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Development of Adaptive Algorithm for CFAR in non-homogenous environment

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Abstract*— Constant False Alarm Rate (CFAR) processor is commonly used detectors in radar system to maintain control of false alarm rate in face of local variation of background noise/clutter. Radar detection procedure involves the comparison of received signal amplitude to a threshold. The Cell Averaging approach is an adaptive procedure that adaptively sets the threshold low by estimating mean level in reference window of N range cells. In this paper, CA-CFAR algorithm is simulated and verified for real time radar detection and tracking operation using MATLAB software and represent the CFAR technique for a target through radar GUI. Beside this a comparison of different algorithm (GO-CFAR,SO-CFAR) states that Cell Averaging has the least threshold value ,which gives good probability of detection for false alarm rate of 10^{-6} to a target in non-homogenous environment.

***Index Terms*— Constant False Alarm Rate (CFAR), Cell Averaging (CA), Probability of detection (Pd), Pro, threshold.**

I. INTRODUCTION

Radar systems must overcome unwanted signals in order to focus only on the actual targets of interest. These unwanted signals may originate from internal and external sources, both passive and active. The ability of the radar system to overcome these unwanted signals defines its signal-to-noise ratio (SNR). SNR is defined as the ratio of a signal power to the noise power within the desired signal; it compares the level of a desired target signal to the level of background noise (atmospheric noise and noise generated within the receiver). The higher a system's SNR, the better it is in isolating actual targets from the surrounding noise signals. Signal detection in noise or clutter is very important factor in each radar receiver. The noise and clutter background will be described by a statistical model e.g Rayleigh or exponentially distributed random variable of known average noise power. But in practical applications this average noise or clutter power is absolutely unknown and some parameter can vary over range, time and azimuth. The radar received signal is sampled in range and frequency. Each sample is placed in an array of range and Doppler resolution cells. The clutter background in the cell under test is estimated by averaging the output of near by resolution cells. The target detection is declared if the signal value exceeds a preliminary determined threshold. The detection threshold is obtained by scaling the noise level estimate with a constant Tα to achieve a desired probability of false alarm P_{FA} .This is the conventional Cell Averaging Constant False Alarm Rate (CA-CFAR) detector proposed by Finn and Johnson in [1]. Averaging the outputs of the reference cells surrounding the test cell forms this estimate. Thus a constant false alarm rate is maintained in the process of detection. These CA-CFAR [7][8] processors are very effective in case of stationary and non-homogeneous interference. The presence of strong urban pulse interference in both, the test resolution cell and the reference cells, can cause drastic degradation in the performance of the CA-CFAR processor. The CA-CFAR [2] is the basic and the easy way of all algorithms, comparison of this algorithm with GO-CFAR and SO-CFAR provides a better detection of target with a false alarm of 10^{-6}. Finally the target obtained from CA algorithm through the GUI shows the intensity in the range cell.

II. BRIEF OVER VIEW OF CFAR ALGORITHM

Constant false alarm rate (CFAR) is a property of threshold or gain control devices that maintain an approximately constant rate of false target detections when the noise, clutter levels, and/or ECM (electronic Counter measures) into the detector are variable [7]. CFAR techniques are used in reception and signal processing to avoid increased false alarm rates in the presence of jamming, clutter residue, or other interference sources. The two fundamental approaches are to adapt the detection threshold of a given test cell to the environment as determined by statistics of reference cells surrounding the test cell (CA CFAR) or time statistics of past observations in the test cell itself (clutter mapping). In the first method, statistical parameters of the amplitudes in the reference cells may be used to set a threshold, or a nonparametric rank order may be used. The proposed system is shown in Figure 3 below.

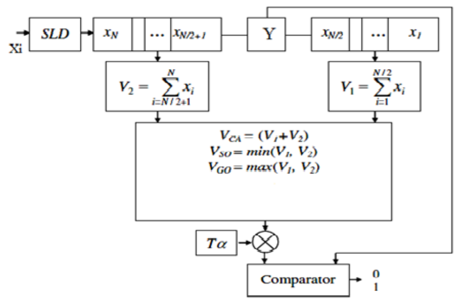

Fig 1: CFAR processor

The CFAR processor is a detector, which maintains a constant false alarm probability in the process of target detection (Fig.1). The received signal $x(t)$ is square law detected and sampled in range by the N+1 range resolution cells as shown in Figure 1 [9]. The set of samples $(xi)N$ is processed resulting in a noise level estimate V. The estimate V is multiplied by a predetermined scale factor Tα resulting in a pulse detection threshold. The sample from the test resolution cell Y is compared with the detection threshold, and the target signal is detect if the sample Y exceeds the detection threshold. In case of Poisson distribution of impulse interference, the analytical expressions of CA CFAR detector for calculating the detection and false alarm probability are

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obtained in [9][10]. The optimized signal processing technique in CA CFAR situation from a statistical point of view is to calculate an estimation of the clutter power level just by applying the arithmetic mean to the received amplitudes inside the considered window. In GO CFAR case, the estimate of the noise level is the maximum of *V1* and *V2*. Analogically, in SO CFAR case, the estimate of the noise level is the minimum of *V1* and *V2*.The statistical performance is excellent, if the assumptions of non-homogeneous clutter inside the reference window are fulfilled in the statistical model and in the real world application. To demonstrate the general CFAR characteristic some typical signal situations are generated which are considered to be characteristic for radar applications. Figure 2 shows the resulting adaptive threshold in noise, clutter, interference and target situation when the CFAR procedure is applied.

