SHIP DETECTION WITH SAR DATA USING A NOTCH FILTER BASED ON PERTURBATION ANALYSIS

Armando Marino, Nick Walker, Iain Woodhouse

eOsphere Ltd, Newbury, UK, www.eOsphere.co.uk
The University of Edinburgh, Geography Department, Edinburgh, UK

1. INTRODUCTION

The aim of the work described in this paper has been the development of an innovative ship detector, based on synthetic aperture radar (SAR) polarimetry and the methodology pioneered in [1-3], namely perturbation analysis. Ship detection is a key topic for the surveillance of coastal areas. In particular, SAR presents an advantageous technology, since the observations are independent on weather condition and solar illumination. Specifically, we achieve the detection by exploiting the difference between the polarimetric characteristics of sea clutter and ships. In the literature, several papers have described ship detection using radar polarimetry [4-6], however the technique proposed here is entirely innovative since it makes use of a methodology introduced by the authors in [1-3]. The proposed detector will be referred to as a notch filter since the detector rejects the target selected (in our case the sea) and detects anything different from sea. It acts in a similar manner to that of a notch filter, with the null corresponding to the target selected, however, the space where the filter is applied is now the polarization space and not that of the frequency). The algorithm is based on a physical rather than a statistical technique. In the following a brief introduction to polarimetry is presented.

A single target can be characterized using a unique scattering matrix or equivalently a scattering vector: $\underline{k} = \frac{1}{2} Trace([S]\Psi) = [k_1, k_2, k_3, k_4]^T$, where $[S]$ is the scattering matrix and Ψ is a complete set of 2x2 basis matrices under a Hermitian inner product [7, 8]. In the case of reciprocal medium and monostatic sensor, $\underline{k}$ is three-dimensional complex. Finally, the scattering mechanism is $\underline{\omega} = \underline{k} / |\underline{k}|$. The targets observed by a SAR system are not idealized single targets, but a combination of different objects which we refer to as a *partial* target. In order to characterize a partial target the second order statistics are required. In this context the target coherency matrix can be estimated as $[C] = \left\langle \underline{k} \cdot \underline{k}^{*T} \right\rangle$, where $\langle . \rangle$ is the finite averaging operator. In general, the scattering vector in a generic basis is $\underline{k} = [k_1, k_2, k_3]^T$, with k_1, k_2 and k_3 being complex numbers. If two different scattering mechanisms $\underline{\omega}_1$ and $\underline{\omega}_2$ are considered, the polarimetric coherence is: [8]: $\gamma = \frac{\underline{\omega}_1^{*T} \langle [C] \rangle \underline{\omega}_2}{\sqrt{\underline{\omega}_1^{*T} \langle [C] \rangle \underline{\omega}_1 \cdot \underline{\omega}_2^{*T} \langle [C] \rangle \underline{\omega}_2}}$. (1)

2. PARTIAL TARGET DETECTOR

The aim of this section is to develop a partial target detector using the same methodology (i.e. perturbation analysis) of the single target detector as presented in [1-3]. First, a formalism similar to the single target is constructed which will work for partial targets. A *feature partial scattering vector* is introduced: $\underline{t} = Trace([C]\Psi) = [t_1, t_2, t_3, t_4, t_5, t_6]^T = \left[\left\langle |k_1|^2 \right\rangle, \left\langle |k_2|^2 \right\rangle, \left\langle |k_3|^2 \right\rangle, \left\langle k_1^* k_2 \right\rangle, \left\langle k_1^* k_3 \right\rangle, \left\langle k_2^* k_3 \right\rangle\right]^T$ where Ψ is a complete set of 6x6 basis matrices under a Hermitian inner product. $\underline{t}$ lies in a subspace of C^6 and it has the first three elements real positive and the second three complex. We can define the partial target (to be detected) with $\underline{t}_T$ and the perturbed one $\underline{t}_P$ which is obtained by perturbing $\underline{t}_T$ [1-3]. Then a change of basis is performed which makes the target of interest lie only on 1 component: $\underline{t}_T = [1,0,0,0,0,0]^T$ and $\underline{t}_P = [a, b, c, d, e, f, g]^T$. In order to calculate the weighted inner product between $\underline{t}_T$ and $\underline{t}_P$, a matrix $[A]$ is constructed with a basis of C^6 obtained by a Gram-Schmidt ortho-normalization where the first axis is represented by the vector $\underline{t}_T$. If $\underline{u}_1 = \underline{t}_T$, $\underline{u}_2$, $\underline{u}_3$, $\underline{u}_4$, $\underline{u}_5$ and $\underline{u}_6$ represent the ortho-normal basis, the $[A]$ matrix can be calculated as: $[A] = diag\left(\underline{t}_T^{*T}\underline{t}, \underline{u}_2^{*T}\underline{t}, \underline{u}_3^{*T}\underline{t}, \underline{u}_4^{*T}\underline{t}, \underline{u}_5^{*T}\underline{t}, \underline{u}_6^{*T}\underline{t}\right)$. The detector is then built as: $\left\langle \left([A]\underline{t}_T\right)^{*T}\left([A]\underline{t}_P\right) \right\rangle = \underline{t}_T^{*T}\left\langle [A]^{*T}[A] \right\rangle \underline{t}_P = \underline{t}_T^{*T}[P]\underline{t}_P$, where $[P] = diag(P_1, P_2, P_3, P_4, P_5, P_6)$.

