ON TWO-DIRECTION SPATIAL SMOOTHING FOR ESTIMATION ANGLE-OF-DIRECTION OF COHERENT SIGNALS

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Abstract Based on Evans' spatial smoothing preprocessing scheme, a new approach called two-direction spatial smoothing preprocessing method is presented. It is proved that the decorrelation, the effective aperture and the maximum number of distinguishable coherent signals (when array size is given) of the new method are better than those of the Evans' method. Simulation results give a comparison between the eigenvector spectrums produced by the two methods.

Key words Array antenna; Coherent signal; Two-direction spatial smoothing method

I. Introduction

In recent years, there has been a great interest in super-angle-resolution techniques of coherent signals because of the urgent need in dealing with multipath interference, low elevation angle tracking and high-resolution radar imaging. Some methods as the MLM and the MEM proposed by Capon and Burg respectively, resolved super-angle-resolution problems of the independent signals successfully, but they give very large angle deviation and can not resolve coherent signals[1]. The MUSIC[2] and EVM[3], which were proposed by Schmidt and Durdnini respectively, break through the limitation of the previous methods, and can give high resolution and unbiased estimation of angle, yet they can not resolve coherent signals.

To cope with super-angle-resolution of coherent signals, the spatial smoothing preprocessing scheme which was proposed by Evans[4] and developed more fully by Shan et al. [5] have shown that when the sensor number of array is equal to or larger than twice the number of signals, the original signal singular covariance matrix of coherent signals becomes nonsingular covariance matrix which has exactly the same form as the covariance matrix of incoherent signals. The minimum eigenvectors of the smoothed covariance matrix are still orthogonal to the signal direction vectors. Using the EVM can resolve coherent signals successfully. However reducing effective aperture is taken as the cost.

In this paper, based on Evans's spatial smoothing preprocessing scheme, a two-direction spatial smoothing (TSS) method is proposed. The decorrelation, the effective aperture and the maximum number of distinguishable coherent signals (when array scale is given) of the new method are better than those of the Evans' method and it can resolve even more coherent signals.

II. Array Model

Consider a uniform linear array with p identical omnidirectional sensors as shown in Fig.1. Let \( q (q \leq p - 1) \) be the number of the narrow-band plane waves, \( \omega_0 \) central frequency, and \( \theta_1, \theta_2, \ldots, \theta_q \) incident angle, respectively.

The statistics of signals and noises are assumed to be as follows:

\[
E[n_i] = 0, \quad E[n_i n_j^*] = \sigma_n^2 \delta_{ij}, \quad E[s_k n_j^*] = 0 \\
E[s_k s_k^*] = \sigma_k^2, \quad \forall i, j = 1, \ldots, p, \quad k = 1, \ldots, q
\]
Assume all element phasing is referenced to the first sensor, then the received signal at the jth sensor can be expressed as

\[ r_j(t) = \sum_{k=1}^{q} s_k(t) \exp(j \omega_0 (i - 1) \sin \theta_k \cdot d/c) + n_i(t) \]  \hspace{1cm} (1)

where \( s_k(t) \) is the complex envelope of the kth signal, \( n_i(t) \) the additive noise of the ith sensor at instant t, \( d \) the interval between sensors, and \( c \) the propagation speed of the wave.

By using vector representation, the received signals of the array can be expressed as

\[ r(t) = As(t) + n(t) \]  \hspace{1cm} (2)

where

\[ r(t) = [r_1(t) \cdots r_p(t)]^T; \hspace{0.5cm} s(t) = [s_1(t) \cdots s_q(t)]^T \]
\[ n(t) = [n_1(t) \cdots n_p(t)]^T \]

\[ A = \begin{bmatrix}
1 & \cdots & 1 \\
\exp(j \omega_0 \tau_1) & \cdots & \exp(j \omega_0 \tau_q) \\
\vdots & \ddots & \vdots \\
\exp(j \omega_0 (p-1) \tau_1) & \cdots & \exp(j \omega_0 (p-1) \tau_q)
\end{bmatrix} \triangleq [a(\theta_1) \cdots a(\theta_q)] \]

where \( a(\theta_i) \triangleq [\exp(j \omega_0 \tau_1) \cdots \exp(j \omega_0 (p-1) \tau_i)]^T \) is referred to the direction vector of the ith signal, \( \tau_i = (d \sin \theta_i)/c, i = 1, 2, \cdots, q. \)

The spatial covariance matrix of the received signals is defined as:

\[ R = E[r(t)r^H(t)] \]  \hspace{1cm} (3)

where \( H \) denotes the complex conjugate transposition, and substituting Eq.(2) into Eq.(3), we have

\[ R = AR_sA^H + \sigma_n^2 I \]  \hspace{1cm} (4)

where \( R_s = E[s(t)s^H(t)], E[n(t)n^H(t)] = \sigma_n^2 I. \) \( R_s \) is the covariance matrix of signals. When signals are incoherent, \( R_s \) is nonsingular (i.e. \( R_s \) is a full rank matrix); and if signals are coherent, \( R_s \) is singular (i.e. \( R_s \) is a deteriorative matrix). Shan et al. [5] showed that the EVM can not resolve coherent signals because of the singularity of \( R_s \) for the coherent case. 

The spatial smoothing method proposed by Evans has been the most promising solution to the coherent signals problem.