Split-band SAR Interferometry For Vessel Tracking: Application On Sentinel-1 Data

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Abstract

Most recent Synthetic Aperture Radar (SAR) sensors use wide band signals to achieve metric range resolution. One can take advantage of this wide band to split a single acquisition into sub-bands and generate several lower-resolution images, centered on slightly different frequencies, performing so a SAR spectral analysis. One application of this process is the vessel detection based on spectral coherence analysis. We present a processing technique of vessel detection using SAR data, combining spectral coherence processing and Constant False Alarm Rate (CFAR) algorithm. The control of open seas areas or marine protected areas (MPAs) is usually performed based on the Automated Identification System (AIS) embarked within most of the vessels. The proposed technique handles a comparison with AIS data allowing to determine the ratio of non-cooperative vessels (or not equipped with AIS) within an area. We performed experiments on SAR data acquired on the Libyan Sea and we compared the results with the ones obtained by the SNAP "Ocean feature" tool, commonly used by the Remote Sensing community.

Keywords: Synthetic aperture radar, split band SAR interferometry, spectral analysis, target detection, vessel tracking.

INTRODUCTION

Objective

- Develop a SAR-based vessel detection tool for marine area surveillance.

Methodology

- Perform band split of a given SAR acquisition.
- Estimate spectral coherence between split-band sub-images.
- Use CFAR algorithm within both spectral coherence and amplitude modalities to perform a detection of targets considered as potential vessels.
- Compare with available AIS data.

TOPS Sentinel-1 data

Specifications in line with the needs of vessel tracking:

- Wide coverage at medium to high resolution (metric).
- Standard acquisition mode: IW mode implemented with TOPSAR in dual-polarization (VV/VH).

Split-band principle

- High range resolution achieved by wide band signals.
- Split-band process: splitting of wide band into sub-bands to generate lower-resolution images from an acquisition, each being centered on a slightly different frequency [1].

Spectral coherence

- One of the split-band applications: computation of interferometric coherence between sub-images.
- For surface scatterers having a random distribution, spectral coherence is equal to percentage of sub-band overlap [2].
- Open sea areas can be considered as randomly distributed surface scatterers.
- For low sub-band overlap, spectral coherence will be almost totally lost on open sea areas and be preserved on man-made structures, like vessels [2, 3].

Spectral coherence processing

- Division into sub-bands.
- Computation of the coherence between each sub-band pairs and the modulus of each sub-band image.
- Computation of their arithmetic average (for increasing the signal-to-noise ratio)
- Resulting products: intensity and spectral coherence images.

CFAR for vessel tracking

- Principle of several ship detectors: thresholding SAR intensity images to identify bright spots [3, 4].
- Use of non-adaptive thresholds: production of false alarms and missing detections of small ships. To circumvent these problems, the threshold can be adjusted based on statistical tests on the local clutter.
- CFAR: adaptive thresholding algorithm commonly used to keep constant the probability of false alarms [4].

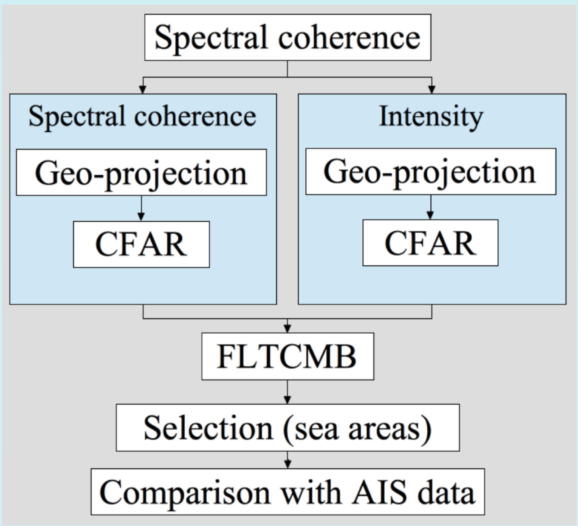
CFAR and spectral coherence

- A first analysis, using CFAR algorithm applied on the intensity and the spectral coherence images, was made for TerraSAR-X Spotlight data over the city of Venice (Italy) [1].
- It shows that all vessels observable in the intensity image are easily detected in the spectral coherence image. Therefore, both images can be considered as very good complementary information channels for vessel detection [1].

