Post-Processing Methods for Ocean Monitoring from SAR Imagery

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***Abstract*— A number of experiments all over the world have proven that satellite borne SAR images constitute a valuable tool to monitor oceanic environment, preventing it from overexploitation or pollution matters and it can also help to evaluate the full implications of natural or man made hazards. In fact, thanks to their capability to cover large areas, in all weather conditions, during the day as well as during the night, spaceborne Synthetic Aperture Radar (SAR) techniques constitute an extremely promising alternative to traditional surveillance methods. Nevertheless, in order to assure further usability of SAR images, specific data mining tools are still to be developed to provide an efficient automatic interpretation of SAR data. In the last years, our group has been studying, analyzing and validating several dedicated methods for different marine applications: namely, ship detection, extraction of the coastline and detection and rough classification of pollutants in the sea surface.**

Keywords- wavelet transform; multiresolution analysis; ship detection; oil spill detection; coastline extraction.

I. Introduction

Nowadays, there is an increasing interest in remote sensing applications from space. In Europe, GMES (Global Monitoring for Environment and Security), which is a joint endeavour of the European Space Agency and the European Community, remains a valuable proof of the actual rise of space technologies. One of the most encouraged applications is maritime traffic surveillance from space, including fisheries monitoring, maritime security, ocean pollution and border control.

A number of experiments all over the world have proven that Synthetic Aperture Radar (SAR) images constitute a valuable tool to monitor oceanic environment, preventing it from overexploitation or pollution matters and it can also help to evaluate the full implications of natural or man made hazards. With respect to optical imagery, this all time and all weather observation capability remains the most valuable distinctive advantage. Nonetheless, the counterpart is that the interpretation of SAR images, mainly affected by speckle, is quite troublesome. Since a manual treatment is unacceptably slow, unpractical and hardly reproducible, fully or eventually partially computerized schemes are desirable. As a consequence, in order to increase further usability of SAR images, more specific data mining methods are still to be developed to provide efficient tools for automatic interpretation of SAR data.

Accordingly, our purpose is to establish a specific framework for the automatic exploitation of SAR imagery. Inspired by the operation of the brain, the environment proposed is structured following three milestones: spot detection, extraction of linear features and texture analysis. The objective of this paper is then to introduce an environment which provides an efficient and combined interpretation of SAR images for oceanic purposes.

First, this paper will overview the main drawbacks affecting the unsupervised interpretation of SAR imagery. Then, the use of a multiscale framework will be justified. The complementariness of the different applications focused will be justified and the details of the algorithms will be separately shown.

II. A Multiscale Time –Frequency Framework for SAR Data Analysis

A. *Particularities of SAR Imagery*

A SAR image $u(x,r)$, where (x,r) are the azimuth and range dimensions respectively, can be modeled as the convolution of the local complex reflectivity of the observed area with the impulse response $u_0(x,r)$ of the SAR system. Since a resolution cell is very large in terms of the wavelength of the illuminating electromagnetic wave, the returned echo $\gamma(x,r)$ is the result of the coherent summation of all the returns due to the single scatterers $\gamma_i(x,r)$ following a random walk process.

$$|u(x,r)| = |\gamma(x,r) * u_0(x,r)| = \left|\sum_i \gamma_i(x,r) * u_0(x,r)\right| \quad (1)$$

Consequently, it is quite obvious that the most appropriate way of facing the interpretation of SAR imagery is by assuming the image samples as realizations of some underlying stochastic process. Then, analysis tools have to be inscribed in a statistical framework.

Each particular application and each particular scenario demands different requirements in the trade-off between space resolution and statistics accuracy. As a consequence, the use of a suitable multiscale time / frequency (space / statistics) framework for the interpretation of SAR data is justified as it may deal with this compromise.

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B. *The Wavelet Transform*

Signal processing with wavelets is just one among other time-frequency methods, but it presents clear advantages, mainly in relation to the analysis of transient phenomena. In this section, some of the aspects of the WT will be briefly discussed. Extended details can be found in [1].

