SHIP DETECTION WITH RADARSAT-2 QUAD-POL SAR DATA USING A IMPROVED NOTCH FILTER BASED ON FREEMAN DECOMPOSITION

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***Abstract*—Ploarimetric Synthetic Aperture Radar (POLSAR) provide more information of targets, advantages of which lays in its capability to acquire useful images with any-weather conditions and at night time. POLSAR image has been used to reconnaissance Ships and vessels. Specifically, this paper proposes an improved notch detector algorithm of ship with full polarimetric image.**

The methodology adopted the result of freeman decomposition instead of coherency matrix for constructing vector space of polarimetric targets. Furthermore, a factor related power is added to the detector in order to separate ships dominated by surface scattering mechanism form the sea. The proposed detector was tested with Radarsat-2 full polarimetric data and show significant agreement with the available sea truth. Comparing with SPAN, Polarimetric whitening filter and Polarimetric notch filter method, the proposed method enhance ship-sea contrast ratio and show higher detection ability.

***Index Terms*—ship detection, polarimetric synthetic aperture radar, Radarsat-2, notch detector, freeman decomposition.**

1. INTRODUCTION

The aim of this study described in this paper is ship detection based on Polarimetric Synthetic Aperture Radar(PolSAR). Ship detection is a key topic for the surveillance of maritime areas largely due to the capability to acquire valuable images independent of solar illumination and (to some extent) weather conditions. The studies on POLSAR target detection mainly exploite the polarimetric statistical and scattering information. Some of the excellent works include the polarimetric whitening filter detector[1], ship detection using polarization cross-entropy[2], and polarimetric target detector using the Huynen fork[2].

It is worth mentioning polarimetric target detector. The algorithm is based on a physical rather than a statistical technique. In the new procedure, ships are detected by exploiting the difference between the polarimetric characteristics of sea clutter and the ships of interest. Actually the name Polarimetric Notch Filter was already introduced in the past by at least two more authors[3][4][6]. In this regard, the latest results come from Geometrical Perturbation Polarimetric Notch Filter(GP-PNF)[6] and improved notch filter[8]. The key of the algorithm is building target scattering model and setting reduction ratio reasonably. Despite reduction ratio was discussed in Literature[7]-[8] in detail, certain results has been achieved. However above algorithm vectorized straightforward coherent matrix as target scattering model, which is difficult to accurately express target scattering mechanism. Thus result in that partial weak target appears lost.

We know that composition of various types of scattering mechanisms could be effectively obtained by model-based polarization decomposition. Aimed at the problem, a new target space scattering vector was constructed with the results of freeman decomposition instead of coherent matrix in the paper and then a new polarization notch filter was formed. Experimental results show that the proposed algorithm effectively enhances the filtering effect and improve the ship detection performance.

2. FREEMAN DECOMPISITION

The scattering power decomposition method based on physical scattering models was first developed by Freeman and Durden[9]. The three-component decomposition scheme divides the polarimetric data of the imaging pixel area into surface scattering, double-bounce scattering, volume scattering. These scattering powers are calculated very easily and are used to compose full color images with red, green, and blue (RGB) color coding: red for the double bounce power, green for the volume scattering power, and blue for the surface scattering power, for which each color brightness is corresponding to the magnitude. They have been successfully applied to POLSAR image analysis since color-coded images are easier to understand and since each color represents a specific scattering mechanism.

Coherency matrix can be expanded into three submatrices which correspond to surface scattering, double-bounce scattering, volume scattering, and helix scattering mechanisms:

$$\langle [T] \rangle = f_s \langle [T] \rangle_{surface} + f_d \langle [T] \rangle_{double} + f_v \langle [T] \rangle_{vol} \quad (1)$$

For the three scattering, the expansion matrix is given in reference[9]. Where f_s, f_d and f_v are the expansion coefficients to be determined.

The corresponding scattering powers (the surface scattering power P_s, the double-bounce scattering power P_d, the volume scattering power P_v) are directly obtained from the expansion coefficients of these matrices when applied to the decomposition.

$$\begin{cases} p_s = (1+|\beta|^2) f_s \\ p_d = (1+|\alpha|^2) f_s \\ p_v = f_v \end{cases} \quad (2)$$

Where α and β are unknowns to be determined.

3. REWISED POLARIMETRIC NOTCH FILTER

The ship detector presented in this paper shares the same general methodology of GP-PNF. More details regarding the mathematical and physical justification of the algorithm can be found in [8].

