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Low Complexity Robust Direction Finding Method for Impulsive Noise in l_p-Space

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Abstract

A robust low complexity direction of arrival (DOA) estimation methodforimpulsive noise is proposed in this paper. The presence of outliers makes it difficult to estimate the subspace accurately, and as a result leads to serious estimation errors. In our method, robust signal subspace is first obtained by iterative re-weight singular value decomposition (IR-SVD) of data matrix. Then subspace rotation operator is calculated via matrix l_p-norm minimization procedureinstead of least squares (LS). Compared to traditional ESPRIT, our proposed method performs more robust in the presence of impulsive noise. Besides, this ESPRIT like method provides close-form solution of DOA, which saves computational load by avoiding grid searching. Simulation results illustrate that proposed method outperforms than several outliers-resistant algorithms in scenario of impulsive noise.

Keywords: impulsive noise, robust DOA, ESPRIT, l_p-space;

1. Introduction

Direction-of-arrival (DOA) estimation is critical in many applications such as radar, sonar, and wireless communication systems. The presence of non-Gaussian noise makes performance of some well-known algorithms degrade, such as MUSIC[1], ESPRIT[2], weight subspace fitting (WSF)[3],and space-alternating generalized expectation maximization (SAGE)[4]. For subspace based methods, the presence of outliers leads to estimation errors of the subspace, and as a result causes serous estimate errors of DOA.

To resist effect of outliers, some improved algorithms have been proposed[5-10]. For example, FLOM-MUSIC[5], ROC-MUSIC[6], FLOC-ESPRIT[7], and FLIC-MUSIC[8] aim to construct a more robust covariancematrix, named low-order moment, which can be used to obtain robust DOA estimations by means ofMUSIC or ESPRIT. However, when the probability density function (PDF) of noise has a heavy tail, this kind of algorithms performs poorly. The algorithm proposed by Yardimic[9] attempts to design an optimal penalty function via maximum likelihood estimation technique according to specific noise model. ZMNL-MUSIC[10] applies zero-memory nonlinear (ZMNL) functions to

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clip the effect of outliers, which can provide more accurate estimations with low computational complexity cost, while the performance may degrade due to rank increase of the signal subspace.

The key step of subspace based methods is to estimate the signal or noise subspace. Under the assumption of Gaussian noise, singular value decomposition (SVD) of data matrix or engine Eigenvalue decomposition (EVD) of covarianceprovide optimal estimation of signal or noise subspace. While the presence of outliers produces estimate errors of subspace, consequently, causes serious DOA estimation error. Different from the above algorithms, another group of methods extend the conventional modus from l_2 to l_p-space, which can produce more robust parameter estimations than above methods, i.e. l_p-MUSIC[11].

The l_p-MUSIC is confirmed outperforms than current outliers-resistant methods[11], while also need grid searching of spectrum, which is an extremely time-consuming process especially in the case of joint azimuth and elevation angle estimation. In order to reduce the computational complexity, a robust ESPRIT like method is proposed which can provide close-form solution of DOA. Robust signal subspace is first obtained by means of IR-SVD of data matrix. Then subspace rotation operator is calculated in l_p-space instead of using least squares (LS). Finally, close-form solution of DOA can be obtained based on above steps. The notations used in this paper are as follows. $|\cdot|$ denotes the modulus of a complex number and $||\cdot||_p$denotes p norm of a vector. $[\cdot]^T$, $[\cdot]^H$and $[\cdot]^*$ denote transpose, Hermitian transpose and conjugate of matrix, respectively.

2. Problem Formulation

2.1. Signal Model

Consider a uniform linear array (ULA) of $M+1$ antennas that consists of two overlapping subarrays of Midentical and omnidirectional antennas each. Let the first subarray is composed of the antennas with the indices $1,2,\cdots,M$ and second one with the indices $2,3,\cdots,M+1$ .Assume that Lnarrow-band, far-field uncorrelated sources impinge on the array. The output snapshot vector of first M antennas (first subarray) can be written as

$$\mathbf{y}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{w}(t) \tag{1}$$

where $\boldsymbol{x}(t)$ isincident signal vector, $\mathbf{A} = \left[\mathbf{a}(\theta_1), \mathbf{a}(\theta_2), \cdots, \mathbf{a}(\theta_L)\right]$ is the array manifold matrix with

$$\mathbf{a}(\theta_i) = [1, e^{-j2\pi d sin(\theta_i)/\lambda}, \cdots, e^{-j2\pi(M-1) d sin(\theta_i)/\lambda}]^T \tag{2}$$

$\theta_i$is the direction of arrival and λ denotes wavelength. The inter-element spacing $d < \lambda/2$. $\mathbf{w}(t)$ is the additive non-Gaussian noise.In the rest of this article, we employ discrete time version of (1) with $n = t/T$, where T is the sampling interval. The received data of first subarray can be expressed as matrix form

$$\mathbf{Y} = \mathbf{A}\mathbf{X} + \mathbf{W} \tag{3}$$

where $\mathbf{Y} \in \mathbf{C}^{M \times N}$ is the received signal matrix with Nbeing the number of snapshots. Similarly, $\mathbf{X} \in \mathbf{C}^{L \times N}$ is the impinging signal matrix and $\mathbf{W} \in \mathbf{C}^{M \times N}$ is the Non-Gaussian noise matrix.Let $\mathbf{A}'$ denote manifold matrix of the second subarray, where $\mathbf{A}' = \mathbf{A}\boldsymbol{\Phi}$, termed rotational invariance among two subarray steering matrixes with

$$\boldsymbol{\Phi} = \text{diag}\left[e^{-j2\pi d sin(\theta_1)/\lambda}, e^{-j2\pi d sin(\theta_2)/\lambda}, \cdots, e^{-j2\pi d sin(\theta_L)/\lambda}\right]. \tag{4}$$

The diagonal matrix $\boldsymbol{\Phi}$ is the desired here, termed rotationalmatrix that carries the information of DOA. The expanded version of $\mathbf{Y}$ and $\mathbf{A}$ are defined as