A NOVEL ALGORITHM FOR AUTOMATIC SHIP AND OIL SPILL DETECTION BASED ON TIME-FREQUENCY METHODS


Departament de Teoria del Senyal i Comunicacions, Universitat Politècnica de Catalunya (UPC), C/Jordi Girona, 1-3, Building D-3, E-08034, Barcelona, Spain.
marivi.tello@tsc.upc.edu ; Phone: +34 934017426 ; Fax: +34934017232

ABSTRACT:

A novel method for automatic ship detection based on the Wavelet Transform (WT) has been recently presented. The results obtained point out the potential of the use of a multiresolution time-frequency framework for the analysis of SAR imagery. On the one hand, this paper aims at reviewing the algorithm for automatic spot detection on speckled images. On the other hand, a novel algorithm for the automatic extraction of linear features, also based on time-frequency methods will be presented, justified and tested. This approach is shown to be useful for a reliable automatic coastline extraction and for oil spill detection.

Keywords: Wavelet Transform, multiscale time-frequency methods, speckle.

1 INTRODUCTION

It is well known that a SAR sensor cannot resolve individual scatterers in such a way that, for each resolution cell, the resulting reflectivity is equal to the random sum of all scatterers contributions. This random walk process affecting to the combination of the different reflectivities within a resolution cell produces speckle which is inherent to any coherent system and which constitutes one of the major disturbances to the correct understanding of SAR images. Hence, analysis tools have to be inscribed in a statistical framework but preserving contextual information since they are dealing with non stationary phenomena. And this leads to the well known trade off between time (or space) and frequency accuracies.

It has already been shown that, as it can perceive a structure in the context of its surroundings, the human vision can manage non stationarities in a convenient way, overcoming existing automatic algorithms in extracting features in a complex scene: for example, the human eye is superior in observing a slick in the context of the surrounding sea and, surprisingly, some vessels undetected by conventional techniques are visible by eye.

Nevertheless, since manual counting is a slow and unpractical process lacking of reproducibility, a computerised scheme is much more desired. Since multiresolution processing is able to model the operation of the human vision, it seems interesting to axe the interpretation of SAR images by means of time-frequency methods and, in particular, by means of the wavelets tools. Signal processing with wavelets is just one among other time-frequency methods but it presents clear advantages. The Short Time Fourier Transform and the Wigner-Ville transform are not always suitable for transient phenomena and the WT holds the key for the successes of detection / estimation in non stationary environment. Moreover, wavelet tools are specially well suited for their use on the processing of natural scenes since they are well adapted to analyze multifractal properties.

2 A NOVEL ALGORITHM FOR AUTOMATIC SHIP DETECTION

2.1 Theoretical principles

Nowadays, several systems have operational status for automatic ship detection purposes. All of them rely on a Constant False Alarm Rate (CFAR) approach. The underlying reasoning associated to CFAR techniques is valid and efficient if the observed scene is sufficiently homogeneous, but it fails elsewhere. Essentially, these algorithms assume...
the homogeneity of the image to be analyzed within a region of fixed dimensions. Through the values of the signal in this cluster of samples, some statistical parameters are estimated and are used to adjust the histogram to the probability density function of a particular statistical distribution previously assumed to characterize clutter (the most popular hypothesis is the K-distribution). Then a threshold is calculated and its application leads directly to a binarized image. Hence, summing up, the validity of CFAR approaches depends on two assumptions: the assumption of a particular and immutable nature of statistical distribution and the assumption that a considerable contrast exists between the vessel and the surrounding sea. Nevertheless, these requirements are not always met. Figure 1 presents two heterogeneous scenes with their corresponding histograms which do not follow an expected statistical distribution. Figure 2 shows two difficult situations of detection with low contrast.

Fig. 1. Two fragments of SAR images of heterogenous scenes and their corresponding histograms.

Fig. 2. Two fragments of SAR images with vessels with a low contrast.

The objective of the proposed algorithm (Fig. 3) is to provide an alternative approach to CFAR methods, focusing on facing the detection not only taking exclusively into account the intensity characteristics of the image but also studying its very localized statistical behaviour (this can be extremely useful for the automatic detection of wooden vessels for example).

Fig. 3. Flow chart of the proposed algorithm for automatic spot detection
The algorithm will be reviewed through an explicative example on a simulated image presenting a situation not resolvable by a CFAR approach (Fig. 4) (the intensity of the target is not the maximum intensity in the image). Further details can be found in [1,2].

