

An Adaptive Ship Detection Method In SAR Image Based On CFAR

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Abstract. An intelligent constant false alarm rate (CFAR) method based on Weibull distribution for target detection in SAR images is presented in this paper. The reference window is used to compute an adaptive threshold, it can distinguish multiple targets and clutter edges of nonhomogeneous environments. Valid results show the improvements of the new algorithm compared with the two Parameter CFAR algorithm and global CFAR algorithm.

Keywords: target detection, CFAR, Weibull distribution, nonhomogeneous area, weighted threshold.

1. Introduction

The CFAR algorithm is widely used in target detection of SAR images. An appropriate probability density function (PDF) must be determined which matches the statistical characteristics of background clutter properly first, then CFAR processor dynamically calculates a detection threshold by the local background distribution and the desired Probability of False Alarm (PFA), and compares the grayscale value of each pixel with the threshold to detect target finally^[1].

The most frequently used PDF distributions in SAR images are the Gaussian and Rayleigh distributions. Gaussian distribution is efficient and simple in form while it is not suitable for spiky or heavy-tailed situation of sea clutter^[2]. Rayleigh distribution provides good model for homogeneous region of high-resolution images, however, there exists serious fitting errors in heterogeneous and extremely heterogeneous region. Thus the use of Weibull distribution to model ground clutter is suggested in this paper. Weibull distribution can be used to model both land and sea clutter and offers an accurate representation of the real clutter distribution over a much wider range of conditions than rest of the two models^[3].

The current widely used CFAR algorithms are CA-CFAR, GO-CFAR, etc. Each of them has its individual strengths and weaknesses. CA-CFAR is the most useful method and its detection performance descends in nonhomogeneous area dramatically^[4]. GO-CFAR copes with the clutter edges area better, however, it is inferior to CA-CFAR in stable area and multiple targets area. Algorithm complexity, practicability and range of application are the main factors needed to be considered to choose the most suitable algorithm.

In this paper, the adaptive CFAR algorithm presented here is a composite of CA-CFAR and GO-CFAR. For ship detection the algorithm divides the background of a sliding window into 4 sub-windows and determines whether they belong to homogeneous or nonhomogeneous environment including multi-targets area and clutter edges area. According to the difference of the background types, it dynamically selects sub-windows to calculate threshold. Eventually, the results compared with two-parameter CFAR and global CFAR show good performance in both homogeneous and nonhomogeneous environment^[5].

2. CFAR Detection

2.1.1. CFAR Description

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The CFAR algorithm processes image pixel by pixel. It is based on the feature of SAR images that artificial targets possess a higher backscatter than the background area, which makes the gray scale of artificial targets higher. There are three essential factors in ship target detection: PFA, the distribution model describing the background and CFAR processor. PFA is set according to the demand, and the distribution model has a direct effect on the performance of the CFAR detector. Most of the algorithms select model before detection, and then choose different detector on basis of detection circumstances.

Currently, most CFAR algorithms are committed to select distribution model and detection threshold. Assume $p(x)$ to be the PDF of the background clutter, P_{fa} to be PFA and T to be the threshold. If the gray scale of a test cell is higher than T , it is regarded as target. The relationship between them is shown as:

$$1 - P_{fa} = \int_0^T p(x) dx \quad (2-1)$$

2.1.2. Weibull Distribution

The Weibull PDF is particularly a good model for certain type of return, such as sea clutter and rain clouds. It is shown as below [3]:

$$p(x) = \left(\frac{c}{b}\right) \left(\frac{x}{b}\right)^{c-1} \exp\left(-\left(\frac{x}{b}\right)^c\right) \quad (2-2)$$

This function is described by two parameters, namely the scale parameter b and the shape parameter c . Setting $b=2$ will generate a Rayleigh PDF, while setting $c=1$ for the exponential PDF.

