MORPHOLOGICAL-BASED SOURCE EXTRACTION METHOD FOR HFSW RADAR SHIP DETECTION

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ABSTRACT

In this paper, High Frequency Surface Wave (HFSW) Radars are considered for target detection at long range. The received signals of the HFSW Radar are strongly polluted by different noises. To detect targets in these noisy data, a method based on Morphological Component Analysis (MCA) initially proposed by Starck *et al.* [1, 2] is investigated. Simulated Range-Doppler images are used in this contribution to evaluate the capabilities of this new detection approach.

Index Terms— HFSW radar, electromagnetic model, ship detection, morphological component analysis.

1. INTRODUCTION

High Frequency Surface Wave (HFSW) radars have been efficiently used these last three decades to remotely measure oceanographic parameters. They can provide surface currents, wave spectra, wind intensities and directions.

Recently, these systems proved to be potentially useful in target detection and tracking [3, 4, 5]. The main interest is that they can cover areas up to 200 nautical miles which is a long-range compared to standard microwave radars. Moreover, this range value corresponds to the Exclusive Economic Zone (EEZ). Continuous maritime surveillance of activities within the EEZ is a key question for civil or military applications.

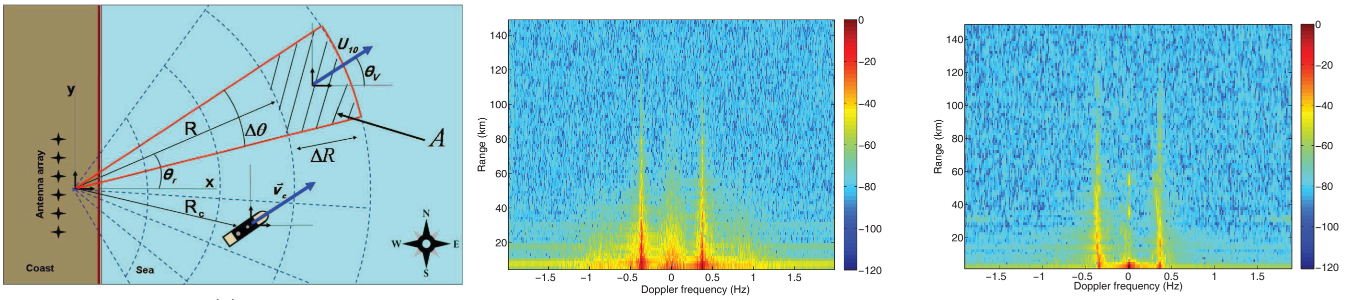
The target detection by HFSW radars is a challenging problem since the signal environment includes a significant background noise, different kinds of clutter and interferences. Indeed, these systems are normally used to estimate parameters by maximizing the sea clutter response (Bragg peaks,...). Unfortunately, the sea signature (in the Range-Doppler image) has harmful effects on the detection part. From the Range-Doppler image (see figure 1.c), one can notice that each physical phenomenon (electromagnetic interactions) and the post-signal processing (range processing, beamforming, and Fourier transform) have or result in a particular morphological signature. This observation leads us to investigate a source extraction method based on the morphology of the components in the image. This method called Morphological Component Analysis (MCA) was initially proposed by Starck *et al.* [1, 2]. In this contribution, a detection method based on this approach is investigated.

In what follows, the HFSW radar setup is presented and the model to generate Range-Doppler images is shortly introduced (section 2). Section3 gives an overview of the MCA method. Then, the proposed approach is tested on the simulated data and some first detection results are proposed (section 4). Finally, a conclusion ended the contribution.

2. HFSW RADAR: SETUP AND MODEL

In this paper, a Wellen Radar (WERA) is considered as measurement system [6]. Figure 1.a illustrates the corresponding HFSW radar setup and introduces the main parameters. From the measured data, the usual processing is to construct a Range-Doppler image. This image gives the spectral density of the power backscattered by scatterers located in the red area schematized in figure 1.a according to the range and the Doppler frequency. In this area the scatterers are essentially ocean waves and targets.

In previous works [7, 8], a model to generate realistic Range-Doppler images has been developed (see figure 1.b). It takes into account the sea clutter (through the sea spectrum, the significant height of the sea waves, dominant wave direction...), the target parameters (speed, range and Radar Cross Section (RCS)) and a given background noise level. Moreover, signal processing effects which appear on the real data have been added.



(a) (b) (c)

Fig. 1. (a) HF radar setup. (b) Modeled Range-Doppler image. The radar parameters are: the integration time $T_i = 1$min, the bandwidth $B = 100$kHz, the chirp duration $T_c = 0.26$s, and the radar look direction $\theta_r = 135°$. The environmental parameters are: the wind direction $\theta_v = 45°$ and the significant height of the sea surface $H_s = 1.4$m. (c) Range-Doppler image constructed from real data.

