Automatic Radar Processing Using OSCA CFAR Detector

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Abstract – **The algorithm for an automated radar processing is analyzed, so the CFAR detector based on order statistics and cell-averaging is examined. By reason of that the expressions of the false alarm rate, the detection probabilities and measure ADT under the Swelling II assumption are calculated and are compared with the analogous parameters to the well known CFAR detectors.**

Keywords – **order-statistics, CFAR, ADT, radar processing**

I. Introduction

The main problem at the radar signal processing is the coherent primary detection of the received signal. The signal processing automation is connected with the development of the algorithms, which work at the wide range of an alteration of the signal statistical characteristics. The detection decision of the radiolocation signals requires the algorithm design, which maximizes the detection probability (P_D) at a constant false alarm probability (P_{f_a}). On the basis on this requirement a lot of CFAR detectors are designed. Constant false alarm rate (CFAR) algorithms are used to detect the targets in noise and clutter backgrounds whose mean power are unknown. Finn and Johnson [1] proposed the well-known CA-CFAR detector (cell-averaging constant false alarm rate). If the outputs of the reference cells are statistically independent and identically distributed random variables from the same population as the cell under test when there is no target, the detection performance of the CA-CFAR detector is optimal. However, the detection performance of the CA-CFAR detector is seriously degraded when the background environment is nonhomogeneous (*Rayleigh* or *Weibull* distributed). To improve the resolution of closely-spaced targets, Trunk [2] Hansen and Sawyers [3,4] proposed the SO-CFAR (smallest-of) and GO-CFAR (greatest-of) detectors respectively, but SO-CFAR processor exhibits severe degradation in false alarm rate control, with respect to the CA and GO-CFAR detectors in the presence of a clutter distribution edge effect. A new class of order statistic (OS) CFAR detectors is firstly introduced by Rohling [5] for multiple target situations.

reduce the processing time of the OS-CFAR detector in ordering magnitudes of the cell in the reference window, some kinds of modified OS-CFAR detectors, such as OSGO, OSCA and OSSO, are examined [6-9]. The best balance between the detection losses and processing time is possessed by the OSCA CFAR detector [9-11].

II. System Description

Due to the best balance of the OS-CFAR detection performance, one of its modified variants is analyzed. The block diagram of OSCA-CFAR detector is shown at Fig. 1. The function of the automatic censoring structure is to censure the target echoes from the reference sliding window. The system collects $M+N$ reference cells and implements the adaptive threshold to estimate the noise background. In the generalized order-statistic cell-averaging CFAR detector the estimation of the noise level in the cell under test is the sum of the outputs of the leading window the k-th order statistics and the lagging window the l-th order statistics. The estimated noise level is multiplied with the threshold parameter level $T(k,l)$ and the corrected noise level is compared with the reference cell value at the comparator to take the decision about the target presence. The scaling factor T is represented at Table 1 according to k and l values at $N = M = 16$, $P_{f_a} = 10^{-6}$. When the leading cell number M is equal to the lagging cell number N, there is $T(k,l) = T(l,k)$. This is also true for the all type of OS-CFAR detectors.

We assume that the noise in the test cell is Rayleigh envelope distributed and that the target returns are fluctuated according to the Swelling II model. The system implements an adaptive threshold test:

$$V \underset{H_0}{\overset{H_1}{\geq}} TZ \,, \tag{1}$$

where Z – the final background noise estimation, T – threshold parameter to control the desired probability of false alarm, V – the cell-under-test variable.

