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An Overview of Automatic Target Detection (ATD) algorithms in SAR Image

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ABSTRACT
Target detection is a conventional problem for synthetic aperture radar (SAR) image. The technology of target detection is very useful in striking military targets, such as ship, tanks, armoured personnel carriers, trucks, bulldozers, cannon and howitzers. Discriminating target from clutter is a challenging task in Automatic target detection (ATD) problem. Different types of clutter and their distribution model are discussed in this work. After many decades of research, robust target detection algorithm still remains a highly challenging task. In this paper a review of the techniques used to solve the Automatic target detection problem is given.

Keywords:- SAR,ATD, Clutter, Constant false-alarm rate (CFAR) detector, Probability of detection, False alarm

I. INTRODUCTION

Development of radar [17] as a tool for ship and aircraft detection was started during 1920s. SAR is coherent imaging radar working in microwave band, which has excellent properties and powerful application potential. Since SAR is an active sensor, which provides its own source of illumination, it can therefore operate day or night; able to illuminate with variable look angle and can select wide area coverage.

The fundamental problem of Automatic Target Recognition (ATR) is to detect and recognize objects of interest (targets) in an environment of clutter imaged by a SAR sensor that introduces noise into the resulting signal.Figure.1 shows the different type of targets in a SAR imagery. Most ATR systems employ a coated interpretation process, which is divided into three stages: detection, discrimination and classification. The first stage is a region of interest (ROI) module that searches the entire image to find regions containing potential targets. Automatic target detection in SAR image is the first stage in the ATR system. The second stage focuses on reducing the natural clutter and part of the man-made clutter discrete from the output of the FOA module. The third stage is to further reduce clutter false alarms and classify the objects of interest. The two stages together are called prescreening. The prescreening is very crucial component in the whole ATR system. If it performs most effectively then the computational complexity in the classification process will be greatly reduced. That means if the prescreener is able to reject all the background clutter then the classification accuracy will be increased.

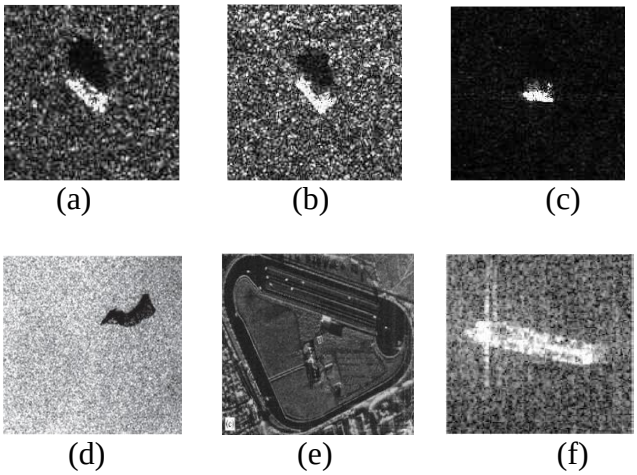


Fig 1. SAR image with target (a) armoured car (b) cannon (c) bulldozer (d) dark spot in oil spill (e) thirteen military vehicles and a hillock (f) Oil tank

Target detection is the process of localizing those areas in the image where a potential target is likely to be present. Targets in SAR images are heterogeneous regions on a homogeneous background. Man-made objects can be divided into linear targets and blob targets. For linear targets, like roads, railways, bridges, and airport runway, they often appear to have obvious characteristics of straight line or curve and can be described approximately through an accurate extraction of the line feature. Blob targets like tanks, ships, vehicles, aircraft, bunkers, oil depots, power plants, and other types of construction usually have a reunion in the spatial distribution, which means that the targets are located in a rectangular area in the image as a whole.

