A MODIFIED FRAMEWORK FOR SHIP DETECTION FROM COMPACT POLARIZATION SAR IMAGE

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ABSTRACT

In recent years, the compact polarimetric SAR (CP SAR) imaging mode has received much attention because of its advantages in swath width compared to the quad-polarization mode and in information of scattering targets compared to the linear dual-polarization mode, respectively. For object detection (e.g., ship, sea ice, and drilling platform) in maritime monitoring which has been widely discussed, it is still a challenge to eliminate the false alarms caused by ocean clutter. Accordingly, a modified feature-based framework for ship detection using CP SAR data was proposed in this paper. In particular, a Guard-filter was used after feature extraction to reduce the effect of ocean clutter. Several simulated CP SAR imageries based on Gaofen-3 quad-polarization SAR image were selected for further investigations on ship detection. A SVM classifier was included in the framework to do a pixel-wise classification. The result shows that the proposed method has a better performance compared to traditional methods (e.g., constant false alarm rate and polarimetric whitening filter) and the feature–based method without filtering. Overall false alarm rates are decreased by 35% with the proposed method.

Index Terms— Compact polarimetric SAR, ship detection, Guard-filter, Gaofen-3, false alarm

1. INTRODUCTION

SAR image has been considered an effective tool in maritime monitoring because of its capability in working at all-time and under all weather conditions. Quad-polarization (QP) SAR image captures abundant information available from the observed scene with the cost of limited swath width and high system complexity [1]. In order to make a tradeoff between the characters mentioned above, the concept of compact polarimetric SAR (CP SAR) imaging mode was introduced [1]. Moreover, the circular transmit-linear receive (CTLR) CP configuration is a better choice due to its advantages in rotational invariance compared to pi/4 CP configuration and the relatively simple architecture compared to dual circular polarization CP configuration [2]. Therefore, the CTLR CP configuration is used for the discussion on the proposed ship detection framework.

Two frameworks were mainly proposed for ship detection with CP SAR image. One frequently-used framework is to reconstruct the QP SAR information from CP SAR scattering information. Souyris *et al.* [3] proposed the approach first. Nord *et al.* [4] modified the proportional relationship between co-polarized and cross-polarized channels contrast to Souyris' algorithm. Collins *et al.* [5] introduced an empirically-based model to reconstruct ocean data for maritime applications. Yin *et al.* [6] designed a helical scattering mechanism for reconstruction. However, these methods are restricted by assumptions on scattering mechanism and relationships between different channels. The proceedings costs time with iterations, while the reconstructing precision is limited [11]. Another framework is feature-based framework by decomposing the CP SAR scattering matrices directly. Shirvany *et al.* [7] used the degree of polarization to discriminate the ship from ocean. A good performance on large target by taking the m-χ and m-δ decomposition on CP SAR image was got by Yin and Yang [8]. Allah and Mohamed [9] adopted a pattern recognition to classify the candidate target by three m-χ decomposition parameters. Michael [10] adopted the incident angle as a component of feature vector. Xu *et al.* [11] formed a new feature by combining the decomposition parameters with a transform. Then a constant false alarm rate (CFAR) detector was used for detection. Accordingly, it is a challenge to keep the information of small target while reducing the false alarms.

In this paper, a modified feature-based framework for ship detection was proposed to reduce the effect of ocean clutter and retain the signal of small size targets. A feature selection from frequently-used features in related works is introduced in Section 2. The Guard-filter and flow chart of proposed method are included. In section 3, experiment result and the comparison with traditional methods are shown. Conclusions on the proposed method are shown in the last section.

2. METHODOLOGY

2.1. Feature selection

In related works, several features were extracted by their physical meanings. The pixel with the highest or lowest feature value was sampled as the pixel of ship in several regions including ship only. After analyzing the characteristics of these features, four of them were selected to form a feature vector due to their large distance between ship and ocean in feature space (normalized to [0,1]) and different representations in describing scattering targets. As shown in Fig. 1, compared to background, ships are higher in the first two features while lower in the last two features. The details of these four features are shown in Table 1. The findings show that the feature vectors are suitable to represent the target (see Section 3.2.).

