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Radar detection in the moments space of the scattered signal parameters

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A B S T R A C T
This paper proposes the theoretical foundations of a novel radar detection method, based on analysis and decision making in the moments space of the scattered signal parameters. Through an adaptive process and from large-size samples of these parameters, several normal-distributed moments are calculated, which allow assigning each resolution cell of the searching region to the background or anomaly classes. Following the Neyman–Pearson criterion two optimal detection algorithms are proposed, one for statistically independent moments and other for correlated moments. Finally, three background-anomaly pairs are simulated, taking the amplitude of the video signal as parameter and two of its moments for decision making. As result, the detection curves for two sizes of the sample are presented, showing the possibilities of the proposed method.

1. Introduction

The radar detection of low observable targets is currently a problem of major interest in the radar field. For example, point targets embedded in sea clutter, stealth targets, local disturbances of the searching region and targets whose scattering properties of radio waves are very similar to the surrounding environment. The masking effect of the environment on the target is a fundamental cause of its low detection probability and methods to overcome this have been developed [1–5].

Current detection methods are based on the analysis and decision making in the space of the parameters (amplitude, frequency, phase, etc.) of the scattered signals and have led to optimal and suboptimal detection algorithms, most of them based on the signal amplitude. These methods have been widely studied both analytically and experimentally, with extensive literature written in this respect. However, when the signal parameters are taken as random variables for detection, a priori indetermination is present due to the ignorance of their distribution laws. For this reason, it is necessary to assume these distributions, with the subsequent deterioration in detection quality for supposing models that could move away from reality.

The method proposed in this paper is based on analysis and decision making in the space formed by a finite number of moments, calculated from a set of selected parameters of the scattered signals. Reference to this method will be made by the Spanish acronym DRACEC (*Detección de Radar por Análisis y Clasificación Estadística de la Emisión Celular*, which may be translated in to English as *Radar Detection through the Analysis and Statistical Classification of Cellular Emission*).

Since the moments are obtained from large-size samples of the parameters, it is possible to accept that they are normal-distributed and therefore DRACEC can be considered as a parametric method. This characteristic decrease the a priori indetermination of the signal parameters distributions, which simplify the detection process and achieve normal distributions with small variances, thus obtaining high detection probabilities as will be demonstrated.

Although the moments have been used in radar as targets features for classification [6–8] and detection [5,9–12], they have not been employed as random variables to obtain optimal detection algorithms. For example, the approaches made in [5,10–12] are based on the different statistical behavior of the backscattered signal by cells hosting a target with small radar cross section and those cells with only sea clutter. However, none of them follows the steps of an optimal detection algorithm. On the other hand, in [9] the authors make use of fractional moments to estimate the probability density functions for clutter and signal using the maximum entropy method, but they do not use these moments as random variables in a detection algorithm. That is, to our knowledge this paper is the first one that use the moments space for developing optimal algorithms to detection of radar targets. DRACEC

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Nomenclature

Acronyms

DRACEC Radar Detection through the Analysis and Statistical Classification of Cellular Emission.
ABR Anomaly to Background Ratio.
NCIM Non-Coherent Integration Method.
AWGN Additive White Gaussian Noise.
LPF Low-Pass Filter.
SNR Signal to Noise Ratio.
IM Independent Moments.
CM Correlated Moments.
jpdf Joint probability density function.