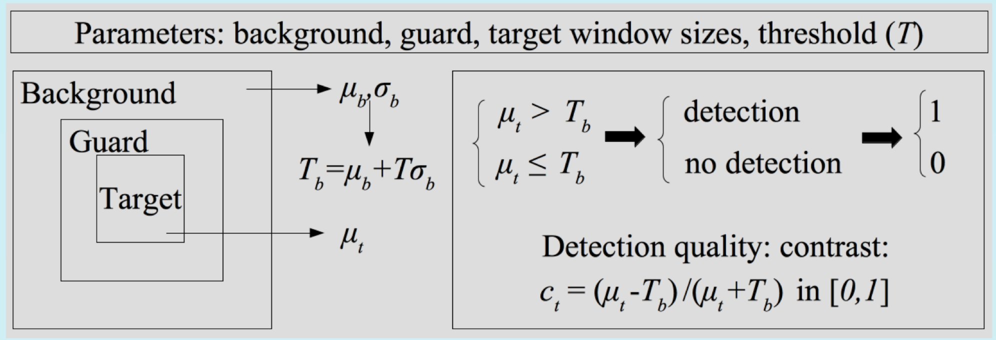
TECHNIQUES

Our processing

The next figure shows the block diagram of the processing. The FLTCMB algorithm consists in filtering the detected targets and selecting some of them by combining results from both channels. The selection stage extracts the targets that are outside the land areas, defined from shape files.



Block diagram of the processing



CFAR: algorithm description

Data: contrasts of spectral coherence and intensity images: c^1_t, c^2_t

Parameters: T^1, T^2, M^1, M^2

Detection in one channel	➡ no detection
Detection in two channels	
$c^1_t < T^1$ and $c^2_t < T^2$	➡ no detection
$c^j_t < T^j$ and $c^k_t \geq T^k$, $c^j_t < M^j T^j$	➡ no detection
$c^j_t < T^j$ and $c^k_t \geq T^k$, $c^j_t \geq M^j T^j$	➡ detection
$c^1_t \geq T^1$ and $c^2_t \geq T^2$	➡ detection

FLTCMB: algorithm explanation

Comparison with AIS data

- Match between detected and AIS targets: when they are close enough considering average speed.
- Output: targets indicated by colored symbols (w.r.t. status (AIS, matching, not matching)) superimposed on the spectral coherence and the intensity images

Evaluation: comparison with SNAP

- We performed a comparison with the SNAP [5] "Ocean feature" tool (commonly used by the Remote Sensing community, CFAR-based).
- To show the benefit of exploiting spectral coherence, we applied this tool on the intensity image obtained after geo-projection.
- Parameters: window sizes, probability of false alarm (p)
- Conversion between SNAP and our parameters:

