multi-baseline Interferometric Synthetic Aperture Radar Systems (InSAR) has been used to enhancing the estimation of the ground digital elevation model (DEM) [1,2], to increasing the image range resolution [3] or to reconstruct a 3D reflectivity map (SAR tomography) [4]. In this paper we consider a method which allows the DEM enhanced reconstruction together with the scene reflectivity amplitude estimation. As far as the DEM estimation is concerned, multi-channel interferometric techniques have the potential of providing DEMs with meter accuracy. They usually exploit only the interferometric phases of SAR images, obtained using different baselines and/or different frequencies, which are directly related to the ground altimetric profile. The height profile estimation is generally performed maximizing the likelihood function (Maximum Likelihood (ML) estimation) of the multiple interferograms [1]. The amplitude of the interferometric images, instead, is not exploited, since it is not directly related to the height profile, and then does not provide additional information on it, unless a scattering model relating the height slopes to the reflectivity intensity is included.

A problem to be considered in the application of ML multi-channel techniques is that the closed form evaluation of the likelihood function of the multiple phase interferograms is not easy to be found when the interferometric phases are mutually correlated, like usually happens in multi-baselines configurations [5]. A closed form has been found only in the case of dual-baselines systems. In the general case of more than two baselines, the interferometric phases are assumed to be statistically independent, so that the multi-baseline likelihood function can be found by computing the product of the single-baseline likelihood functions. This approximation produces a loss of accuracy in the reconstructed height profile, especially when the number of the used baselines increases.

In this paper we present an alternative DEM estimation technique exploiting both the amplitude and the phase of the interferometric images. The use of the amplitude information has not the objective of improving the height estimation accuracy, but allows expressing the exact multi-baseline likelihood function in a closed-form, derived from the well known multivariate Gaussian signal model. The technique can be also applied for reducing the speckle noise on the image amplitude, by coherently combining the multi-look images. Coherent combination requires the use of the estimated height profile and of the images correlation. Numerical results on simulated and real data will be presented in the final paper.

2. MULTI-BASELINE DEM AND REFLECTIVITY ESTIMATION

Let us consider K complex SAR images obtained by processing the signal received by K SAR antennas viewing the same scene with slightly different look angles. Taking the first antenna as a reference, we define the spacing B_{1k} as the distance of the *k-th* antenna and the reference one, measured along the direction perpendicular to the look direction.

Assuming a discrete ground coordinate system, let $Y_k(l)$, $l = 1,..., NxM$, be the complex image signal of a ground region at the discrete image pixel l, acquired by the k-th antenna:

$$Y_k(l) = a(l)e^{j\varphi_a(l)}\, X_k(l)\, e^{j\alpha B_{1k} h(l)} + v_k \qquad k = 1,...,K, \quad l = 1,...,N \times M, \tag{1}$$

where $N \times M$ is the image dimension, k denotes the different channels, $a(l)$ and $\varphi_a(l)$ are amplitude and phase of the radar reflectivity of the l-th image pixel, $X_k(l)$ is the complex valued multiplicative speckle noise, v_k is additive thermal noise, $h(l)$ denotes the height value at the image pixel l, and α is a constant depending on the operating frequency and on the range distance between the reference antenna and the centre of the scene.

The problem consists in estimating the speckle free reflectivity amplitude $a(l)$ and the height values $h(l)$ starting from the K

complex SAR images $Y_k(l)$. Since we consider each image pixel independent from the others, we can neglect the dependence of the pixel coordinate and in each pixel we can define the data vector $\mathbf{Y}=[Y_1 \;\; Y_2 \;\; \ldots\ldots \;\; Y_K]^{\mathrm{T}}$ and the speckle complex vector $\mathbf{X}=[X_1 \;\; X_2 \;\; \ldots\ldots \;\; X_K]^{\mathrm{T}}$. Moreover we neglect the presence of the additive thermal noise, since signal to thermal noise ratio is sufficiently high after SAR image focusing. In the assumption of fully developed speckle, **Y** is a proper complex Gaussian vector with a joint probability density function (pdf):

$$f_{\mathbf{Y}}(\boldsymbol{y}) = \frac{1}{\pi^K a^{2K} \left|\mathbf{C}_{\mathbf{Y}}\right|} exp\left\{ - \frac{1}{a^2} \boldsymbol{y}^H \mathbf{C}_{\mathbf{Y}}^{-1} \boldsymbol{y} \right\} \tag{2}$$

where the covariance matrix depends on the parameter h , $\mathbf{C}_{\mathbf{Y}}=\mathbf{C}_{\mathbf{Y}}(h)$, and can be expressed as $\mathbf{C}_{\mathbf{Y}}=\mathbf{\Phi}^{\mathrm{H}}\mathbf{\Gamma}_{\mathbf{X}}\mathbf{\Phi}$, where H denotes the Hermitian, $\mathbf{\Phi} = diag\left[1, \mathrm{e}^{j\alpha B_{12}h}, \ldots, \mathrm{e}^{j\alpha B_{1K}h}\right]$ and $\mathbf{\Gamma}_{\mathbf{X}}=\{\gamma_{mn}\}$ is the covariance matrix of the speckle vector **X**. For obtaining the ML estimation of the unknown parameters h, a and φ_a we have to maximize the log-likelihood function, obtained by substituting the measured complex radar images in the log of (2). It is easy to show that the log-likelihood function is independent from φ_a (which can not be estimated from **Y** and does not influence the estimate of a and h). while the estimate $\hat{h}_{ML}$ of h is independent on the parameter a and can be found by solving the equation:

$$\mathbf{Y}^H \mathbf{D}^{-1} \mathbf{Y} = 0 \tag{3}$$

where **D** is a matrix whose generic elements are given by $d_{nm} = j\lambda_{nm} a B_{nm} \; e^{j\alpha B_{nm}h}$, with λ_{nm} the (n,m) element of the matrix $\Gamma_{\mathbf{X}}^{-1}$. Once estimated h, the ML estimation of a can be expressed in the closed form:

$$\hat{a}_{ML} = \sqrt{\frac{\mathbf{Y}^H \hat{\mathbf{C}}_{\mathbf{Y}}^{-1} \mathbf{Y}}{\mathrm{K}}} \tag{4}$$

Note that $\hat{a}_{ML}$ depends on $\hat{h}_{ML}$ through the matrix $\hat{\mathbf{C}}_{\mathbf{Y}}^{-1} = \mathbf{C}_{\mathbf{Y}}^{-1}\left(\hat{h}_{ML}\right)$.

The method has been tested SAR images **Y** of a ground scene with different reflectivity levels simulated using the model of Eq. (1) and the Envisat-ASAR parameters. The DEM has been estimated using Eq. (3), while the image amplitude has been estimated by using Eq. (4). Obtained results are compared with those obtained by estimating h starting from only phase data and assuming independent interferograms and with the multi-look amplitude obtained by performing the average value of the image amplitudes (incoherent multi-look). The root mean square values (rms) of the reconstruction error and the Equivalent Number of Looks (ENL) are presented in Table 1, showing the better performance of the presented method.

	rms for h [m] (Eq.(3))	rms for h [m] (only phase data)	rms for a (Eq. (4))	rms for a (incoherent multi-look)	ENL (Eq. (4))	ENL (incoherent multi-look)
3 baselines	6.03	5.95	1.53	1.99	2.5078	1.43
6 baselines	4.16	5.26	1.11	1.93	5.5201	2.55
9 baselines	3.57	5.11	0.91	1.93	7.6539	1.60

Table 1. Results obtained on simulated multi-baselines images.

3. REFERENCES

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