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LETTER

Automatic censoring CFAR detector for heterogeneous environments

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ABSTRACT

In radar detection, many constant false alarm rate (CFAR) processors have been proposed in the literature. It is well known that a processor is optimal only for one type of environment and that its detection performances are seriously degraded in presence of unknown irregularities. In such situations, the main difficulty resides in the estimation of the background configuration. That is, depending upon the non-homogeneity of the environment, one would choose the adequate optimal detection algorithm among a variety of known conventional ones that offer the best detection probability. Based on unknown transitions; *i.e.*, in the presence of a priori unknown numbers of interfering targets and/or clutter edge, we propose an automatic censoring CFAR (AC-CFAR) detector for heterogeneous Gaussian clutter. The censoring technique used in this work offers a good discrimination between homogeneous and non-homogeneous environments. The proposed detector dynamically switches to the optimal conventional detector CA-, CMLD- or TM-CFAR. The performances of the proposed detector is evaluated and compared to existing detectors in various background situations. Monte Carlo simulations show that the AC-CFAR detector performs like the CA-CFAR in a homogeneous background. Moreover, the proposed detector exhibits considerable robustness in the presence of interfering targets and/or clutter-edge situations.

1. Introduction

In modern radar systems, automatic target detection is based upon a binary decision for which the presence and absence hypotheses are noted H_1 and H_0, respectively. The detection algorithms are then optimized subject to a particular criterion such as the Neyman–Pearson. In unknown background levels, these detectors make use of an adaptive threshold that insures the constancy of a desired probability of false alarm (P_{fa}). In Gaussian environments, the conventional CFAR schemes are the well-known mean level detectors such as the cell averaging (CA-CFAR), the greatest of (GO-CFAR) and the smallest of (SO-CFAR) detectors [1–3]. Since these detectors have shown great CFAR losses in the presence of secondary targets, the order statistics (OS)-based CFAR have been proposed to circumvent these multiple target situations [4–6]. In [4], Rickard and Dillard developed the censored mean level detector (CMLD-CFAR) in which the largest range cells are censored from the reference window prior to noise level estimation. This detector is robust in multiple target situations as long as the number of censored cells exceeds the number of secondary targets. In [5], Rohling proposed an improved version of the CMLD-CFAR detector, known as the ordered statistics (OS-CFAR) detector. In [6], the trimmed mean (TM-CFAR) detector is seen as a generalization of the OS-CFAR and CMLD-CFAR detectors. This detector simply excises the upper and lower ends of the ordered reference window cells and sums up the remaining cells to estimate the unknown background level. It is well known that the above cited detectors suffer from the unknown a priori knowledge of the number of secondary targets and/or clutter edge location. For this, several research works have dealt with the automatic detection of these transitions [7–13].

In [7], Barkat et al proposed the generalized CMLD-CFAR (GCMLD-CFAR) which does not require any prior knowledge of the number of interfering targets. In [8], the same authors introduced the automatic CMLD (ACMLD) and the generalized two levels CMLD (GTL-CMLD). The ACMLD and the GTL-CMLD are based on the same cell-by-cell procedure for rejecting the unwanted cells. However, they both suffer from substantial computational requirements. In [9], Srinivasan introduced the Ensemble-CFAR (E-CFAR). This detector switches to detectors that are known to adjust themselves to particular situations. Later, the variability index-CFAR (VI-CFAR) [10] was proposed. An improved version of this detector namely the IVI-CFAR was analyzed in [11]. Based on the outcomes of the VI and the mean ratio hypothesis tests, these detectors dynamically switch to the CA-, SO-, GO- or the OS-CFAR. In [12], Farrouki and Barkat proposed the automatic censoring cell averaging ordered data

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variability (ACCA-ODV-CFAR) detector. Based on an ODV scheme, this detector starts by censoring outlying samples corresponding to the secondary targets, and then estimates the detection threshold through the conventional CA-CFAR algorithm. However, this detector suffers from excessive false alarm rate in clutter edge situations. In recent years [13], a new CFAR detector composed of an automatic dual censoring algorithm and cell-averaging CFAR (ADCCA)-CFAR detector is proposed. This detector does not require any prior knowledge about the background observation. It uses fuzzy membership function to determine and censor the unwanted samples in the reference window. Moreover, a new switching constant false-alarm rate (CFAR) detection algorithm (S-CFAR) has been proposed and analyzed in [14]. The S-CFAR algorithm selects CFAR reference samples using the magnitude of the sample in the test cell. The S-CFAR is also simple to implement since no sample ordering is required. This work has been commented by Meng [15] who recommended the use of the order statistic theory to obtain alternative expressions for the detection probability and the false-alarm rate of the S-CFAR in a homogeneous background.

In multiple target and clutter edge situations, fixed point censoring CFAR detectors based on order statistics have been known to improve the detection performance by excising the lower and higher unwanted reference cells. However, these detectors give good results only if the respective numbers of interfering targets and clutter transitions present in the reference window are known a priori, which is not always available in real applications. Consequently, a considerable degradation in the detection performance of the fixed point censoring is observed in [16]. Automatic censoring techniques have, for their part, many contributed to the improvement of the detection performance of these detectors. The well-known approaches proposed in the literature are found in [9,12,13] for a Gaussian clutter. Therein, the authors use ordered statistics to discriminate between homogeneous and heterogeneous environments.

