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Comparative Analysis of CFAR Structures for GPS Signals under Conditions of Intensive Urban Pulse Interference[1]

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1. Introduction

Signal detection in noise or clutter is a very important device in each receiver. In theory the noise and clutter background will be described by a statistical model with e.g. Rayleigh or exponentially distributed random variables of known average noise power. But in practical applications this average noise or clutter power is absolutely unknown and some statistical parameter can additionally vary over range, time and azimuth. In automatic radar detection, the received signal is sampled in range and frequency. Each sample is placed in an array of range and Doppler resolution cells. The clutter background in the cell under test is estimated by averaging the outputs of the nearby resolution cells (range and/or Doppler). The target detection is declared, if the signal value exceeds a preliminary determined threshold. The detection threshold is obtained by scaling the noise level estimate with a constant T_α to achieve a desired probability of false alarm P_{FA}.

This is the conventional Cell Averaging Constant False Alarm Rate (CA CFAR) detector, proposed by F i n n and J o h n s o n in [1]. Averaging the outputs of the reference cells surrounding the test cell forms this estimate. Thus a constant false alarm rate is maintained in the process of detection. These CA CFAR

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processors are very efficient in case of stationary and homogeneous interference. The presence of strong urban pulse interference in both, the test resolution cell and the reference cells, can cause drastic degradation in the performance of the CA CFAR processor. Such type of interference is non-stationary and non-homogenous and it is often caused by adjacent radar or other radio-electronic devices. In non-homogenous environment, the detection performance and the false alarm regulation properties of CA CFAR detector may be seriously degraded.

In recent years different approaches have been proposed to improve the detectability of CFAR detectors operating in random impulse noise [2-9]. One of them is the use of ordered statistics for estimating the noise level in the reference window, proposed by R o h l i n g [2]. In Ordered Statistic CFAR (OS CFAR) pulse detectors, the *k*-th ordered sample in the reference window is an estimate of the background level in the test resolution cell. The performance of such OS CFAR detector in the presence of multipath interference in existing communication networks is evaluated and studied in [3].

H a n s e n and S a w y e r s [4, 5] proposed the greatest of selection logic in the cell averaging constant false alarm rate (GO CFAR) detector to control the increase in the false alarm probability. A detailed analysis of the false alarm regulation capabilities of the GO CFAR detector has been performed by M o o r e and L a w r e n c e [6]. W e i s s [7] has shown that if one or more interfering targets are present in the reference window, the performance of the GO CFAR detector is very poor. He suggested the use of the smallest of selection logic in the cell averaging constant false alarm rate (SO CFAR) detector. The SO CFAR detector was proposed by T r u n k [8] to improve the resolution of closely spaced targets.

The detection performance of CFAR processors is proposed by H o u in [9] for the case of homogeneous environment and chi-square family of fluctuating target models (Swerling I, II, III, IV). In our paper, we study the situation for a highly fluctuating target – Swerling II type target model detection under conditions of strong urban pulse interference.

In this paper we investigate the detection probability of the CFAR processors under conditions of strong urban pulse interference. Research is made in MATLAB environment. The results obtained can be used both in radar and communication networks.

2. The signal model

In this paper we use the Swerling II target model for analysis under conditions of urban impulse interference, described by Poisson distribution law. The Poisson model describes a real radar situation when the impulse noise arrivals from a single impulse-noise source [10-16]. According to this model, in each range resolution cell the signal sample may be corrupted by urban impulse noise with constant probability e_0. Therefore, the elements of the reference window are drawn from two classes. One class represents the interference-plus-noise with probability e_0. The other class represents the receiver noise only with probability $1 - e_0$. According to the theorem of total probability, the elements of the reference window are independent random variables distributed with the following probability density function

(1) $$f\left(x_i\right)=\frac{1-e_0}{\lambda_0}\exp\left(\frac{-x_i}{\lambda_0}\right)+\frac{e_0}{\lambda_0\left(1+I\right)}\exp\left(\frac{-x_i}{\lambda_0\left(1+I\right)}\right),\quad i=1,\ ...,\ N,$$

where λ_0 is the average power of the receiver noise, S is the per pulse average signal-to-noise ratio (SNR), I is the average per pulse Interference-to-Noise Ratio (INR) at the receiver input, and N is the number of samples in the reference window.

In the presence of a desired signal in the test resolution cell the signal samples are independent random variables distributed with the following probability density function

(2) $$f\left(x_0\right)=\frac{1-e_0}{\lambda_0\left(1+S\right)}\exp\left(\frac{-x_0}{\lambda_0\left(1+S\right)}\right)+ \\ +\frac{e_0}{\lambda_0\left(1+I+S\right)}\exp\left(\frac{-x_0}{\lambda_0\left(1+I+S\right)}\right).$$

The probability of occurrence of a random pulse in each range resolution cell can be expressed as $e_0=F_j \cdot t_c$, where F_j is the average pulse repetition frequency and t_c is the transmitted pulse duration.