With appropriate parameter setting, the model will provide a better fit for measured data of certain clutter types. b and c can be evaluated according to the following formula:

$$z = \frac{u}{\sqrt{\hat{\sigma}}} = \frac{\Gamma\left(1 + \frac{1}{c}\right)}{\sqrt{\Gamma\left(1 + \frac{2}{c}\right) - \Gamma^2\left(1 + \frac{1}{c}\right)}} \quad (2-3)$$

Suppose u to be the mean pixel value of reference window, $\hat{\sigma}$ to be the variance, and $\Gamma(\bullet)$ represents Gamma function. c can be expressed by a fitting-well polynomial, and $a_2 = 0.079$, $a_1 = 0.848$, $a_0 = 0.0817$,

$$c = a_2 z^2 + a_1 z + a_0 \quad (2-4)$$

$$b = \frac{x}{\Gamma\left(1 + \frac{1}{c}\right)} \quad (2-5)$$

At last, the threshold can be determined by the reference window statistical properties:

$$T = b(-\log_e(P_{fa}))^{\frac{1}{c}} \quad (2-6)$$

2.1.3. Reference Window Type Determined

CA-CFAR achieves good detection results in homogeneous environment. CA-CFAR calculates the threshold via mean value and variance of the background window, and the threshold behaves reasonably with steady clutter. Clutter edges in the background makes the threshold lower than strong clutter, thus the false alarm increased; while multiple targets make the threshold higher, as a consequence missed alarm happens. Unlike CA-CFAR, GO-CFAR select background window with greater intensity.

The method introduced in this paper is a combination of CA-CFAR and GO-CFAR. CA-CFAR is adopted in steady background area and GO-CFAR is used to eliminate the interference in clutter edges area. Besides when it comes to multi-targets inference area, reference window which could excludes interference targets is employed to avoid adjacent targets occlusion. The background window is segmented into 4 sub-windows, then parameter VR and parameter M are calculated respectively where VR represents statistical properties and M represents distribution characters. The sub-windows can be classified into homogeneous area and nonhomogeneous area including clutter edges area and multi-targets interference area.

2.1.4. Definition of parameter VR

VR stands for the changes of background, and it can be balanced by variance. Noise in SAR images is multiplicative, which leads to weak fluctuation of clutter in low intensity area and strong fluctuation in high intensity area. Variance can't represent the changing degree of background exactly.

To get rid of the dependence on background, let the variance of sub-block $\hat{\sigma}^2$ divided by the of average value u , which is used as the index of change of background. There should be a threshold T_{VR} to classify the background. If VR is above T_{VR} , the sub-block belongs to clutter edges area or multi-targets area, on the opposite ,it belongs to homogenous background area. X is the pixel value and n is the number of pixels.

$$T_{VR} = 1 + \frac{\hat{\sigma}^2}{u^2} = 1 + \frac{1}{n} \sum_{i=1}^n \frac{(X_i - \bar{X})^2}{(\bar{X})^2} \quad (2-7)$$

2.1.5. Definition of parameter M

In nonhomogeneous area, it is hard to distinguish multi-targets and clutter edges area relying on mean value and variance because they can't reflect the spatial distribution of gray value. Parameter M is introduced.

M shows the number of gray value crossing over half of the highest value in the sub-window. The interference targets usually distribute concentrated when the sub-window belongs to multi-targets area. It's easy to differentiate them from clutter with a higher M. Conversely, the gray space distributes randomly when the sub-window belongs to clutter edges area, and the value of M is lower. Threshold T_M is defined for M according to the width of the sub-window.

$$\begin{aligned} M \geq T_M &\Rightarrow \text{multi-targets area} \\ M < T_M &\Rightarrow \text{clutter interference area} \end{aligned} \quad (2-8)$$

2.1.6. Weighted Threshold

Global threshold or local threshold is generally used singly in CFAR algorithm. The global threshold of CFAR is based on the assumption that SAR image conforms to Weibull distribution and can be calculated according to formula (2-1).The local threshold is obtained by dividing SAR image into sub-windows and calculating thresholds of each window based on Weibull distribution.