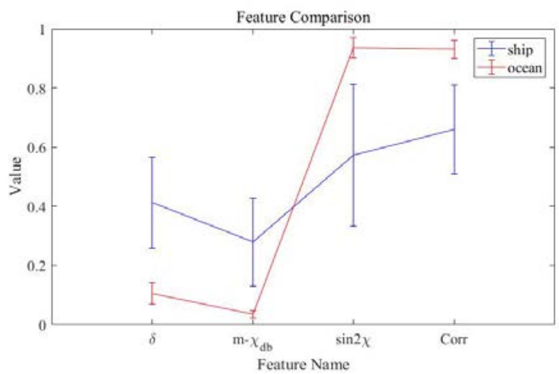

Fig. 1. The features selected for constructing feature vector.

Table 1. Details of selected features

Symbol	Name	Formula
δ	Phase difference [8]	$\delta = -arctan(\frac{g_3}{g_2})$
$\sin 2\chi$	Degree of circularity [8]	$\sin 2\chi = \frac{-g_3}{(m * g_0)}$
$Corr$	Correlation coefficient [12]	$Corr = \frac{Re\{-i\langle E_H E_V^* \rangle\}}{\sqrt{\langle \lvert E_H \rvert^2 \rangle \langle \lvert E_V \rvert^2 \rangle}}$
$m\text{-}\chi_{db}$	Double bounce scattering [8]	$\sqrt{\frac{m g_0 (1 + \sin 2\chi)}{2}}$

In Table 1, g_0, g_2, and g_3 are the stokes parameters, while m denotes the degree of polarization. E_H and E_V are the elements of CP SAR scattering matrix.

2.2. Guard-filter

To restrain the effect of ocean clutter, the Guard-filter is introduced which is similar to the idea of CFAR protection window with guard-pixels [9], [11]. The sliding window shown in Fig. 2 is used to compute the feature value of the pixel in center. The size of inside-box is 3×3. The median processing over inside-box is to make the ocean clutters not classify as ships. The white pixels are the guard-pixels which are not considered in Guard-filter processing. In ocean environment, the number of ship represented pixels are usually less than the number of ocean represented pixels. Accordingly, the median value of the gray pixels are treated as the feature value of ocean background. The Guard-filter is formulated as Eq. (1).

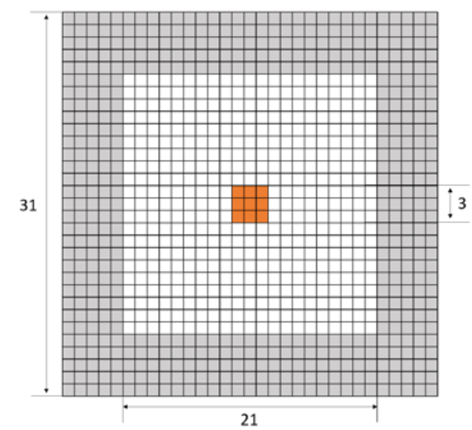

Fig. 2. Diagram of Guard-filter

$$DN = \frac{median(DN_{inside\_box})}{median(DN_{outside\_box} - DN_{middle\_box})} \quad (1)$$

where, DN is the digital number of pixel. The (–) denotes the difference operation to get the pixels in outside box but not in middle box (the pixels in gray area). After a Guard-filter processing, the feature values of ocean clutter are closed to 1. The feature values of ship are much larger than 1.

