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A GLRT for multichannel radar detection in the presence of both compound Gaussian clutter and additive white Gaussian noise ☆

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Abstract

Motivated by multichannel radar detection applications in the presence of both white Gaussian noise and Gaussian clutter with unknown power, we develop maximum likelihood parameter estimates for the disturbance process. Both cases with known and unknown white noise variance are treated. As the estimators do not admit closed-form solutions, numerical iterative procedures are developed that are guaranteed to at least converge to the local maximum. The developed estimates allow us to construct a generalized likelihood ratio test (GLRT) for the detection of a signal with constant but unknown amplitude. This GLRT has important applications in multichannel radar detection involving both white Gaussian noise and spherically invariant random process clutter and is shown to have better detection performance and CFAR property compared with existing statistics.

Keywords: Maximum likelihood estimate; Generalized likelihood ratio test; Spherically invariant random processes; Multichannel radar detection

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1. Introduction

Multichannel radar detection considers the detection for the possible presence of a target at a given steering direction in background clutter/noise. For air-borne high resolution radars operating at low gazing angles, the compound Gaussian process has emerged as a viable model to describe the backscattering process. For this clutter model, the clutter vector $\mathbf{c}$ is expressed as $\mathbf{c} = \sqrt{s}\mathbf{g}$, where $\mathbf{g}$ is complex Gaussian with covariance matrix $\mathbf{\Sigma}$ and s is a real nonnegative scalar, unknown clutter component (also called texture component) statistically independent of $\mathbf{g}$. The power variation of ground clutter among range cells is captured by the variation of s while the Gaussianity is dictated by the central limit theorem applied locally to each range cell. Thus, multichannel radar detection in the presence of compound Gaussian clutter and additive white Gaussian noise (AWGN) can be formulated as the following hypothesis testing problem:

$$\begin{aligned} &\mathbf{H}_0, \quad \mathbf{x} = \sqrt{s}\mathbf{g} + \mathbf{n}, \\ &\mathbf{H}_1, \quad \mathbf{x} = a\mathbf{v} + \sqrt{s}\mathbf{g} + \mathbf{n}, \end{aligned} \tag{1}$$

where $\mathbf{x} \in C^N$ is the complex observation data vector, N is the vector size,[2] $\mathbf{v}$ is the steering vector, a is the unknown complex signal amplitude, and $\mathbf{n}$ is the complex AWGN vector with covariance matrix $\sigma^2\mathbf{I}$. We further denote $\mathbf{M} = s\mathbf{\Sigma} + \sigma^2\mathbf{I}$ as the covariance matrix for the overall disturbance for the cell under test. Here we consider s as a deterministic, unknown clutter parameter. However, it is worth mentioning that a widely referenced class of random processes, the so-called spherically invariant random process (SIRP) is a special class of compound-Gaussian by imposing a stochastic parametric model on the scalar term. Examples for SIRP clutter [1–5] include the K and Weibull envelope distributions for specific shape parameter values.

While much effort has been undertaken in finding a good detector for signals embedded in compound Gaussian clutter, most existing work assumes a clutter-only model; i.e., the presence of AWGN at the receiver is largely ignored. Consider the clairvoyant case of known $\mathbf{\Sigma}$, i.e., the covariance structure of $\mathbf{g}$ is known. In the absence of white Gaussian noise $\mathbf{n}$, the maximum likelihood (ML) estimate of the unknown parameters, namely the signal amplitude a and the scalar power term for the compound Gaussian component s, can be readily derived. Substituting the ML estimate under the two hypotheses into the likelihood ratio for the hypothesis testing problem [4], one arrives at the well-known test statistic in the form of

$$\Gamma_1 = \frac{|\mathbf{x}^H\mathbf{\Sigma}^{-1}\mathbf{v}|^2}{(\mathbf{x}^H\mathbf{\Sigma}^{-1}\mathbf{x})(\mathbf{v}^H\mathbf{\Sigma}^{-1}\mathbf{v})}. \tag{2}$$

We remark here that this test statistic has been independently developed in Ref. [5] as an asymptotically optimum test for radar detection in compound Gaussian clutter using the representation theorem for SIRP derived in Ref. [3]. Since this test statistic added to the matched filter detector a normalizing constant $\mathbf{x}^H\mathbf{\Sigma}^{-1}\mathbf{x}$, we will term it the normalized matched filter (NMF).

[2] In the context of space time processing, $N = JL$ where J is the number of antenna elements and L is the number of pulses within one coherent processing interval.