Correlation Based Cfar Detection of Range Spread Targets in Complex White Noise

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Received: March 21, 2012 Revised: May 20, 2012 Accepted: April 1, 2012

ABSTRACT:

Detection of the range spread target in high resolution radar (HRR) is studied and a novel method based on scattering centers with high entropy in complex white noise is proposed. The proposed detector uses two-threshold strategy. The first threshold determines high entropy centers of the target then, these centers are used in a GLRT test to decide about presence of target. It is shown that the proposed detector can estimate the variance of background noise so it exhibits a CFAR property.

KEYWORDS: high resolution radar; range spread target; constant false alarm rate; generalized likelihood ratio test; Mont Carlo simulation

1. INTRODUCTION

High resolution radar (HRR) can resolve a target into a number of scattering centers, depending on the range extent of the target and the range resolution capabilities of the radar [1]. The range resolution size or "range cell" can be made quite small by using modern pulse compression techniques.

Radar detection of range spread target in white noise with known variance has been addressed in [2] and [3]. It is shown in [2] that properly design of high resolution radar allows for significant enhancements of detection performance. in [3] a detector is developed that incorporates the a priori knowledge of scattering density and it is shown that the proposed detector is a robust solution when the scattering density parameter is known. A novel detector based on strong scattering centers is also proposed in [4]. This detector uses two-threshold strategy and it is claimed that it can estimated the variance of noise. For this detector, two situations are considered. In the first, it is assumed that the number of strong scattering centers is known and in the second situation, it is considered that there is not any a priori knowledge of the scattering centers. Under this consideration, the first threshold is determined based on given probability of false alarm. This procedure for variable background noise variance is not useable then, it cannot actually estimate the noise variance and doesn't have constant false alarm rate (CFAR) property.

For this development, it is assumed that the radar transmits several pulses. On receive, these pulses are matched filtered (or pulse compressed) so that individual scatterers on a target are resolved. There are J range cells that target scattering can occur in. it is assumed that complex adaptive zero main white noise present on each return of the J range cells, and there are P pulses from each target and scattering centers don't differ from one pulse to another (target doesn't move rapidly). It is also assumed that each of the scattering centers has different phase that is reasonable assumption for range spread targets because of distance between scattering point on target [5] which is simulated by random variable with uniform distribution.

In this paper a generalized likelihood ratio test (GLRT) detector is developed based on entropy concept in order to estimate the target scattering centers then this detector is called EB-GLRT, briefly. First of all, the detector determines the scattering centers of the target. The scattering centers are estimated by the comparing the entropy of the echo of the P Pulses which are occurred in each J range cells. The variance of noise is estimated from range cells at which the target scatterings are absent. Finally, the target is judged to be present or not by using the scattering centers which estimated in the first step. Theoretical analysis shows that the detector has constant false alarm rate (CFAR) property. In the next sections, detection procedure and thresholds determination way is described and finally, the performance of the detector in different target models and conditions is evaluated.

2. DETECTION PROCEDURE

It is assumed that similar to any other radar systems, the received signal is matched filter to generate J samples representing returns of contiguous range cells across some range extent. The range cell's width is equal to radar rang resolution. Thus, there are J possible range cells that the target scatterers can occupy.

The aim is to construct a hypothesis test that decides between the signal plus noise hypothesis (H_1) and the noise only hypothesis (H_0).

$$H_1 : x_{i,k} = n_{i,k} + s_i \quad i = 1,...,J \quad k = 1,...,P \qquad (1)$$
$$H_0 : x_{i,k} = n_{i,k}$$

where $x_{i,k}$ is the observed value of the i th range cell in k th received pulse and $n_{i,k}$ is the noise component of the *i*th range cell in *k*th received pulse. The noise samples are complex white Gaussian with zero mean and σ^2 variance. s_i is also target scattering value of ith range cell. J and P are the number of range cells and pulses which is received from each target, respectively. As mentioned above, the detection is done in two steps which are described in the two next sections.

2.1. First Step of Detection

In the information theory, entropy is a measure of the uncertainly associated with a random variable [6]. When the probability mass function of the random variable is uniform, its entropy is maximum value. This concept can be used to determine the scattering centers of the target. Here, we construct the following statistics.

$$y_i = \left|\sum_{k=1}^{p} x_{i,k}\right| \qquad (2)$$

$$\hat{y}_i = \sum_{k=1}^{p} \left|x_{i,k}\right|^2 \qquad (3)$$

$$Z_{i,k} = \frac{\left|x_{i,k}\right|^2}{\hat{y}_i} \qquad (4)$$

$$E_i = -\sum_{k=1}^{P} Z_{i,k} \times \log_2 Z_{i,k} \qquad (5)$$

Where $Z_{i,k}$ is the ratio of the i th range cell and k th received pulse energy content to the total energy of i th range cell which is achieved from hole of P pulses. Then, E_i will be the entropy value of the i th range cell. Consider that target scattering is located in i th range cell. Then, by increasing SNR, $Z_{i,k}$ approaches to $\frac{1}{P}$ for each k so as was mentioned earlier, we expected to have maximum entropy value in this situation.

