Performance Analysis of Various Constant False Alarm Receivers in non-homogeneous background for Multi-Mission Radar

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Abstract:- Constant False Alarm Rate (CFAR) in non-homogeneous environment is an essential requirement of modern military radars. This paper compares various CFAR techniques and proposes a new approach for selecting the best CFAR method for ground based radar which has multiple receive beams in both elevation and azimuth within a single burst. The CFAR selection scheme provides an improved performance as compared to applying uniform algorithms across the entire RADAR's volume coverage. False alarm control performance of different CFAR schemes is exhaustively studied across various papers. This paper extends towards how these CFAR techniques can be effectively utilized in Multi-Mission radar, which is having multiple beams in a single dwell.

I. INTRODUCTION

In order to achieve the best possible update rate, the latest active phased array radars are configured with wide transmit beam and multiple receive beams, both in elevation and azimuth angle. The detection of signal becomes complex and time consuming in case of a radar having multiple beams in both elevation and azimuth, because its returns are non-stationary (added with noise-plus-clutter) in lower elevation angle and near range. But the other regions are clear compared to low elevation, in the absence of Electronic Counter Measures (ECMs) and atmospheric clutters. In this type of scenario if the radar depends only on conventional type of CFARs, that can lead to complete obliteration of the radar display or can lead to overloading of the tracker which makes Yes/No decisions for a valid echo. To reduce this problem, radar detection processing can be chosen based on the scenario of operation as well as processing range and elevations.

The radar environment is sectored into two low-angle/altitude and high altitude regions. Clutter is more in low angle and low altitude regions. In high altitude, the possibility of weather clutter is unavoidable. Different CFAR schemes are analyzed for non-homogeneous conditions like clutter edge and multi-target conditions .Best usable schemes are proposed for different sectors / beams.

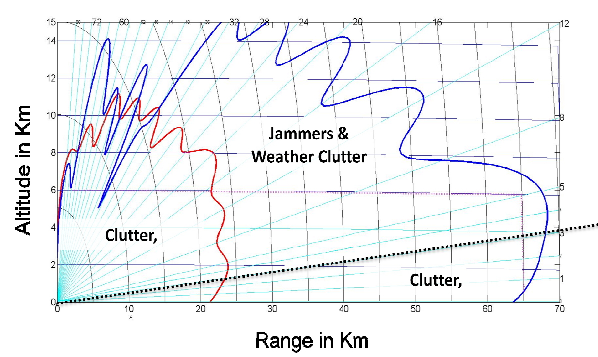

Figure -1: Radar Environment

II. Typical CFAR detector

CFAR detection is performed at each resolution cell in the range-Doppler map using a sliding window along each row of the matrix as shown in Figure 1. If a target is present at range gate x_0, also known as the test cell, a few immediate neighboring range gates are used as guard to avoid signal spillover from x_0. Data from 'N' range gates outside the guard region on the left and right are used to compute the detection threshold and the following two hypothesizes are to be verified.

$$x \underset{H_0}{\overset{H_1}{\gtrless}} \textit{Detection Threshold}$$

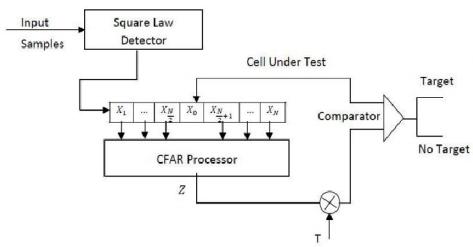

Figure -2: Typical CFAR detector

Comparison of various CFAR techniques:

CA-CFAR:

In the CA (Cell Averaging) - CFAR processor, the total noise power is estimated by the sum of N-range cells from the reference window. It is the optimum CFAR processor (maximizes detection probability) in a homogeneous background when the reference cells contain independent and identically distributed (IID) observations governed by an exponential distribution. As the size of reference window increases the detection probability approaches the optimum detector which is based on fixed threshold. But this CFAR scheme shows performance degradation in non-homogeneous environments. It generates excessive number of false alarms in the clutter edges and p_d degradation happens at multiple target conditions.

$$Detection\ Threshold = \propto \times \sum_{n=1}^{2N} x_n \quad (1)$$

$$N = Number\ of\ CFAR\ cells$$

$$\propto = Threshold\ multiplier$$

The required threshold multiplier is calculated based on the following equation.

$$\propto = N \times \left(\overline{P}_{FA}^{\frac{-1}{N}} - 1\right) \qquad (2)$$

$$\overline{P_{FA}} = Probability\ of\ false\ alarm$$

SO-CFAR:

In the SO (Smaller Of) -CFAR scheme, the leading and lagging reference window average noise powers are calculated independently, out of which the minimum one is used for estimating CFAR threshold. As compared to CA-CFAR it has better performance in multiple target environments, where the targets are closely spaced. But its detection performance degrades if the targets are located in both the leading and lagging windows. It also fails to maintain a constant false alarm at clutter edge conditions.

