CLUTTER MAP CFAR ANALYSIS IN WEIBULL CLUTTER

M. HAMADOUCHE, M. BARKAT and M. KHODJA

Université de Constantine Institut d'Electronique

Constantine, 25000 Algeria, Phone / Fax 213-4-66-13-68

Abstract

Non-Rayleigh clutter statistics result when sea or ground clutter are viewed with resolution radars (pulse width <0.5μs) at low grazing angle (φ<5 degrees). In this paper, we consider the problem of Clutter Map Constant False Alarm Rate detection (CMAP-CFAR) in Weibull distribution with a shape parameter known. The target is assumed to be fluctuating according to Swerling I model. Closed form expressions for the probabilities of detection and false alarm in terms of shape and scale parameters are determined and the performance of the system is investigated and analyzed.

1. Introduction

One of the main goals in automatic radar detection is to maintain the probability of false alarm constant. Finn and Johnson [1] developed a theory based on the arithmetic mean of the nearby resolution cells of the test cell. This is known as the CA -CFAR, Cell Averaging Constant False Alarme Rate, detector. The CA-CFAR detector was shown to be not efficient in nonhomogeneous environment or in the presence of interfering targets. Many other techniques based on cell averaging and order statistics have been developed in the literature. Some are discussed in [2,3]. A different approach to obtain CFAR based on clutter map exploits the intrinsic local homogeneity of the radar environment in which the detector output of each range resolution cell is averaged over several scans in order to obtain an estimate of the background level. For a Rayleigh distributed background, Nitzberg [4] developed the clutter map CFAR processor using digital filtering to update the background power estimate corresponding to the map cell in each scan . Lops and Orsini [5] suggested the use of a maximum selector device. The returns of M range cells belonging to the map cell being scanned are fed to a maximum-selector device to provide a certain amount of protection against locally nonhomogeneous clutter. In [6], a new CFAR procedure is introduced, which relies on a hybride clutter-map/L-CFAR strategy, aimed at improving the system robustness against possible nonhomogeneities, while preserving target detectability in a homogeneous environment .

The Weibull clutter offers the potential to accurately represent the real clutter distribution over a much wider range of condition than either the log-normal or Rayleigh model. By appropriately adjusting its parameters, the Weibull distribution can be made to approach either the Rayleigh (which is a special case of the Weibull distribution) or log-normal distribution . Conte *et al.* [10,11] proposed a clutter-map CFAR scheme, which relies on a combination of space and time processing as well as on the relevant properties of the location-scale distributions. The performance in the presence of point targets was investigated, subject to both Weibull and log-normal clutter, so as to elicit the influence of the system parameters.

We observe from the above literature that in [4-6], the problem of CMAP-CFAR for Rayleigh distributed clutter was treated. In [7-12], CFAR analysis for a Weibull background was considered while in [10,11], the problem of CMAP-CFAR in Weibull clutter was treated. Thus, the problem of clutter-map CFAR detector, given by Nitzberg [4], in Weibull clutter was not investigated which is considered in this paper. We assume a high resolution radar operating at low grazing angle and the target model is of Swerling I. We derive closed form expressions for the probabilities of false alarm and detection. The performance of the system under consideration is investigated and studied using Monte Carlo simulations. In Section 2, we formulate the problem and calculate the probabilities of detection and false alarm; the CFAR-loss is also determined. Section 3 is devoted to the discussion of the results obtained. Finally, the conclusion is given in Section 4.