After calculating E_i for each of the J range cells, E_i's are compared with first threshold. If the value of E_i is greater than threshold, it is assumed that i th range cell contains one scattering center of the target. The value of E_i is depend on P. For any value of P, we can set the average of E_i in noise only situation as first threshold which can be calculated by simulation. Let the noise variance of each range cell be σ^2. Then, under H_0 hypothesis, $x_{i,k}/\sigma$ is zero mean Gaussian random variable which its variance equals one. From (4), we obtain:

$$Z_{i,k} = \frac{\left|x_{i,k}\right|^2}{\hat{y}_i} = \frac{\left|x_{i,k}/\Omega\right|}{\sum_{k=1}^{P}\left|x_{i,k}/\Omega\right|^2} \qquad (6)$$

It is clear that $Z_{i,k}$ is independent of the noise variance. Therefore, from (5), E_i is independent of the variance. Thus, first thresholding has CFAR property.

2.2. Last Step of Detection

Let $i_1, i_2,..., i_n$ donate the indices of the range cells which we assumed to contain scattering centers of the target. Then, the target consists of n scattering centers, and according to [3], the equivalent GLRT statistic over $s_{i_1}, s_{i_2},..., s_{i_n}$ which are the target scattering centers, can be expressed as:

$$L_{EB-GLRT}(\bar{y}) = MAX_{s_{i_1}, s_{i_2},..., s_{i_n}} \left(L(\bar{y})\right)$$
$$= \frac{1}{2P\sigma^2} \sum_{m=1}^{n} \left|y_{im}\right|^2 \qquad (7)$$

Where y_{im} is calculated from (2). It is clear that $i_1, i_2,..., i_n$ which are the indices of the range cells containing scattering centers of the target, are estimated at the first step of detection. ($E_{i_1}, E_{i2_1},..., E_{in}$ are greater than first threshold). The noise variance, σ^2, could be estimated by average the squared amplitude of range cells where the target scattering centers is estimated not to be present.

3. PERFORMANCE OF THE DETECTOR

The distribution of detection statistic, $L_{EB-GLRT}$, is complex , whether the target exist or not, and it is difficult to calculate probability of detection, P_d, versus SNR and second threshold for a given P_{fa}. Thus, the detection performance of EB-GLRT detector is analyzed using Mont Carlo simulation. It is assumed that the number of the range cells, J, is equal to 24 and the number of the received pulses, P, is 4. In the simulation, the probability of false alarm, P_{fa}, equals 10^{-4} and the number of Mont Carlos simulation used to estimation of detection probability, P_{fa}, and the two thresholds is 10^3 and 10^6, respectively.

The signal to noise power ratio parameter (SNR) is defined as ratio of the of the signal powers over the J range cells, E, to the noise power over the J range cells, $2J\sigma^2$.

3.1. Modeling for Target Scattering Centers

In order to obtain the detection performance of the EB-GLRT detector, several scattering pattern models are considered that these models determine amplitude of the target scattering centers. These models are used in [2] as target models with flare point energy location and energy reflected from each flare point.

TABLE 1. Energy distribution of target over rage cells

Model Number	cell number									
	1	2	3	4	5	6	…	12	13	…	24
1	1	0	0	0	0	0	…	0	0	…	0
2	$\frac{1}{3}$	0	$\frac{1}{3}$	0	$\frac{1}{3}$	0	…	0	0	…	0
3	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{12}$	…	$\frac{1}{12}$	0	…	0
4	$\frac{1}{24}$	$\frac{1}{24}$	$\frac{1}{24}$	$\frac{1}{24}$	$\frac{1}{24}$	$\frac{1}{24}$	…	$\frac{1}{24}$	$\frac{1}{24}$	…	$\frac{1}{24}$

Let K_i and α_i be some coefficient in Table 1 and amplitude of the scattering center in i th range cell, respectively.

$$\sum_{i=1}^{J} K_i = 1 \tag{8}$$

$$E = \sum_{i=1}^{J} K_i E = \sum_{i=1}^{J} \alpha_i^2 \tag{9}$$

Where E is total energy reflected from target. The phases of scattering centers, Φ_i's, are modeled as random variable with uniform distribution. Thus, the scattering center in i th range cell is equal to $E\sqrt{K_i}e^{j\Phi_i}$.

