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# Distributed target detection in subspace interference plus Gaussian noise

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ABSTRACT

In this paper, the problem of detecting distributed targets in the presence of subspace interference and Gaussian noise is addressed. The subspace interference signals are modeled as linear combinations of the linearly independent columns of a known subspace matrix. Two kinds of distributed matched subspace detectors are derived to handle this detection problem. The first kind of distributed matched subspace detector referred to as I-DMSD is obtained on the assumption of known noise power level. The other one referred to as II-DMSD is developed on the basis of unknown noise power level. Expressions for the probabilities of false alarm and detection of the I-DMSD and II-DMSD for unfluctuating and fluctuating target models are derived, which are confirmed with Monte Carlo simulations. Numerical simulations are conducted to illustrate the detection performance of the two detectors. It is demonstrated that both detectors ensure a constant false alarm rate (CFAR) property against the interference, and the II-DMSD also exhibits the CFAR property with respect to the noise power level.



## 1. Introduction

A target observed by a high resolution radar (HRR) may be resolved into many isolated scattering centers, and occupy a few range cells. Experiments reveal that many targets (e.g., aircrafts), when observed by HHRs, can be modeled as a number of dominant scattering centers [1,2]. The number of the scattering centers or the occupied range cells is determined by the range extent of the target along the line of sight and the range resolution capability of the radar [3]. Notice that the spatially resolved target model is not only valid for a HRR, but also for a low/medium resolution radar. For example, several targets may be spatially distributed and appear in many range cells, even though they are observed with a low/medium resolution radar. In practice, large ships, when viewed through low/medium resolution coastal radars, can be separated into several range cells [4,5]. In addition, a cluster of point-targets (or multiple point-like targets), spatially close to each other and moving at the same velocity, may be equivalent to a large-scale target, and thus can be well described by the resolved target model [6]. Throughout this paper, the target separated into a number of range cells is referred to as distributed (or range-spread or extended) target.

Several algorithms have been developed to detect distributed targets in white Gaussian noise with known power level [7,8]. In [9], a modified generalized likelihood ratio test (GLRT) is derived for detecting distributed targets in correlated Gaussian noise with unknown covariance matrix. Interestingly, this modified GLRT does not require secondary data. It is worth noting that the probability of false alarm of the modified GLRT is associated with the true noise covariance matrix, and thus it ceases to be a constant false alarm rate (CFAR) detector. Nevertheless, the modified GLRT is proved to bear a bounded CFAR. Using polarization diversity, De Maio proposed a polarimetric modified GLRT to improve the detection performance of a radar system

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[10]. The detection of a target distributed both in range and in Doppler frequency is considered in [11,12]. When the scattering centers of distributed targets occupy only a fraction of the range extent of the target, the detectors developed on the assumption that the target scatters occupy all range cells may undergo considerable performance loss. Effective detection algorithms based on *a priori* knowledge about the spatial scattering density of the sparse target scatters are provided in [8,13,14]. In partially homogeneous and compound Gaussian clutters, the problem of detecting distributed targets is examined in [15,16], respectively. Ref. [17] considers the problem of waveform design for improving detection of extended targets.

When target echoes are contaminated by interference, these detectors designed without taking into account the interference inevitably suffer considerable performance degradation. In some cases such as sinusoidal interference [18] and interference from multiple angles [19], the interference can be well described by subspace models where the interference denoted by $\mathbf{J}$ is assumed to belong to the subspace spanned by the columns of an interference subspace matrix denoted by $\mathbf{B}$, i.e., $\mathbf{J}=\mathbf{Bb}$ with $\mathbf{b}$ representing the interference coordinate [20–24]. In order to account for partial uncertainty with regard to a target's spatial signature, a subspace target model is adopted in [25], namely, the useful target echoes are modeled as vectors confined to a known signal subspace. The treatment of useful target returns with subspace models can also be found in many publications (e.g., [11,18,19,26]). It is worth noting that target echoes can be modeled as deterministic signals [18] or random signals [26]. The former case is referred to as unfluctuating target model, and the latter is called fluctuating target model.