Target detection algorithms are generally classified into two major categories: single feature based and multi feature based [1]. Single feature approach is most commonly used detection methodology in SAR images. Usually the property

is pixel brightness or radar cross section (RCS). Most of the literature addresses this method. CFAR [2, 3] is the most popular single-feature-based detection algorithm. It is based on sliding window. The sliding window may be fixed size or variable one. The various types of CFAR algorithm are Cell average CFAR (CA-CFAR), smallest of CA-CFAR (SOCA-CFAR), greatest of CA-CFAR (GOCA-CFAR), two-parameter CFAR (TP-CFAR) detector, and order statistics CFAR (OS-CFAR). The multifeature based technique extract number of features from the input SAR image. The fusion of two or more feature is used for detection. RCS feature is fused with fractal dimension or multiresolution RCS. The pixels in a manmade object are generally closer together than the pixels in a natural-clutter object. Fractal dimension is used to measure the closeness of pixels in a binary image. A natural-clutter object will have a fractal dimension of less than 1; whereas a target object will have a value between 1 and 2.Figure.2 shows the flow diagram of different target detection method.

This paper is organized as follows. Section II highlights review on the subject of ATD. In Section III performance analysis parameters for ATD algorithms is discussed. In section IV conclusion is made. Finally in Section V references are given.

II. REVIEW ON TARGET DETECTION

A number of works related to ATR have been done in the past three decade's .but it still remains highly challenging task. This section highlights a few recent papers on the subject of ATD. The ultimate aim of any ATD algorithm is to propose a very fast, robust, and effective automated approach with best detection rate and fewer false alarms. Most of the recent papers address the following targets: Manmade targets such as building, car, Natural targets, Ship, Vehicle, Dark spot detection. Clutter [16] is characterized as the return of a physical object or a group of objects that is undesired for a particular application. In military application target identification perspective, the return from vegetation and other natural objects would be considered as clutter. In remote sensing perspective vegetation is considered as essential focus of intrest.Therefore clutter is characterized in view of utilization. Clutter may be classified as Surface clutter, volume clutter and point clutter.Fig.3 lists the various types of clutter. Sea clutter, Land clutter, Natural clutter and Cultural clutter are considered as a clutter and these clutters are modelled by suitable distribution clutter have different statistical distributions Table.1 describes various clutter distributions and the corresponding probability density function.. Mostly sea clutters are modelled by Gaussian, log normal, Weibull, Gamma, G0, and K distributions. Land clutter and Natural clutter are modelled by Rician distribution. Automatic Ship detection system consists of the following three essential steps such as Land masking, pre-screening and Discrimination. The consolidated review of ATD is listed in Table.2.

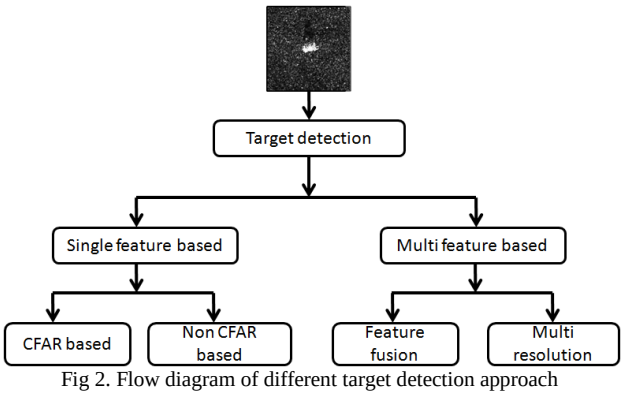


Fig 2. Flow diagram of different target detection approach

Many ship detection algorithms are based on statistical model. A Parzen-window-kernel-based algorithm [4] was used to detect the ships with the Gaussian distribution as the kernel function. In [5], an iterative censoring scheme is proposed to improve the convergence speed for CFAR ship detection in VHR SAR images. Multilayer CFAR [6] method is combined with log-normal distribution is designed to overcome the holes and the fracture in the traditional detected results. This method can retain more details of ships and takes much less time than the traditional CFAR method for VHR SAR images CFAR detector based on truncated statistics [7] detector provides accurate background clutter modelling, a stable false alarm regulation property, and improved detection performance in high-target-density situations. The approach is aimed at high-target-density situations such as busy shipping lines and crowded harbors, where the background statistics are estimated from potentially contaminated sea clutter samples. When applying the constant false alarm rate (CFAR) detector to ship detection on synthetic aperture radar (SAR) imagery, multiple interferers such as upwelling, breaking waves, ambiguities, and neighboring ships in a dense traffic area will degrade the probability of detection. Variable index and excision CFAR (VIE-CFAR) [8] based ship detection method to alleviate the masking effect of multiple interferers. Along-track interferometric synthetic aperture radar (ATI-SAR) images [9], based on the sea interferogram's magnitude and phase (SIMP) metric