3. Analysis of CFAR detector structures

The CFAR processor is a detector, which maintains a constant false alarm probability in the process of target detection (Fig. 1). The received signal $x(t)$ is square law detected and sampled in a range by the N+1 range resolution cells as shown in Fig. 1 [16]. The set of samples $(x_i)_N$ is processed resulting in a noise level estimate V. The estimate V is multiplied by a predetermined scale factor T_α resulting in a pulse detection threshold. The sample from the test resolution cell x_0 is compared with the detection threshold, and the target signal is detected if the sample x_0 exceeds the detection threshold. In case of Poisson distribution of impulse interference, the analytical expressions of CA CFAR detector for calculating the detection and false alarm probability are obtained in [11, 16].

The optimized signal processing technique in CA CFAR situation from a statistical point of view is to calculate an estimation of the clutter power level just by applying the arithmetic mean to the received amplitudes inside the considered window.

In GO CFAR case, the estimate of the noise level is the maximum of V_1 and V_2. Analogically, in SO CFAR case, the estimate of the noise level is the minimum of V_1 and V_2.

In OS CFAR case to estimate the average noise and clutter power a single rank x^* of the ordered statistic is used instead of the arithmetic mean. In this case a very few large amplitudes in the sliding window have a very small effect to the estimation results. The OS CFAR detector is robust in multiple target situations. The threshold is hardly influenced by a second or third target inside the window.

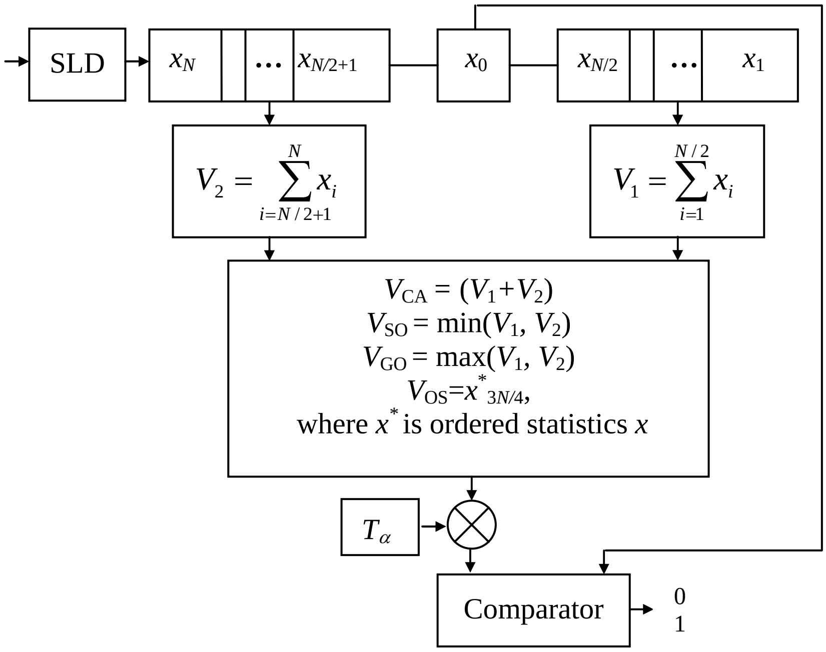

Fig. 1. Block diagram of different CFAR detectors

The statistical performance is excellent, if the assumptions of homogeneous clutter inside the reference window are fulfilled in the statistical model and in real world applications. To demonstrate the general CFAR characteristics, some typical signal situations are generated which are considered to be characteristic for radar applications. Fig. 2 shows the resulting adaptive threshold in noise, clutter, interference and target situation when the CFAR procedure is applied.