$$p = \frac{1}{2} - \frac{1}{2}\mathrm{erf}(T/\sqrt{2})$$

RESULTS

Data

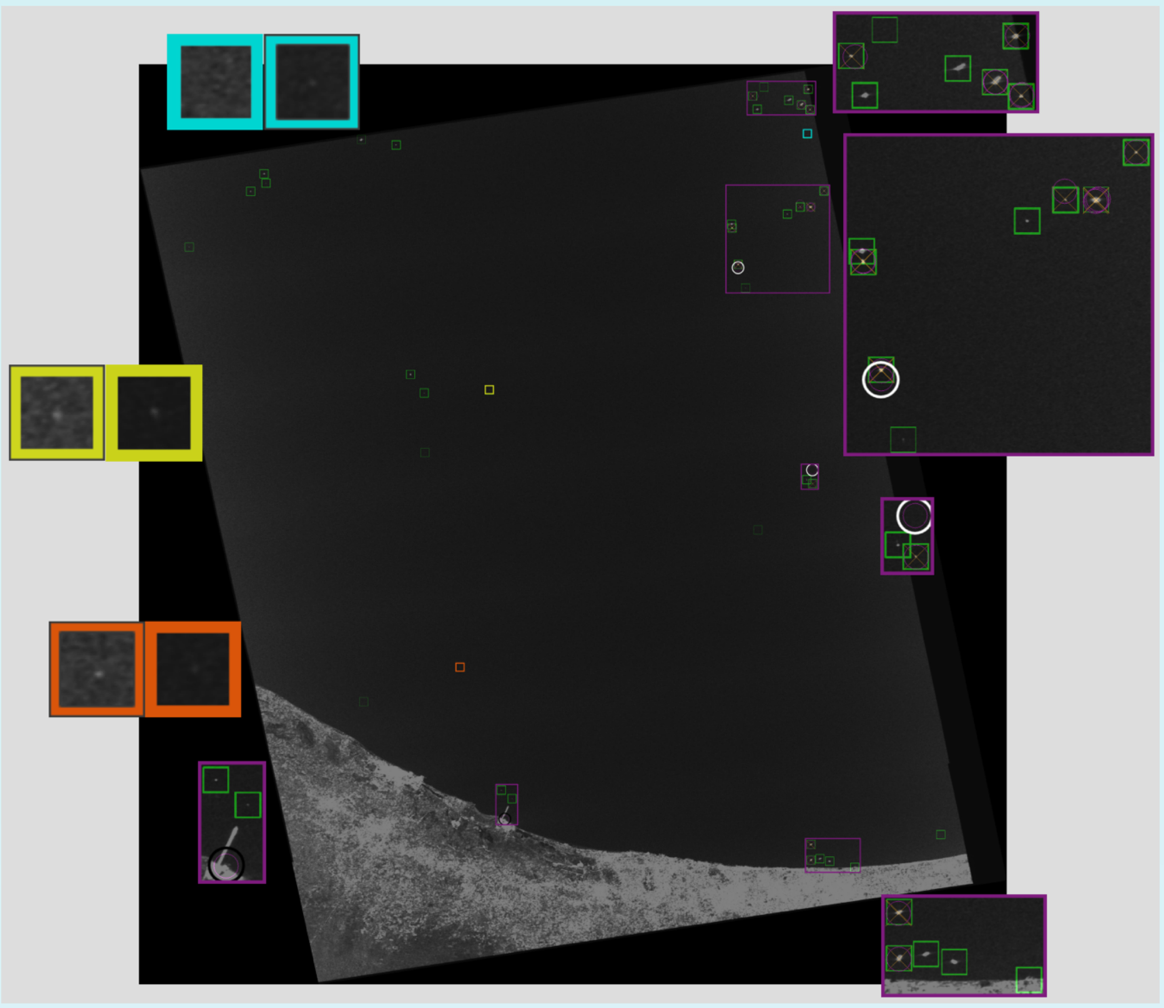
Sentinel-1 image (48.3 MHz) acquired on the Libyan Sea on April 12 2018.

Parameters setting

- Spectral coherence: number of sub-bands = 51, sub-band bandwidth = 5 MHz.
- CFAR: window sizes = 90, 210, 270 *m*, T = 5.612.
- FLTCMB: $T^1 = 0.0125$, $T^2 = 0.05$, $M^1 = M^2 = 0.9$.
- SNAP: window sizes = 90, 210, 270 *m*, $p = 10^{-8}$.