In this work, we propose a detector based on a censoring procedure and assess its detection performance in a Gaussian environment. Based on unknown transitions; *i.e.*, in the presence of an unknown number of interfering targets and/or clutter edge in the reference window, we propose an automatic censoring CFAR detector for homogeneous and non-homogeneous background. The censoring algorithm proposed in this work offers a good discrimination between homogeneous and non-homogeneous environments. The first step consists of determining the transitions (k_1, k_2) using the scaling factor of transition according to the desired probability of false censoring (P_{fc}). Secondly, the proposed detector dynamically switches to the optimal conventional detector CA-, CMLD- or TM-CFAR which is chosen depending on the transitions k_1 and k_2. The detection algorithm selects repeatedly a suitable set of the ranked reference cells surrounding the cell under test to estimate the unknown background level and set the adaptive threshold detection accordingly. The performances of the AC-CFAR is evaluated in different environments and compared to the performance of the CA-, CMLD-, ACCA-ODV- and ADCCA-CFAR detectors.

In Section 2, we describe the proposed detector, then give the assumptions and formulate the problem at hand. The censoring procedure is presented in Section 3. In Section 4, we discuss the system performances by means of Monte-Carlo simulations. Finally, in Section 5, we provide conclusions and perspectives.

2. Assumptions and problem formulation

At the input of the envelope detector, the in-phase and quadrature phase signals (I, Q) are square-law envelope detected and fed into a tapped delay line of length $N+1=2n+1$. The $(N+1)$ samples correspond to the reference cells $X_i (i=1, \ldots, N)$ surrounding the cell under test X_0 as shown in Fig. 1. We consider single pulse detection and assume that the target fluctuates according to the Swerling II (SWII) models [16]. For homogeneous noise plus clutter level, the I and Q signals are assumed to be independent and identically distributed (*iid*) random Gaussian processes with zero mean and unit variance. Consequently, the samples in the reference window are also *iid* processes with an exponential distribution. Thus, the probability density function (*PDF*) of the ith cell is then given by

$$f_{Xi}(x) = \left(\frac{1}{\mu}\right) \exp\left(\frac{-x}{\mu}\right) \quad (1)$$

where μ denotes the scale parameter of the distribution from which the observation x is generated. In non-homogeneous environments, the value of μ depends on the content of the observed cell. When the ith reference cell is immersed in clutter containing an interfering target, μ may be written as

$$\mu = \mu_t(1 + CNR + INR) \quad (2)$$

μ_t denotes the thermal noise power (normalized to unity), *CNR* and *INR* represent, respectively, the clutter-to-noise ratio and the interference-to-noise ratio. If the reference cell contains thermal noise only, $CNR = 0$ and $INR = 0$. On the other hand, when the test cell X_0 is considered under the hypothesis of the presence of a primary target, *INR* is replaced by *SNR* (signal-to-noise ratio) in (2). The detector discussed in Fig. 1 does not require any knowledge about the environment, *i.e.*, the number of interferences and/or location of the clutter edge.

The censoring procedure first ranks the outputs of all reference range cells in ascending order according to their magnitudes to yield:

$$X(1) \le X(2) \le \cdots \le X(N) \quad (3)$$

where the *PDF* of the $X(i)$, $i = 1, 2, \ldots, N$, are given by [17]

$$f_{X(i)}(x) = i\binom{N}{i}(1-\exp(-x))^i\, exp-(N-i+1)x \quad (4)$$

Note that the samples in (3) are neither independent nor identically distributed. However, for the X_i'*s* whose *PDF's* are given by (1), it is proved in [17], that the random variables Y_i, defined by (5) are not only *iid* but also exponentially distributed,

$$Y_i = (N-i+1)(X(i) - X(i-1)), \quad i = 1, 2, \ldots, N \quad (5)$$

we assume that the $X(0) = 0$.

That is, as far as (5) is concerned, we can make use of the CA-CFAR algorithm only to localize any transitions in the ranked reference cells. To this effect, we first consider the case of a single transition k_1 from a lower total noise background power level to a higher level (clutter edge or interferences plus thermal noise). The k_1 transition is computed according to the following statistical test:

$$k_1 = \begin{cases} j+1 & \text{if } Y_{j+1} \ge T_j \sum_{i=1}^{j} Y_i \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

where $j = 1, 2, \ldots, (N-1)$ and T_j is the constant scale factor of the CA-CFAR algorithm which maintains a constant (P_{fc}) [1]:

$$P_{fc} = (T_j + 1)^{-j} \quad (7)$$

or

$$T_j = P_{fc}^{-(1/j)} - 1 \quad (8)$$

in which case, if $0 < k_1 \le N/2$, we search for a second possible transition k_2 from a lower clutter-plus-thermal noise power level to a higher level (interferences immersed in the clutter-plus-thermal