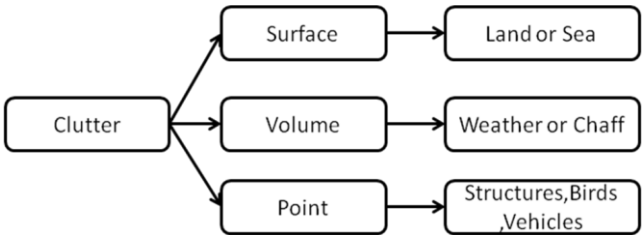
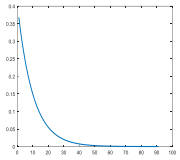
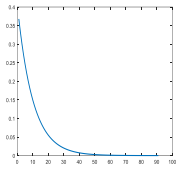
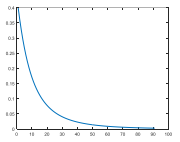
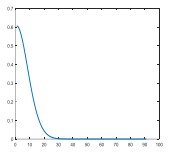
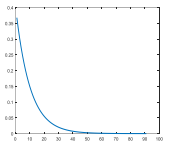
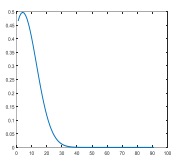


Fig 3. Different Types of RADAR clutter

In the Super pixel based CFAR detection algorithm [10], super pixels are generated in the segmentation stage. In the detection stage the super pixels based clutter distribution parameters for each pixel can be adaptively estimated, even in the multitarget situations. This algorithm turns the detected

pixels into super pixels which partially preserve the shapes of vehicles. Therefore, it can reduce the disturbances from the adjacent targets and improve the clustering performance. Semantic CFAR Algorithm [11] employs the strong scattering features and shadow features of the target and establishes semantic relationship to partly reduce the false alarm targets**.** Nonzero-Mean multivariate normal distribution [12] utilizes scattering vector of polarimetric SAR (PolSAR) images and produced accuracy of 88% and outperforms than zero mean model. The combination of Weibull multiplicative model and neural network method [13] effectively identifies the dark spot in oil spill detection. The contribution of the feature, scaling, and classifier are considered to improve classification performance [14].

Table.1. Various Radar clutter probability model

Clutter Distribution Type	Pdf function	Pdf plot
Exponential	$f(x)=\lambda e^{-\lambda x}$	
Weibull	$f(x)=\begin{cases}\alpha\beta^{\alpha}x^{\alpha-1}e^{-(\beta x)^{\alpha}} & x>0\\ 0 & x\le 0\end{cases}$	
Log-Normal	$f(x;\mu,\sigma)=\left\{\frac{1}{x\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{(\ln(x-\mu))}{\sigma}\right)^2}\right.$	
Rayleigh	$f(x;\alpha)=\frac{x}{\alpha^2}e^{-\frac{x^2}{2\alpha^2}}$	
Gamma	$f(x)=\frac{x^{\alpha-1}e^{-\frac{x}{\theta}}}{\Gamma(\alpha)\theta^{\alpha}}$	
Ricean	$P(x)=\frac{x^{\alpha-1}\ e^{-x/\theta}}{\Gamma(\alpha)\theta^{\alpha}}$	

III. PERFORMANCE ANALYSIS

The performance of any detection module is typically analyzed based on the following parameters

1. Computational complexity,
2. Probability of Detection (PD),[18]

$$PD=\int p(x/w_T)dx \quad \text{--- (1)}$$

Where w_T is the target class

3. Probability of false alarm. (PFA)[19].

$$PFA=\int p(x/w_B)dx \quad \text{--- (2)}$$

Where w_B is the Background class

4. F1 Score[20]

$$F1\quad score=\frac{2*precision*recall}{precision+recall} \quad \text{--- (3)}$$

