EAI Endorsed Transactions
on AI and Robotics

Research Article EAI.EU

Peaks Detector Algorithm after CFAR for Multiple Targets Detection

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Abstract

The constant false alarm rate (CFAR) algorithm is a strong technique to detect and track dynamic targets in an environment of an unknown noise floor. Multiple reflections of a pulse from a target and different signal processing techniques applied to the received pulse, make it spread along the range and/or Doppler axis. Spreading of a pulse results in a cluster of targets detection for a single target when the CFAR technique is applied to it. This causes difficulties in calculating those target's parameters which require only a single maximum peak for a target, such as Radar cross-section (RCS), relative phase, etc. This manuscript proposes a solution, which extracts a single independent peak for a target that had clusters of peaks after CFAR. The novelty of the algorithm is that it works well to extract a single peak for each of all targets in the multiple targets environment, as compared to the conventional global maxima finding techniques which outputs only one target of the maximum amplitude while suppressing the rest of the small targets. The algorithm is basically a local maxima finder algorithm termed as peaks detector algorithm. An attractive feature of this algorithm is that it neither disturbs the Probability of false alarm rate (Pfa) of CFAR nor it affects the probability of detection (Pd) of a target. The algorithm is tested and its performance is evaluated in a multiple targets environment on the output of 1D and 2D CFAR.

Received on 22 May 2022; accepted on 06 July 2022; published on 13 July 2022

Keywords: Radar Signal Processing, Constant False Alarm Rate (CFAR), Detection of spread targets, Multiple targets detection.

doi:10.4108/airo.v1i.1124

1. Introduction

One of the primary goals in radar signal processing is to search and track targets in a noisy environment. The noise consist of thermal noise and unwanted reflections from surroundings known as clutter [14]. In a standard constant threshold square-law detector it is assume that the noise floor level is constant therfore, threshold for detection of target is also set constant. This constant threshold guarantees a constant false alarm rate only when the level of noise floor is constant [13]. In practice the noise floor depends upon many stochastic factors like environmental conditions, clutter, etc and is generally not constant [20]. This necessitates the use of a constant false alarm rate (CFAR) detectors to calculate the threshold according to the background noise in order to keep the false alarm rate constant. A class of CFAR processors is discussed in [13] such as CA-CFAR, GO-CFAR, SO-CFAR, OS-CFAR, etc. These techniques calculates the threshold according to background noise and compares it with reflections in order to search for targets [7].

In a pulsed Doppler radar a transmitted pulse is reflected from a target. Due to multiple reflections from different points of a target the received pulse is slightly longer then a transmitted pulse [18]. This received signal passes through various analog stages like down-converters, filters, compactors, etc. and a chain of signal processing techniques are applied to it like ADC, digital filtration, pulse compression, Doppler processing, etc. Theses stages make the target returns spread in the neighbouring range and Doppler bins. When a CFAR technique is applied to this signal, target as well as these neighbouring bins passes the threshold resulting in a cluster of targets deceleration for a single target [18]. This causes problem in calculation of different targets parameters like, SNR, Radar cross-section (RCS), relative phase, etc. which require only

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single peak for a target.
A simple technique to resolve this issue is by finding a global maxima of the whole data which will give you one target of maximum peak. But it will suppress other small targets. The stated problem can also be addressed if the false alarm rate of CFAR is set lower because a target normally spread in a manner that it has maximum peak is in the center and the neighbouring bins have smaller magnitude [21]. But decrease the false alarm rate of the CFAR can also result in lower probability of detection [19] which will affect the performance of a RADAR.
This paper propose a solution to this problem by introducing a techniques which finds a maximum peak out of a cluster of targets appearing in consecutive bins while suppressing the neighbouring bins of lower amplitudes. The technique is basically a local maxima finder window, termed as Peaks Detector Algorithm, which is slid over the whole data after CFAR. Since the technique finds local maxima therefore, it does not suppresses the other targets of lower amplitude in an environment of multiple targets. The technique is tested on both 1D and 2D data in multiple closely spaced targets scenarios.
Rest of the paper is arranged in a following way. At first CA-CFAR algorithm along with its mathematical equations is stated in 1D as well as 2D. Then pseudo algorithm for the proposed technique in both 1D and 2D are presented. In the end these algorithms are applied on the output of CA-CFAR and results are analysed.