Figure 1.b and 1.c show respectively a simulated Range-Doppler image and an obtained one from real data. The used radars are owned by 'Service Hydrographique et Océanographique de la Marine' (SHOM) and operated by the company ACTIMAR. The parameters in this simulation match the estimated ones during the measurement. Notice that we only have access to global values of these parameters in the considered area during the experiments. This can explain some of the differences. One can also notice that our model do not incorporate the local variations of the sea state. Finally, the main difference between the two images in figure 1 is the low range sea clutter power. It can be explain by the experimental use of a low-pass filter on the received signal to avoid radar blinding by close scattering. This filtering affect low range (up to 30km in this case).

Figure 2 illustrates the simulation of a time-evolving target signature (the target is moving away from the radar).

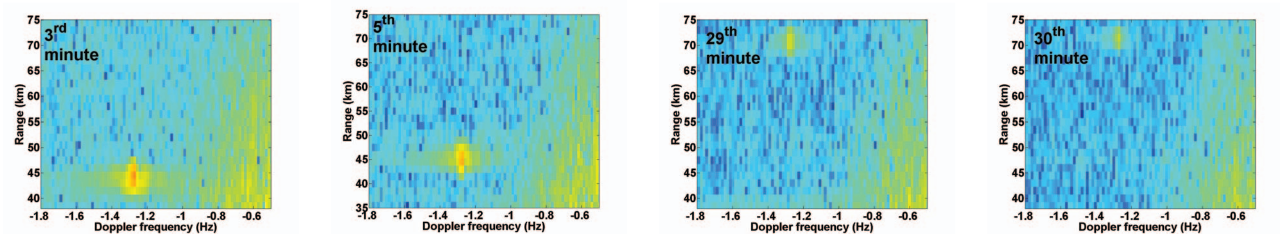


Fig. 2. Zoom on the target signature for successive Range-Doppler images. The target is initially located at 45km from the radar and it is moving away from the radar with a radial velocity of 15m/s (i.e. the Doppler frequency is equal to 1.23Hz). The target RCS is 20dB.

The difference in the morphological profiles between the target, the sea signature and most of the interferences lead us to investigate the MCA method to separate these components in the Range-Doppler image. The target signature can be considered as an isotopic and high-scale source. The sea clutter can be considered as an low-scale source with a ray profile. The main rays are due to the Bragg peaks but they are other lower rays due, for instance, to the second harmonic peaks or corner peaks. It can be noted that secondary lobes along the Doppler frequency due to the Fourier transform of the high power level of the Bragg scattering have a ray profile too.

3. OVERVIEW OF THE MCA FOR SHIP DETECTION

The MCA method has been proposed by Starck *et al.* [1, 2, 9] for blind source separation tasks. In our study one considers a signal $X \in \mathbf{R}^N$ which is assumed to be a linear combination of two sources S_1 (essentially the sea clutter) and S_2 (the target signature) and an additive Gaussian noise N:

$$X = \sum_{k=1}^{2} S_k + N. \tag{1}$$

An over-complete dictionary $T_k \in \mathbf{M}^{N \times L_k}$ is associated with each source ($L_k >> N$). One assumes that a sparse representation vector $\hat{\alpha}_k$ exists for each source such as

$$\hat{\alpha}_k = \underset{\alpha}{\text{Argmin}} \, ||\alpha_k||_0 \;\text{ with }\; S_k = T_k \alpha_k. \tag{2}$$

The sparse nature of the representation $\hat{\alpha}_k$ means that $||\alpha_k||_0 << L_k$. Moreover each representation vector $\hat{\alpha}_{kl}$, defined as

$$\hat{\alpha}_{kl} = \underset{\alpha}{\text{Argmin}} \, ||\alpha_{kl}||_0 \;\text{ with } S_k = T_l \alpha_{kl} \;\text{ and } k \neq l, \tag{3}$$

