2020 28th Iranian Conference on Electrical Engineering (ICEE)

FAST VI-CFAR SHIP DETECTION in HR SAR DATA

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***Abstract*— Since past times the use of SAR images is growing dramatically. One of the reasons that these images were considered is which is independent of climatic conditions. This kind of images is getting more applicable in the field of military and civilian. Some applications of them is to identify marine targets. Many articles have been published in this field, and each has tried to improve performance of detection targets. Due to large size of these data, the detection process going to reduce the processing time. This process leaded to methods such as adaptive and Fast CFAR, II-CFAR, fast double step, and etc. In this paper, a method is provided that in addition to good performance in detection, has as a short time of processing and it works well in removing false alarms. At the end, we compare this method with others in 3 experiments.**

***Keywords*—synthetic aperture radar (SAR), ship detection, Constant false alarm rate (CFAR), fast VI-CFAR.**

I. INTRODUCTION

In order to increase the speed of SAR data processing, the two methods are ahead. First, we can use a more powerful systems to do this, which is not economically useful. The second strategy is to find algorithms that have good speed at data processing. Maybe, these algorithms have not a better performance in terms of the old and traditional methods, but have the advantage of reducing the processing time to big size data. Of course, some new fast CFAR methods are also being improved, which are comparable to the results of traditional methods, and some have better performance results. In this paper, we introduce a method to achieve this goal and will compare to other traditional and new fast CFAR methods via three experiments between their performance and time of processing. then, we will explain simulations results and finally we state conclusion.

II. ALGORITHM STEPS

Almost always the CFAR based methods are used to detect marine targets. So far, many methods have been proposed for this purpose that tried to improve detection performance. In the meantime, there are some methods, moreover, considering the accuracy of detection, also consider processing time. Each of which has its own advantages and disadvantages. We explain the proposed method to achieve both of our goals. This occurs in some steps as stated below.

A. First step: land masking

First, we need to make sure that our SAR image does not contain the ground and only has target and sea clutter. As mentioned in [1] by implementing of CFAR algorithms on such ground areas, will face a large amount of false alarms. So, before we use the image algorithm, we provide this kind of data.

It should be noted that the data used in this article has been received from the website "earth.esa.int". It is related to the satellite Sentinel-1a in mode IW of the HR type. More information about HR images are deeply stated on this website. The advantage of HR images to compare to others is their resolution and the less speckle, and Therefore there is no need to perform some pre-processing procedures.

Another explanation should be said is how to provide a no-land data (or land masking). We can use SNAP software which is downloadable from "esa.int" website. then, the image is ready to process and execute the algorithm.

B. Second step: set a global threshold

At the beginning, we need a zero-padding on data to prevent losing information from corners and image sides. After that we apply a simple but useful way to reduce the processing time on the image. This method is to implement a global threshold on whole all data. Then, the algorithm focuses on points which their intensities are higher than the threshold level. As a result, we have a binary image (index matrix) that guide us to apply the main algorithm.

C. Third step: choose CFAR algorithm

In this step, we want to use one of the old but golden CFAR methods to detect targets. Different methods are expressed like CA-CFAR, SO-CFAR, GO-CFAR, II-CFAR, Adaptive and Fast CFAR, fast OS-CFAR, Fast double step CFAR and etc. They depicted various behaviors in different data conditions such as homogeneous or non-homogeneous, which indicates the weakness of these methods. Among these methods described, the VI-CFAR method has a very good performance and as mentioned in [2] an intelligence to choose appropriate method in different image modes, including homogeneous, heterogeneous, variable or non-variable. By calculating some parameters decide to use several CFAR based methods in different situations. These algorithms include: CA-CFAR, SO-CFAR and GO-CFAR. Of course, this method was mentioned in [3] and by using E-CFAR tried to improve the results. But, we are using the same old way.