$$h = \alpha_{so} \times min(\textstyle\sum_{n=1}^{N} x_n\ ,\ \ \sum_{n=N+1}^{2N} x_n\ ) \quad (3)$$

$$Th = Detection\ threshold$$

$$\alpha_{so} = Threshold\ Multiplier$$

α_{so} is calculated based on the following equation [7].

$$\overline{P}_{FA}/2 = \left(2+\frac{\alpha_{SO}}{(N/2)}\right)^{-N/2}\left\{\sum_{k=0}^{\frac{N}{2}-1}\binom{\frac{N}{2}-1+k}{k}\left(2+\frac{\alpha_{SO}}{(N/2)}\right)^{-k}\right\}$$

Figure-3 shows the P_{fa} Vs threshold multiplier. For a SO-CFAR receiver, with N=36 and pfa=10^{-6} the threshold multiplier calculated is 22.3.

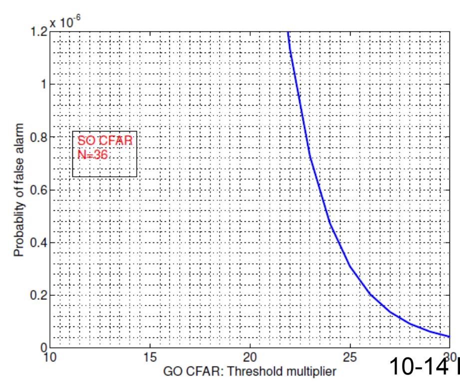

Figure -3: α_{so} Vs Pfa

GO-CFAR:

The GO (Greater Of) -CFAR procedure is specifically aimed at reducing the number of false alarms at clutter edges. The total noise power is calculated from the greater of two separate noise averages are calculated from the leading and lagging window. Though GO-CFAR performs well in clutter edge conditions, it is incapable to resolve closely spaced targets. It also introduces additional loss of detection compared with the CA-CFAR processor in the homogeneous environment. However the loss is found to be less and is generally quite acceptable.

$$Th = \alpha_{GO} \times max\left(\sum_{n=1}^{N} x_n , \quad \sum_{n=N+1}^{2N} x_n \right) \quad (4)$$

$$\alpha_{GO} = Threshold\ Multiplier$$

The threshold multiplier is calculated based on the following equation [7].

$$\overline{P}_{FA}/2 = \left(1 + \frac{\alpha_{GO}}{(N/2)}\right)^{-N/2} - \left(2 + \frac{\alpha_{GO}}{(N/2)}\right)^{-N/2} \times \left\{ \sum_{k=0}^{\frac{N}{2}-1} \binom{\frac{N}{2} - 1 + k}{k} \left(2 + \frac{\alpha_{GO}}{(N/2)}\right)^{-k} \right\}$$

Figure-4 shows the P_{fa} Vs threshold multiplier. For a GO-CFAR receiver, with N=36 and pfa=10^{-6} the threshold multiplier calculated is 15.5

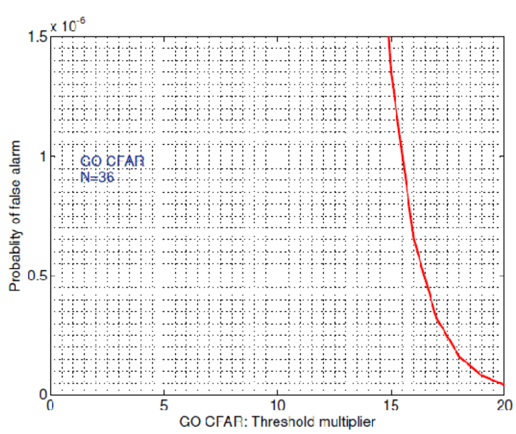

Figure -4: α_{GO} Vs Pfa

OS CFAR

For an Order-Statistics CFAR receiver, threshold is obtained from one of the ordered samples of the reference window. The range samples are first ordered according to their magnitudes, and the noise sample is taken to be the k^{th} largest sample, the required threshold multiplier α_{OS} is calculated based on the following equation [7].

$$\overline{P}_{FA} = \frac{N!(\alpha_{OS} + N - k)!}{(N-k)!(\alpha_{OS} + N)!}$$

Figure-5 shows the pfa Vs threshold multiplier. For a OS-CFAR receiver, with N=36 and pfa=10^{-6} the threshold multiplier calculated is 13.86.