Where

$$precision=\frac{TP}{TP+FP} \quad \text{--- (4)}$$

$$recall=\frac{TP}{TP+FN} \quad \text{--- (5)}$$

TP, FP, FN are True positive, False Positive and False Negative.Low computational complexity, High probability of detection, low probability of false alarm and high F1 score are the expected conflicting demands on detection. A confusion matrix is also utilised to show classification performance wherein the percentage of correct classifications are shown on the main diagonal and errors on the off diagonals.

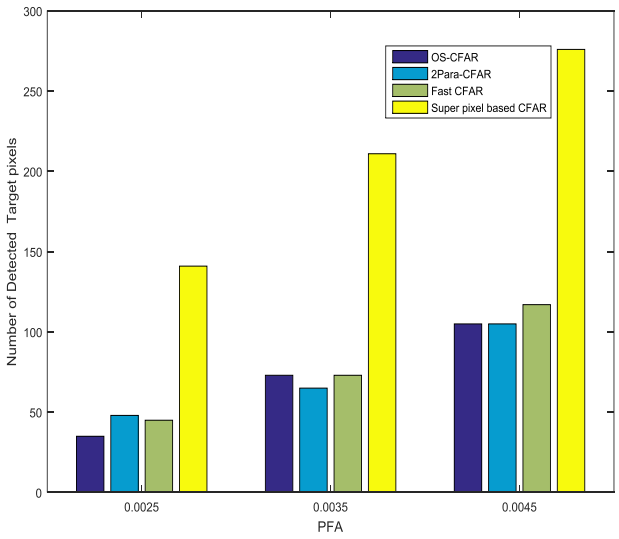


Fig.4 probabilty of false alarm Vs Number of Detected pixels for various CFAR based method [10]

Table 1: Review on Target detection from recent literatures

No.	Author& Year	Target	Clutter & model	Dataset	Method	Merits
1.	Ding Tao et.al, 2016	Ship	Sea clutter & Exponential and gamma distribution	Radarsat-2 SLC fine quad-polarization SAR imagery	Uses Constant false alarm rate (CFAR) detector based on truncated statistics (TSs)	Does not require prior knowledge of the interfering targets. Provides accurate background clutter modelling, a stable false alarm regulation property, and improved detection performance in high-target-density situations.
2.	Wenyi Yu, et.al, 2016	Vehicle	Natural and cultural clutter/	MiniSAR data from the Sandia National Laboratories, USA,	Super pixel based CFAR method is proposed. Super pixel generating algorithm is utilized to segment the SAR image.	Applicable for targets of different sizes, The clutter pixels can be adaptively chosen, and the disturbances from adjacent targets in the multi target situations are reduced.
3.	Yong Huang, et.al, 2016	Cars	Natural and cultural clutter/	MiniSAR data from the Sandia National Laboratories, USA,	Semantic constant-false alarm-rate (CFAR) method is proposed for High resolution SAR image. Semantic relationship between the strong scattering features and the shadow features is established to partly reduce the false alarm targets.	Outperforms the CFAR Algorithm by a much lower false alarm rate.
4.	Kefeng Ji et.al, 2015	Ship	Homogeneous clutter edges and multiple interferers.	ENVISAT and TerraSAR-X SAR data.	Uses variable index and excision CFAR (VIE-CFAR)	Robust in the presence of multiple interferers than VI-CFAR & CA-CFAR
5.	Biao Hou et.al, 2015	Ship	Sea clutter & log normal distribution	TerraSAR-X image	Uses Multilayer constant false alarm rate (CFAR) detection	Outperforms the CFAR in terms of detection ratio of pixels instead of the number of ships. Computing time is reduced compared to traditional CFAR.
6.	Gui Gao, et.al, 2015	Moving Ship	Sea Clutter & Gamma Distribution	NASA/JPL AirSAR airborne SAR System	Based on the sea interferogram's magnitude and phase (SIMP) metric	Devised an adaptive threshold approach within the framework of CFAR theory.