As stated in [2], we need a series of calculations before the implementation of these algorithms, which we are trying to summarize them bellow:

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The VI method is based on decision between using the average of leading or lagging half of stencil or both of them, and in each case, it assigns certain coefficients which are defined as the names of C_N and $C_{N/2}$ as follows:

$$C_N = (P_{fa,nominal}^{CA})^{-1/(N)} - 1 \quad (1)$$
$$C_{N/2} = (P_{fa,nominal}^{CA})^{-1/(N/2)} - 1$$

Where N is equal to the total cell numbers of background area of stencil, the N/2 is half of the N value, C_N is chosen when both sides of lagging or leading part are needed, $C_{N/2}$ is chosen when one side of them needs to be calculated and $P_{fa,nominal}^{CA}$ is false alarm value. Gaussian distribution was commonly used in old algorithms, but nowadays authors decide to apply G^0 distribution for the background because of better performance in results. We also benefit of this distribution. We expressed VI* and VI equations bellow. Utilize VI* is better than original one because of simplification of calculations which is mentioned in [2] it works properly for algorithm and has acceptable approximation.

$$VI = 1 + \frac{\hat{\sigma}^2}{\hat{\mu}^2} = 1 + \frac{1}{n+1}\sum_{i=1}^{n}(X_i - \overline{X})^2 / (\overline{X})^2$$

$$VI^* = 1 + \frac{\hat{\sigma}^2}{\hat{\mu}^2} = 1 + \frac{1}{n}\sum_{i=1}^{n}(X_i - \overline{X})^2 / (\overline{X})^2 \quad (2,3)$$
$$= n\sum_{i=1}^{n}(X_i)^2 / (\sum_{i=1}^{n} X_i)^2$$

Where $\overline{X}$ is average of n=N/2 cells in half background stencil window.

In a homogeneous environment, the VI probability density function (PDF) is independent of the noise power. However, the VI value is changed considerably when there is edge clutter and multiple interferers. Therefore, we must define how the medium is, variable or non-variable. This is done by comparing VI value with the threshold of K_{VI} using the following hypothesis: [3]

$$VI \le K_{VI} \Rightarrow \text{Nonvariable}$$
$$VI \ge K_{VI} \Rightarrow \text{Variable} \quad (4)$$

Another parameter which is help us to decide between different states of pixels is MR. This was made to determine that lagging and leading windows are in the same medium or not. It is obtained by following equation: [3]

$$MR = \overline{X}A / \overline{X}B = \sum_{i\in A} X_i / \sum_{i\in B} X_i \quad (5)$$

Where $\overline{X_A}$ and $\overline{X_B}$ stand for average of leading and lagging windows. Similar to VI parameter, pdf obtained from MR is independent of noise power in homogeneous medium. However, the value of MR increases when interfering targets and higher power of clutters are present in the leading window while it decreases when they are present in the lagging window. To determine whether the means of the leading and lagging windows are the same or not, we use the following hypothesis test by comparing the MR with a threshold K_{MR} and its reciprocal [2]:

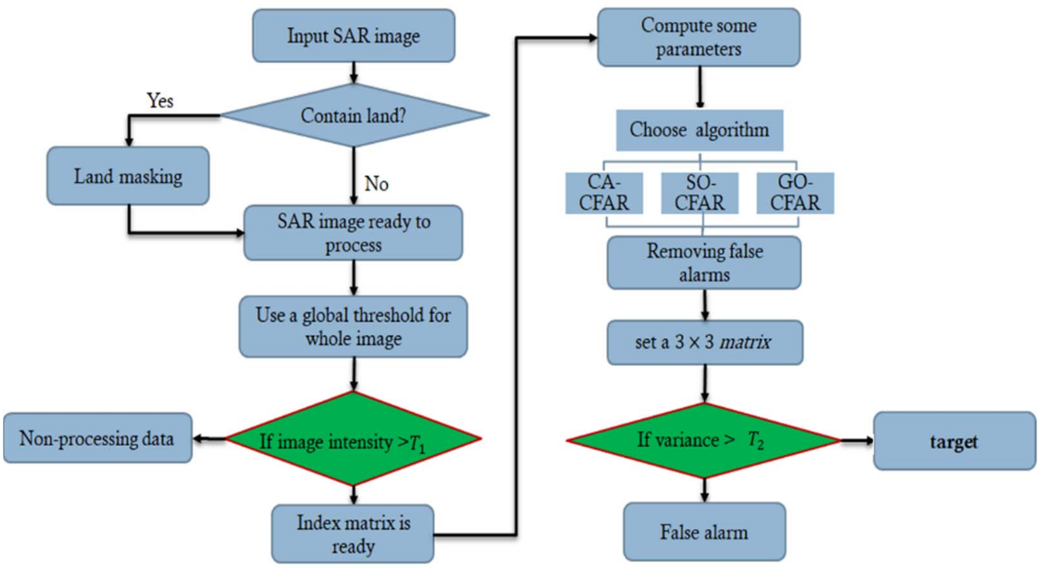
$$K_{MR}^{-1} \le MR \le K_{MR} \Rightarrow \text{Same Means}$$
$$MR < K_{MR}^{-1} \text{ or } MR > K_{MR} \Rightarrow \text{Different Means} \quad (6)$$