2.3. Flow chart of the proposed method

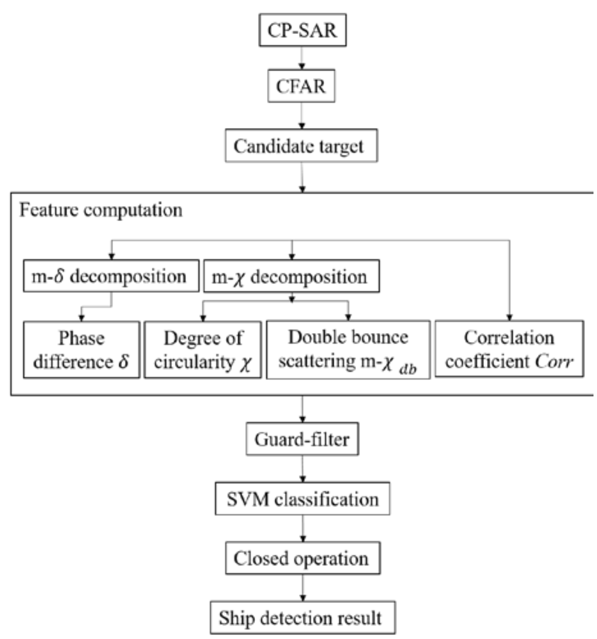

Fig. 3. Flow chart of the proposed ship detection framework

The proposed ship detection framework is summarized in Fig. 3. Firstly, the CTLR mode CP SAR image was simulated based on Gaofen-3 QP SAR image (http://www.cresda.com/CN/). As the related work in [9], the CFAR detector was selected as a second step, to produce candidate targets and to make further prediction more efficient. Empirically, the result obtained by two-parameter CFAR detector is accurate while including many false alarms. The third step was to calculate δ, χ, m-χ_{db}, and *Corr* separately. Then, a Guard-filter was used to restrain the effect of ocean clutter. After training the SVM classifier, a prediction of candidate targets was taken. Finally, a closed operation was introduced to ensure the integrity of a ship target.

3. EXPERIMENT AND RESULTS

3.1. Data summary

Five consecutive Gaofen-3 QP SAR images acquired on Dec. 26th 2016 were selected in this study. The incidence angles of near range to far range are 33.68° to 35.62° respectively. The imageries were acquired over the East China Sea near Taizhou, Zhejiang province with the resolution of 8 meters. The CTLR mode CP SAR images were simulated from above images after being calibrated by PIE software (http://www.piesat.com.cn/).

3.2. Experiment

Fig. 4 shows a comparison example of Guard-filter operation on m-χ_{db}. Five regions of interest with several ship targets were selected in simulated CP SAR images respectively. As shown in Fig. 4 (a), due to the orientation of ship with respect to radar beam, ship size, material from which the ship is made and other factors, the feature values of ship are varied. With the influence of wind and ocean clutter, the feature values of ocean background are inconsistent also. It's hard to train a robust and universal classifier model with these feature vectors. After operating with Guard-filter (Fig. 4 (b)), the feature value of ocean is stable and separated from that of ship. It contributes significantly for model convergence and further ship detection.

As shown in Fig. 5, the detection results for static ship (1), ship with weak scattering (2), ocean clutter (3), and sidelobes (4) are listed in 4 rows respectively. For static ship, only polarimetric whitening filter (PWF) method gets a false alarm marked by rectangle. In the second row, the ship with weak scattering is undetected by SVM method without Guard-filter. By PWF and CFAR method, the false alarms appear. The result of the proposed method (Fig. 5 (e)) is accurate although represented by a few pixels. The proposed method reduces the false alarms while retaining the targets with weak scattering signal.

Four evaluation indices [12] formulated as following equations are used in this paper.

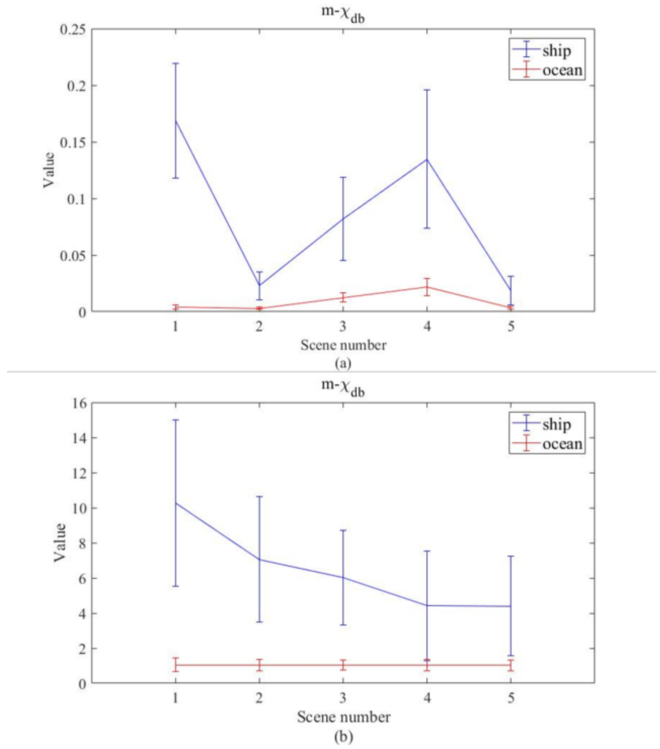

Fig. 4. Comparison of Guard-filter operation on m-χ_{db}. (a) Feature value of ship and ocean before using Guard-filter; (b) Feature value of ship and ocean with Guard-filter operation.

