A NOVEL UNIVERSAL PREPROCESSING APPROACH FOR HIGH-RESOLUTION DIRECTION-OF-ARRIVAL ESTIMATION

Wu Renbiao (吴仁彪)
(Xidian University, Xi'an, 710071)

Abstract A novel universal preprocessing method is proposed to estimate angles of arrival, which is applicable to one- or two-dimensional high resolution processing based on arbitrary center-symmetric arrays (such as uniform linear arrays, equal-spaced rectangular planar arrays and symmetric circular arrays). By mapping the complex signal space into the real one, the new method can effectively reduce the computation needed by the signal subspace direction finding techniques without any performance degradation. In addition, the new preprocessing scheme itself can decorrelate the coherent signals received on the array. For regular array geometry such as uniform linear arrays and equal-spaced rectangular planar arrays, the popular spatial smoothing preprocessing technique can be combined with the novel approach to improve the decorrelating ability. Simulation results confirm the above conclusions.

Key words Array signal processing; Direction finding; Spectrum estimation; High resolution techniques

I. Introduction

In recent years, signal subspace techniques for high-resolution direction-of-arrival (DOA) estimation attract the attention of many researchers in the field of array signal processing. These methods improve the angular resolution by signal processing rather than enlarging the aperture of the array. If the data covariance matrix were exactly known, they could resolve signals with arbitrary separation angles, and the resolution is independent of the signal-to-noise ratio (SNR). With the development of VLSI technology, they have promising applications in various areas such as radar and sonar array signal processing.

In spite of the brilliant future, there are still many problems in need of solving, among which the expensive computational cost and the detection of coherent signal sources are more striking. The signal subspace techniques consist mainly of two steps, one being the estimation of signal (or noise) subspace by taking orthogonal decomposition over the data covariance matrix; the other being the extraction of DOAs by picking the spectra peaks representing the incident angles of emitting sources. Either of the above two steps is confronted with taxing computational load. Although some separable approaches have been proposed to reduce computations, their resolution performance suffers much loss when the separable parameters roughly encounter annexation. As for the detection of coherent signals, the spatial smoothing preprocessing approach is widely used at present. Unfortunately it
applies only for uniform linear arrays.

Aiming at the above issues a novel preprocessing approach is presented in this paper, which manifests significant computational advantages and has some decorrelating capability, while the preprocessing itself involves only a little computation.

II. The Principle of the Novel Approach

For simplicity we will illustrate the basic principles of the novel approach using a uniform linear array, from which it is not difficult to generalize it to arbitrary center-symmetric arrays.

Assuming \( p \) narrow band signal sources impinge on a uniform linear array as shown in Fig.1 with incident angles \( \theta_1, \theta_2, \ldots, \theta_p \). Assuming that "\( d \)" denotes array element spacing and "\( o \)" represents the array reference point. Divide the whole array into two subarrays denoted by \( U_1 \) and \( U'_1 \). \( U_1 \) and \( U'_1 \) are composed of array elements labeled by \( 1, 2, \ldots, N \) and by \( 1', 2', \ldots, N' \), respectively.

For subarray \( U_1 \) the received data model can be written in vector notation as follows

\[
X_1 = A_1 \times S(t) + W_1(t) \tag{1}
\]

where \( X_1(t) = [x_1(t), x_2(t), \ldots, x_N(t)]^T \): the received data vector; \( S(t) = [s_1(t), s_2(t), \ldots, s_p(t)]^T \): the signal source vector; \( W_1(t) = [w_1(t), w_2(t), \ldots, w_N(t)]^T \): the received noise vector; \( A_1 = [a_1(\theta_1), a_1(\theta_2), \ldots, a_1(\theta_p)] \): the signal direction matrix; \( a_1(\theta_k) = \exp(j\pi d \cos \theta_k/\lambda) \), \( \exp(j3\pi d \cos \theta_k/\lambda) \), \( \ldots \), \( \exp(j(2N-1)\pi d \cos \theta_k/\lambda) \)^T (\( 1 \leq k \leq p \)) : the \( k \)-th steering vector; "\(^T\)" and "\( \lambda \)" denote transpose and the wavelength, respectively.

For subarray \( U'_1 \) the received data can be modeled as

\[
X_1' = A'_1 \times S(t) + W_1'(t) \tag{2}
\]

The meaning of every term in Eq.(2) is the same as that in Eq.(1).

Assuming that subarray \( U_1 \) and \( U'_1 \) are symmetric about the origin "\( o \)", then it follows

\[
A_1' = (A_1)^* \tag{3}
\]

where "\(^*\)" is the notation of complex conjugate. Define

\[
Y_1(t) = (X_1(t) + X_1'(t))/2
\]

\[
Y_2(t) = (X_1(t) - X_1'(t))/(2j)
\]