2. Problem formulation

Consider the CMAP-CFAR system using a first order recursive filter as shown in Figure 1. A fraction α of the present sample is added to $(1-\alpha)$ of the previous estimate to form the new estimate. By using exponential smoothing instead of a moving-window the average of that cell instead of the last m inputs from one cell. The background estimate is formed from previous scans and for the m[th] scan the output of the recursive filter is given by

$$y(k) = \sum_{l=0}^{m} \alpha.(1-\alpha)^{l}.q_{m-l}(k) \tag{1}$$

where q_l is the output of the l[th] resolution cell and α is the coefficient gain of the filter. The probability density function (pdf) of the clutter sample q under the null hypothesis H_0 (presence of clutter only) is Weibull with scale parameter B_p and shape parameter C_p as given below

$$p(q/H_o) = \frac{C_p}{B_p}\left(\frac{q}{B_p}\right)^{C_p-1}\exp\left(-\left(\frac{q}{B_p}\right)^{C_p}\right) \tag{2}$$

The probability of false alarm is given by

$$P_F = \int_0^{\infty} \Pr(q > T.y/H_o).p(y).dy$$

$$= \prod_{l=0}^{m}\left\{1+\left(T.\alpha(1-\alpha)^{l}\right)^{C_p}\right\}^{-1} \tag{3}$$

We observe that for $C_p=1$, we obtain the Nitzberg's case for Rayleigh distribution.

Since we are dealing with the single pulse case, both Swerling I and Swerling II are covered. A closed form expression for the pdf of the target plus background cannot be obtained and thus, a compact form for the probability of detection cannot be determined. To overcome this difficulty, we use the approximation given in [9]. That is, we compute the probability of detection for the case of a fluctuating target with Rayleigh pdf since when the signal-to-clutter power ratio is high, the contribution of the clutter-to-signal in the cell under test is small, and the exact pdf of the contribution is not very important. We will therefore assume that the cell under test contains the Rayleigh target plus Rayleigh clutter with the same mean energy as the Weibull clutter in the cells (reference cells) used for the estimation of the threshold. This approximation will become exact when the reference cells also exhibit a Rayleigh pdf. The probability of detection is given by

$$P_D = \int_0^{+\infty} \Pr(q > T.y/H_1).p(y).dy$$

$$= \sum_{l=0}^{m}\prod_{\substack{i=0\\ i\neq l}}^{m}\sum_{k=0}^{+\infty}\left\{1-\left[\frac{\alpha(1-\alpha)^{i}}{\alpha(1-\alpha)^{l}}\right]^{C_p}\right\}^{-1}.$$

$$\left\{\frac{T.\alpha(1-\alpha)^{l}}{B_p.\Gamma(1+2/C_p).(1+S)}\right\}^{-C_p.(k+1)}.\Gamma(C_p.(k+1)) \tag{8}$$

where S is the signal to clutter power ratio.

The CFAR loss for a known shape parameter is the ratio between the SCR required to achieve a specified P_D and P_F , and the SCR of the non-CFAR case (coefficient gain filter $\alpha=0$) in which the clutter level is known. Hence, we have

$$CFAR_{loss} = \frac{SCR(P_F, P_D, C_p, \alpha)}{SCR(P_F, P_D, C_p, \alpha=0)} \tag{9}$$

3. Results and discussion

In this section, we present the performance of the Clutter Map CFAR detector in Weibull clutter. The assumption considered for the pdf in Section 2 to overcome the mathematical difficulty in order to obtain an exact expression for the probability of detection was not used in the simulations since we can generate directly Weibull random variables as described in [12]. Figure 2 shows the effect of the coefficient gain α on the threshold multiplier in terms of the shape parameter C_p for $P_F=10^{-5}$. The threshold multiplier is smaller for a higher shape parameter. In Figures 3 and 4, we present the probability of detection versus SCR with the probability of false alarm as a parameter. For a coefficient gain filter of $\alpha=0.1$, we observe that for Cp=0.6, the probability of detection is better than the Rayleigh case ($C_p=1$) ; while for $\alpha=0.5$, we observe that for $C_p=1$ the inverse situation. Since α small corresponds to using a longer data window to estimate the clutter power, the probability of detection for $\alpha=0.1$ and Cp=0.6 is better than the probability of detection for $\alpha=0.1$ and Cp=1 even though the case of C_p small (Cp=0.6) corresponds to « high » tails of the pdf [4,10]. When α increases (map settling time reduced), the probability of detection for $\alpha=0.5$ and Cp=0.6 becomes smaller as expected. Figure 5 shows that for $\alpha < 0.4$ the CFAR-loss for smaller C_p are smaller, and the inverse occurs when $\alpha > 0.4$.

