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# Book Review

# Why Constant False Alarm Rate?

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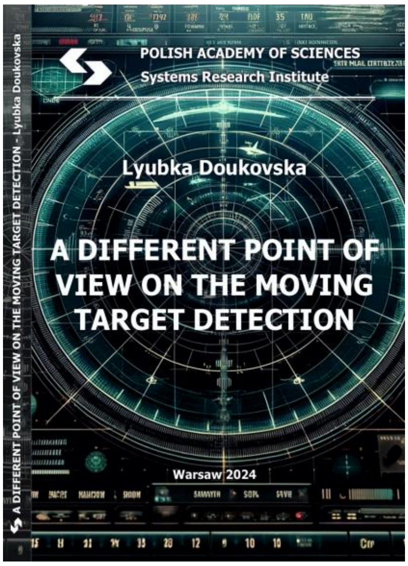


“The book presents the algorithms that ensure the maintenance of a constant false alarm rate (CFAR detectors) in the detection of radar targets in conditions of an intensively noisy environment. This type of detectors uses an adaptive threshold dependent on the disturbance level, thus ensuring that a constant false alarm probability is kept. The rapid development of algorithms in this area in recent years can be explained both by the very pronounced need in various fields of science and technology to automatically perform the procedure of detecting a useful signal against the background of disturbances, and by the theoretical interest to interpret the classical approaches to the detection tasks in a modern way” [1].

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Maintaining a constant false alarm probability is an invariable condition that is fulfilled by algorithms for detecting moving targets in radar. The need to apply this approach is justified by practice. At the height of the Cold War, a situation arose in which a flock of birds, registered during the radar survey as enemy targets, put humanity on the verge of a nuclear catastrophe, and only the quick reaction of the observing officer prevented it. Thus, the need arose for a new requirement for algorithms for detecting moving targets, that they ensure the detection and recognition of the observed targets. Scientists responded to this challenge and in the late 1960s the first works were published in which this problem was already solved [2].

Today, there is a wide variety of different modifications of detection algorithms that provide a constant false alarm rate [3, 4]. Detection algorithms that work in a heavy noise environment have also been synthesized [5]. The author of the book has developed a library of original algorithms for detecting moving targets in such harsh conditions, which also includes the application of a mathematical transformation of the signal reflected by the target [6]. The monographic work [1] includes the entire variety of developed algorithms that meet the requirement to ensure a constant probability of false alarm.

**Chapter 1** justifies the need to select an appropriate structure for a radar detector against the background of powerful, intentional and high-frequency impulse interference.

The detection of radar targets is performed in the signal processor, after preliminary detection and discretization of the input signals. During processing in the signal processor, consistent filtering of the single signal (or compression of the complex signal), adaptive selection of moving targets, incoherent accumulation of the signal and adaptive detection of the summary signal are sequentially performed, by comparing its value with a pre-formed adaptive threshold. The radar target is considered detected if the signal exceeds this threshold.

The detection threshold is formed on the basis of a current assessment of the level of interference in the training window. The assessment from [2] is often used to assess the level of interference. This assessment is formed by averaging the signal values in the training window. In this way, a constant level of false alarms is maintained in the process of target detection. Such processors, providing a constant false alarm rate, are very effective for stationary and uniform disturbances and approach the optimal Neyman-Pearson detector in efficiency when the training sample size is large enough.

Fig. 1 shows the general structure of a CFAR detector, where the training sample is formed from distance resolution elements. After coordinated filtering, the useful signal passes through a quadratic detector at the output, at which the signal envelope is obtained. The discrete values of the envelope form the information data array. In the next stage of the detection process, a training window is structured, part of the elements of which participate in the formation of the detection threshold. In the comparator, the value of the tested element from the training sample is compared with the value of the detection threshold. The output of the comparator is the last stage of the detection process in the CFAR detector.