Essentially, the WT is the projection of a given complex phenomenon in a function space in which the basic functions or atoms are localized in both time and frequency, coming from dilations and translations of a *mother* wavelet, ψ . In 1D,

$$Wf\left[z,a^j\right]=\sum_{m=0}^{N-1} f\left[m\right]\psi_j^*\left[m-z\right], \tag{2}$$

where z is the discrete temporal (or spatial) variable and the parameter a^j allows adjusting the temporal (or spatial) duration of the wavelet ψ_j

$$\psi_j\left[z\right]=\frac{1}{\sqrt{a^j}}\psi\left[\frac{z}{a^j}\right]. \tag{3}$$

The WT can also be seen as a multiscale differential operator. More specifically, a continuous wavelet ψ has n vanishing moments if and only if there exists a function θ such that

$$\psi\left(t\right)=\left(-1\right)^n\frac{d^n\theta\left(t\right)}{dt^n}. \tag{4}$$

As a consequence

$$Wf\left(u,s\right)=s^n\frac{d^n}{du^n}\left(f*\bar{\theta}_s\right)\left(u\right), \tag{5}$$

where s is the continuous scale, u is the spatial variable and $\bar{\theta}_s$ is the conjugate of the corresponding wavelet at scale s , constructed from a dilation of the function θ . Hence, singularities can be detected by finding the abscissa where the wavelet modulus maxima converge at fine scales.

III. SET OF AUTOMATIC ALGORITHMS DEVELOPED FOR MARINE APPLICATIONS

A. *Automatic ship detection in SAR imagery*

Taking advantage of the difference of behavior of the noise and the target in the wavelet domain, a novel approach for ship detection in SAR imagery is proposed (see Fig. 1). This algorithm has a multiscale capability and it consists on two operations per iteration. The first one is the application of a single iteration of the OCWT which leads to three different components D_j^1, D_j^2 and X_j . Then, the second one consists of merging the three components into one result by a spatial product. The spatial product accounts for the different behavior of the noise and structural information and privileges co-occurrence of local maxima in the wavelet subbands. As a result, the presence of the structure is enhanced with respect to clutter. This basic step can be iterated by applying it to the wavelet subband X_j corresponding to a low pass filtered version of the input image. Essentially, this technique reveals the presence of a coherent target in a noisy background, with a low dependency on the intensity. Subsequent automatic thresholding is greatly simplified. More details about the properties and features of the technique may be found in [2].

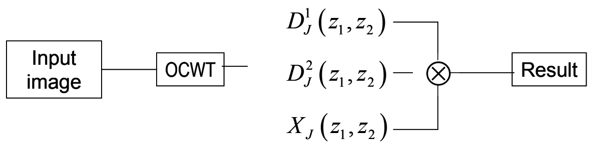

Figure 1. Flowchart of one iteration of the proposed algorithm for unsupervised spot detection in SAR images.

Some representative examples of the operation of the method proposed for ship detection applied to ENVISAT and RADARSAT images are shown in Fig. 2. Groundtruth data was available through VMS positions. It should be noticed that no threshold has been applied to the direct output.

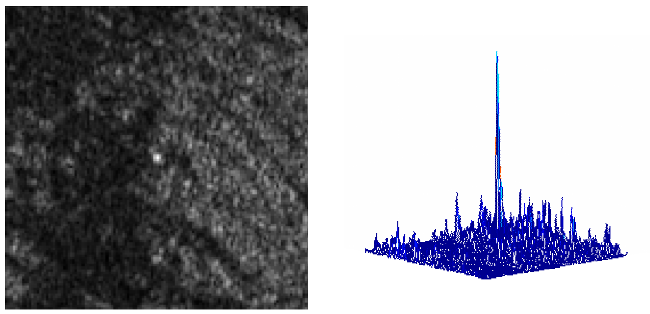

Figure 2. Enhancement of contrast performed by the proposed algorithm. Input SAR image with a ship in the centre (left) and result (right).