Weighted threshold used in the paper is a compromise between global threshold and local threshold, which makes the threshold having a connection with its neighbourhood. First, SAR image is segmented into $N \times M$ windows, the local threshold can be obtained for each window, and then local threshold and the global threshold are added according to suitable proportion. The weighted sum is the new threshold T which is shown below, where the Weight coefficient a lies between 0 and 1.

$$T = a \cdot T_{global} + (1 - a) \cdot T_{local} \quad (2-9)$$

2.1.7. Interference Removal

Due to the environmental complexity, speckle noise often appears in SAR images. An isolated spot with lower gray value of neighborhood can be considered as speckle noise. Generally, pixel numbers in speckle noise area are less than pixel numbers in target area evidently.

A method considering the gray value of neighbourhoods for each cell is introduced to decrease the noise. Since speckle noise with small area and the mean value of neighbor lower than the gray value of noise, mean value of neighbourhood is used to replace gray value of noise to eliminate speckle noise. The expression is as following where $F(x, y)$ is the reconstructed gray value, $\overline{f_{rect}}(x, y)$ is the neighborhood's average gray value of the current pixel, $f(x, y)$ is the current pixel value and d is the weight coefficient lying between 0 and 1.

$$F(x, y) = d \cdot f(x, y) + (1 - d) \cdot \overline{f_{rect}}(x, y) \quad (3-1)$$

3. Procedure of the algorithm

The input images need to be processed by several steps and then targets can be determined. The procedure of the algorithm is summarized as following:

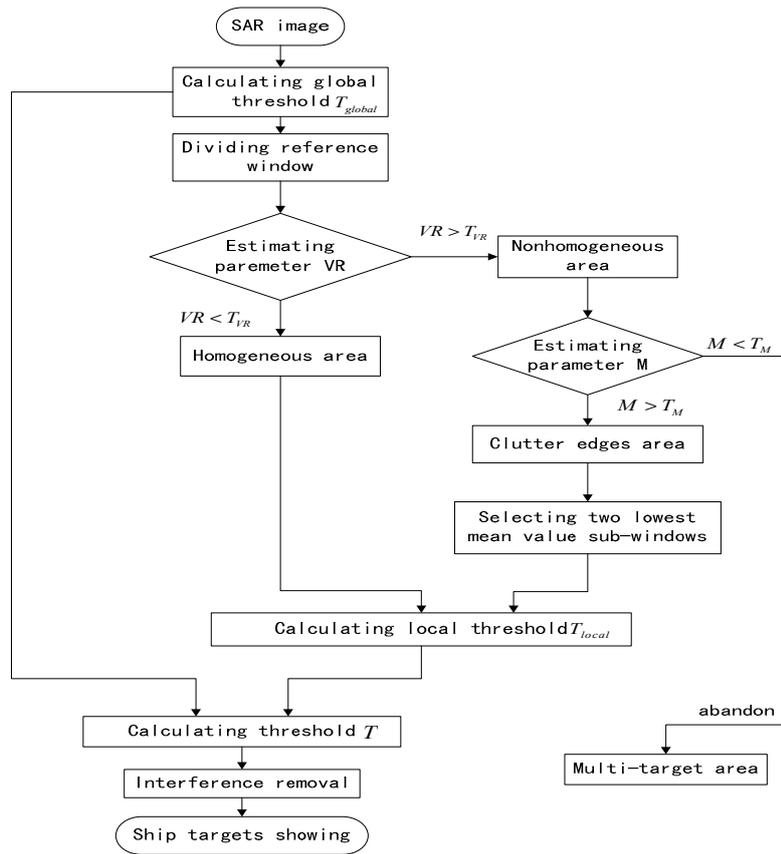
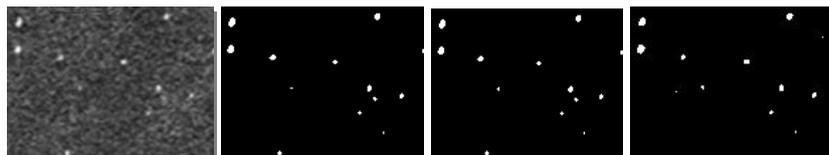


