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Array Signal Processing: DOA Estimation for Missing Sensors

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***Abstract*—**Array signal processing involves signal enumeration and source localization. Array signal processing is centered on the ability to fuse temporal and spatial information captured via sampling signals emitted from a number of sources at the sensors of an array in order to carry out a specific estimation task: source characteristics (mainly localization of the sources) and/or array characteristics (mainly array geometry) estimation. Array signal processing is a part of signal processing that uses sensors organized in patterns or arrays, to detect signals and to determine information about them. Beamforming is a general signal processing technique used to control the directionality of the reception or transmission of a signal. Using Beamforming we can direct the majority of signal energy we receive from a group of array. Multiple signal classification (MUSIC) is a highly popular eigenstructure-based estimation method of direction of arrival (DOA) with high resolution. This Paper enumerates the effect of missing sensors in DOA estimation. The accuracy of the MUSIC-based DOA estimation is degraded significantly both by the effects of the missing sensors among the receiving array elements and the unequal channel gain and phase errors of the receiver.

***Keywords*—**Array Signal Processing, Beamforming, ULA, Direction of Arrival, MUSIC

I. Introduction

ARRAY processing can be applied to many applications ranging from radar and sonar to mobile communications. The most common applications of array signal processing involve detecting acoustic signals. In various applications, the objective might be to determine the number of sources and direction of arrival. Array signal processing has received much attention in the last two decades [1]. Research in this area has been applied in many fields, such as seismology, acoustics, sonar, radar, and mobile communication systems [2]. Beamforming techniques try to separate super-positions of source signals from the outputs of a sensor array [3]. Direction-of-arrival (DOA) estimation of multiple narrowband signals is an important problem in array signal processing. Many high-resolution DOA estimation methods [4]–[7] have been developed over the years. However, these methods generally need a prior knowledge of the array manifold [8]. Their performance will be inevitably corrupted by the unknown manifold errors, such as the mutual coupling between neighboring array elements [9]-[10]. Many calibration methods have then been proposed. With the help of the calibration sources at known locations, the literature [10] presents a maximal likelihood calibration method to compensate the mutual coupling as well as gain, phase and position errors. The methods in [7]–[9] are auto-calibration methods and do not require the calibration sources at known locations. The literature [7] presents an iterative alternate method to estimate DOA, the mutual coupling matrix, gain and phase. In [8], a modified noise subspace fitting method is utilized to eliminate the influence of the mutual coupling, but it needs a multidimensional searching to get the DOAs. The method in [9] sacrifices the array aperture but avoids the compensation for the mutual coupling effect. The coherency problem is also one that can not be ignored in DOA estimation. During the course of signal propagation, the signals may suffer the reflections from various surfaces, such as buildings, hills, etc. The resulting multipath propagation will make the received signals highly correlated or coherent. Since those high-resolution DOA estimation methods generally require the signals to be uncorrelated or lowly correlated, they will fail in such multipath environments and need some extra techniques to resolve this problem. The most famous technique is the spatial smoothing technique [11], [12], which segments the array into several overlapped sub arrays and then utilizes the average of the covariance matrices of sub arrays to decorrelate the coherency of signals.

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II. DOA Estimation

The purpose of Direction of Arrival (DOA) estimation is to use the data received by the array to estimate the direction of arrival of a signal [18]. The results of DOA estimation are then used by the array to design the adaptive beamformer, which is used to maximize the power radiated towards users, and to suppress interference [19]. DOA estimation of multiple signals impinging on an antenna array is a well-studied problem in signal processing.

DOA estimation methods exploit either parametric structure of the array manifold or properties of the signals such as being non-Gaussian, or cyclo-stationary. In these kinds of methods, the estimation of the signals' waveform is done by multiplying a weight matrix by the received data matrix [17]. Parameters that affects the DOA [15], [16]

- Spacing between the array elements
- Angular separation between the incident signals
- Number of samples taken for the incident signals
- Signal-to-Noise Ratio

- Number of array elements
- Mutual Coupling between the sensor arrays

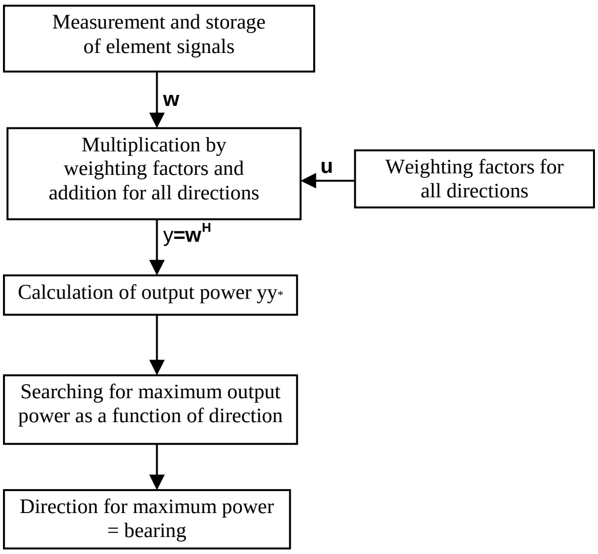

Fig. 1 Block Diagram of DOA

MUSIC algorithm is a high resolution **MU**ltiple **SI**gnal **C**lassification (MUSIC) technique based on exploiting the eigenstructure of the input covariance matrix. It provides information about the number of incident signals, DOA of each signal, strengths and cross correlations between incident signals, noise power, etc.