4. Conclusion

In this paper, we analyzed the Nitzberg's Clutter map CFAR detector [4] for a Weibull distribution clutter background. We note that Weibull distribution gives both Rayleigh and more spiky clutter by solely changing of the Weibull shape parameter. We assumed that the shape parameter was known *a priori*. However, in practice this parameter may not be known but may be estimated using the Maximum-Likelihood algorithm developped in [9]. The exponential distribution was the special case with $C_p=1$. For a Swerling target model I, we derived expressions for the probabilities of detection and false alarm. We, also, investigated the effect of the shape parameter and the coefficient gain on the clutter map CFAR processor.

References

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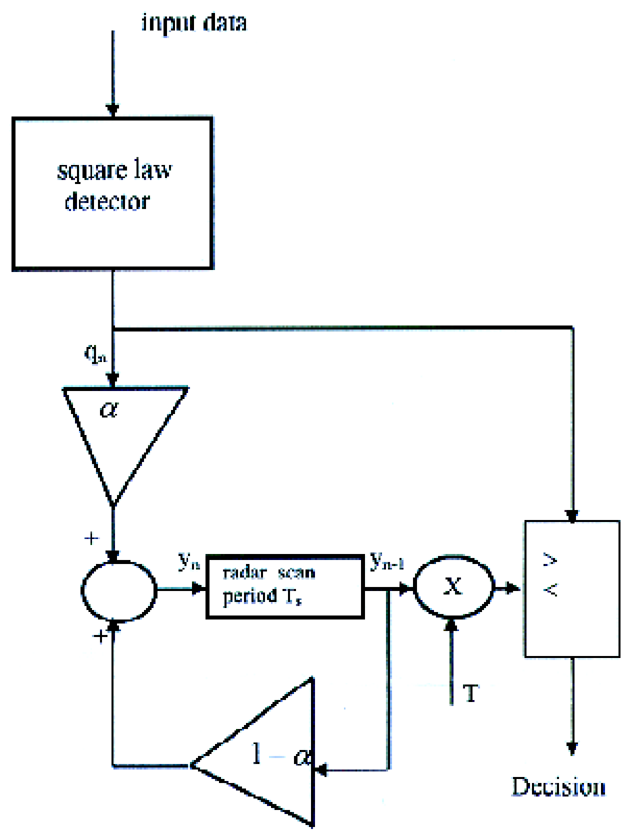

Fig. 1 Clutter map CFAR processor

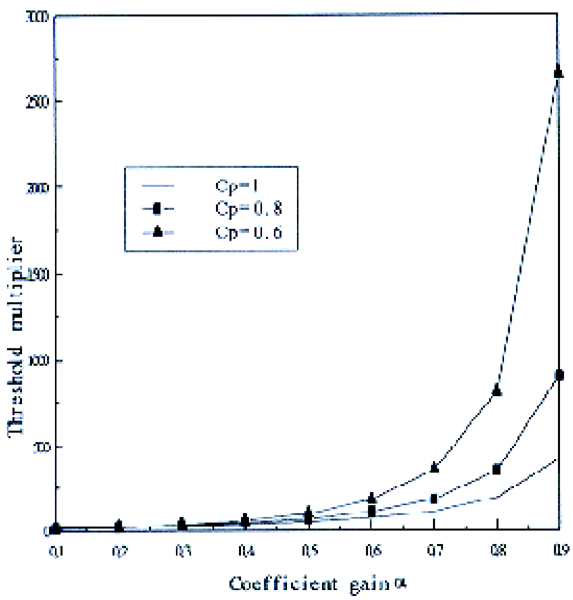

Fig. 2 Threshold multiplier versus coefficient gain α, $P_F = 10^{-5}$.

