A 2-Dimensional Smoothing Technique in Non-stationary Environments

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1. Introduction

Subspace methods have been widely used in various wireless communication applications such as space-time antenna array signal processing, system identification and channel estimation [1], [2]. It is well known that the subspace method is focusing on decomposing the orthogonal signal and noise subspace by block-wise processing over empirical covariance matrix, with which performance suffers from non-stationarity in environment due to short measurement period of fast-moving targets, such as air-crafts, trains, and cars. Moreover, due to the fact that the empirical covariance matrix calculated from the received signals for eigenvalue decomposition (EVD) must be non-singular, the decorrelation of coherent signals is a fundamental task in non-stationary environments.

The conventional spatial smoothing technique is used in decorrelation. The array elements are divided into several sub-arrays and calculate the spatially smoothed empirical covariance by taking average of covariance over all sub-arrays in spatial domain. The decorrelation performance is relying on the large size of array elements. However, in practical, temporal smoothing by taking average in time domain is frequently used to replace with the spatial smoothing because of the difficulty of managing large size antenna in low frequency band. The performance of temporal smoothing is depending on the large number of snapshots which is hard to achieve with fast moving targets in terms of short measurement duration. Therefore, to overcome such problems, a 2D smoothing by utilizing vectorization operation to combine parameters both in spatial and time domains is introduced in this paper.

2. Proposals

Consider the uniform linear array (ULA) consisting of M elements is managed to receive L narrow band signals from direction $\{\theta_0, \theta_1, \cdots, \theta_{L-1}\}$ sent from the moving target during $n\triangle t$ ($n = 0, 1, \ldots, N-1$, $\triangle t$ is sampling interval) measurement period. In 2D smoothing, all snapshots are divided into several sub-rectangles in spatial and time domains, as shown in Fig.1. The 2D smoothed signal model in vector notation is given by:

$$\mathbf{r} = \mathbf{A}(\boldsymbol{\theta}, \mathbf{f}_d)\boldsymbol{\alpha} + \mathbf{n}, \tag{1}$$

where $\mathbf{A}(\boldsymbol{\theta}, \mathbf{f}_d)$ is combined steering vector by vectorization operation (the column-wise Kronecker matrix product $\mathbf{A}(\boldsymbol{\theta}) \bigotimes \mathbf{A}(\mathbf{f}_d)$), related to the direction-of-arrival (DOA) of incoming waves and Doppler frequency shift due to the motion of the target, respectively, $\boldsymbol{\alpha}$ is the vector including amplitude, initial phase components, shift matrix of DOA and Doppler parameters and $\mathbf{n}$ is the Gaussian noise. Note that the 2D smoothing procedure in Fig.1 is in relative to uniform rectangular array (URA). The 2D smoothed covariance matrix is calculated by taking average of all covariance in each sub-rectangle.

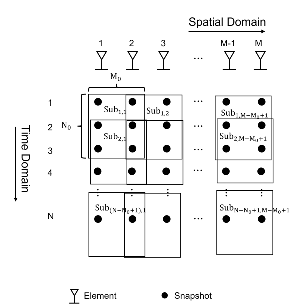

Fig. 1 2D smoothing process

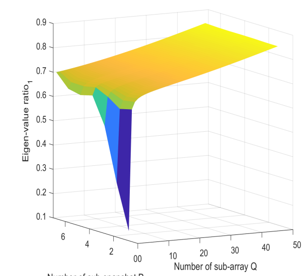

Fig. 2 Eigenvalue ration

3. Conclusion

The eigenvalue ratio is defined by the fraction between the smallest eigenvalue and largest eigenvalue in signal subspace for evaluating the performance of decorrelation, as in Fig. 2. Compared with the conventional spatial or temporal smoothing technique, the proposed 2D smoothing is more flexible to adjust the size of antenna array and measurement period. Even in non-stationary environments, the coherent signals can be decorrelated so that the system robustness is further improved.

References

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