3.2. Description of Optimal Threshold Calculations

The optimization of detection thresholds is done in two aspects. The first is detection improvement of the detector in known variance condition for all target models and the second is improvement of the detector capability in estimation of background noise variance and locations of target scattering centers. There are two thresholds which must be set so that the probability of false alarm, P_{fa}, be equal to 10^{-4} then by increasing the first threshold, the second threshold reduce which is shown in Fig.1. Note that the maximum value of entropy is 2 when the number of the received pulses, P, is equal to 4 then the first threshold must be lower than 2.

In order to improvement in the variance and target scattering pattern estimation, the first threshold must be increased to near 2. By increasing the first threshold, detection performance of the detector reduce then there are a tradeoff between capability of the target scattering pattern estimation and detectability. Selection of average of entropy, E_i, in noise only situation is approximately best suggestion for the first threshold which in this situation is equal to 1.67.

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3.3. Evaluation of The detector performance

The EB-GLRT detector is evaluated in two sections. In the first section of evaluation, the new detector is compared with two famous classical detectors in known variance condition. These two detectors are spatial scattering density (SSD) GLRT and integrator which are represented in [3]. The scattering density parameter in SSD-GLRT is equal to 0.1 in any target model of Table 1. The simulation results are shown in Figures 1 through 5. It is shown that in single scattering model (Figure 2), the EB-GLRT performance is 2 dB lower than SSD-GLRT. By increasing the number of the scattering centers, its performance is dropped. Finally, in dense scattering model (Figure 5), its performance is 2.5 dB lower than integrator which has the best performance in this target model.

In the second section of evaluation EB-GLRT detector performance in known an unknown variance condition is compared. Four target models of Table 1 are used in this comparison. The simulation results are shown in Figures 6 through 9. As it is seen, the performance degradation due to unknowing the noise variance is approximately 1dB.

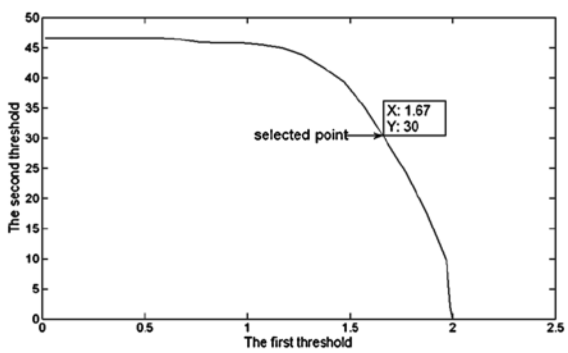

Fig 1. The second threshold versus the first threshold while p_{fa} is equal to 10^{-4}.

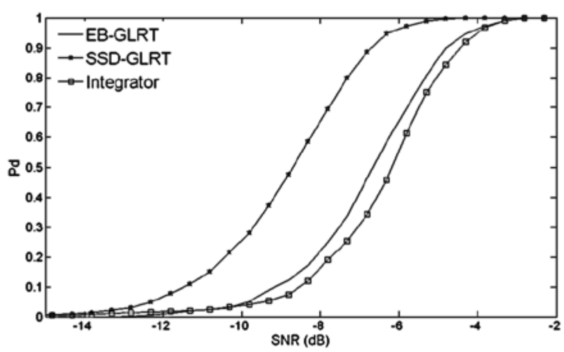

Fig 2. P_d versus SNR for EB-GLRT, SSD-GLRT and integrator in the first target model.

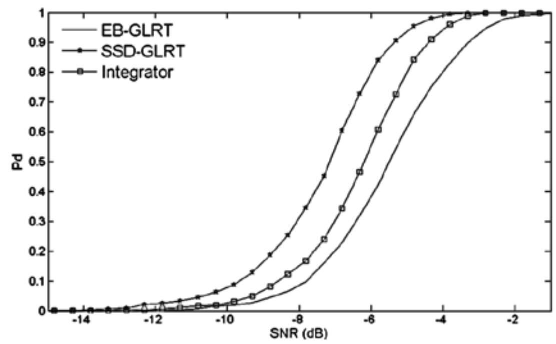

Fig 3. P_d versus SNR for EB-GLRT, SSD-GLRT and integrator in the second target model.