The calculations expressed above are executed for all pixels specified in the second step.

D. Fourth step – try to choose best algorithm for best place

By applying the previous steps, it is turn to determine the proper CFAR method according to the calculated parameters for each candidate pixel. The table 1 describes how to use them.

Fig 1. Fast VI-CFAR flow chart



E. fifth step: remove False alarms

In this step, we need to remove the false alarms that did not exist by applying the VI-CFAR method lonely. The method used for this explained as follows:

Here is a new way to remove false alarms. The use of variance in fingerprint images is used to remove unwanted points, however, this method has not been used in SAR images yet. By using a threshold for the value of variance of cells around the test cell, and like the previous steps, the wrong target cells are converted to clutter. It should be noted that for this goal the 3×3 boxes are used. Proposed method is depicted in Fig. 1.

III. SIMULATION AND RESULTS

In this section, the results of simulation and comparison of the proposed method are expressed in three different experiments to evaluate the performance of the method in detecting targets and its processing speed.

A. First experiment: detect targets

In the first experiment, we evaluate the number of targets detected by different CFAR methods.

Before this, we need to find out more about a series of equations which are used for this purpose. It is usually to calculate FOM parameter. The nearer FOM to 1, the better performance of algorithm in detection. Which is expressed as follows:

$$\text{FOM} = \frac{N_{td}}{N_{fd}+N_{rt}} \tag{7}$$

Where N_{td} , is number of targets that have been correctly detected, N_{fd} expressing number of false alarms and eventually the total number of targets is N_{rt}. The parameter that is not mentioned in tis fraction (of course is hidden) is N_{miss} the number of the missing or did not detected targets. The statistics on the targets showed in Fig. 2 depicted in the table 2.

As seen in table 2, almost all targets are detected and only difference is in number of false alarms. This itself shows ability of algorithms to use in operations, but it seems that this examination does not help us to know which algorithm is exactly the best one.

Table 1. the way of opting algorithms

Equivalent CFAR detector	VIE- CFAR adaptive threshold	different means	lagging window variable	Leading window variable
CA-CFAR	$C_N \Sigma_{AB}$	NO	NO	NO
GO-CFAR	$C_{N/2}.\max(\sum_A, \sum_B)$	YES	NO	NO
CA-CFAR	$C_{N/2}(\Sigma_B)$	--	NO	YES
CA-CFAR	$C_{N/2}(\Sigma_A)$	--	YES	NO
SO-CFAR	$C_{N/2}.\min(\Sigma_A, \Sigma_B)$	--	YES	YES

B. Second experiment: detect pixels of targets

In the first experiment, the number of targets was discused. This experiment is also almost like that, with a difference. Instead of checking the number of targets, the number of detected target pixels is examined. To check these pixels, we need a source picture called ground-Truth to compare the results. Ground-Truth image includes the actual location of targets in the picture. To perform this test, we introduce some parameters which are needed:

T_P (True positive) is the number of target pixels belong to both ground-truth image and the result image. F_N (False negative) is number of target pixels that belong to Ground-Truth image but do not belong to the result. F_P (False positive) is number of target pixels not belong to Ground-Truth image but they belong to the result. T_N (True negative) is number of target pixels not belong to both Ground-Truth image and the result. By calculating each of these parameters for each method, then we can calculate the following values:

$$TRP = \frac{T_p}{T_P + F_N} \tag{8}$$

$$FRP = \frac{F_p}{F_P + T_N} \tag{9}$$

In article [4], the TRP and FRP was used as P_D and P_{FA}, Respectively.