$$\gamma = \frac{\underline{t}_T^{*T}[P]\underline{t}_P}{\sqrt{\left(\underline{t}_T^{*T}[P]\underline{t}_T\right)\left(\underline{t}_P^{*T}[P]\underline{t}_P\right)}} = \frac{1}{\sqrt{1 + \frac{b^2}{a^2}\frac{P_2}{P_1} + \frac{c^2}{a^2}\frac{P_3}{P_1} + \frac{|d|^2}{a^2}\frac{P_4}{P_1} + \frac{|e|^2}{a^2}\frac{P_5}{P_1} + \frac{|f|^2}{a^2}\frac{P_6}{P_1}}}. \tag{2}$$

In order to have unbiased results the best choice is $b = c = |d| = |e| = |f|$. If we define the clutter as $P_c = P_2 + P_3 + P_4 + P_5 + P_6$ and target as $P_1 = P_T$, the detector can be simplified as $\gamma = 1 \Big/ \sqrt{1 + \frac{b^2}{a^2}\frac{P_C}{P_T}}$. (3)

The final detector is obtained setting a threshold on γ as: $H_0 : |\gamma(P_T, P_P)| \geq T$ and $H_1 : |\gamma(P_T, P_P)| < T$. (4)

3. NOTCH FILTER

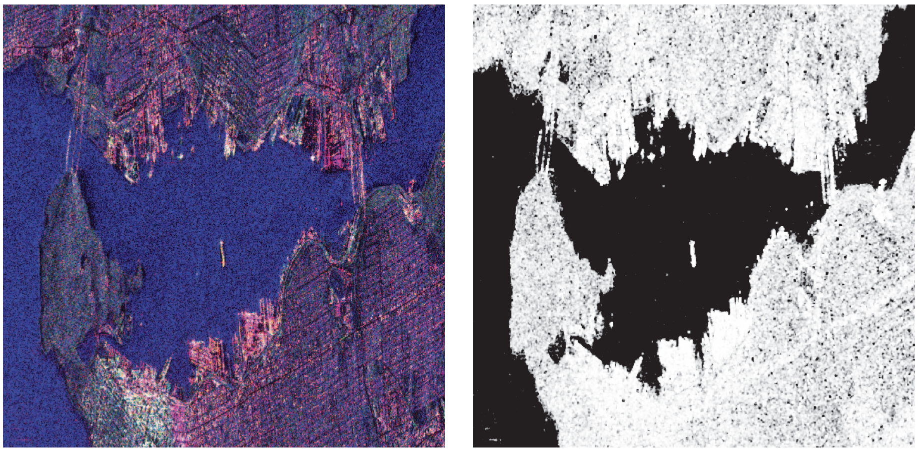
The partial detector presented in the previous section was employed in other papers [1-3] to build up a classifier. Here, the application under consideration is the detection of marine targets in a background which is always composed of the sea. For this reason, the detector is adapted as a notch filter. Sea clutter is polarimetrically well characterized (unless the backscattering is below the noise floor). A classical model to characterize the sea is the Bragg surface. The idea is to build a filter that is able to reject the sea clutter and extract the remaining features. The sea clutter can be completely characterization with a vector in a six dimensional complex space $\underline{t}_{Sea}$. This can be obtained theoretically with a Bragg model, or practically by extracting it straight from the dataset (i.e. by selecting a region of relatively homogeneous sea). Once obtained $\underline{t}_{Sea}$, the power of the sea clutter can be calculated pixel by pixel as: $P_S = \left\langle \left| \underline{t}^{*T} \cdot \underline{t}_{Sea} \right|^2 \right\rangle$. The total power of the feature vector can be estimated as: $P_{tot} = \left\langle \left| \underline{t}^{*T} \cdot \underline{t} \right|^2 \right\rangle$. Hence, the power of the non-sea targets is $P_T = P_{tot} - P_{Sea}$. Applying the detector as in eq.3 we have : $\gamma = 1 \Big/ \sqrt{1 + \frac{b^2}{a^2} \frac{P_{Sea}}{P_T}}$ (5)