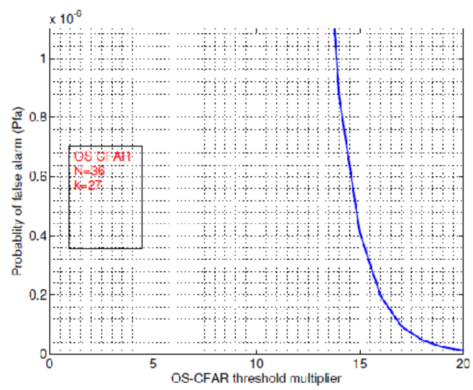

Figure -5: α_{so} Vs Pfa

Variability Index CFAR (VI-CFAR)

VI-CFAR is a composite of CA-CFAR, SO-CFAR and GO-CFAR The background estimation algorithm dynamically selects the appropriate of these three by utilizing the variability index (VI) and Mean ratio (MR) statistics [8]. VI-CFAR has satisfactory performance in homogeneous background. For homogeneous environment its performance approaches that of CA-CFAR, offering low loss CFAR operation. It provides robustness against non-homogeneities.

III. Simulation Results

Figure 6 shows the SNR vs probability of detection plot for CA, SO, GO, OS and VI CFAR receivers in homogeneous environment. It shows almost similar performance in homogeneous environment. In multi target environment OS and SO CFAR schemes performs better than other CFAR schemes. Its shown in figure 7. In case of SO CFAR, the clutter edge is not affecting, hence it shows higher probability of detection. The Signal to Clutter Ratio (SCR) Vs probability of detection is plotted in figure8. The P_{fa} is higher for SO-CFAR in clutter edge environment. Figure 9 shows the Signal to Clutter Ratio Vs number of false alarms for various CFAR schemes. Figure10 shows the bar plot of number of false alarms at different SCRs.