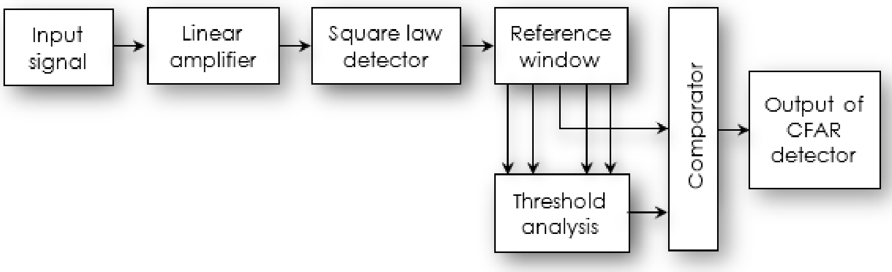


Fig. 1 General structure of the CFAR detector

The behavior of a Hough detector synthesized for white Gaussian noise under conditions of an intense stream of randomly arriving impulse disturbances has been studied [7]. In this practically real and unexplored situation, the detector does not maintain the false alarm probability and worsens the probability of detection. This necessitates the use of various types of signal processors that ensure the maintenance of a constant false alarm rate before applying the Hough transform under conditions of a stream of intense impulse disturbances.

This detection algorithm allows the process of detecting a moving target to be combined with the detection of its trajectory. Fig. 2 shows the distributions binary piled signals reflected from a large and a small target, represented in the Hough parameter space [10].

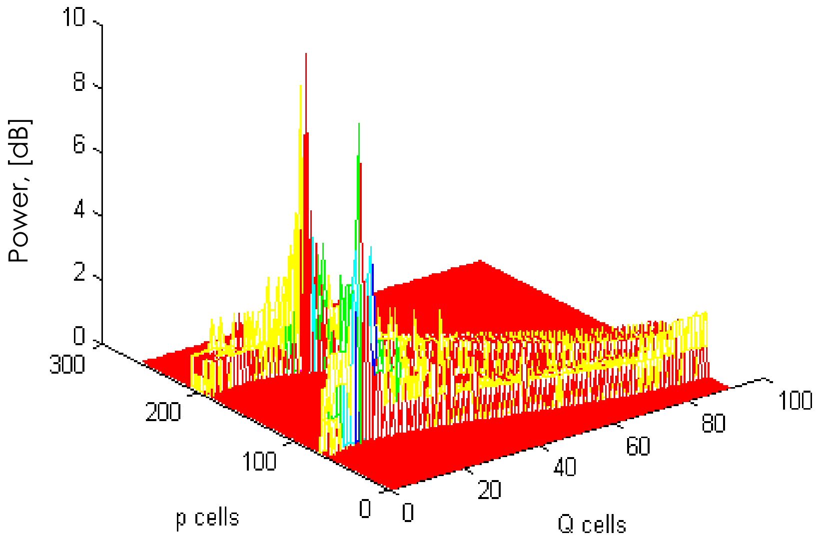


Fig. 2 Binary accumulation in Hough space

As can be seen from the simulation results, which are presented in the figures, binary stacking allows the Hough transform to detect both large and small targets equally well by establishing a common detection threshold. The algorithm provides localization with equal probability of detection of both large and small moving targets and simultaneous determination of their motion parameters.

**Chapter 2** defines and solves the statistical problem of detecting single and burst radar pulses in conditions of intense noise environment.

New results are obtained for the probabilistic characteristics (probability of detection, probability of false alarm) for a two-dimensional adaptive detector, ensuring maintenance of a constant probability of false alarm. The obtained new mathematical relationships take into account the influence of the disturbance parameters on the detectability of targets in the detector. The obtained solution of the problem with an adaptive threshold is close to the optimal one for a fixed threshold in conditions of intense noise environment [8, 9].

The presence of impulse interference increases the average detection threshold of the CFAR detector, the increase being significant with increasing average power of the interference. Increasing the probability of occurrence of impulse interference in turn does not significantly change the threshold. This is due to the additional threshold processing of the detector's training window.

