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.

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 hypotheses are to be verified.

$$\alpha = \text{Threshold multiplier}$$

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

$$\alpha = N \times \left( P_{FA}^{-1} - 1 \right) \quad (2)$$

$P_{FA}$ = 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.

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

$\alpha_{so}$ is calculated based on the following equation [7].

$$Th = Detection\ threshold$$

$$Th = \left( 2 + \alpha_{so} \left( \frac{N}{N/2} \right) \right) \left( \frac{1}{2} \sum_{k=1}^{N/2} \left( \frac{N-1+k}{k} \right) \right) \left( 2 + \alpha_{so} \left( \frac{N}{N/2} \right) \right)$$

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.
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.

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

\[ \alpha_{GO} = \text{Threshold Multiplier} \]

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

\[ P_{FA/2} = \left( 1 + \frac{\alpha_{GO}}{(N/2)} \right)^{-N/2} - \left( 2 - \frac{\alpha_{GO}}{(N/2)} \right)^{-N/2} \]

\[ \times \left\{ \sum_{k=0}^{N} \left( \frac{N}{k} - \frac{1}{k} \right) \left( 2 + \frac{\alpha_{GO}}{(N/2)} \right)^{-k} \right\} \]

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

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 \( \alpha_{OS} \) is calculated based on the following equation [7].

\[ P_{FA} = \frac{N!(\alpha_{OS} + N - k)!}{(N-k)!(\alpha_{OS} + N)!} \]

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.

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 figure 8. 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. Figure 10 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
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.

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 > 30°), as is have better performance in multiple target and clutter edge conditions. For the region less than 30°, 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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