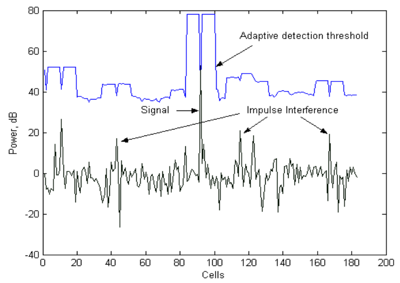

Fig 2: Signal Detection

CFAR detection is a term for methods that generate adaptive thresholds, and maintains a constant probability of false alarm. Consider a fixed threshold in a clutter environment with varying clutter mean level. In this case, the false alarms will be dependent on the mean, as threshold crossings are more likely to occur in regions with high mean. This may be avoided by using CFAR techniques, and their general operation will be presented in this section. The purpose of CFAR is to maintain *Pfa* both locally and globally. The idea is to employ a sliding window consisting of *N/*2 reference cells in front of and behind the cell under test, as shown in Figure 3. The cell under test may be denoted by a random variable Y , and the reference cells may be denoted by random variables *Xi*, where $1 \leq i \leq N$. Values in the reference cells are used to calculate an estimate of the clutter mean. After estimation, the local threshold value *T* is to be obtained. This is done by multiplying the estimated mean with some scaling factor α, and it is derived from a statistical distribution model plotted to the amplitude or power of the clutter. α is commonly termed as the CFAR multiplier. Finally, a decision rule is applied to determine whether a target is present or not. It may be given as the following hypothesis test [4].

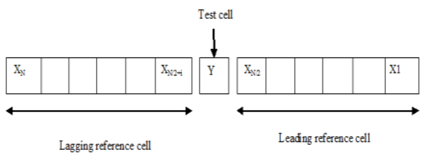

Fig.3: The reference cells Xi are located in front of and behind the test cell Y , where 1 ≤ i ≤ N.

$$Decision = \begin{cases} H0: no\ target\ present, if\ Y < T \\ H1: target\ present, \quad if\ Y > T \end{cases}$$

α is usually calculated for a predetermined value of *Pfa*. The relation between the two parameters involves the probability distribution of the clutter statistics. For most CFAR methods, *Pfa* is a fixed value, and given as a part of the design. *Y* takes values from the clutter Probability Density Function (PDF). The probability of *Y* taking a value which is larger than a threshold *T* is denoted the probability of false alarm.

$$Pfa = P(Y \geq T) = \int_T^{\infty} p(y)dy$$

where *p*(*y*) is the clutter PDF, but it is worth noticing that in literature, a detection method is said to be CFAR if the relation between α and *Pfa* is independent of the true clutter statistics. That is, the method is guaranteed to provide a constant false alarm rate. The difference between CFAR methods is how the mean estimate is obtained. A method will be presented in this paper, and it is convenient to start with the Cell Averaging (CA) CFAR.

III. CA CFAR

The CA CFAR method is frequently mentioned in theory and it is often used as reference when investigating other CFAR methods. This is because it provides the maximum detection probability *Pd* in homogeneous backgrounds if the clutter environment is Exponential distributed. Also, it requires the values in the reference cells to be independent and identically distributed. In this section, the CA CFAR method will be presented along with some of its properties. The operation is to calculate the average of the values in the reference cells and multiply with α. That is,

$$T = \alpha\left(\frac{1}{N}\sum_{i=1}^{N} Xi\right)$$

Where *Xi* is the *i*'th reference cell. In addition, guard cells are employed in front of and behind *Y* . This is to prevent the threshold to rise due to target energy located outside *Y*.A block diagram of the CA CFAR method is shown in Figure 4. As mentioned, this method works well when the clutter is homogeneous. However, when the clutter is non-homogeneous, the performance may be degraded. Nonhomogeneous environments occur when a clutter edge is present or when targets are closely located in range. The threshold is derived by averaging the *N* reference cells, and multiply with the CFAR multiplier α. *Y* is then compared to the threshold to make a decision on target presence. A clutter edge is a rise in the local mean value, and may occur when e.g. rain or snow is present in parts of the reference cells. This will result in rising the threshold, and targets in the low clutter region may not be detected. Also, when values in the high clutter region are evaluated in *Y* , false alarms will occur. This is due to the low clutter values still included in the reference cells, contributing to a threshold that is too low. For the situation where targets are closely located in range, target masking may occur. In general, when a target is present, the threshold will rise significantly in front of and behind the target. If other targets are located in these areas, they may not

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be detected. In addition, large *N* will yield better estimates of the mean value, but it is on the expense of the detectors adaptability [10]. To combat these problems, numerous CFAR methods has been invented. In the next section, one of these methods will be presented and compared to the CA CFAR method.