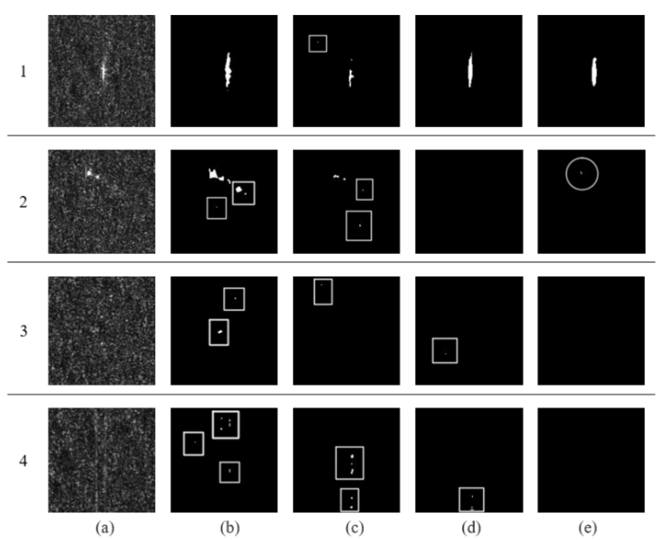

Fig. 5. Examples of detection result on typical targets. (a) CTLR span image; (b) CTLR span-CFAR result; (c) QP PWF method result; (d) Feature vector-SVM without Guard-filter; (e) Proposed method.

$$False\ alarm\ rate(FAR) = \frac{FP}{TP + FP} \quad (2)$$

$$Precision = \frac{TP}{TP + FP} = 1 - FAR \quad (3)$$

$$Recall = \frac{TP}{TP + FN} \quad (4)$$

$$F_1\ score = \frac{2Precision * Recall}{Precision + Recall} \quad (5)$$

where, TP means the number of positive targets detected correctly; FP means the number of negative targets detected as positive targets; FN means the number of undetected positive targets. F_1 score is the harmonic average of the precision and recall, where an F_1 score reaches its best value at 1 (perfect precision and recall) and worst at 0.

Table 2. Detection result on test area

Method	FAR	Precision	Recall	F1 score
CFAR	52.62%	47.38%	100%	0.67
PWF	32.56%	67.44%	100%	0.81
SVM	25.66%	74.34%	98.57%	0.85
Proposed	1.41%	98.59%	100%	0.99

Assessments of detection results are listed in Table 2. The traditional methods (e.g., CFAR, PWF) get high recalls which mean the abilities on detecting all ships. However, due to the effect of ocean clutters, the false alarm rate (FAR) of them are high. As a result of the inconsistent feature vectors, the feature-based framework without Guard-filter gets a few missing detections and a higher FAR, compared to the proposed method. The proposed method is obviously superior to other three methods based on the evaluating indices. The SVM model trained with features after Guard-filter operation is universally in discriminating the ocean clutter and ship target. Therefore, the proposed framework has a great performance on reducing the false alarms while retaining the targets with weak scattering signal.

4. CONCLUSION

In this paper, a modified feature-based ship detection framework was proposed. For CP SAR image with CTLR mode simulated from Gaofen-3 QP SAR image, the framework is effective in ship detection. As shown by evaluation indices, the proposed method reduces the false alarms while retaining the targets with weak scattering signal. The incidence angle is an important factor on radar scattering characteristics. Accordingly, it will be taken into account in future research. Furthermore, the size of Guard-filter is designed to fit the ship with usual size. A sensitive investigation on the size will be considered further.

5. ACKNOWLEDGMENTS

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