2. Constant False-Alarm Rate (CFAR) detector

CFAR detector adaptively changes it threshold, according to the level of noise floor, in order to keep its false alarm rate constant [17]. CFAR detectors are also known as sliding window detectors because a filter like window is slide over the received signal in order to detect target. Although the proposed algorithm works fine with any CFAR algorithm but here only the most commonly used cell average (CA)-CFAR will be used to test the algorithm. We will discuss the use of both 1D and 2D CA-CFAR along with the proposed algorithm.

2.1. 1D CA-CFAR

In 1D CFAR a 1-dimensional averaging and comparison window is sided over each of the required range bins to search for targets. The sliding window is shown in the figure.1 Threshold is found by averaging the Training cells in both left and right hand side of the cell under test(CUT). In order to exclude the spread of a target in the range bins guard cells are included in the main window whose cells are not involved in the averaging process. The mathematical operation performed by the window is defined by [3]:

Figure 1. ID CFAR window

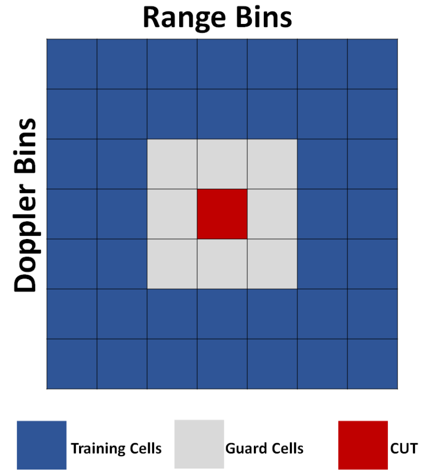

Figure 2. 2D CFAR window

$$\hat{T} = \frac{\alpha}{N} \sum_{j=1}^{N} x_j \tag{1a}$$

$$\alpha = N(P_{FA}^{-\frac{1}{N}} - 1) \tag{1b}$$

Where x_j are the range bins of leading and lagging window, N is number of bin of averaging length. α is a constant whose value depends upon the set false alarm probability rate [17]. A target will be declared in a range bin if that particular range bin under test crosses it surrounding threshold [6] value measured by eq. 1a and eq. 1b.

2.2. 2D CA-CFAR

2D CFAR is used to find a target in the two dimensional space i.e. in rang and Doppler. A 2D sliding window shown in figure 2 is used to find targets in each of the range bin under test.

The mathematical operation performed by the window shown in the figure 2 is defined as [17]

$$\hat{T} = \frac{\alpha}{N+M} \sum_{j=1}^{N} \sum_{k=1}^{M} x_{jk} \tag{2a}$$

$$\alpha = (N+M)(P_{FA}^{-\frac{1}{N+M}} - 1) \tag{2b}$$

Where x_{jk} are the elements of the 2D window, N + M are total numbers of reference cells in rows and columns of the 2D window and α is a constant whose value depends upon the set false alarm probability rate [3]. A target will be declared in a range bin and Doppler bin if that particular range bin under test which crosses it surrounding threshold value measured by eq. 2a and eq.2b.