B. *Automatic extraction of the coastline in SAR imagery*

The automatic extraction of linear features in a noisy background is a critical matter in a number of SAR applications. In particular, this section is concerned with the automatic extraction of the coastline. Besides, the granular characteristics of SAR images makes it difficult to segment ocean and land areas by direct thresholding of intensity levels. Accordingly, the alternative proposed consists essentially on two steps: edge enhancement and application of a Geodesic Active Contour technique, which leads to a binarized image.

The method for edge enhancement is obtained with an algorithm based on a particular combination of coefficients in the wavelet domain (see Fig. 3). Apart from assuring a reliable highlighting of elongated patterns, some additional requirements have been previously established. One of the priorities is to build a method simple and not computationally costly in order to be able to process complete commercial SAR images in manageable durations. Moreover, systems based on neural networks requiring long training are avoided because they are time consuming and they show a quite poor efficiency in heterogeneous SAR scenes. Finally, in order to preserve as much as possible the resolution of the input image, no previous filtering step is performed.

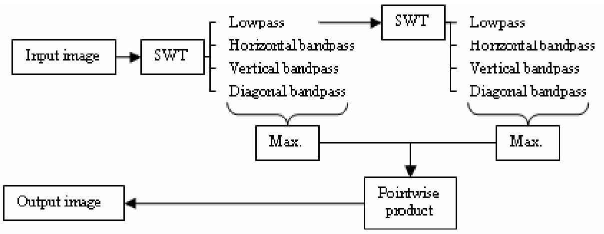

Figure 3. Flowchart of the algorithm proposed for edge enhancement.

A more exhaustive explanation of the features of the proposed technique can be found in [3]. In order to evaluate its performance, it has been compared to a Sobel filter which is a gradient estimator commonly used in image processing for the automatic enhancement of edges. Some representative results are shown in Fig. 4.

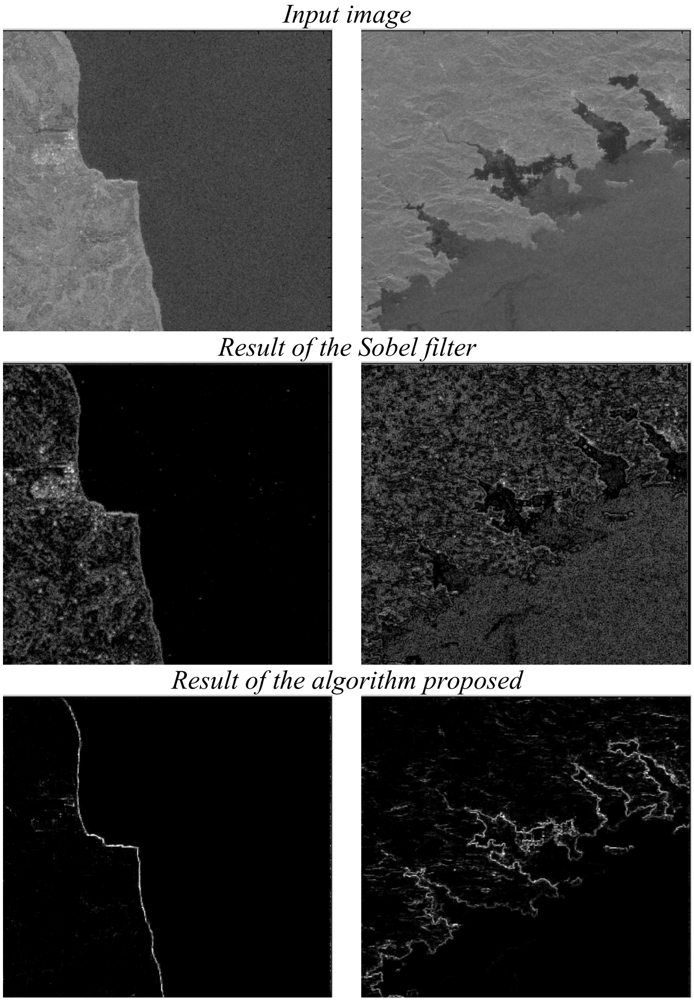

Figure 4. Examples of operation of the proposed algorithm and comparison with the performance of the Sobel filter.