Table 2. Simulation results of first experiment on the first and second data

Algorithm	DATA	N_{rt}	N_{td}	N_{fd}	N_{miss}	FOM
Adaptive	1	36	36	0	0	1
	2	31	31	9	0	0.775
II-CFAR	1	36	36	1	0	0.972
	2	31	31	1	0	1
Proposed	1	36	36	1	0	0.972
	2	31	31	1	0	1

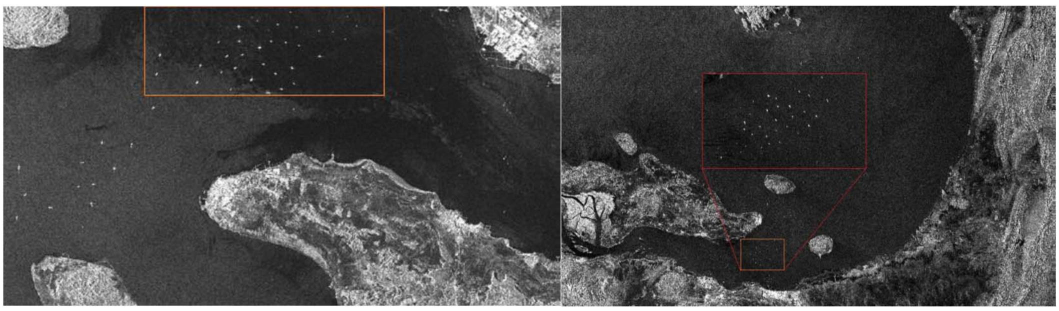


Fig 2. SAR data were used

The vertical axis of the ROC curve is PD and the horizontal axis is PFA. Considering the values obtained in the previous section we plotted this curve. Here, the performance of the proposed and others including adaptive CFAR [7], II-CFAR [8], Local CA-Fast CFAR [9] and IS-CFAR [10] are comparable.

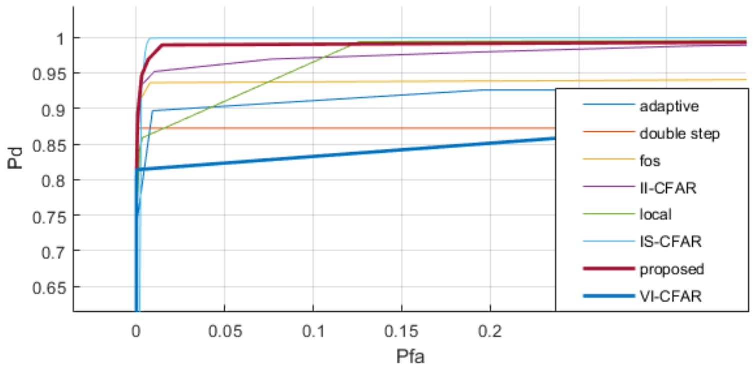


Fig 3. ROC curve, comparing propesed algorithm with others

What is specified in the curve is that the proposed method has a decent amount of P_D and will quickly reach to value of 1. By calculating the area below the curve (AUC) also seems to be the proposed method to compare other fast CFAR methods has acted better.

It obvious that IS-CFAR has a bit better performance in compare to proposed algorithm. This difference will be answered in the next experiment.

The result of mentioned algorithms in the ROC curve, by applying in the part of the data included 4 targets are shown in figure 4.

C. *Third experiment: time consuming*

As mentioned before, the main goal of this study was to reduce time of processing data. Last experiment is comparing algorithms considering their time consuming. To simulate, a Core i7-4702MQ with 8GBs RAM system and MATLAB 2018b software has been used. Fig. 5 is the result of comparison of the processing time of different methods including traditional and fast CFARs.