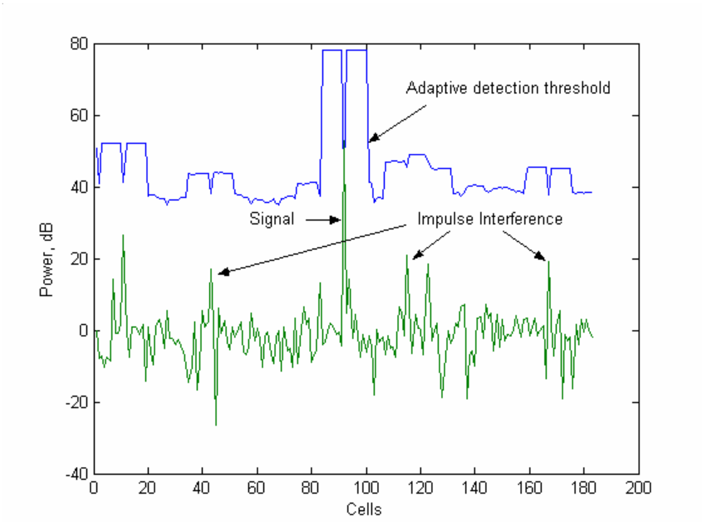

Fig. 2. Signal detection

The clutter and noise signals are varying in time and position and the average clutter power level can fluctuate in different range areas and range cells. If a CFAR procedure is applied in the radar detector, it may happen that the sliding window is located in the transition between a pure noise and strong clutter area with different average power level, as shown in Fig. 2 as an example.

4. Numerical results

The research is carried out by means of modeling in Matlab environment. In order to keep the constant false alarm rate with probability value – $P_{fa}=10^{-3}$, the scalar factors for the investigated algorithms are determined. The results are presented in Table 1.

Table 1. The value of the scale factors for CFAR detectors

CFAR $P_{fa}=10^{-3}$	e_0	N = 16	
		I = 10 dB	I = 30 dB
CA	0.01	1.6	130
	0.1	2.6	190
SO	0.01	4.2	370
	0.1	8.1	720
GO	0.01	2.6	240
	0.1	4.1	320
OS	0.01	21	1850
	0.1	40	3500

The research is based on Monte Carlo simulational analysis with the following input parameters: average power of the receiver noise – $\lambda_0 = 1$, number of reference cells – N = 16, interference-to-noise ratio (INR) I is equal to 10 and 30 dB, probability for appearance of urban pulse interference – e_0 is equal to 0.01 and 0.1.

The detection probabilities of the studied CFAR processors are shown in Figs. 3-6.

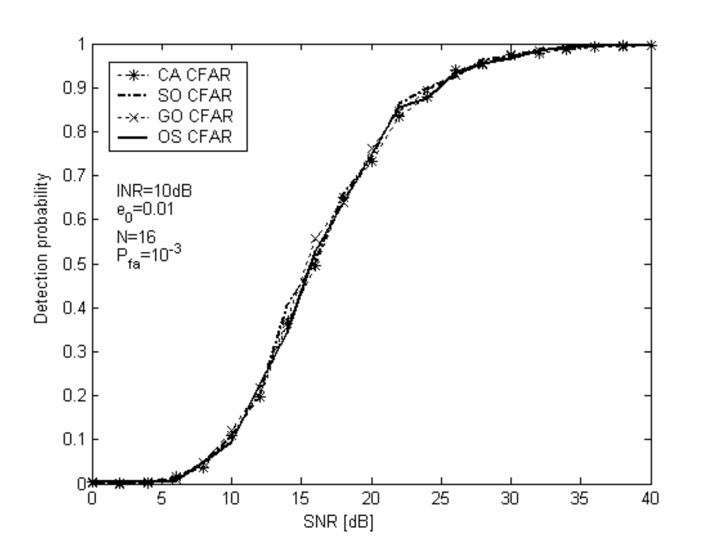

Fig. 3. Detection probability of different CFAR processors (e_0 = 0.01, I = 10 dB)

Figs. 3 and 4 show the detection probabilities of different CFAR processors in conditions of urban impulse interference with average power level of INR 10 dB and values for appearance probability 0.01 and 0.1. In urban impulse interference with higher appearance probability, the detection probability decreases.

The results Achieved show that for minor values of INR, the studied detector structures perform almost equally.

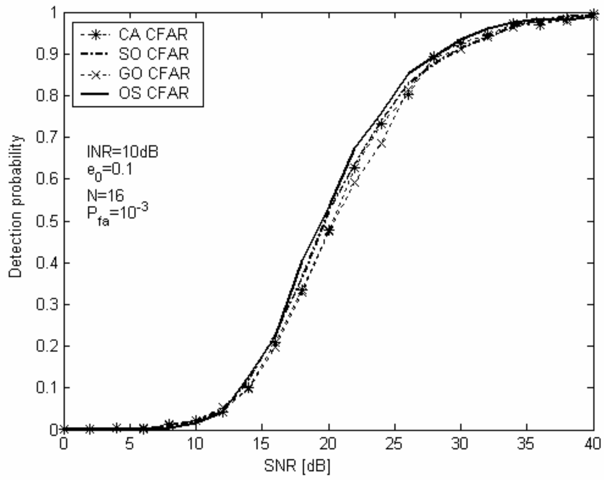

Fig. 4. Detection probability of different CFAR processors ($e_0 = 0.1$, $I = 10$ dB)

Figs. 5 and 6 show the detection probabilities of different CFAR processors in conditions of urban impulse interference with average power level of INR – 30 dB and values for appearance probability 0.01 and 0.1.

