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# Ship Detection Using Polarization Cross-Entropy*

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## 1. Introduction

Polarimetric Synthesis Aperture Radar (SAR) has been widely adopted in the earth surveillance due to its all-day and all-weather capability. Ship detection, an important application in earth surveillance, has been deeply studied by researchers for many years. Standard polarimetric detectors, such as Polarimetric Whitening Filter (PWF) [1] and Intensity Likelihood Ratio Test (ILRT) [2] have been successfully applied in ship detection. The basic idea under these standard detectors is to reduce multi-channels of polarimetric data to single decision criteria, in order to perform a detection process. Extracting appropriate parameters from polarimetric data are other solutions for ship detection. In 1990, Cameron proposed the coherent target composition method [3], which was then applied to ship detection by Robert Ringrose in 1999 [6], using SIR-C single-look complex image. In 1996, Cloude and Pottier took a review of target decomposition theory and proposed the concept of polarization entropy [4]. The polarization entropy is defined to be the logarithm sum of the normalized eigenvalue of the polarimetric coherency matrix. The polarization entropy can reflect the randomness of the target's scattering mechanism and is proved to be useful in the detection of ship [8], [9] and ship wakes [5].

In this paper, the polarimetric cross-entropy is proposed to provide a discriminative rather than descriptive feature for ship detection. Based on the new parameter, we employ a constant false-alarm rate (CFAR) method to detect ships in sea region. The usefulness and effectiveness of the presented method is validated through experimental results.

## 2. Ship detection using polarization cross-entropy

### 2.1 Eigen-decomposition of Polarimetric Coherence matrix

For reciprocal scattering matrix, the scattering vector (Pauli basis) is

$$\vec{k} = \frac{1}{\sqrt{2}}\left[s_{hh} + s_{vv}, s_{hh} - s_{vv}, 2s_{hv}\right]^T . \tag{1}$$

The coherence matrix $T = \left\langle \vec{k} \bullet \vec{k}^H \right\rangle$ can be decomposed as

$$T = \sum_{i=1}^{3} \lambda_i \left( \vec{e}_i \bullet \vec{e}_i^H \right), \tag{2}$$

where $\lambda_i$ is the eigenvalue of the coherence matrix and $\vec{e}_i$ is the corresponding eigenvector.

Polarization entropy is then introduced via calculating the logarithmic sum of eigenvalues

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$$H = -\sum_{i=1}^{3} p_i \log_3 p_i, \quad p_i = \lambda_i \Big/ \sum_{i=1}^{3} \lambda_i \, . \tag{3}$$

Polarization entropy measures the randomness of the scattering characteristics, ranging from 0 to 1. For the sea and ships have different scattering characteristics, it is reported that polarization entropy can be useful to detect ships in oceans [8], [9]], even ship wakes [5].

### 2.2 Polarization cross-entropy

Suppose the polarimetric coherency matrices of a target and clutter are $T_t$ and $T_c$, respectively.

Decompose $T_t$ and $T_c$ as

$$T_t = U_t \begin{bmatrix} \lambda_1 & & \\ & \lambda_2 & \\ & & \lambda_3 \end{bmatrix} U_t^H, \quad T_c = U_c \begin{bmatrix} \mu_1 & & \\ & \mu_2 & \\ & & \mu_3 \end{bmatrix} U_c^H \tag{4}$$

The polarization cross-entropy is then defined as

$$PCE = \sum_{i=1}^{3} q_i \log \frac{q_i}{p_i} \tag{5}$$

where $p_i$ and $q_i$ are the normalized eigenvalues of $T_t$ and $T_c$, respectively,

$$p_i = \frac{\lambda_i}{\sum_{i=1}^{3} \lambda_i}, q_i = \frac{\mu_i}{\sum_{i=1}^{3} \mu_i} \tag{6}$$

The polarization cross-entropy has the following properties:

(1) $PCE \geq 0$ for arbitrary polarimetric coherency matrices $T_t$ and $T_c$

(2) $H_t = H_c$ if $PCE = 0$, where $H_t$ and $H_c$ are the polarization entropies derived from matrices $T_t$ and $T_c$