The algorithm has also been tested on more complex scenarios such as for a precise delineation of the contour of oil spills (Fig. 5) and for the detection of rivers and inland waters.

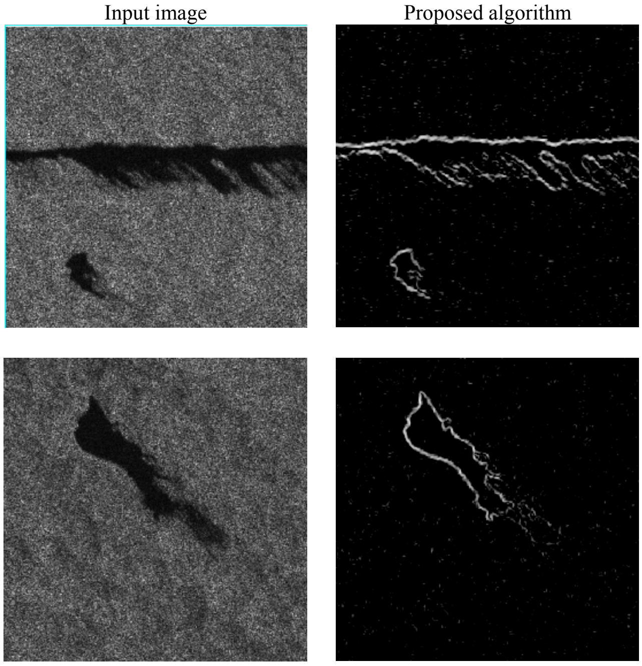

Figure 5. Application of the proposed algorithm to the precise delineation of the contour of oil spills in the sea surface.

C. *Automatic oil spill detection in SAR imagery*

The presence of an oil spill in the ocean surface appears in the SAR image as a dark patch. Nevertheless, this dampening effect can also be caused by many different natural and unpredictable phenomena (mainly lack of wind). Hence, the main drawback that unsupervised methods for oil spill detection in SAR imagery have to face is the discrimination of false alarms due to look-alikes. A method is being studied to provide a quantitative measure as local as possible and as precise as possible of the regularity of the signal which directly reflects the roughness of the sea surface observed. A more detailed analysis can be found in [4]. On the one hand, a technique for automatic texture analysis based on the WT is tested on simulated images. Some preliminary results are shown in Fig. 7. It can be observed that the method employed is sensitive enough to discriminate an oil spill from a look-alike, even with the same mean intensity, in a simulated homogeneous image.

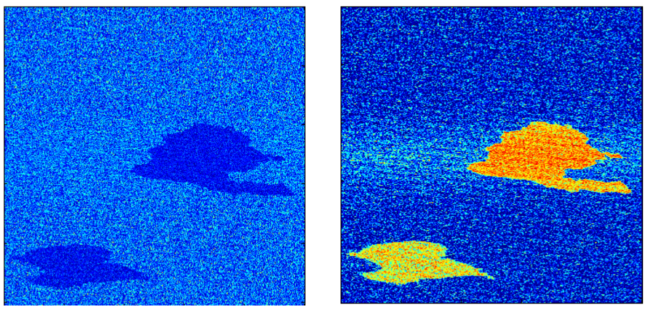

Figure 6. Lipschitz exponents with a small number of scales(right) of a simulated image (left) with two dark patches (oil spill and look alike).

An example on a SAR image is shown in Fig. 7.