Original results are presented for the following one- and two-dimensional pulse detectors: cell-averaging constant false alarm rate (CA CFAR), excision constant false alarm rate (EXC CFAR), constant false alarm rate with binary integration (CFAR BI), excision constant false alarm rate with binary integration (EXC CFAR BI), constant false alarm rate with post detection integration (CFAR PI), adaptive post detection integration constant false alarm rate (API CFAR). The comparative analysis of these detectors is made using the average detection threshold of these CFAR detectors when operating under conditions of intense flows of impulse disturbances.

Fig. 3 presents the results obtained from the analysis of the average detection thresholds of the studied two-dimensional detectors obtained through Monte Carlo simulation analysis [8, 9, 14].

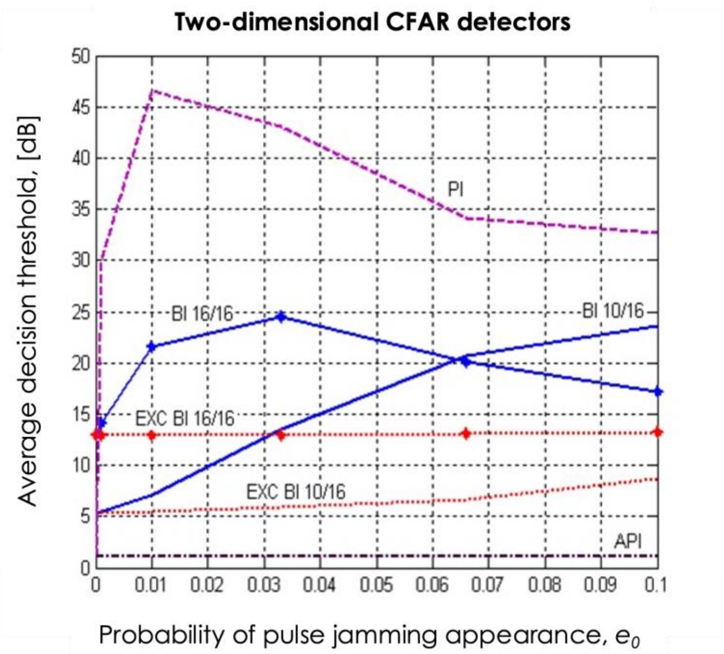


Fig. 3 Average detection thresholds of two-dimensional CFAR detectors under Poisson model conditions of pulse jamming interference

A methodology is proposed for assessing the effectiveness of the considered signal detectors based on the use of the criterion for the effectiveness of the CFAR detectors, the average detection threshold.

**Chapter 3** deals with new detector structures using Hough transform of the target received signal, working together with one-dimensional and two-dimensional signal processors. By means of numerical experimentation, the probabilistic characteristics of the newly obtained structures have been studied in the conditions of randomly arriving impulse disturbances with Poisson and binomial law of occurrence and Rayleigh fluctuation of amplitudes. As a result of the used methodology, new results have been obtained for the probabilistic characteristics, detection thresholds, threshold in the Hough parametric space, for different flow parameters. The task of joint detection and estimation of the moving target parameters with the application of Hough transform has been further developed. A significant reduction in losses expressed in the signal-to-noise ratio has been proven through the use of censoring and adaptive to disturbance techniques [11, 13, 17, 19]. A new approach for estimating the speed of a moving target in the conditions of an intense noise environment is presented. It has been shown that applying the Hough transform to the signal received by the target improves the performance of the velocity estimator [12, 15, 16].

Fig. 4 shows the results obtained for the decision rule $M/L = 10/16$ (the dashed line) and for the rule $M/L = 16/16$ (the solid line). The Hough detector with a two-dimensional censoring CFAR processor using the $M/L = 10/16$ rule is better in the case where there is a low probability of appearance of impulse interference, having values up to $e_0 = 0.5$. For higher values of $e_0$, it is more appropriate to use the binary rule $M/L = 16/16$, which provides smaller losses expressed in the signal-to-noise ratio.