Symbols

i, j, h Spatial coordinates of the analyzed resolution cell.
u Order number of a resolution cell.
w Order number of the selected signal parameter.
W Maximum number of selected signal parameters.
$\xi_u^w(t)$ Random process representing the w parameter of the signal at the u resolution cell.
x_g Random variable at time t_g.
x_g Values of the random variable x_g.
k_g Exponent of x_g for the moment calculation.
g Order of the statistic.
G Maximum order of the statistic.
$m^w_{k_1,\dots,k_g}(t_1,\dots,t_g)$ Moment of the random process $\xi_u^w(t)$ of order $k_1+\dots+k_g$ and statistic order g.
M Sample size of the selected parameter.
N Number of moments calculated from the samples of the random process $\xi_u^w(t)$.
$m_q(u, w, g)$ Moment of the random process $\xi_u^w(t)$, corresponding to the triad u, w, g.
q Ordering number of the moment $m_q(u, w, g)$.
$\mathbf{M_c}\ (u)$ Classification matrix of the u resolution cell.
$Q\ (w, g)$ Number of components of the vector corresponding to the element (w, g) of the classification matrix.
$\mathbf{I}\ (u)$ Classification vector of the u resolution cell.
η Dimension of the classification vector.
C_1 and C_2 General classes.
$d_{1,2}$ Euclidean distance between classes C_1 and
C_2 which coordinates are the population means of the moments.
μ Vector whose components are the moments.
s Ordering number of the components of vector μ.
$m^P_{C,s}$ Population mean of the s moment corresponding to class C.
$\sigma^2_{C,s}$ Variance of the s moment corresponding to class C.
$p_C(\cdot)$ Probability density function of class C.
$\Lambda\ (\mu)$ Likelihood ratio of vector μ.
P_D Probability of detection.
P_F Probability of False Alarm.
Z Sufficient statistic for decision making.
Z_0 Decision threshold for Z.

method has its groundwork in [13] and has been presented in [14], previously, the information offered in this respect was limited to local reports of restricted access.

This work is organized as follows: in section 2 the problem formulation is made and section 3 presents the procedure to form the selected moments from the random samples of the parameter. The definitions of contrast ratio between classes and, in particular, the *anomaly-to-background* ratio are given in section 4. In section 5 the optimal detection algorithms based on the Neyman–Pearson criterion are developed for independent and correlated moments. Section 6 shows the improved detection performance of DRACEC when compared to the widely employed non-coherent integration method (NCIM) and finally, in section 7 the conclusions are presented.

2. Problem formulation

In [14] were defined the surveillance region and the searching area for a two dimensional case. These concepts are expanded here to its three dimensional counterparts. The searching volume, inside the surveillance region as illustrated in Fig. 1, is chosen with appropriate dimensions so that the medium contained therein and the random processes taking place in it can be considered respectively homogeneous and stationary spatially and temporarily, existing methods such as those shown by [15,16], that guarantee the fulfillment of these conditions. The searching volume is divided into resolution cells, representing the indexes $i = 1, \dots, m$; $j = 1, \dots, n$; $h = 1, \dots, s$, the distance ring, the azimuth sector and the inclination sector of the cell under analysis.

When a disturbance occurs in the searching volume, the random processes that characterize the scattered signals contain information about the phenomenon that modified the *background* statistical behavior, making possible the cellular emission classification. The term *radar target*, considered as any disturbance of the observed environment, is replaced by that of *anomaly*, while

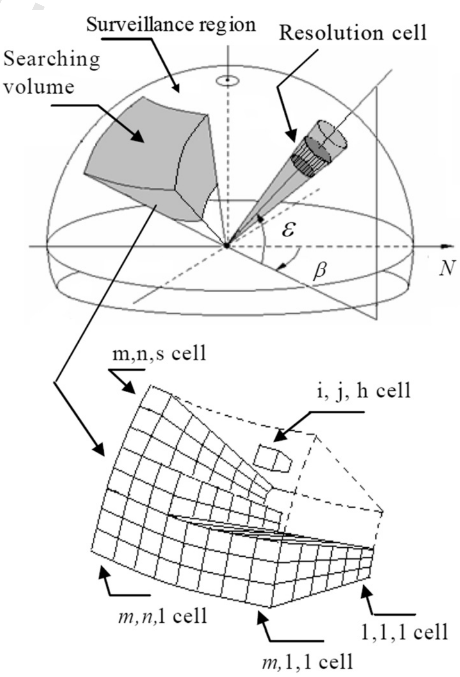

Fig. 1. Surveillance region and searching volume divided into resolution cells.

the observed medium hereafter will be called *background*. During the detection process, each resolution cell is assigned to the *background* class or to the *anomaly* class.

This classification (anomalies detection) is carried out by calculating the moments of one or a set of the scattered signal parameters (amplitude, frequency, phase, etc.). The parameters are random processes that will be symbolized by $\xi_u^w(t)$, where $w = 1, \dots, W$ and $u = j + (i-1)n + (h-1)mn$, represent the ordering given to

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