In signal theory, it is quite intuitive that the difference between noise and a structure is the spatial correlation. More specifically, spatial correlation in the noise is low, i.e., pixels are usually not related to each other and the probability of a pixel to have a similar intensity than its neighbours is low. On the contrary, spatial correlation on a structure is high, i.e., pixels are related to each other and the probability of a pixel to have a similar intensity than its neighbours is high. When applying the WT (and particularly the Over Complete Wavelet Transform OCWT), this difference of behaviour is transferred much more amplified to the wavelet domain because the WT is an effective whitening process. As a consequence, the probability of coincidence of local maxima in the different subbands within a scale is low in the background noise whereas the probability of co-occurrence of local maxima is high in the presence of a structure (Fig. 5). Then, the spatial product greatly enhances the presence of a target (Fig. 6).

\[ \text{significance} = \frac{\text{peak of the target} - \text{background mean}}{\text{background standard deviation}} \]  

(1)

Some illustrative examples are shown below (Fig. 7).
This alternative technique appears to be simple and not computationally costly. It is robust, it preserves the resolution, it can manage different discontinuities at different scales and it works properly in heterogeneous scenarios (Fig. 8), being thus specially appropriate to its application to near-shore waters.

3 A NOVEL ALGORITHM FOR THE AUTOMATIC DETECTION OF LINEAR FEATURES

3.1 Theoretical principles

It is widely assumed that the WT is an efficient edge detector, enhancing edges at different orientations (different subbands of a same scale) and at different scales, by iterating the process [4]. Moreover, a local maxima in the wavelet domain produced by the presence of a discontinuity in one direction is transmitted over scales, whereas noise rapidly decreases. Based on these considerations, a novel algorithm for the extraction of linear features is proposed.

By correlating different subbands of wavelet coefficients belonging to the same direction but at different scales, a frontier can be drastically highlighted. On the contrary, as the probability of having oriented structures in the surrounding background is low, the correlation of the subbands reduces noise.
3.2 Application to the automatic extraction of the coastline

Conventional ship detection algorithms include a first step which consists on a land masking of the input image. This is a quite problematic and time consuming operation which requires the availability of precise and actualized maps. In fact, ship detection rates are considerably lower in the near-shore region than in the open sea. Aiming to provide an alternative to conventional land masking processes assisting automatic ship detection, the proposed algorithm for the automatic detection of linear features based on the WT has been applied to the automatic extraction of the coastline in real ENVISAT images (Fig. 9). It may be noticed that the results shown correspond directly to the output of the algorithm: no additional threshold has been applied.

![Fig. 9. Two examples of application of the algorithm for automatic coastline extraction on real SAR images.](image1)

3.3 Application to automatic oil spill detection

The proposed algorithm for the extraction of linear features has also been tested on real ENVISAT images for oil spill detection purposes (Fig. 10). Automatic identification of oil spills in SAR images is a complex task because objects that resemble oil spills frequently occur, particularly in low wind conditions [5]. Nevertheless, the dampening effect due to the presence of an oil spill is usually more abrupt than that produced by a natural mechanism which is more progressive. As a consequence, the technique presented in this paper which enhances discontinuities between two patterns is more sensitive to the presence of an oil slick and it is less affected by look alikes than conventional methods based on adaptive thresholding (Fig. 11).

![Fig. 10. Two examples of application of the algorithm for oil spill detection on real SAR images.](image2)
4 CONCLUSIONS

Taking into account the particularities of oceanic SAR images, two novel segmentation algorithms based on the WT have been presented. The first one is focused on providing a robust and reliable automatic ship detection and it has been successfully tested on a large set of RADARSAT and ENVISAT images. The second one addresses the extraction of elongated features and it has been applied to coastline extraction and to oil spill detection, both in an automatic way. The originality of the proposed scheme is working in the transformed domain by conveniently combining wavelet coefficients at different subbands. This technique permits the simultaneous consideration of both purely morphological – deterministic and statistical aspects, approaching the operation of the visual system.

ACKNOWLEDGEMENTS

This work was supported by the Spanish MCYT and FEDER funds under project TEC2005-06863-C02-01. The authors would like to thank the DECLIMS project for providing access to the SAR images database.

REFERENCES