Results were used, obtained from the analysis of the Hough detector with a censoring CFAR processor operating in the conditions of binomially distributed impulse interference. For purposes of comparative analysis of performance of the Hough detector, the average detection thresholds were obtained according to the methodology proposed in [1], with the same values of the probability of detection, $P_D = 0.5$, for different values of the binary rule thresholds.

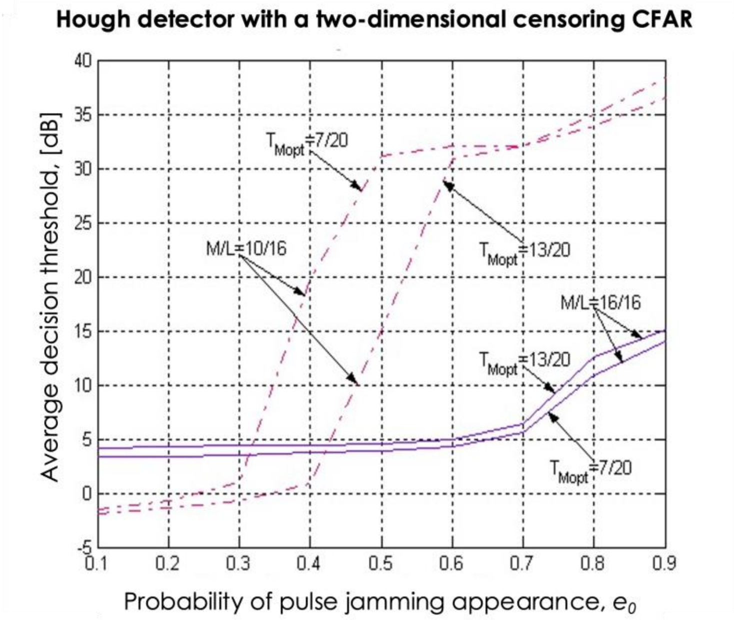


Fig. 4 Loss values in the signal-to-noise ratio of the Hough detector with a two-dimensional censoring CFAR processor for different values of the threshold constants in the Hough parameter space

The results obtained show that the use of a Hough detector, in which an adaptive CFAR processor is present in the signal processor, is more effective in conditions of randomly arriving pulse disturbances with changing intensity compared to a Hough detector operating with a fixed threshold. The use of averaged characteristics for the analysis of different detectors is a very convenient mathematical tool, with which the energy gain when using a given type of detector is very accurately and easily determined.

**Instead of a conclusion**

Why Constant False Alarm Rate? The results presented in the monograph confirm the well-known fact that with increasing intensity of pulse interference, the detectability of the useful signal reflected from the target deteriorates, increasing losses in the signal-to-noise ratio. The main advantage in choosing detector that includes in its detection algorithm a mathematical transformation of the received signal, for operation in a heavy noise environment, is the possibility of ensuring a constant false alarm frequency, regardless of whether the environmental parameters and the probability of occurrence of pulse interference change.

The obtained results are applicable to solving a wider range of tasks in radar, communication, medicine and other research areas working with information from infrared, ultrasonic and other types of sensors [18, 20, 21].

The monograph was published by the Systems Research Institute at the Polish Academy of Sciences as part of the series Systems Research with chairman of the editorial board Acad. Janusz Kacprzyk (foreign member of the Bulgarian Academy of Sciences), scientific editor Prof. Olgierd Hryniewicz, reviewers Acad. Janusz Kacprzyk and Prof. Maciej Krawczak, graphic design Assoc. Prof. Irina Radeva and typesetting Mrs. Aneta Pielak. The Systems Research Institute at the Polish Academy of Sciences should be congratulated for their very good judgment in terms of the substantive monograph and proven professionalism in selecting the manuscripts for publication.

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