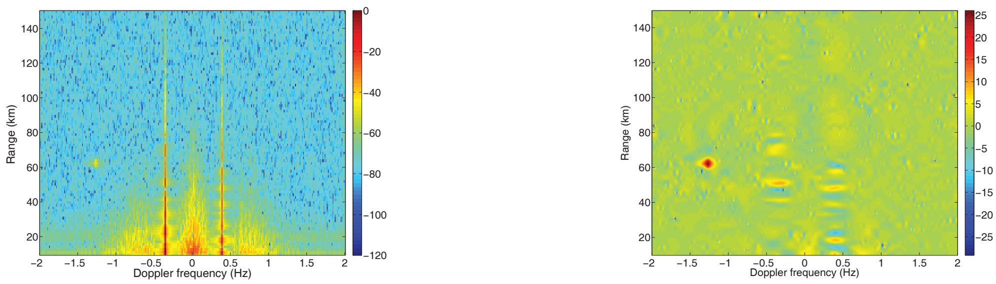
is assumed to be non-sparse. These hypotheses lead to assume that each source has a sparse representation only with its own dictionary. This condition makes possible the decomposition of the signal (i.e. find S_1 and S_2). The first difficulty is to find the appropriate dictionaries. The MCA decomposition method takes advantage of the difference in morphological characteristics of each source to find appropriate dictionaries. A description of some dictionaries can be find in [1, 10, 11]. Here, the fast Curvelet Transform (CT) has been used as T_1 and the UnDecimated Wavelet Transform (UDWT) has been used as T_2. Assuming a Gaussian Noise with standard deviation σ^2, the separation task can be sum up in the following minimization problem

$$\{\hat{\alpha}_1, \hat{\alpha}_2\} = \underset{\{\alpha_1, \alpha_2\}}{\text{Argmin}} \, ||\alpha_1||_0 + ||\alpha_2||_0 + \frac{1}{\sigma^2} ||X - T_1\alpha_1 - T_2\alpha_2||_2^2, \tag{4}$$

with $||.||_0$ the l^0-norm. To achieve this minimization, Starck *et al.* in [1] propose the Block Coordinate Relaxation method (BCR) [12].

4. SHIP EXTRACTION FROM RANGE-DOPPLER IMAGES

The MCA method has been applied for detection purpose on simulated Range-Doppler images. Figure 3.b illustrates the target signature extraction for a target with a medium RCS (20dB) in the background noise. Of course, it is an easy case for target detection but it permits to clearly illustrate this approach.



(a) (b)

Fig. 3. (a) Simulated Range-Doppler image with a target signature at 60km and 1.2Hz. (b) Range-Doppler image after target extraction by MCA.

The detection part can be achieved by a CFAR (Constant False Alarm Rate) technique. From [4, 13, 14] the ordered statistic CFAR procedure seems to be better suitable for target detection in Range-Doppler images (from HF radars). It consists to rank-order the selected cell according to increasing magnitude. The selected cells are defined by a window around the cell under test. The local noise level is estimated by selecting a cell at a certain rank from the previously calculated sequence. The target is detected if the cell under test is the highest value of the cells in the window and the signal to local noise ratio is above a given threshold (theoretically calculated by fixing the false alarm probability). The global method is called GOOS-CFAR (Greatest Of Order Statistic).

The GOOS-CFAR is applied on the original Range-Doppler image (figure 3.a) and the image obtained at the end of the MCA procedure (figure 3.b). Notice that for the original image the considered window is longer along the range axis in order to consider the dominant sea clutter (Bragg peaks). Figures 4.a and 4.b show the obtained number of false alarm according to the threshold for a sea with a significant height equal to 0.5m and 1.4m, respectively.

The first results proposed in this section show the interest of the proposed approach for target detection. In the final paper more details and results will be presented.

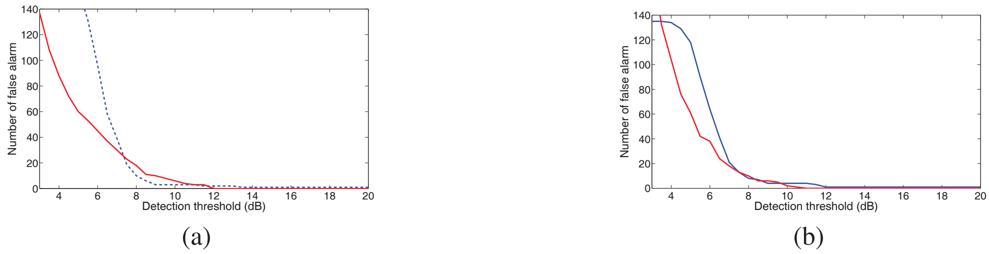


Fig. 4. Number of false alarm according to the threshold for (a) a sea with $H_s = 0.5$m and (b) a sea with $H_s = 1.4$m.

5. CONCLUSION

The main purpose of our project is to use HFSW radars, initially designed for remote sensing sea state, as a continuous maritime surveillance system. In this contribution, a Range-Doppler image model is presented as a tool to test detection methods. A new method based on morphological component analysis has been tested and proved to have interesting potentialities compare to classical methods. Future works will focus on the adaptation enhancement of this approach as detector.

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