4. VALIDATION

In order to test the potential of the notch filter, it is applied on fully polarimetric SAR data. We decided to validate with C-band RADARSAT2 because of the reported high quality of the data. In **figure 1,** the detection over the area of the Vancouver harbor is presented (Fine Quad Pol; 2008-04-15). **Figure 1.a** depicts the Pauli RGB image as comparison, while in **1.b** the mask obtained by the notch filter is depicted. Firstly, it is clear that the land is firmly detected since it is polarimetrically different from the sea. In the channel area, different points can be detected. In general, we expect several ships in this sea window since the channel is generally busy. Some of the detected points are strong enough to be easily visible on the RGB image, but others are not clearly extractable from the simple survey of the RGB image. **Figure 2** shows another example of detection again with RADARSAT2 in the area of San Francisco (Fine Quad Pol; 2008-04-09). This is another region where we expect a large number of ships. Most of the targets seem to be bright enough to be visible on the RGB image, however the detector is able to reject areas where noise effects creates red sparkling regions on the RGB image. These could be confused with non-sea features by a superficial visual analysis. However, they are so many that they should constitute a fleet of small ships. Only averaging and weighting the components, we can reject those points. The interesting difference with **Figure 1** is that in the latter the sea state is rough while in **Figure 2** it is calm. In both the cases the detection mask shows feasible results. Hence, the detection can be theoretically performed with any sea state, even though a very calm state could lead to a sea backscattered signal below the noise floor. In the later occurrence, a simple threshold on the HV image can be used for ship detection.

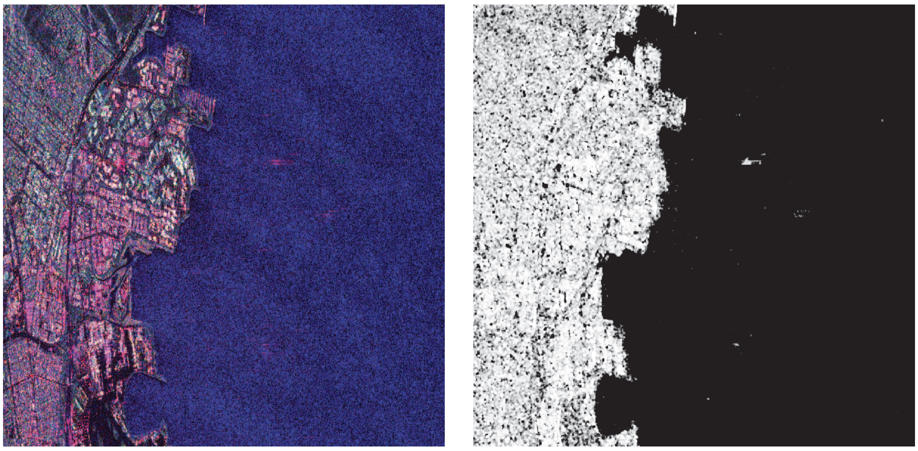
5. CONCLUSIONS

A notch filter for partial targets was developed starting from the single target detector [1-3] using the perturbation analysis. The detector aims to highlight the features which are polarimetrically different from the sea clutter. Validation against satellite data (RADARSAT2 on Vancouver and San Francisco) is provided showing the capability of the detector to detect non-sea features independent of the sea state. In the future work we will try to validate the detector in regions for which we have ground truth of known ships' positions.



(a) (b)

Figure 1. *Notch filter on RADARSAT2 (Vancouver); (a) RGB Pauli image; (b) detection with the notch filter*



(a) (b)

Figure 2. *Notch filter on RADARSAT2 (San Francisco);* ***as Figure 1****.*

6. REFERENCES

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