### 2.3 The distribution of polarization cross-entropy over ocean regions

Now we discuss the statistical distribution of polarization cross-entropy over ocean regions, which would be beneficial for our following detection algorithm. The theoretical form of polarization cross-entropy can be quite complex given the assumption of a Whishart distribution of polarimetric coherency matrix. Rather than deriving a theoretical solution, we aim at observing the result from practical data. By computing the histogram of ocean regions for nearly 100 sets of polarimetric SAR data, we find the distribution of PCE over ocean regions can be well approximated by an exponential distribution $f_{PCE}(x) = \frac{1}{a} e^{-\frac{x}{a}}, x \geq 0$.

### 2.4 PCE based CFAR detection algorithm

Given the exponential distribution of clutter, it can be proved that the false alarm $P_{fa}$ and the detection threshold $t$ have the following relationship,

$$t = -a \ln P_{fa} . \tag{8}$$

The procedure of proposed CFAR detection algorithm can be summarized as Table 1.

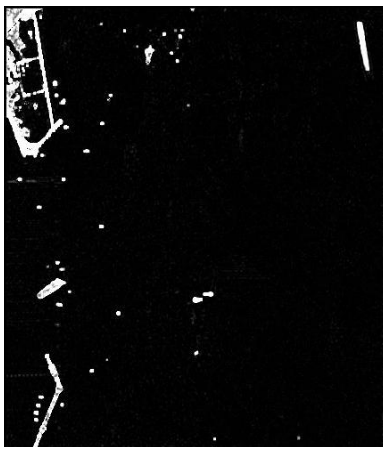
Table 1 Procedure of the proposed detection algorithm

| |
|---|
| (1) Calculating the polarization cross-entropy over the whole polarimetric SAR image; |
| (2) For each pixel $(i, j)$, given a false alarm rate $P_{fa}$ . |
| (a) Calculate target's PCE $x_{i,j}^{t}$ from the target cell around pixel $(i, j)$ . |
| (b) Estimate the distribution parameter $\hat{a}_{i,j}$ from the clutter cell. |
| (c) Calculate the local detection threshold $t_{i,j}$ with $P_{fa}$ and $\hat{a}_{i,j}$ . |
| (d) If $x_{i,j}^{t} > t_{i,j}$ then mark the pixel $(i, j)$ as target, else mark as non-target. |

**3. Experimental results**

The proposed detection algorithm is validated through polarimetric SAR data captured by NASA/JPL AirSAR. The image is selected from the Sydney coast, Australia. Figure  shows a set of images from original data to final detection result. The false alarm rate is set to be 0.2%. For comparison, we also calculated the polarization entropy (Figure 1(c)). It can be seen that the polarization entropy can reflect descriptive scattering characteristics of ocean, e.g., one can even observe patterns of ocean current from the entropy image. However, the point target such as ships is difficult to recognize. But for the polarization cross-entropy image (Figure 1(b)), it is very clear to discriminate targets from background ocean clutter, and the cross-entropy of ocean pixel itself provides a very little response. This is propitious to the following detection step which is also demonstrated by the detection result (Figure 1(d)).

(a) Span image



(b) PCE image

(c) Polarization entropy image

(d) Detected result

Figure 1 Experimental results for CFAR detection algorithm.

**4. Conclusion**

Polarization cross-entropy has been proposed in this paper as a discriminative parameter to detect ships in ocean areas. The new parameter is based on eigen-decomposition of polarimetric coherency matrix and could well reflect the difference of scattering characteristics of target and local clutters. Polarization cross-entropy is validated to be very effective to discriminate ships from ocean background through extensive experiments. Furthermore, we proposed a new CFAR ship detection algorithm based on polarization cross-entropy, which is evaluated to be efficient by NASA/JPL AirSAR data. It is worthy to note that in the presented detection algorithm we only utilize the proposed parameter. It is expected to achieve better result if we add other polarimetric information, such as power intensity and similarity parameters [7] in our detection algorithm.

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