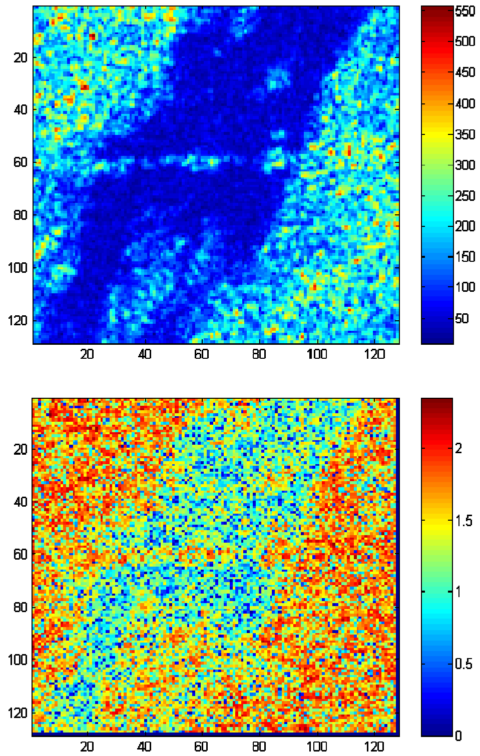

Figure 7. Hölder exponents (right column) of an ENVISAT SAR scene in the presence of an oil spill (left column).

IV. COMPLEMENTARINESS OF MARINE APPLICATIONS

Even if usually treated separately, the main oceanic applications of SAR imagery (vessel monitoring, coastline extraction and spill detection) are very closely related to each other. For example, any algorithm for automatic ship detection requires a previous land mask step which is usually performed with maps available from other sources. This is a problematic and time consuming operation which could be rendered easier by applying a method for automatic coastline extraction sufficiently robust. Moreover, the constitutive peakiness of SAR images can be reduced with a slight evolution of the technique used for ship detection and this increases substantially the performance of the algorithms used for coastline extraction or for the analysis of textures involved in oil spill detection. Besides, the discrimination of large elongated patterns can drastically reduce false alarms when the objective is to perform ship detection. It can also be used to locate oil spills in the sea surface. Additionally, the automatic detection of oil spills aims at revealing responsibilities and it is deeply associated to ship detection. Hence, previous examples suggest that the most efficient exploitation of oceanic SAR images implies a simultaneous use for different but complementary applications.

The three methods presented in this paper are based on suitable combinations of the coefficients in the wavelet domain. Therefore, the application of the WT to the image is a common step to all of them. The automatic extraction of linear features provides an easy way to obtain a mask of land areas and oil spill candidates. Once the mask applied , automatic ship detection can be reached through a recombination of the wavelet coefficients and oil spill candidates preselected can be similarly classified. The output of all three algorithms can then be interpreted in a combined fashion in order to obtain more reliable results (see Fig. 10).

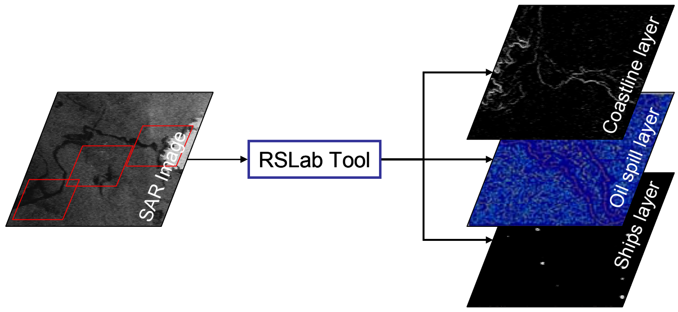

Figure 8. Flowchart of the RSLab Tool for ocean applications.

V. CONCLUSION

This paper proposes a combined exploitation of oceanic SAR images for different related applications, namely ship detection, coastline extraction and oil spill detection. Three different methods, one for each different application have been proposed separately. Since they all rely on the same wavelet framework, they can be easily combined, enhancing both global and individual results and saving computing cost.

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