Scharf investigated in detail the problem of detecting a point-like target, described with the subspace model in the background of subspace interference plus white Gaussian noise, and developed several kinds of matched subspace detectors (MSDs) according to different assumptions [18]. However, the detection of distributed targets is not considered in [18]. The problem of detecting distributed targets embedded in subspace interference plus Gaussian noise has been studied in [23], where the noise may be either homogeneous or partially homogeneous, and the interference subspace is either known or unknown. The one-step and two-step GLRT-based detectors have been proposed to deal with this problem. It is indicated that the proposed detectors generally outperform the ones designed without considering the presence of the interference. Nevertheless, these detectors proposed in [23] are highly complicated, and cannot even be expressed explicitly. Consequently, it is difficult to describe the statistical properties of these detectors, and Monte Carlo (MC) simulations are used to assess the performance of these detectors.

Here, we concern ourselves with the problem of detecting distributed targets in interference-plus-noise environments where the interference subspace is known and the noise is modeled as a white Gaussian process with known or unknown power level. Notice that the detection problem considered here is different from that examined in [23], since the noise covariance matrix is assumed to be unknown in [23] and hence a set of secondary data is needed for the estimation of the noise covariance matrix, whereas the noise covariance matrix in this study is assumed to be an identity matrix multiplied by a known or unknown power factor.

When the noise power level is known, the first kind of distributed MSD referred to as I-DMSD is proposed. With unknown noise power level, the second kind of distributed MSD called II-DMSD is then derived. The two detectors are applied to unfluctuating and fluctuating target models. In the unfluctuating target model, the target signal in each range cells is assumed deterministic while in the fluctuating target model, the target signals in different range cells are supposed to be independent but not necessarily identically distributed complex Gaussian variables. It is worth noticing that we examine not only the case of unfluctuating target model, but also the case of fluctuating target model which is not considered in [23]. Particularly, expressions for the probabilities of false alarm and detection of the I-DMSD and II-DMSD for both the unfluctuating and fluctuating target models are derived. It is found from these derived expressions that both the detectors guarantee the CFAR property against the interference, and the II-DMSD also possesses the CFAR property with respect to the noise power level. In addition, the detection probabilities of the two detectors are irrelevant to the interference coordinates, which means that the interference can be completely suppressed by using the proposed detectors.

The remainder of this paper is organized as follows. Section 2 introduces a signal model. In Sections 3 and 4, the I-DMSD and II-DMSD are proposed, respectively. In Section 5, the fluctuating target model is considered. Simulation results are illustrated in Section 6 and finally the paper is summarized in Section 7.

## 2. Signal model

Suppose that a target across $K$ range cells is observed by using an array consisting of $N_a$ antennas, and each antenna collects $N_t$ samples from each of those range cells. Here, we assume that the target echoes appear in each of the $K$ range cells.[1] The target return from the $k$th range cell is denoted by an $N$-dimensional complex vector $\mathbf{x}_k \in \mathbb{C}^N$, where $N=N_aN_t$. These vectors referred to as primary data or testing data are constrained to be of the form [23]

$$\mathbf{x}_k=\mathbf{S}\mathbf{a}_k+\mathbf{B}\mathbf{b}_k+\mathbf{n}_k, \quad k=1,2,\ldots,K \tag{1}$$

where

- $\mathbf{S}\in\mathbb{C}^{N\times q}$ is a known full-column-rank signal subspace matrix; $\mathbf{a}_k\in\mathbb{C}^q$ are deterministic but unknown $q$-dimensional complex vectors accounting for both the target reflectivity and the channel propagation effects; it implies that we know the subspace where the target signal lies but we do not know its exact location, since $\mathbf{a}_k$ is unknown.
- $\mathbf{B}\in\mathbb{C}^{N\times p}$ denotes a known full-column-rank interference subspace matrix, and the $p$-dimensional complex

[1] The case where the target returns occupy only a fraction of range cells can be handled by the approaches similar to those in [8,14,27].