The central interest is estimating the Direction-Of-Arrivals (DOAs), the angles of the signal sources impinging on the receiving array, given a finite sampled data set. The signals can be either narrowband or wideband. The focus is on the estimation methods based on the second-order statistics. Among them, the methods with high-resolution (HR) property are of primary concern. Most of the HR methods are subspace-based techniques such as MUSIC [9], Root-MUSIC and ESPRIT. Other methods use the subspace fitting concept to achieve maximum likelihood statistical performance with lower computational cost.

Many practical arrays contain sensors [21],[22] with uncertain or unknown characteristics (such as gain, phase shifts and locations), which leads to performance degradation [23]. One way to alleviate the problem is to apply array calibration methods to estimate the unknown array parameters. Another way is to utilize whatever known and correct array parameters available (partly-calibrated array) in order to estimate the DOAs.

III. The Basics of MUSIC

If there are D signals incident on the array, the received input data vector at an M-element array can be expressed as a linear combination of the D incident waveforms and noise

$$u = \sum_{i=1}^{D} a(\phi_i)s_i + n = As + n \qquad (1)$$

where A is the matrix of steering vectors

$$A = [a(f_1), a(f_2), \ldots\ldots, a(f_D)] \qquad (2)$$

s=[s_1, ... , s_D]' is the signal vector, and n=[n_1, ... ,n_M] is a noise vector with components of variance s_n^2.
The received vectors and the steering vectors can be visualized as vectors in an M-dimensional vector space.
The input covariance matrix is

$$R_{uu} = E[uu^H] = AR_{ss}A^H + s_n^{\,2}I \qquad (3)$$

Here R_{ss} is the signal correlation matrix.

The eigenvectors of the covariance matrix R_{uu} belong to either of the two orthogonal subspaces, the principal eigen subspace (signal subspace) and the non-principal eigen subspace [20].
The dimension of the signal subspace is D, while the dimension of the noise subspace is M-D.

The M-D smallest eigenvalues of R_{uu} are equal to sn^2, and the eigenvectors q_i, i=D+1…M, corresponding to these eigenvalues span the noise subspace.
The D steering vectors that make up A lie in the signal subspace and are hence orthogonal to the noise subspace [8].

By searching through all possible array steering vectors to find those which are orthogonal to the space spanned by the noise eigenvectors q_i, i=D+1,..,M, the DOAs f_1, f_2, ... ,f_D, can be determined.

To form the noise subspace, we form a matrix Vn containing the noise eigenvectors q_i, i=D+1, ... ,M.
The DOAs of the multiple incident signals can be estimated by locating the peaks of a MUSIC spatial spectrum [10]

$$P_{MUSIC}(\phi) = \frac{1}{a^H(\phi)V_n V^H{}_n a(\phi)} \qquad (4)$$

The resolution of MUSIC is very high even in low SNR. The algorithm fails if impinging signals are highly correlated. When the ensemble average of the array input covariance matrix is known and the noise can be considered uncorrelated and identically distributed between the elements, the peaks of the MUSIC spectrum are guaranteed to correspond to the true angle of arrival of the signals incident on the array.

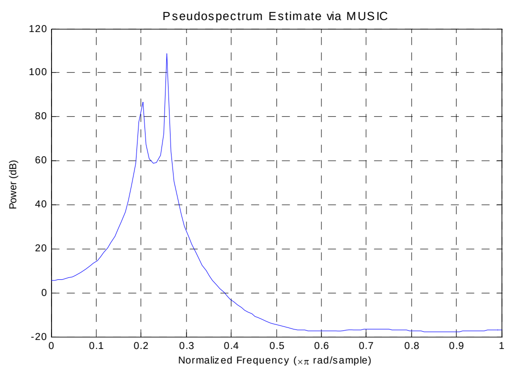

Fig. 2 Pseudo MUSIC Spectrum

IV. Result and Discussion

The estimation of Direction of Arrival for an Adaptive antenna system is one of the significant parameters. A one-dimensional projection of each array response estimate onto the known array response gives the estimation of the DOA for the corresponding signal [24],[25]. The presented method for DOA estimation is applicable to other sub-space techniques as well namely, Estimation of Signal Parameter using Rotational Invariance Technique (ESPIRIT), Root MUSIC etc.

It is difficult to find Direction of Arrival estimation using Multiple Signal Classification Algorithm, in particular when one or more sensors are missing. This problem associated with DOA estimation in a Uniform Linear Array is presented here. To analyze the performance of the MUSIC algorithm, a Uniform Linear Array of length 5 is considered. Signal directions are taken from 30^0, 60^0, 80^0, 135^0, and 150^0.

The output is a quadratic measure of signal presence in different directions. The output can be either a power spectrum or a pseudo spectrum. Peaks of the DOA-spectrum give the DOA estimate.