The results indicate that urban interference with higher average power level significantly diminishes the detection probability. The best performing of all studied structures in these conditions is the Order Statistic Constant False Alarm Rate detector (OS CFAR).

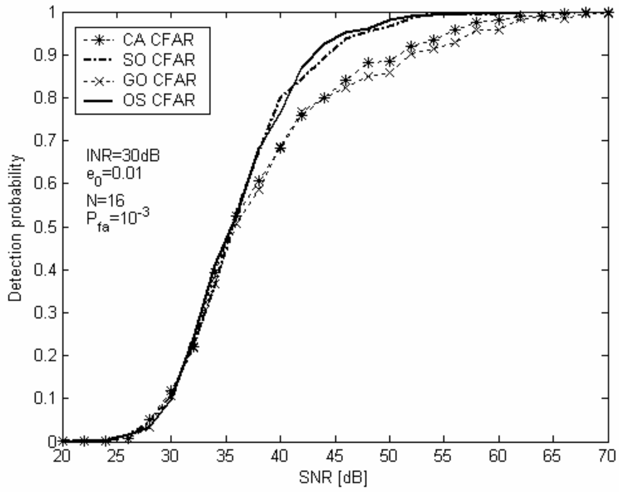

Fig. 5. Detection probability of different CFAR processors ($e_0 = 0.01$, $I = 30$ dB)

Under conditions of urban impulse interference with parameters – e_0 = 0.1 and I = 30 dB, the benefit of OS CFAR detector is 5 dB higher than that of SO CFAR detector, about 30 dB higher than GO CFAR detector and about 38 dB higher than CA CFAR detector.

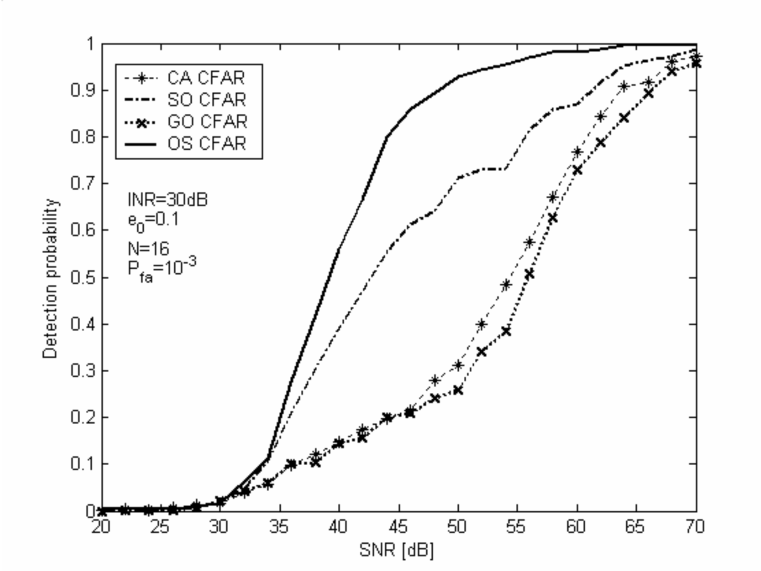

Fig. 6. Detection probability of different CFAR processors
(e_0 = 0.1, I = 30 dB)

5. Conclusions

The detection probability of the researched CFAR detectors decreases in the presence of urban impulse interference. Having higher values of appearance probability of impulse interference with high average power decreases the detection probability. The use of OS CFAR detector is the best solution for environment with impulse interference. The advantage of OS CFAR is compared to the rest of the researched structures under conditions of strong flow from impulse interference.

The results obtained in this paper could be practically used in the design of modern communications systems.

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Сравнительный анализ ПУЛТ обнаружителей для GPS сигналов в условиях интенсивных городских импульсных помех

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(Р е з ю м е)

В настоящей статье исследована эффективность ПУЛТ обнаружителей с усреднением по выборке шума при наличии на входе приемника городских импульсных помех. Выражения для расчета эффективности обнаружителя в терминах вероятностных характеристик обнаружения и среднего порога обнаружения были получены аналитическим путем. Результаты сравнительного анализа показывают, что использование ПУЛТ обнаружителей особенно ефективно, когда отношение сигнал/шум на входе приемника сравнительно мало. Численные результаты получены в вычислительной среде МАТЛАБ. Полученные результаты могут быть использованы в радиолокационных или коммуникационных сетях.