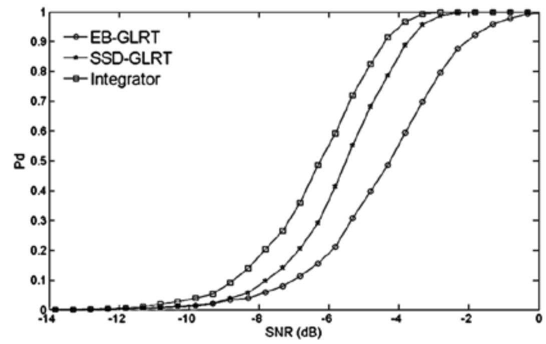

Fig 4. P_d versus SNR for EB-GLRT, SSD-GLRT and integrator in the third target.

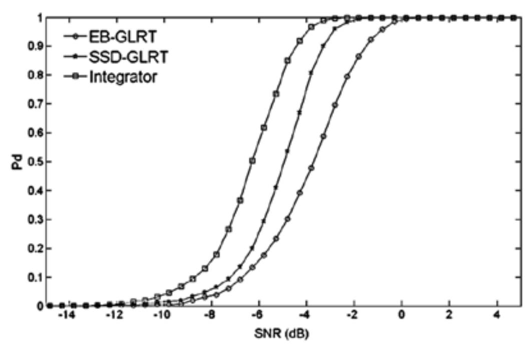

Fig 5. P_d versus SNR for EB-GLRT, SSD-GLRT and integrator in the fourth target model.

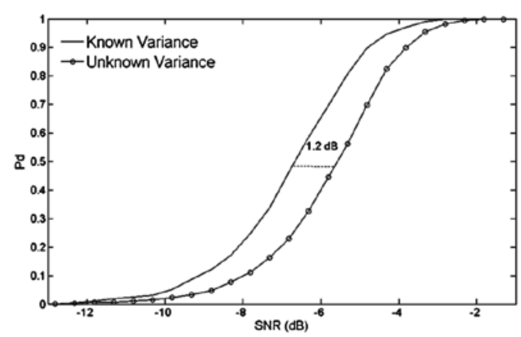

Fig 6. P_d versus SNR for EB-GLRT in known and unknown noise variance and the first target model.

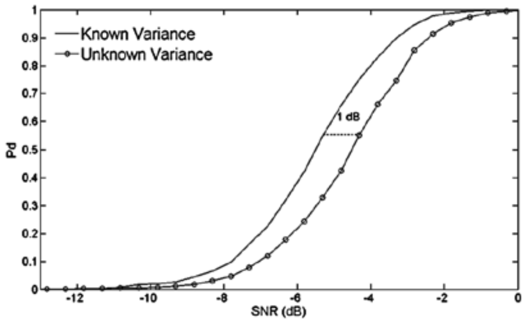

Fig 7. P_d versus SNR for EB-GLRT in known and unknown noise variance and the second target model.

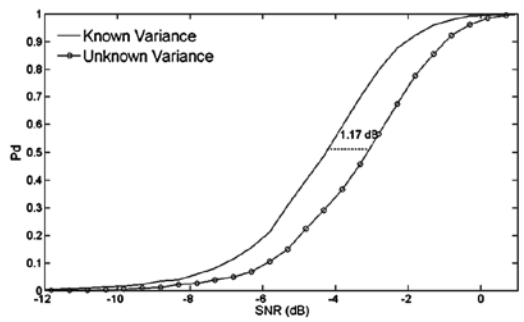

Fig 8. P_d versus SNR for EB-GLRT in known and unknown noise variance and the thirt target model.

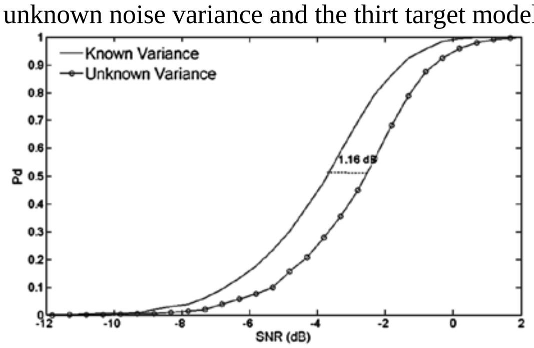

Fig 9. P_d versus SNR for,m EB-GLRTin known and unknown noise variance and the fourth target model.

4. CONCLUSION

In summary, we have developed a detector of range spread target in complex white noise. Although, its performance is lower than the other classical detectors, it can estimate the variance of noise and location of the scattering centers in range cells.

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