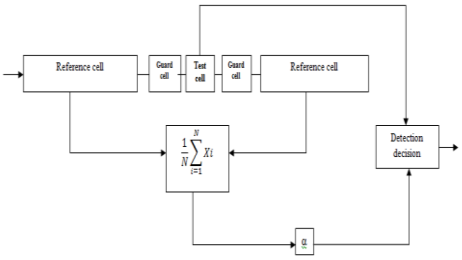

Fig.4: The CA CFAR scheme.

IV. RESULTS AND DISCUSSION

A. Simulation of CA-CFAR processor

A return signal from radar which is a mixture of interference and if present a target, were target is identified by setting the threshold to limit the false alarm. Second block figures out the use of digital pulse compression which advantageous to use of short pulses in Signal to Clutter Ratio (SCR) sense since clutter power reduces in echo signal as pulse shortens. The moving target indicator (filtering process) use the pulse compression output to discriminate target against clutter [11], since stationary signal are considered constant from pulse to pulse, as a result stationary signal would cancel out and target signal would not as it has phase changes. Hamming window is one of the most simple window functions, the idea is to select the window type and filter length that will give a filter with the correct rate of roll-off and level of attenuation in the stop band. The Doppler processing identifies the return from moving object and provide a figure for their radial velocity (motion along the direction of target). A received echo signal contain reflection from clutter, target and noise, each of these reflection has different Doppler characteristics. Finally the CFAR technique identifies a moving target at a particular range in the range bin, by setting up a threshold value for the target. Thus it clearly shows the radar return target against the clutter and other interferences. Figure 5 describes the output which clearly shows the targets at different locations shown in Table I .Here there are four targets and by using CFAR technique the targets at location 155 and 755 gives the highest strength of target by the use of wiener filter. The number of filters are increased so that the frequency response is not zero at the Pulse Repetition Frequency (PRF), and its harmonics. The objective of the threshold is to detect targets, but it should also minimize the number of false alarms. Increasing the threshold will reduce the probability of falsely detecting clutter reflections and increase the probability of detection. The targets amplitude in Figure 5 shows that at range cell 23-25 GUI represent the target with high intensity, the red line is the guard cell on either side of main target, where light vertical blue is the intensity of static target, and dark pixels are intensity of background noise in radar antenna range frequency direction of incoming target.

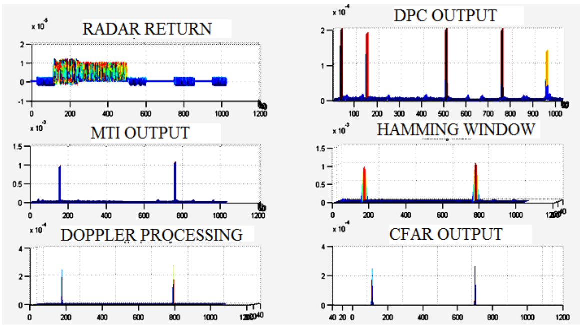

Fig.5: CA- CFAR processor output

Table I: Target locations

Serial no	Filter	Target location	Target strength
1	3	35	0.9430
2	14	150	17.201
3	20	755	18.487
4	30	955	0.9841

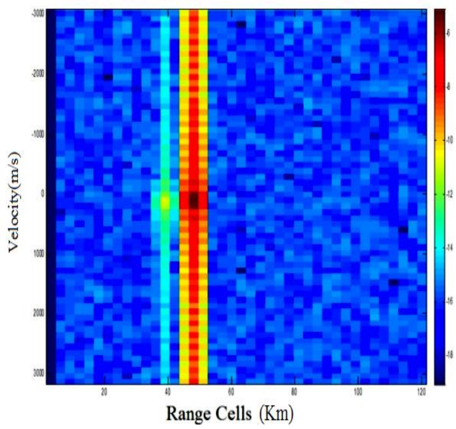

Fig. 6 Amplitude in range cell

B. Comparison Of Algorithm

The detection performance in no homogeneous [8] background for the CA-CFAR, GO-CFAR and SO-CFAR processors as a function of the primary target SNR at Pfa = 10^{-6} for different window size N is defined by Finn [1]. The detection probabilities approach that of the optimum detector as *N* increases. The GO-CFAR processor exhibits minor additional degradation in performance of multiple target when compared with the CA-CFAR processor. On the other hand, performance of the SO-CFAR processor is highly dependent on the value of *N* and slightly worse than CA in detection probability. For small ***N*** the loss is quite large compared with the other CFAR schemes, but decreases considerably for increasing *N* as explained by Weiss [3].Table III and IV lists the values of *T* for the GO- and SO-CFAR processors, respectively. The behavior is similar to that of the CA-CFAR processor. The values of T for the