The first step is to construct a vector containing the second order statistics of the observed target. A feature partial scattering vector is introduced:

$$\underline{t} = [p_s, p_d, p_v]^T \quad (3)$$

$\underline{t}$ lies in a subspace C3 representing all the physically feasible partial targets. The normalized version of $\underline{t}$ can be considered: $\hat{\underline{t}} = \underline{t} / \|\underline{t}\|$. After a series of mathematical manipulations, the final expression of the RPNF is:

$$\gamma_d = \frac{1}{\sqrt{1 + \frac{b^2}{a^2 span^2} \cdot \left(\frac{\hat{\underline{t}}^{*T} \cdot \hat{\underline{t}}}{\left| \hat{\underline{t}}^{*T} \hat{\underline{t}}_T \right|^2} - 1 \right)}} > T_n \quad (4)$$

where $\hat{\underline{t}}_T = [0,1,1]$ represents the signature of the target to be detected (and can be any unitary vector in the space of the physically feasible targets), $\hat{\underline{t}}$ is the partial vector extracted from the scene (i.e., observables), T_n is the threshold and b^2 / a^2 is a detector parameter that can be set using a rationale based on the SCR.

4. VALIDATION WITH RADARSAT-2 PALSAR DATA

A. Presentation of the Datasets

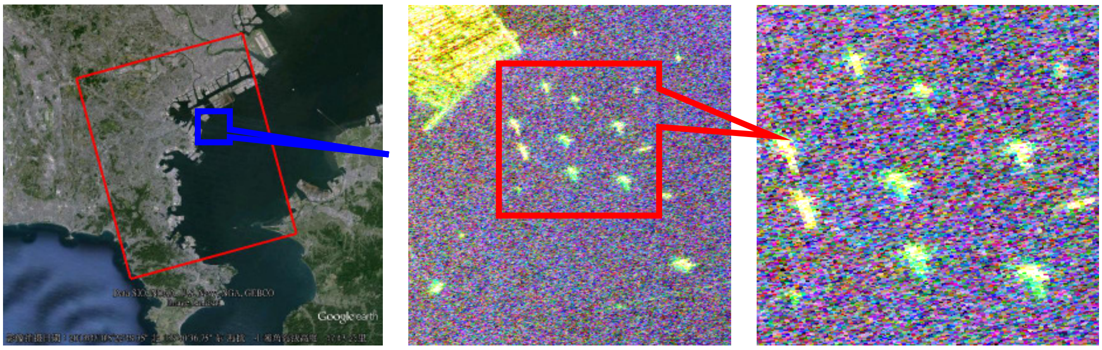
To demonstrate and validate the proposed target detection algorithm, a RADARSAT-2 Fine Quad-Pol mode scenes were acquired off the east-south port in Tokyo Bay at the 28th December 2012. To facilitate the analysis, Google Earth optical image was given for comparison. **Fig 1.a** depicts the Google Earth image of the area. The size of this image patch is 500Pix × 500Pix with a resolution of 8 meters. **Fig 1.b** illustrates the Pauli RGB image. The size of experimental image slice in red box is 270Pix × 270Pix, which contains a total of 12 ships. **Fig 1.c** illustrates the corresponding Pauli RGB image.

B. Validation Results and Analysis

The Selected comparison methods conclude classical Span detector, PWF detector, PCE entropy detector, generalized optimal polarization(GOPCE) detector and improved polarization Notch Filter(IPNF) detector.

For characteristics image of Span, PWF, PCE and GOPCE, the results of detection ship were obtained by dual-parameter CFAR. Here probability of false alarm was set 10^{-5}. The maximum size of ship is 400m*200m and the minimum size of 15m*10m. **Fig 2.a-2.d** illustrate corresponding test results. The value of threshold *Tn* in IPNF and the proposed method is

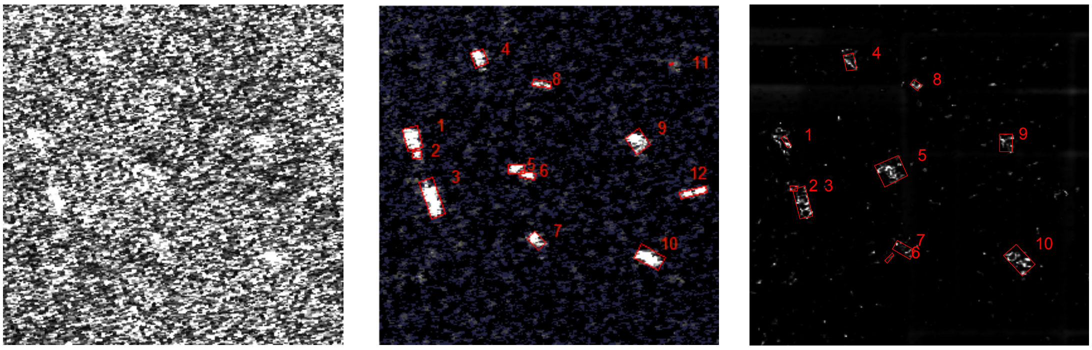
0.5. Reduction Ratio $(b/a)^2$ is 0.95. **Fig 2.e-2.f** illustrate corresponding test results.