7.	W.Wu, et.al, 2014	Man made targets & Natural targets	Land Clutter & Rician Distribution	Full-polarization E-SAR data (airborne)	Exploits nonzero-mean model and the multivariate normal distribution	Better detection rate for natural targets and higher accuracy,
8.	Alireza Taravat, et.al, 2014	Dark-spot detection(oil spill detection)	Sea clutter & Weibull Distribution	Envisat ASAR and ERS2 SAR data	Combination of Weibull multiplicative model (WMM) and pulse-coupled neural network (PCNN) techniques is used for well defined homogeneous background	very fast, robust, and effective approach
9.	Chao Wang, et.al, 2014	Ship	Sea clutter & Weibull, Gamma, G0, and K Distribution.	TerraSAR-X and COSMO-SkyMed images	Detection is based on feature analysis for high-resolution SAR images. Based on the kernel density estimation of ships, aspect ratio, and pixel points, ships are identified	Time-saving, high precision ship extraction, feature analysis, and detection.
10.	Wenjin Wu, et.al, 2013	Man made targets	Natural clutter& Rician distribution	E-SAR (an airborne SAR system at the German aerospace Center(DLR)	Azimuth stationarity property is used for man-made target detection. Rician distribution is used to describe SAR images in urban areas.	Better detection results compared with traditional method based on Wishart distribution.
11.	Mehdi Amoon et.al, 2013,	Ground vehicles	Natural Clutter	MSTAR public release dataset	Zernike moments, GA-based feature selection with SVM classifier is used.	small amount of Zernike moments features is sufficient to achieve the recognition rates
12.	Haitao Lang, et.al, 2016,	Ship	Sea clutter	TerraSAR-X & Radarsat-2	Joint feature and classifier selection method by integrating the classifier selection strategy into a wrapper feature selection framework is formulated	Select the optimal combination of a nonredundant complementary feature subset, appropriate scaling, and classifier to improve the performance of ship classification in a SAR image.
13.	Hui Dai, et.al, 2016,	Multiple Ship	Sea clutter	RADARSAT-2	use the object proposal generator to generate a small set of object proposals with different sizes, and then use the proposal-based CFAR detector,	Good detection performance in the multiscale situation, identify accurate target regions

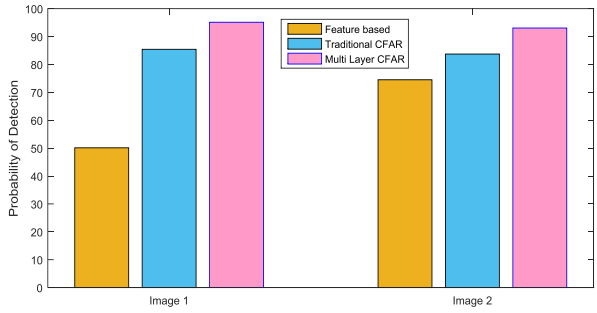


Fig.5 Probability of detection for various CFAR based methods.[6]

In Fig.4 for various values of probability of false alarm the super pixel based CFAR is compared with order statistics CFAR, two parameter CFAR and Adaptive Fast CFAR detection strategies. Super pixel based CFAR outperforms than other traditional CFAR based method interms of number of detected target pixels. In Fig.5 Multilayer CFAR target detection algorithm is compared with traditional CFAR based method and feature extraction and comparison based detection algorithm. Multilayer CFAR provides good result than others.

IV. CONCLUSION

Target detection for synthetic aperture radar (SAR) images has incredible impact on the progressive discrimination based on the object regions.This paper has presented an overview of various methods for automatic target detection algorithms in SAR image. From the literature it is clearly evident that most of the ATR algorithms are based on single feature CFAR methods with homogeneous clutter model for single target situations in the homogeneous clutter environment. Very few research papers address the multi target situations as well multi feature based algorithms.

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