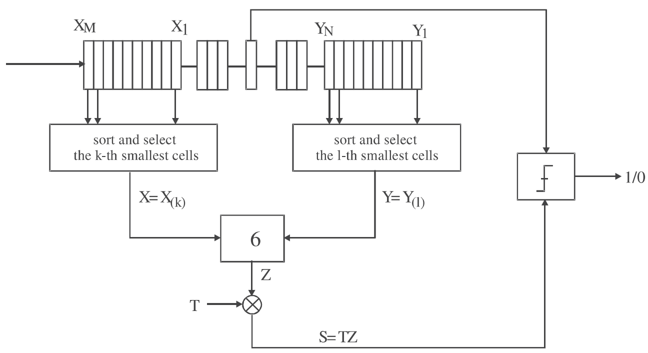

Fig. 1. OSCA-CFAR detector block diagram

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A binary hypothesis testing paradigm under the Swerling II assumption is [7]:

$$V = \begin{cases} \dfrac{1}{\mu}\exp\left(-\dfrac{\nu}{\mu}\right),\ H_0 \\ \dfrac{1}{b\mu}\exp\left(-\dfrac{\nu}{b\mu}\right),\ H_1,\ \nu > 0 \end{cases}, \quad (2)$$

where $b = 1 + S$, S – per pulse average SNR.

For any CFAR detector employing Eq. (1) the detection probability is expressed by the equation [12]:

$$P_D = \Pr[V \geq TZ] = -\int\limits_{-C} \frac{d(u)}{i2\pi} u^{-1} h(u) d(-Tu)\ , \quad (3)$$

where $h(u) = E\left(e^{-u\nu}\right)$, $d(u) = E\left(e^{-uz}\right)$ – moment generating functions (MGF)

The PDF (probability density function) of Z defined by Eq. (1) is given by [13]:

$$f_z(Z) = \int\limits_0^x f_X(x) f_Y(z-x)dx,\ z > 0\ . \quad (4)$$

The MGF of the noise level estimation is given for the homogeneous environment by [7]:

$$d(u) = d_X(u) d_Y(u)\ , \quad (5)$$

where

$$d_Y(u) = k\binom{M}{k}\int\limits_0^\infty e^{-uz}[\exp(-z)]^{M-k+1}[1-\exp(-z)]^{k-1}dz$$
$$= k\binom{M}{k}\frac{\Gamma(M-k+1+u)\Gamma(k)}{\Gamma(M+u+1)}$$

and

$$d_Y(u) = l\binom{N}{l}\int\limits_0^\infty e^{-uz}[\exp(-z)]^{N-l+1}[1-\exp(-z)]^{l-1}dz$$
$$= l\binom{N}{l}\frac{\Gamma(N-l+1+u)\Gamma(l)}{\Gamma(N+u+1)}$$

Therefore, the detection probability and false alarm probability is calculated by the expressions:

$$P_{f_a} = (P_{f_a})_1 (P_{f_a})_2 \quad (6)$$
$$(P_{f_a})_1 = k\binom{M}{k}\frac{\Gamma(M-k+1+T)\Gamma(k)}{\Gamma(M+1+T)}$$
$$(P_{f_a})_2 = l\binom{N}{l}\frac{\Gamma(N-l+1+T)\Gamma(l)}{\Gamma(N+1+T)}$$
$$P_D = (P_D)_1 (P_D)_2\ , \quad (7)$$
$$(P_D)_1 = k\binom{M}{k}\frac{\Gamma\left(M-k+1+\dfrac{T}{1+S}\right)\Gamma(k)}{\Gamma\left(M+1+\dfrac{T}{1+S}\right)}$$
$$(P_D)_2 = l\binom{N}{l}\frac{\Gamma\left(N-l+1+\dfrac{T}{1+S}\right)\Gamma(l)}{\Gamma\left(N+1+\dfrac{T}{1+S}\right)}\ ,$$

where S – signal-to-noise ratio.

It is known that ADT (average detection threshold) is an alternative measure to compute the loss of detection performance in a CFAR processors. For given values of P_{f_a}, M and N, the ADT is independent of the detection probability. The ADT for the OSCA-CFAR detector is calculated by the equation [7]:

$$ADT = T\left(\sum_{i=1}^{k}\frac{1}{M-k+i} + \sum_{j=1}^{k}\frac{1}{N-l+j}\right)\ . \quad (8)$$

The average detection threshold value is represented at Table 2 according to k and l values at $N = M = 16$, $P_{f_a} = 10^{-6}$

III. Numerical example

The OSCA-CFAR algorithm is analyzed using MATLAB® routine. The detection performance and detection losses are analyzed and compared with the analogue parameters of the other type of CFAR detectors. The scaling factor T is represented at Table 1 according to k and l values at $N = M = 16,\ P_{f_a} = 10^{-6}$. When the leading cell number is equal to the lagging cell number N, there is $T(k,l) = T(l,k)$.