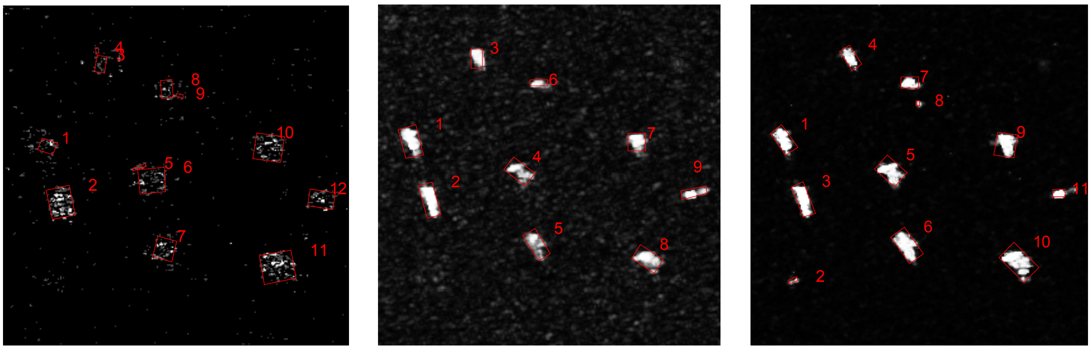
(a) **(b)** **(c)**

Fig. 1. (a) Google Earth image (b)whole Pauli RGB image

(c) Pauli RGB image of experimental are



(a) SPAN **(b) PWF** **(c) PCE**



(d) GOPCE **(e) IPNF** **(f) the proposed method**

Fig. 2. Test results of various methods

For the quantitative evaluation of the performance of the above algorithm, correct detection rate(Cdr), false alarm rate(Far), leakage alarm rate(Lar) and quality factor(Fq) indicators were used. Here quality factoras follows:

$$F_q = \frac{\text{The number of correct detection}}{\text{The number of false alarms} + \text{The actual number}} \quad (5)$$

When the number of false alarms detected or undetected too much, the quality factor will decrease. Only when all the real targets correctly were detected and false alarm and missing alarm does not exist, its value was 1. the smaller its value is the worse detection results.

From the test results, the SPAN detector does not detect any target, the ship is fully submerged in strong noise. The proposed algorithm detected 11 correct targets and the detection rate of 100%. Only a ship is missed. Table 1 shows the comparison result of the five detection algorithms apart from SPAN detector.

Table 1 Comparison test results

detector	Total Detection (Fq)	Number of correct detection (Cdr)	Number of errors detected(Far)	Number of missing target(Lar)
PWF	12(0.71)	10(83.3%)	2(16.7%)	2(16.7%)
PCE	10(0.50)	8(66.7%)	4(40%)	3(25%)
GOPCE	12(0.71)	10(83.3%)	2(16.7%)	2(16.7%)
IPNF	9(0.75)	9(100%)	0(0%)	3(25%)
proposed method	11(0.92)	11(100%)	0(0%)	1(8%)

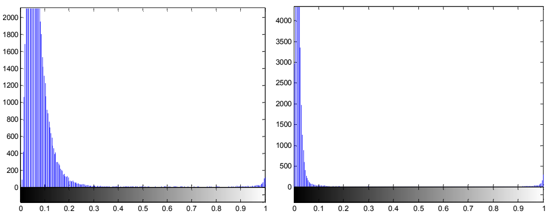
As can be seen from **Table 1**, false alarm rate of PWF, PCE and GOPCE are higher that notch-like algorithms. We can find these false alarms are mainly caused by the target split from **Fig 2.b-2.d**.

Fig 2.e depicts the IPNF mask exploiting quad polarimetric data. **Fig 2.f** depicts the proposed method mask exploiting quad polarimetric data. In contrast, the proposed method reduces leakage alarm rate of ship targets. Are shown in **Fig 2.f** weak small target 8 and target 2 were effectively strengthened and detected. Success is that results of based-model polarimetric decomposition can be more accurate reflection of ocean scattering mechanisms. The traditional notch method use directly odd scattering coherent matrix, surface scattering of pauli decomposition as bragg scattering to characterize marine electromagnetic scattering model. In fact besides surface scattering components, there is a certain double-bounce scattering component in sea clutter. It is difficult to accurately reflect the ocean surface scattering only using pauli decomposition results. In contrast, the results of based-model polarimetric decomposition can be more accurately reflect the actual marine feature.

To further analyze the performance of the detectors, statistics histogram was extracted from feature maps of IPNF and the proposed method. The results shown in **Fig. 3.** It can be seen that the proposed method effectively enhance contrast between ship and sea. In term of quality factor, the value of the proposed method was 0.92, which the largest fully reflect the its superiority compared to the rest of the algorithm.

5. CONCLUSIONS

A new kind of polarization notch filter detector was developed based-model polarization decomposition. Detector combine creatively freeman decomposition and notch filter, which effectively distinguish ship and the sea clutter. The algorithm has been tested using satellite data (RADARSAT-2 acquired over Tokyo Bay) showing the capability of the proposed algorithm for vessel detection.



(a) **(b)**

Fig. 3. Statistics Histogram
(a) IPNF (b) proposed method

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