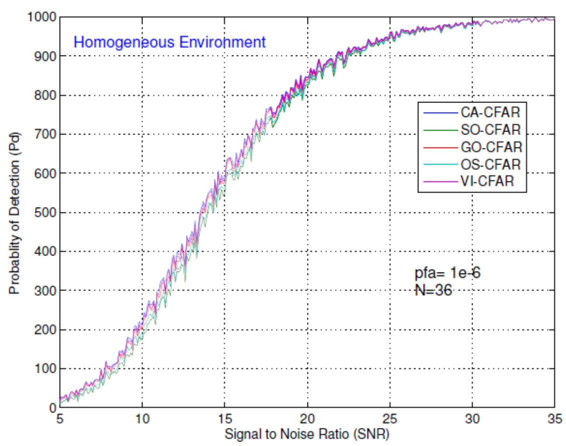

Fig.6: SNR Vs Pd plot for homogeneous environment

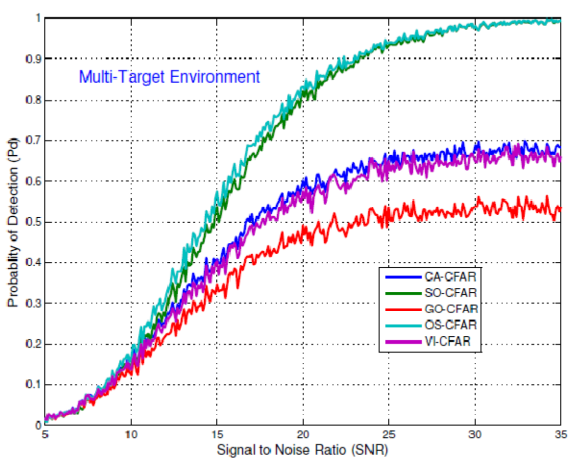

Fig.7: SNR Vs Pd plot for Multi-Target Condition

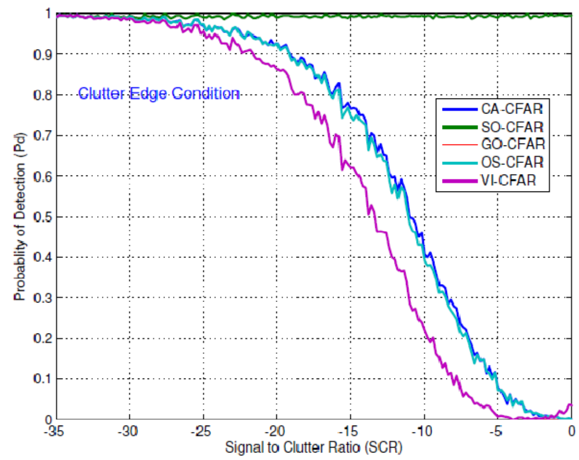

Fig.8: SCR Vs Pd plot for Clutter-Edge Condition

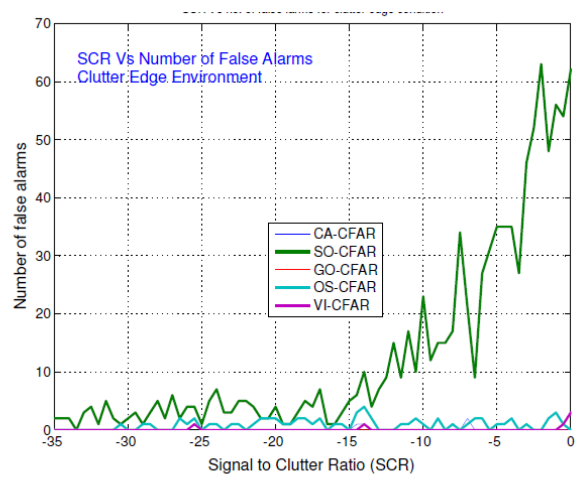

Fig.9: SCR Vs number of false alarms plot for Clutter-edge environment

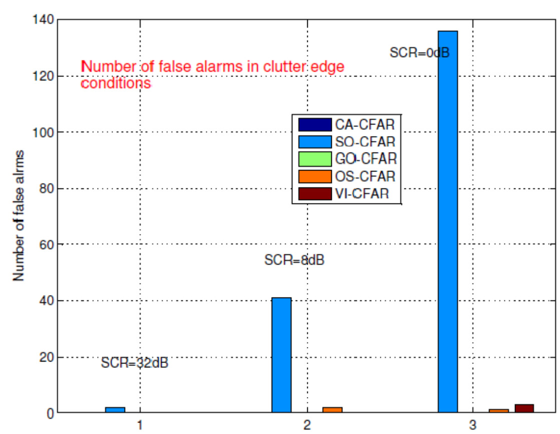

Fig.10: false alarms for different SCRs

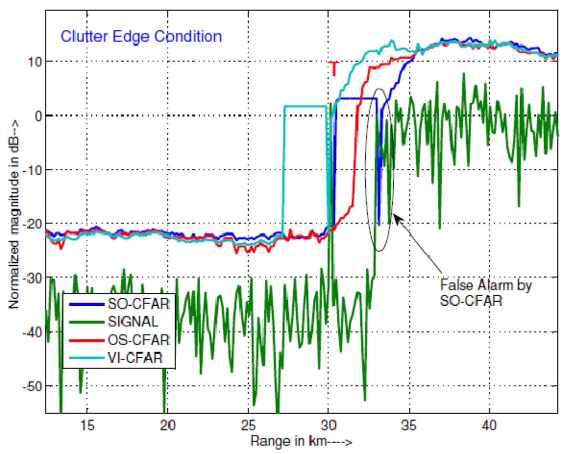

Fig.11: Various CFAR performance in Clutter edge condition

Figure 11 shows the performance of SO, OS and VI CFAR schemes in the clutter edge environment. Here N is selected to be 36 and k=27 (for order static CFAR). Here it is seen that SO-CFAR produces false detection while VI and OS CFAR performance is satisfactory. Figure 12 shows the performance of SO, GO, CA and VI CFAR schemes in the multi target environment. CA and GO CFARs misses the detection while OS and VI have a satisfactory performance.

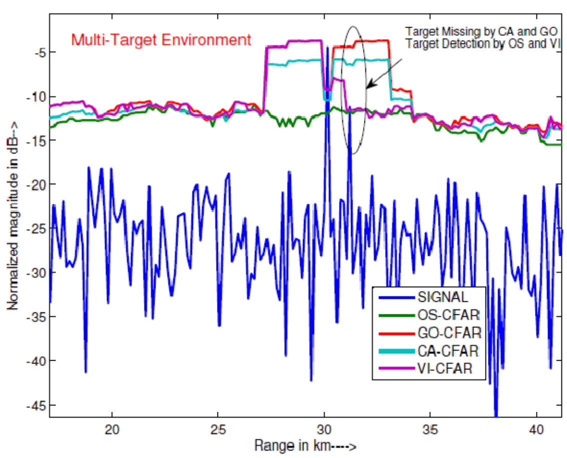

Fig.12: Various CFAR performances in multi-target environment

IV. Proposed Approach for Multi MiSsion Radar

During the search mode of operation, OS CFAR is used for the entire volume as it has comparatively higher probability of detection and lesser CFAR loss compared to other modified CFAR receivers.

During the track mode of operation, OS CFAR algorithm is used for the high angle region (Angle > 3^0), as is have better performance in multiple target and clutter edge conditions. For the region less than 3^0, VI-CFAR is used.

Over and above the provision has provided to over ride the existing automatic CFAR selection schemes provided at signal processor based on commands from the radar data processor.

V. CONCLUSION

In this paper we have presented the CFAR analysis for the multi-function ground based phased array radar. Here the CFAR will be implemented in an FPGA/PPC based signal processor board, where these complex algorithms can be implemented in much efficiently.

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