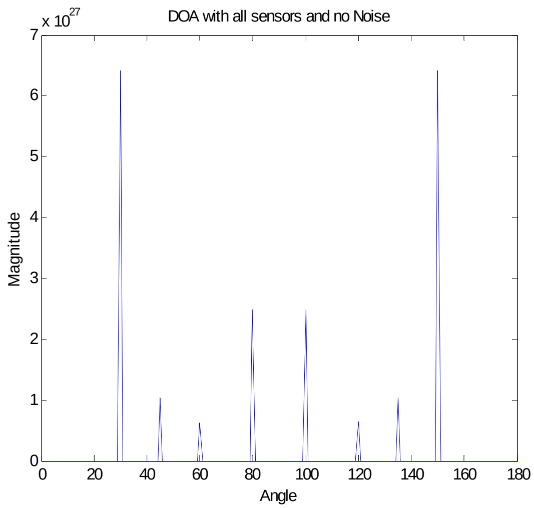

Fig. 3 Direction of Arrival estimation with all sensors and no noise

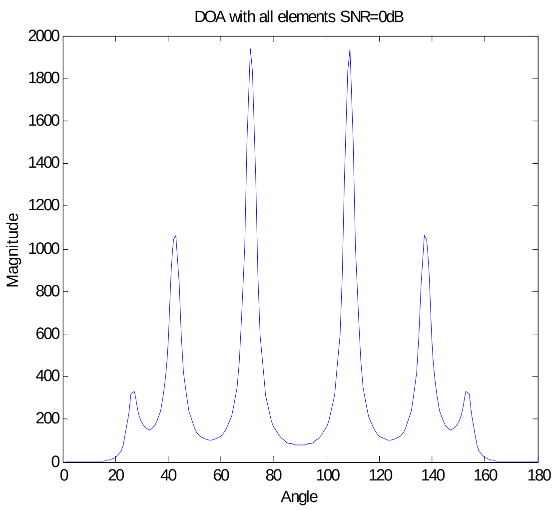

Fig. 4 Direction of Arrival estimation with all sensors and SNR=0dB

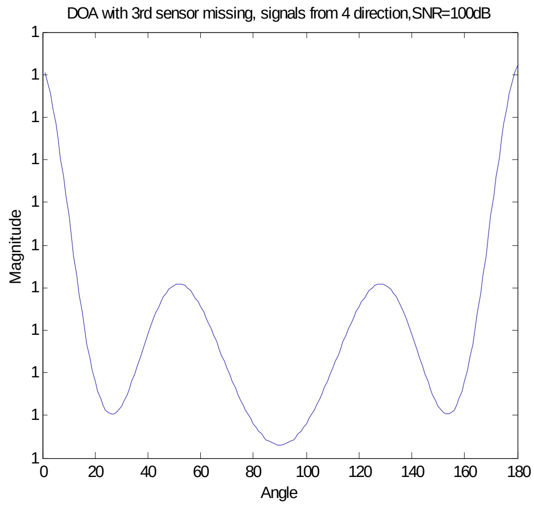

Fig. 5 Direction of Arrival estimation with 3^{rd} sensor missing and SNR=100dB

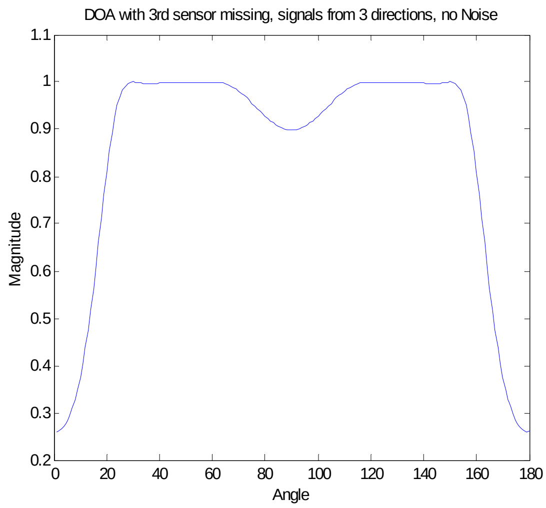

Fig. 6 Direction of Arrival estimation with 3^{rd} sensor missing, signal is from 3 directions and no noise

We observed MUSIC spectrum by changing the Number of missing sensor array elements. Fig. 3 shows the MUSIC spectrum generated with all sensor array elements, where as Fig.4 shows the MUSIC spectrum generated with all sensor array elements in presence of noise, from Fig. 3 and Fig. 4 using more array elements improves the resolution of the MUSIC spectrum. Fig. 5 and Fig. 6 shows the DOA MUSIC spectrum when 3^{rd} sensor is missing.

V. Conclusion

The MUSIC estimation produced a high angular resolution for signals arriving from any azimuth when the elevation was zero degrees. The DOA estimation for missing sensor array is useful in calibration of Uniform Linear Array when the DOAs of calibration sources were not known. The estimation errors of missing sensor matrix elements and DOAs are large, which can be estimated by LS Method. We consider the problem of estimating the direction-of-arrival (DOA) of one or more signals using an array of sensors, where one or more sensors are missing before the measurement is completed.

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