Comparison with AIS data

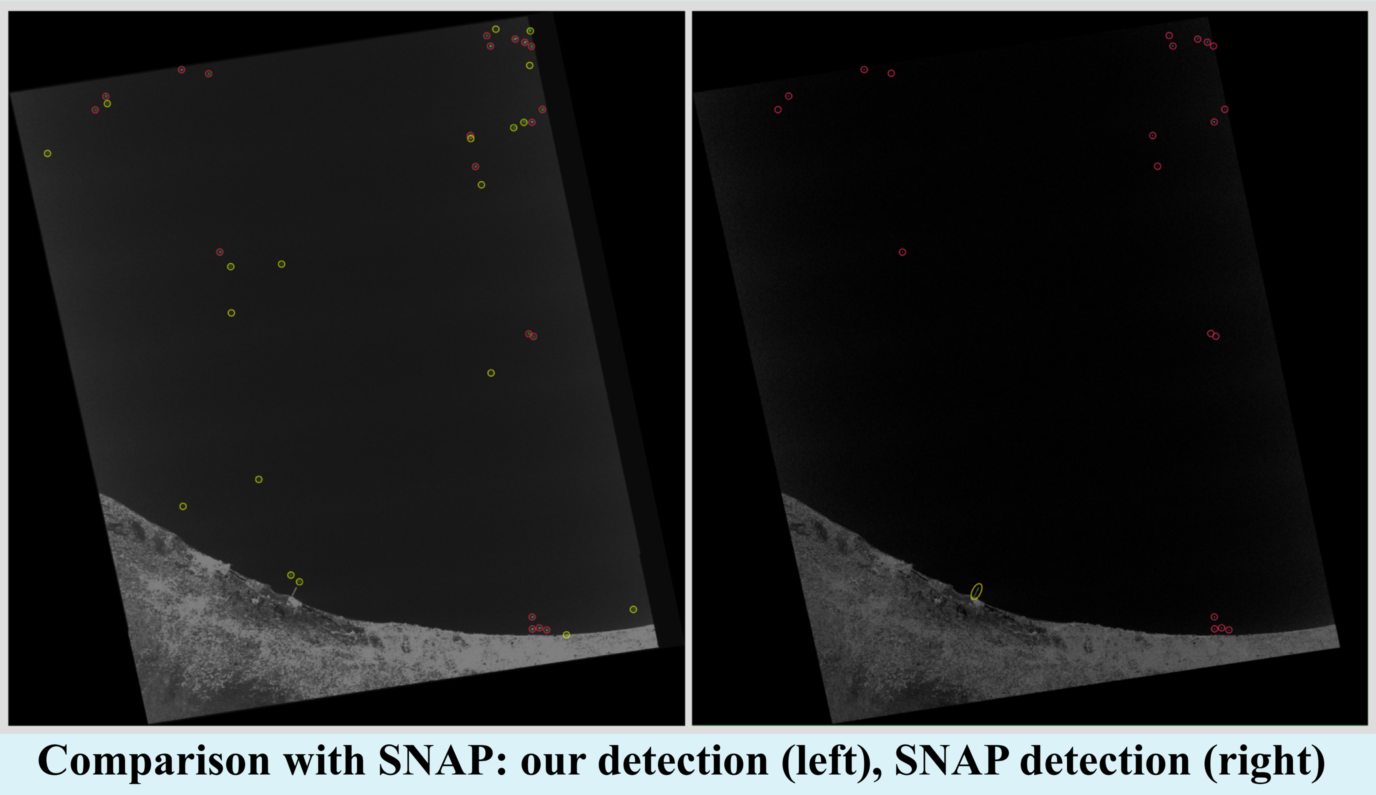
- Magenta circles: AIS data (15), green squares: detected targets (39), orange crosses: matches (12)
- The 3 AIS targets not detected are either too close to the coast (see black circle), or not visible in the original data (see white circles).
- Pairs of cyan, yellow, and orange squares show the spectral coherence (left) and the intensity (right) images. The **better visibility** of targets in **one** of these **channels** is indicated by **grey outlines**. They demonstrate the **usefulness of combining both spectral coherence products**.



Comparison with AIS data

Comparison with SNAP

- Red circles: targets detected by both algorithms (20), yellow circles: other targets (only detected by our algorithm (19) or SNAP (1)).
- Additional target detected by SNAP: not a vessel but the harbor.
- Better performance by using spectral coherence and applying CFAR on the spectral coherence products instead on the original intensity image.



Comparison with SNAP: our detection (left), SNAP detection (right)

CONCLUSIONS

We have presented a processing technique for detecting potential vessels within open sea areas using SAR data. This technique is based on a dual modalities (intensity and spectral coherence) CFAR processor and includes selector to limit detection to open sea surfaces, excluding lands delimited from shapefiles. A comparison with AIS data is also presented. It allows determining the ratio of non-cooperative vessels (or vessels not equipped with AIS) within the area. This technique and the one of the SNAP "Ocean feature" tool, commonly used by the Remote Sensing community, were compared. Experimental results on SAR data acquired on the Libyan Sea show that this processing succeeds in detecting targets. Moreover, results outperformed the ones of the SNAP "Ocean feature" tool. Some processing parts would still need improvements, as the CFAR detection of targets close to the coasts.

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