3. Proposed Peaks Detector Algorithm

As discussed earlier CA-CFAR compares the target return with the surrounding noise floor. Due to spread of target in range and Doppler can result in multiple target declaration for a single target. This issue can be resolved by using the proposed peak detector algorithm. A simple technique to find a target peak out of multiple peaks for one target (after CFAR) is to find maxima of the whole output of CFAR. But this technique works only in case of single target return. In the case of multiple targets this technique will mask all the other targets and outputs the only one with maximum signal to noise ratio (SNR). As discussed earlier the proposed algorithm works very well in the data with multiple targets while suppressing multiple peaks for one target after CFAR. In this algorithm a local maxima finding window is used. This window operation is then performed over all the outputs bins of CFAR output resulting in a single maximum peak for a target. Since the probability of false alarm rate (PFa) and probably of detection (Pd) has already been set by the CFAR and target return level, the proposed local maxima finder does not miss any target therefore the Pfa and Pd of the system is not disturbed by the algorithm. We will discuss the algorithm in 1D in case of range detection and 2D in case of range as well as Doppler detection of target.

3.1. 1D peaks detector

1D peaks detector window is shown in the figure.3. Where $X = [x_0, x_1, x_2, ..., x_k]_{1\times K}$ is output of CFAR and the length of window is N. The pseudo code for the proposed technique is shown in the Algorithm 1

After this algorithm has been completely executed the vector X will contain only single maximum peaks of the targets identified by the CFAR. A care should be taken while choosing the length of the window N. If the

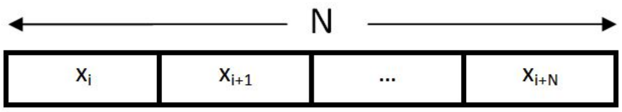

Figure 3. 1D peaks detector window

Algorithm 1 1D peak detector algorithm

1: **procedure** 1D LOCAL MAXIMA FINDER WINDOW
2: $X \leftarrow [x_0, x_1, x_2, ..., x_k]_{1\times K}$ ▷ Output of CFAR
3: **For** $i = 1$ ▷ Start Loop counter
4: $T \leftarrow X(i, i+1, \dots, i+N)$ ▷ Take N elements under test from of vector X into vector T
5: $[I_{max}, x_{imax}] \leftarrow \mathbf{max}(T)$ ▷ Find local maxima of the window where x_{imax} is local maxima and I_{max} is its index in the window
6: $Z \leftarrow [0, 0, \dots, 0]_{1\times N}$ ▷ Create a vector of zero elements equal to the size of the window
7: $Z(I_{max}) \leftarrow x_{imax}$ ▷ Replace I_{max}-th element of Z by the local maxima x_{imax}
8: $X(i, i+1, \dots, i+N) \leftarrow Z$ ▷ Replace the N elements, under test, of vector X
9: $i \leftarrow i+1$ ▷ Increment the loop counter
10: ***Go to** step (4) until* $(i <= K)$ ▷ Using the updated X jump back to step 4

target spread is greater than length of the window N this may result in more than one peak detections for a single target. And if it is chosen greater then range resolution it may affect the range resolution by giving one peak for two closely spaced targets. A general rule of thumb is to choose the length in such a way that it does not affect resolution.

3.2. 2D peaks detector

In this section we will extend out previously mentioned algorithm to the 2-diementional space. 2D peaks detector is used when the target is spread in 2 dimensions i.e. Doppler and range, after 2D CFAR. The algorithm consists of a 2 dimensional window as shown in the figure 4.

The steps performed by the above mentioned window are shown in the form of psudo code in Algorithm 2

In 2D peaks detector different lengths for M and N, of the maxima finder window, can be chosen. This will have the same effect on the range and Doppler

