FRACTAL BASED FILTERING OF SAR IMAGES

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1.INTRODUCTION

The new generation of Synthetic Aperture Radar (SAR) sensors has marked a huge increase in the resolution of microwave images of the Earth. TerraSAR-X and COSMO-SkyMed are providing SAR data with the remarkable resolution of 1 x 1 m^2 in the high resolution spotlight operational mode. Owing to this improvement in resolution, new models, techniques and tools are required to adequately deal with this new scenario. In fact, the availability of very high resolution data calls for a change in the analysis and elaboration approach of microwave images of both urban areas (where the development of techniques for the extraction of deterministic parameters of man-made objects becomes now possible) and natural zones. In particular, regarding the last ones, until now it was only possible to identify macroscopic topological features (mountains, rivers, seas, etc.) of the observed areas, roughly distinguishing them from urban ones: with the new generation sensors the extraction of meaningful stochastic parameters of the observed surface at microscopic level is now in order. In this paper we present an innovative technique for the analysis and interpretation of SAR images of natural areas. Our analysis is based on a sound direct modeling of the observed surface and of the SAR imaging process [1]. In particular, the observed natural surface is modeled as a fractal two-dimensional stochastic process [2]: for such a process, the key parameter to be estimated from the image is the fractal dimension D of the imaged surface. In fact, this parameter is strictly related to the roughness and geophysical characteristics of the surface and its knowledge can be of key importance for a wide range of applications. In the open literature, no reliable technique for the estimation of this parameter from a radar image is known. With regard to the imaging model it takes into account both the interaction between the surface and the incident electromagnetic wave, through appropriate fractal scattering models [3], and the SAR impulse response. In this paper we present a novel technique for the retrieval of the fractal dimension D of the observed surface based on an appropriate spatial filtering of the amplitude SAR image, whose rationale comes from the inversion of the direct models presented by the authors in [1].

In the following we summarize the theoretical and methodological aspects of the proposed approach. Full details, along with applications to actual SAR data, will be provided in the final version of the paper and during the conference presentation.

2.THEORETHICAL AND NUMERICAL SETUP

It is widely recognized that fractal models represent the best way to describe the irregularity of natural scenes [2], [3]. Among this kind of models, we choose the regular stochastic fBm (fractional Brownian motion) process that completely describes natural surfaces by means of two independent parameters: the Hurst coefficient, H (which is linked to the fractal dimension by the simple relation D=3-H) and the standard deviation of surface increments at unitary distance, s [m^{1-H}]. Besides the surface model, in order to retrieve the fractal dimension of a natural scene starting from its SAR image we need a direct model relating the surface to its final amplitude image. In [1] the authors presented a complete imaging model based on the assumption of a small slope regime for the observed surface: if this is the case, the image intensity comes out to be a linear function of the partial derivative of the surface evaluated along the *range* direction, as summarized in Fig. 1. Note that the proposed model accounts for both the interaction between the incident electromagnetic wave and the observed surface (through appropriate fractal scattering models [3]) and the SAR system impulse response.

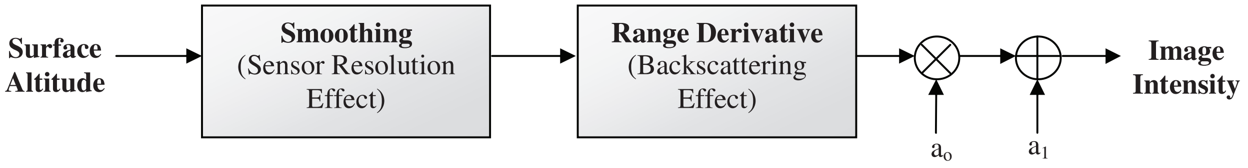

Fig. 1: Block diagram of the Imaging Process; a_0, a_1 depending on the scattering model used

The expressions of the autocorrelation functions of the SAR image and of the power density spectra of two cuts of the image in the *range* and *azimuth* directions respectively, have been evaluated by the authors in [1]. The behaviors of these spectra change according to the considered cut, thus highlighting an intrinsic asymmetry in the structure of SAR data, that is also intuitively referable to the particular acquisition geometry of a side looking mono-static radar. In particular, the spectrum of an image *range* cut, in an appropriate range of spatial frequencies, presents a power law behavior - thus showing on a log - log plane a linear behavior with a slope related to the Hurst coefficient of the observed surface - as clearly shown by the following expression, which holds for adequately low wavenumbers:

$$S_p(k_y) = s^2 \Gamma(1+2H) sen(\pi H) \frac{1}{|k_y|^{2H-1}} \tag{1}$$

where k_y is the wavenumber of the *range* cut of the image and Γ is the Euler Gamma function.

Starting from Eq. (1), it is possible to implement linear regression algorithms on the spectrum of range cuts of the image in a log - log plane, thus retrieving the fractal dimension, according to the scheme presented in Fig. 2.

Fig. 2: Block diagram of the extraction of the fractal dimension

Furthermore, we cannot set aside the *speckle* phenomenon, which is responsible for the well-known *salt and pepper* effect on SAR amplitude images. As a matter of fact, the spatial scales involved by the *speckle* are mainly those on the order of the sensor resolution, hence in the wavenumber domain the high frequency range of the image spectrum is degraded. However, our algorithm performs the linear regression in a range of spatial frequencies in which the spectrum is not significantly affected by this phenomenon.

The implemented algorithm extracts the local fractal dimension of the imaged surface working on homogeneous patches of the SAR image and iterating the procedure on the whole image, through a moving window, whose dimension can be set by the user according to its specific needs, as a trade-off between accuracy and resolution of the output fractal dimension map. In particular, the algorithm performs this estimation selecting in each window *range* cuts that are sufficiently spaced from each other to be considered uncorrelated. Then the spectra of these cuts (whose number can be again chosen by the user, as a trade-off between accuracy and computation time) are evaluated using a Capon estimator [4]. Finally, these spectra are averaged and a linear regression is performed on this mean power density spectrum. As a result, we obtain a map of the fractal dimension of the observed scene: the resolution of this map depends on both the resolution of the input image (the higher the resolution of the image, the better the resolution of the map) and the dimension of the estimation window. By means of such a type of filtering - whose application to real cases will be presented in the final version of the paper and during the conference presentation - different applications can be carried out. For instance, it is possible to accurately distinguish man-made objects (which show a non-fractional dimension) from rural areas; most of all, the extraction of the point by point fractal dimension of the scene under survey enables us to classify natural surfaces according to this fractal parameter.

3.CONCLUSIONS

In this paper an innovative fractal based filtering for the analysis of SAR images of natural surfaces is presented. It is based on a complete direct imaging model developed by the authors, relying on adequate fractal model for both the description of the surface and of the electromagnetic problem. This sound theoretical foundation makes the SAR image post-processing steps simple, reliable and unsupervised. Applying this new kind of techniques to SAR images, it is possible to obtain a complete map of the fractal dimension of the observed scene. Starting form high resolution images, it is possible to accurately distinguish man-made objects from rural areas. Moreover, regarding the last ones, a stochastic microscopic characterization is now for the first time available, through a point by point description of the roughness of the scene under survey. In the final version of the paper and during the conference presentation the filtered images obtained from the application to actual SAR data will be presented.

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