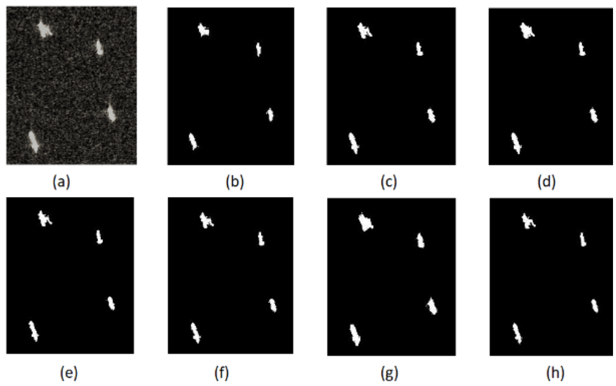


Fig 4. (a) original piece of SAR data. Result of (b)Adaptive and Fast CFAR, (c) Double-Step Fast CFAR, (d)fast-vi CFAR (proposed), (e) FOS, (f)II-CFAR, (g)IS-CFAR, (h) Local Cell-Averaging Fast CFAR algorithm.

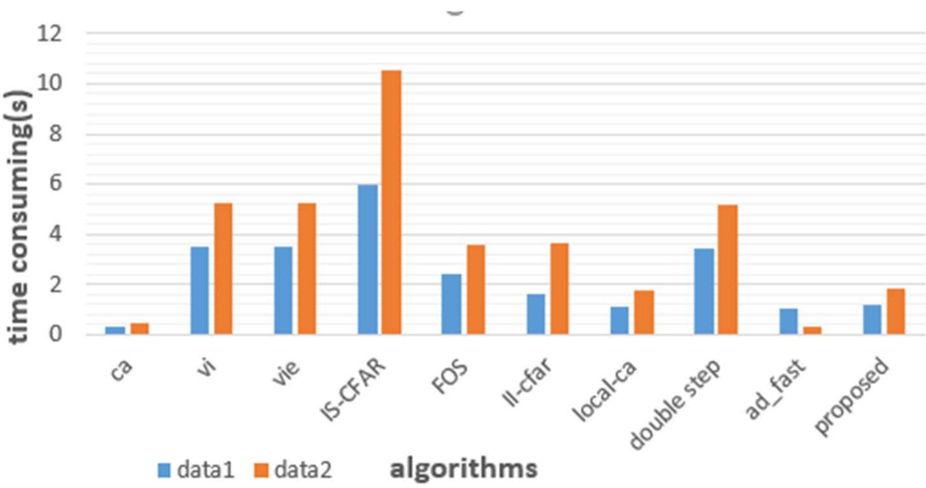


Fig. 5, Comparison chart of conventional and fast processing methods

IV. Analysis

According to the proposed algorithm was based on VI algorithm and we tried to reduce the time of processing. We have reached our first goal, in addition to the processing speed of the procedure, the performance is better than many other methods. The IS-CFAR algorithm in ROC curve was better than the proposed method, but we saw the last test that has a high processing time and is not comparable to the time of other methods and is not suitable for operations. Methods such as cell averages in heterogeneous images do not provide a acceptable result, and since this method is one of the most basic algorithms in detection of the ships and has low and simple calculations, it was expected to assign a short processing time, but the new algorithms due to their greater resistance in heterogeneous images, it is more important and because of more calculations to detect the targets in the image, it will certainly have more processing time. Therefore, there is no doubt about obtaining the speed of processing by our algorithm, but in some cases, we have to consider some trade-offs between performance and time of processing in different cases such as homogenous or nonhomogeneous conditions.

V. Conclusion

By observing and reviewing the results, we concluded that the proposed method in both processing time and target detection is appropriate, and works better than many algorithms. As mentioned before, nowadays systems needs to decrease time of processing and detect targets as fast as possible that, our algorithm works well in this field.

Acknowledgment

The present article was written by Javad Karimi and Mojtaba Abolghasemi and was supported by Malek Ashtar University of Technology. The authors would like to thank the reviewer for the constructive feedbacks.

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