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A Monte Carlo simulation for two novel automatic censoring techniques of radar interfering targets in log-normal clutter

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Abstract

In this paper, we present two novel algorithms for automatic censoring of radar interfering targets in log-normal clutter. The proposed algorithms consist of two steps: removing the corrupted reference cells (censoring) and the actual detection. Both steps are performed dynamically by using a suitable set of ranked cells to estimate the unknown background level and set the adaptive thresholds accordingly. The proposed detectors do not require any prior information about the clutter parameters nor do they require the number of interfering targets. The effectiveness of the proposed algorithms is assessed by computing, using Monte Carlo simulations, the probability of censoring and the probability of detection in different background environments.

Keywords: CFAR; Log-normal clutter; Censoring; Probability of detection; Probability of false alarm; Probability of false censoring

1. Introduction

The signal returns from radar targets are usually buried in thermal noise and clutter. Target detection is commonly performed by comparing radar returns to an adaptive threshold such that a constant false alarm rate (CFAR) is maintained. The threshold in a CFAR detector is set on a cell by cell basis according to the estimated noise/clutter power, which is determined by processing a group of reference cells surrounding the cell under investigation. For example, the cell-averaging (CA)-CFAR processor adaptively sets the threshold by estimating the mean level in a window of N range cells. The detection performance of the CA-CFAR processor is optimum in a homogeneous background when the reference cells contain independent and identically distributed (IID) observations governed by an exponential distribution [1,2]. In practice, the environment is usually nonhomogeneous due to the presence of multiple targets and/or clutter edges in the reference window. In such situations, order statistics (OS)-detectors have been known to yield good performance as long as the nonhomogeneous background and outlying returns are properly discarded [3–5]. However, most of the work in the literature considers some type of censoring based on a priori knowledge or a judicial guess.

Some approaches based on automatic censoring of unwanted cells have been proposed in the literature. In [6–8], censoring is performed by first

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using some initial set, which should be free of interferences, and the assumedly signal-free samples are sequentially added to the clean set which is then exploited in signal detection. In [9], a new approach synthesizing the advantages of known CFAR processors and designed for robust CFAR detection has been introduced. In [10], the concept of variability index (VI) detection has been presented and utilized for automatic reference window selection and adaptive threshold generation in various nonhomogeneous environments. Recently, the automatic censored cell-averaging (ACCA) CFAR detector based on ordered data variability (ODV) for nonhomogeneous background environments has been proposed [11]. The ACCA-ODV detector selects dynamically, by doing successive hypothesis tests, a suitable set of ranked cells to estimate the unknown background level and set the adaptive threshold.

It is worth noting that the automatic censoring algorithms mentioned above have been developed for maintaining CFAR detection in Rayleigh clutter. In this work, we consider the problem of automatic censoring of unknown number of interfering targets in log-normal clutter. The main motivations behind the development of such automatic censoring algorithms are due to the following:

(i) With high resolution radar, low grazing angles, and horizontal polarization at high frequencies, the amplitude statistics of clutter returns deviates from Rayleigh distribution and shows long-tail characteristics which, in many practical situations, can be modeled by log-normal distribution [12–16].
(ii) The automatic censoring algorithms developed for Rayleigh clutter may not straightforwardly be extended to the case where clutter samples are drawn from log-normal distribution. For example, the ordered data variability index based on which the detector of [11] has been developed may be difficult to use for automatic censoring in log-normal clutter because this index, as formally defined in [10], is highly dependent on the shape parameter of clutter distribution; a parameter difficult to estimate reliably in practice.
(iii) The adaptive threshold of OS-CFAR processors is formally defined in terms of ranked samples of reference cells. To reduce the CFAR loss and improve detection probability of log-normal OS-CFAR processors, the largest sample of ranked cells, involved in the computation of detection threshold, can be properly selected when the exact number of interfering targets is accurately determined.

Therefore, the results of this research work has an attractive feature in that it adds to the available log-normal CFAR detectors [17–20] the potential to determine and censor (efficiently) the unwanted targets samples in the reference window, which may cause an excessive number of false alarm or a poor probability of detection.

The organization of the paper is as follows. In Section 2, the problem to be addressed is first formulated. In Section 3, two novel automatic censoring algorithms, which use a set of ranked thresholds to discriminate between homogeneous and nonhomogeneous populations, are proposed. In Section 4, performance of the proposed censoring algorithms is evaluated in different environments to show their ability in eliminating unwanted cells.

2. Problem formulation

In a CFAR processor, the linear envelope-detected matched-filter outputs $\{X_i\colon i=0,1,\ldots,N\}$, obtained by range resolution and/or Doppler resolution, are stored in a tapped delay line, as shown in Fig. 1. The cell with the subscript $i=0$ is the resolution cell under test. The remaining N surrounding cells are the auxiliary cells used to construct the CFAR procedure. These auxiliary cells are processed by an operator f to yield an adaptive threshold T; that is,

$$T=f(X_1,X_2,\ldots,X_N). \tag{1}$$

Let $X(1)$, $X(2)$,…, $X(N)$ represent IID random variables ranked in order, where $X(i)$ is the ith largest sample drawn from log-normal distribution with probability density function

$$f(x)=\frac{1}{\sqrt{2\pi}\sigma x}\exp\left[\frac{-(\ln x-\mu)^2}{2\sigma^2}\right],\quad x>0, \tag{2}$$

where μ is the scale parameter and σ is the variance shape parameter. The cell under test X_0 is to be compared with the threshold T to decide whether a target is present or not. Choosing [17]

$$T=X(i)^{\alpha}X(j)^{1-\alpha}, \tag{3}$$

leads to a CFAR processor independent of μ and σ. Note that the threshold T is parameterized by the variable α. The two subscripts i and j are taken to