Table 1. Scaling factor T according to k and l values at $N = M = 16,\ P_{f_a} = 10^{-6}$

l	10	11	12	13	14	15
k						
10	10.885					
11	9.8432	8.9641				
12	8.8647	8.1294	7.4214			
13	7.9316	7.3222	6.7278	6.1381		
14	7.0188	6.5222	6.0315	5.5383	5.0299	
15	6.0892	5.6964	5.3029	4.9019	4.4826	4.0239

The detection performance is the main characteristic, which is defined by the dependence of the detection probability P_D from the signal to noise ratio (S) at the fixed value of the false alarm probability P_{f_a}. It is estimated from the equation (6) and (7) and is shown at Fig. 2.

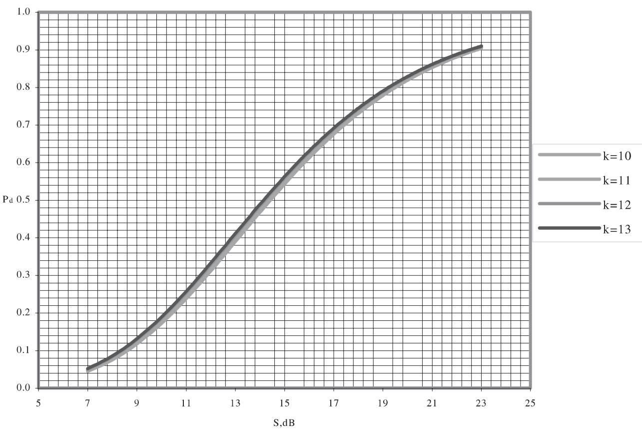

Fig. 2. The detection probability P_D according to k and l values at $N = M = 16,\ P_{f_a} = 10^{-6}$

The represented analyze shows that the detection probability values increase upon k and l augmentation and depend on the small degree from k and l values. But if k is near close to M or l is near close to N, the detection performance may be significantly degraded by the influence of the interfering target in the leading or lagging windows. At $k = M$ and $l = N$ OSCA-CFAR detector is identical with the CA-CFAR detector.

The next analyzed parameter of the CFAR detector is ADT value. It is calculated by the equation (8) and is represented at Table 2 according to k and l values at $N = M = 16,\ P_{f_a} = 10^{-6}$.

Table 2. The average threshold average value according to k and l values at $N = M = 16,\ P_{f_a} = 10^{-6}$

l	10	11	12	13	14	15
k						
10	20.261					
11	19.961	19.674				
12	19.751	19.468	19.257			
13	19.655	19.365	19.139	18.996		
14	19.733	19.424	19.169	18.986	18.919	
15	20.164	19.812	19.504	19.266	19.102	19.160

The shown results represent the low detection losses of OSCA-CFAR detector in relation to the other CFAR detector types. Regarding to that parameter the analyzed CFAR processor is compared to CA-CFAR one and exceeds all type of CFAR detectors [10].

These results define the intermediate position of the OSCA-CFAR detector in relation to CA-CFAR and OS-CFAR detectors. It combines the low detection losses and computing effectiveness of the CA-CFAR detector with the detection behavior of the OS-CFAR detector in the nonhomogeneous background multiple target situations.

IV. Conclusion

The represented CFAR algorithm for the automated radar processing allows a detection of the target returns in the homogeneous and nonhomogeneous backgrounds with an optimal detection performance. The favorable detection performance defines OSCA-CFAR detector as an optimal CFAR detector in relation to the detection losses, processing time and detection conduct in the nonhomogeneous background and interfering targets in the leading or lagging windows.

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