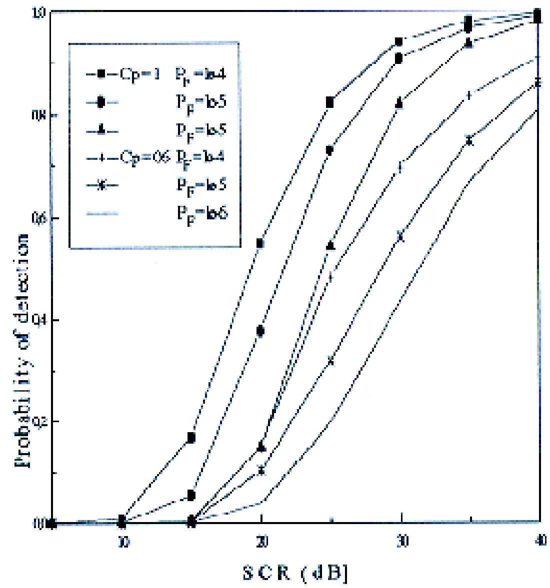

Fig. 4 Probability of detection versus SCR, α = 0.5.

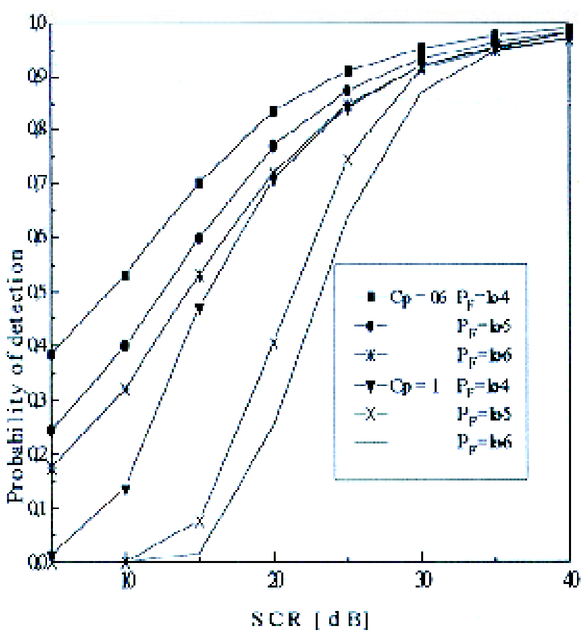

Fig. 3 Probability of detection versus SCR, α = 0.1.

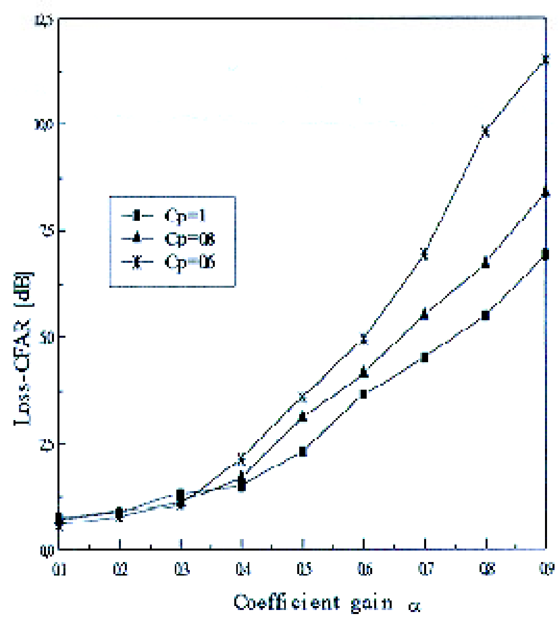

Fig. 5 CFAR-loss versus coefficient gain α of recursive filter, $P_F = 10^{-5}$, $P_D = 0.5$.