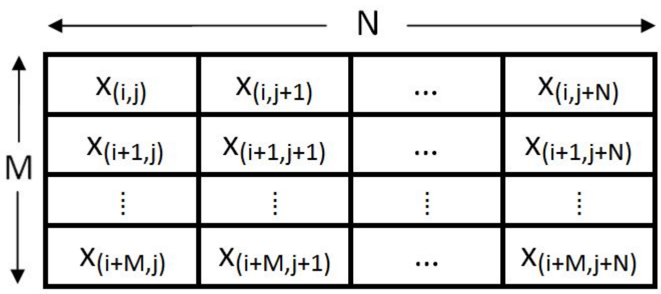

Figure 4. 2D peaks detector window

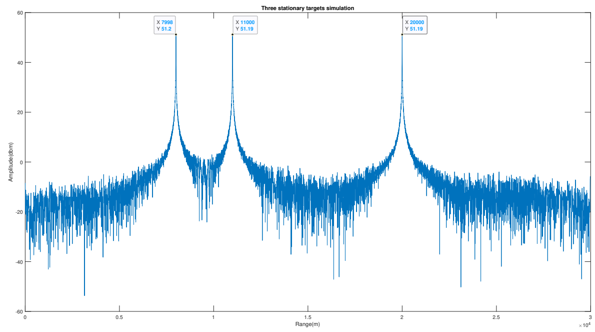

Figure 5. 1D data after of three targets spaced in different ranges. Along X-axis is range and along Y-axis is the amplitude in db

Algorithm 2 2D peak detector algorithm

1: **procedure** 2D Local maxima finder window

2: $X \leftarrow \begin{bmatrix} x_{00} & x_{01} & \cdots & x_{0k} \\ x_{10} & x_{11} & \cdots & x_{1k} \\ \vdots & \vdots & \cdots & \vdots \\ x_{L0} & x_{L1} & \cdots & x_{Lk} \end{bmatrix}_{L \times K}$ ▷ Output of CFAR

3: **For** $i = 1$ and $j = 1$ ▷ Start Loop counter for row(i) and column(j)

4: $T \leftarrow \begin{bmatrix} x_{i,j} & x_{i,j+1} & \cdots & x_{i,j+N} \\ x_{i+1,j} & x_{i+1.j+1} & \cdots & x_{i+1.j+N} \\ \vdots & \vdots & \cdots & \vdots \\ x_{i+M,j} & x_{i+M,j+1} & \cdots & x_{i+M,j+N} \end{bmatrix}_{M \times N}$

▷ Take MxN elements under test from of matrix X Into matrix T of same dimension MxN

5: $[(I_{max}, J_{max}), x_{ij_{max}}] \leftarrow \mathbf{max}(T)$

▷ Find local maxima of the window where $x_{ij_{max}}$ is local maxima and (I_{max}, J_{max}) is its location in the window

6: $Z \leftarrow 0_{M \times N}$ ▷ Create a matrix of zeros of dimension $M \times N$ equal to the size of the window

7: $Z(I_{max}, I_{max}) \leftarrow x_{ij_{max}}$

▷ Replace I_{max}-th element of Z by the local maxima x_{imax}

8: $\begin{bmatrix} x_{i,j} & x_{i,j+1} & \cdots & x_{i,j+N} \\ x_{i+1,j} & x_{i+1.j+1} & \cdots & x_{i+1.j+N} \\ \vdots & \vdots & \cdots & \vdots \\ x_{i+M,j} & x_{i+M,j+1} & \cdots & x_{i+M,j+N} \end{bmatrix} \leftarrow Z$

▷ Replace the $M \times N$ elements under test of Matrix X

9: $j \leftarrow j + 1$ ▷ Increment the loop counter for column(j)

10: ***Go to** step (4) until* $(j <= K)$

▷ Using the updated X jump back to step 4

11: $i \leftarrow i + 1$ ▷ Increment the loop counter for row(i)

12: ***Go to** step (4) until* $(i <= L)$

▷ Using the updated X jump back to step 4

resolution as discussed in the previous section. A general practice is to choose M and N such a way that it does not affect the range and Doppler resolution. So the size of window varies from application to application.

4. Application Examples

In this section we will test the proposed algorithm in two different scenarios of stationary and moving targets in order to test it in 1D and 2D environment. The algorithm is independent of the other parameters of the radar like RF frequency, PRF, Pulse Width, etc. Therefore, in order to keep the results generalized we will discuss the processing after pulse compression or Doppler processing.