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GO-CFAR processor are slightly higher than those for the CA-CFAR processor. The T for the SO-CFAR processor is very high for low values of ***N,*** but approaches the value of T for the CA processor for large ***N.*** As T increases, the Pd characteristics translate to the right implying higher detection loss in terms of the SNR. Comparison of Cell Averaging, Greatest Of CFAR and Smallest Of CFAR, is done for different window size of N=8, 16, 32 [4]. The graph shows the performance of different algorithm for probability of false alarm of 10^{-6} which automatically sets the threshold for the probability of detection to signal to noise ratio (SNR). Table II shows the threshold value for Cell Averaging CFAR for window size 32 and for different probability of false alarm. As the window size exceeds in Cell averaging, the threshold value gets lower. Such that lower the threshold value better is the detection of targets. The reference window length N must be selected by the designer as a balance of performance in non homogeneous environment. Cell averaging gives a better probability of detection for higher signal to noise ratio.

The code for cell averaging is written in Matlab and simulated using Matlab R 2012a. Where comparison of two other algorithm is run under the program proving under the graph that Figure 7 gives the least detection for a particular target for different false alarm and different window size. As the size of the reference window increases, the detection probability approaches that of the optimum detector which is based on a fixed threshold. So Cell Averaging CFAR successfully sets the threshold to keep the desired false alarm.

Table II: Threshold value of different algorithm for window size 32

T (N=32)			
Pfa	**CA**	**GO**	**SO**
1e-4	0.33352	0.60192	0.85190
1e-6	0.53993	0.98276	1.47540
1e-8	0.77828	1.42564	2.30216

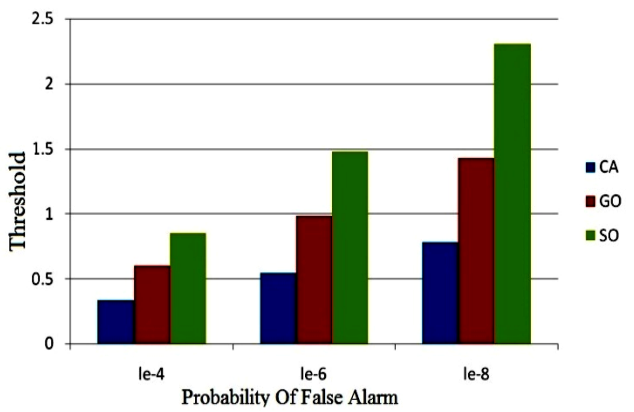

Fig 7 Comparison CA, GO, SO based on threshold and PFA value for window size 32

Table III: Percentage Improvement of CA over GO and SO in its threshold for lower Window Size

P_{FA}	Window size 16				
	CA (proposed)	**GO**	**SO**	**% Imp. of CA over GO**	**% Imp. of CA over SO**
le-4	0.778	1.359	2.445	42	68
le-6	1.3714	2.419	5.132	43	73
le-8	2.1623	3.841	9.905	43	78

Table IV: Percentage Improvement of CA over GO and SO in its threshold for higher Window Size

P_{FA}	Window size 32				
	CA (proposed)	**GO**	**SO**	**% Imp. of CA over GO**	**% Imp. of CA over SO**
le-4	0.3335	0.601	0.852	44	86
le-6	0.5399	0.982	1.475	45	89
le-8	0.7782	1.426	2.302	45	92

Table III and IV describes for N = 32 CA takes over GO by 45% than 43% when N = 16, an improvement of 89% over SO when N = 32 and 73% during window size 16. Thus cell averaging giving good detection probability having false alarm of 10^{-6}.

V. CONCLUSION

This project had presented architecture for detection of moving target amidst various intensity of clutter or noise using various CFAR processors in non-homogenous environment. Through implementation and survey it has been found out that using CA-CFAR as computational unit makes implementation easier. Cell Averaging is the basic algorithm for target detection in non-homogenous environment which automatically set the threshold value so that it can have a clear look at the target giving high probability of detection having a constant rate of false alarm in all medium. From Table II and III it is clear that the CA-CFAR processor take

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an edge over other CFAR processors and there is considerable improvement in the parameters like threshold, probability of detection and probability of false alarm. There was considerable improvement, if the window size is large and if the threshold is low then probability of detection is high.

VI. ACKNOWLEDGMENT

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