Figure 1. Flowchart of the Improved Method

4. Experiments and Results

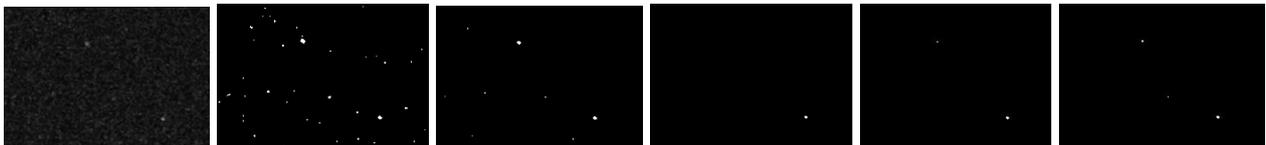
A set of meaningful experiments are shown and discussed to demonstrate the effectiveness of the proposed method. Gaussian and Rayleigh distribution are used to fit sea clutter respectively in order to produce a contrast with Weibull distribution. Global CFAR and two-parameter CFAR are also adopted to make a comparison with the proposed method. All these methods are under the same circumstances.



(a)Original image (b)global CFAR (c)two-parameter CFAR (d)adaptive CFAR

Figure 2. Detection Results in multi-targets area based on Gaussian Distribution

In figure2, image (b) and (c) based on the Gaussian distribution show global and two-parameter CFAR exist false alarm and missed alarm. (d) shows adaptive CFAR method in this paper with better performance.



(a)Original image (b)two-parameter (c)global in gaussian (d)global in rayleigh (e) adaptive (Pfa=0.0005) (f)adaptive (Pfa=0.0001)

Figure 3. Detection results in different conditions of complex clutter area

In figure 3, (b) and (c) shows the results of global CFAR in Gaussian distribution and two parameter CFAR have massive false alarm, and the real targets are submerged in speckle noises. (d) shows that global CFAR in Rayleigh distribution has missed alarm, it can't detect targets exactly. (e) and (f) are the results of the proposed method with different setting of PFA and speckle noises are eliminated effectively. They show better performance. For PFA=0.0005, the targets can be detected accurately; for PFA=0.0001, the result show not serious false alarm. Proper setting of PFA can effectively enhance the accuracy of the detection.

To measure the performance of these methods, quality factor can be defined as $FoM = N_{tt} / (N_{fa} + N_{gt})$. N_{tt} is the number of correct detection of targets. N_{fa} is the number of false alarm targets. N_{gt} is the number of actual targets. The accuracy of the detection result is judged by the degree of closeness to 1.

Table 1 analysis of detection results

		Improved CFAR		Global CFAR		Two parameter CFAR
Figure2	Actual target	10		10		10
	Detected	10		12		12
	False alarm	0		2		2
	FoM	1		0.83		0.83
Figure 3	Pfa	$5e^{-4}$	$1e^{-4}$			
	Model			Gaussian	Rayleigh	
	Actual target	2	2	2	2	2
	Detected	2	3	7	1	much clutter
	False alarm	0	1	5	0	much clutter
	FoM	1	0.67	0.29	0.5	much clutter

5. Conclusion

An improved CFAR algorithm based on Weibull distribution for detection on SAR images is presented in this paper. Reference window is divided to verify its type and sub-windows are selected to calculate threshold. The method take both global and local information into account, which show good performance in nonhomogeneous environment. Mean gray value of local area is used to reconstruct the gray value in current pixel, which effectively decreases the interference of speckle noise and detects targets from interfered images. The results show the performance has been greatly improved, meanwhile, the efficiency is also guaranteed.

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7. References

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