4.1. 1D Peaks detector

Reflection from three target at three different ranges after pulse compression is shown in figure 5. It is clearly visible that each target has a spread along the range bins. This is due to the windowing process during pulse compression.

When a one dimensional CFAR algorithm, with CFAR rate 10^{-4} and averaging and guard length of 32 and 4 bins respectively, is applied on this data the output is shown in the figure 6

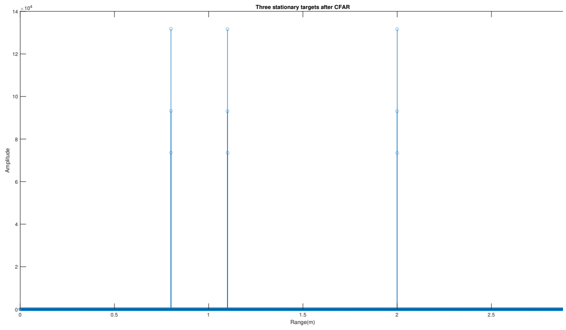

Figure 6. Result of 1D CFAR. A cluster of 2-3 targets a| for each of the three target after applying CFAR on fig. 5

After CFAR, due to targets spread, three peaks in three consecutive range bins for each of the targets is found. This will cause problems in the declaration targets especially when targets are closely spaced. T situation will be more highlighted in the next secti of 2D CFAR. When the proposed 1D peaks detec algorithm with window length of N=3 is applied on t output of CFAR the results are shown in the figure 7

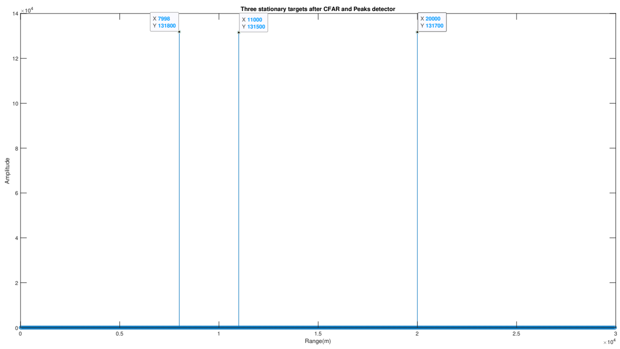

Figure 7. Result of the proposed 1D peaks detector algorithm applied on fig. 6 which results in 1 single peak for each of the three targets

A single maximum peak for each of the targets is visible from the figure. This clearly explains presence three targets in our look window. The amplitude as well as the range bins of the target is not disturbed.

4.2. 2D Peaks detector

In this example we will consider two closely spaced target moving at the two different relative velocities (with respect to RADAR), 1mac and 6mac(1mac = 330m/s). Figure 8 shows the results of Doppler processing and coherent pulse integration of the received pulses in the look window of 11.5 to 12.5KM in range and -10 to 10 km/s in Doppler. It can be seen from

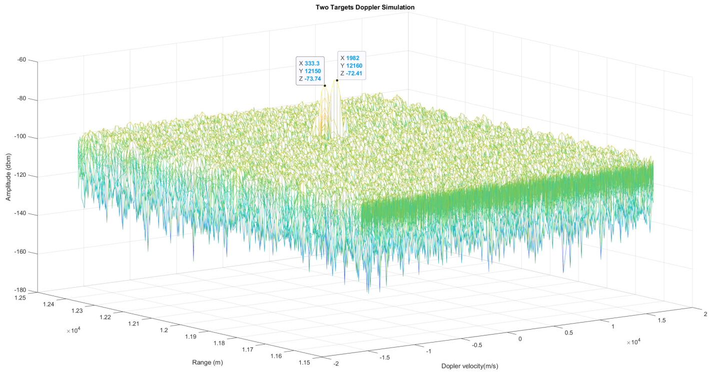

Figure 8. 2D Doppler data of two targets spread along range and Doppler axis

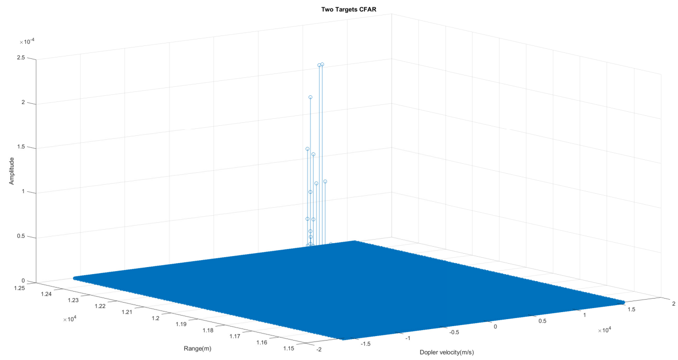

Figure 9. Result of 2D CA-CFAR applied on fig. 8. Clusters of target detected for only two real targets.

the figure that two targets at 12.15km and 12.16km have spread along range and Doppler bins.

When 2D CFAR algorithm is applied the results are shown in the figure 9. The CFAR rate is set to 10^{-4} while the size of average and guard windows are 32×32 and 4×4 respectively. Due to spread of target along both the axis there are multiple peaks for each target. Since the targets are closely spaced in range therefore it is very difficult to distinguish them and identify parameters for each of the target. In this case, finding a single peak for each of the targets becomes very critical.

When the proposed 2D peak detector alhorithm 2, with size of window 6x6, is applied to the output of CFAR, the results are shown in the figure 10. Two discrete targets with Doppler velocities almost equal to 1mac and 6mac at the range of 12.15km and 12.16km respectively are found in the figure. Note that before applying peaks detector algorithm, the target at 6mac had two peaks and both had higher amplitude than the target at 1mac. But since they were spaced

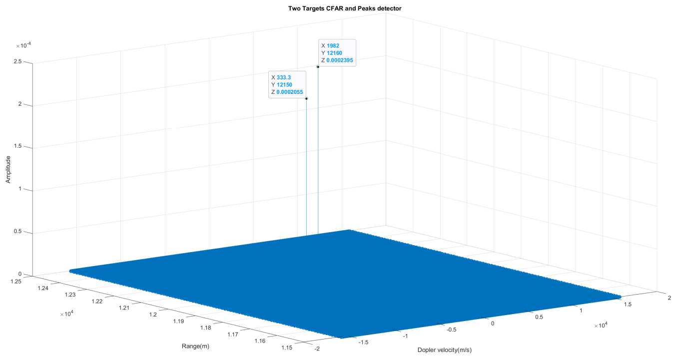

Figure 10. Two targets declared after applying the proposed 2D peaks detector algorithm on the data in fig. 9. Two distinguished targets can be seen.

consecutively in the bins that why they were declared to be the return from one target and only one peak is detected by the algorithm that target.

5. Conclusion

In this manuscript we showed that after CFAR detector the problem of multiple peaks output for each target in a multiple targets scenario can be resolved using the proposed local maxima finder algorithm termed as peaks detector. The pseudo algorithm was proposed in both 1D and 2D. The algorithm was applied to the three simulated targets returns in 1D (range) and two simulated target returns in 2D (range and Doppler). The targets were spread in their neighbouring bins. And when CFAR was applied on the it, a cluster of targets appeared for each target. When the proposed algorithm was applied to the results of CFAR. It suppressed the multiple peaks for a target and allowed only one single peak for a target to pass. Through simulation results it was shown that the Peaks detector algorithm is capable of distinguishing different closely spaced targets with multiple peaks after CFAR. The algorithm does not disturb the probability of false alarm PFA and the Probability of detection Pd as it has already been set by the CFAR. However, the analysis of effect of choosing size of window for the algorithm, on the range or Doppler resolution is left for future study.

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