Performance Enhancement of MUSIC DOA Estimation

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Abstract- Idea of wireless communication systems, which utilize smart antennas, is based on digital signal processing algorithms. Smart antennas have ability to locate and track signals. Smart antenna performance depends on efficiency of digital signal processing algorithms. The Direction of Arrival (DOA) estimation algorithms is used for estimate the number of incidents signals on the antenna array and their angle of incidence. This paper based on MUSIC DOA estimation method on the uniform linear array in the presence of white Gaussian noise. The simulation results show classical MUSIC algorithm estimation. Multiple Signal Classification (MUSIC) algorithm is the most commonly used DOA estimation method because it is simple but effective. MUSIC algorithm have ability to estimate independent signals DOA effectively, but it is failure to coherent signals. Concerning the issue, Modified MUSIC algorithm, Spatially Smoothed MUSIC Algorithm and Toeplitz approximation based MUSIC algorithm used when the coherent signals present. the simulation results shows that Toeplitz approximation based MUSIC algorithm method has better direction finding performance.

Keywords - *Smart antenna, Direction of Arrival, MUSIC, Modified MUSIC algorithm, Spatially Smoothed MUSIC Algorithm and Toeplitz approximation based MUSIC algorithm.*

I. INTRODUCTION

In the field of engineering wireless communication is one of the fastest growing. Over the last few years, research related to the smart antenna system has burst. Because smart antenna system have ability to utlilize spectrum efficiently and provides increased capacity of wireless communication. The smart antenna system having array of antennas and a signal processing unit. In direction finding, the signals received from independent antenna elements are pass through the signal processing part which is used to perform the DOA estimation using a suitable direction finding algorithm. As the demand of wireless communication increases the demand of higher capacity also increases. Capacity can improve by enlarging the spectrum but it is a limited resource to overcome this issue new approach is purposed know as Smart Antenna. Smart Antenna is a combination of multiple antenna and DSP unit it use spectrum more efficiently and enhance the capacity of [1].

II. DIRECTION-OF-ARRIVAL

Direction-of-arrival (DOA) estimation has also been known as spectral estimation, angle-of-arrival (AOA) estimation, or bearing estimation. One of the important signal processing blocks in smart antenna systems is the direction of arrival (DOA) algorithm. The main purpose of DOA estimation is to use the data received by the array to estimate the direction of arrival of the signal and the results of DOA estimation are then used by the array to design the adaptive beam former in such way as to maximize the power radiated towards the users and to suppress the interference. For the successful design of adaptive array smart antenna depends highly on the performance of DOA estimation algorithm [2, 3].

III. MUSIC (Multiple Signal Classification)

MUSIC is the one of most popular method of DOA estimation. MUSIC is stands for MUSIC is Multiple Signal classification MUSIC algorithm is given by Schmidt in 1979 and this higher resolution technique based on exploiting the eigen-structure of input covariance matrix. This method is to decompose the covariance matrix into eigenvectors in both signal and noise subspaces. The direction of sources is calculated from steering vectors that orthogonal to the noise subspace, which is by detecting the peak in spatial power spectrum [4, 5, 6].

A. Problems with MUSIC algorithm

MUSIC algorithm has various advantages but it have some limitations when applied in real systems. The main problems are given below:

- Channel lost pairing

MUSIC algorithm is more sensitive to error in the system, when the system is in long course of work, making the ageing characteristics of each channel increasingly serious. With differences that cause channel mismatch, it will give the performance of MUSIC algorithm serious trouble.

Correction of irregularity in channels can be classified into two types, self-correction and active correction. Active correction is a relatively mature correction method, as long as it predicts the direction of the signal source, and it can perform channel amplitude correction or directly compensate for the algorithm through the general correction matrix. In terms of self-correction, it is by use of a priori knowledge of the structure of the array to conduct a pre-process to the received data. In addition, there have existed many algorithms to improve the robustness of the MUSIC algorithm, such as the Toeplitz algorithm, but there are special requirements for the array structure.

- How the coherent interference source influences the algorithm

When the interference sources are coherent, MUSIC algorithms have problems when determining the number of interferer sources; they cannot divide the signal subspace and noise subspace, and thus will not be able to estimate the spatial spectrum.

To solve this problem we generally have the following categories: spatial smoothing technique, signal feature vector technique and frequency smoothing technique. The spatial smoothing method is the most commonly used method. Spatial smoothing method requires a specific spatial structure of the array that can be divided into several sub arrays, and then each sub-array can be calculated of the signal correlation matrix. Afterwards, we do the direction estimation for each sub-array correlation matrix.

B. Method for overcome the problems

- Modified MUSIC Algorithm

MUSIC algorithm is limited to uncorrelated signals. When signal sources are coherence correlated signal or a signal with low SNR then the estimated performance of the MUSIC algorithm deteriorates or even completely loses. Hence, if we want to estimate the coherent signal DOA accurately, we have to eliminate the correlation between the signals. The modified MUSIC overcomes the problem by conjugate reconstruction of the data matrix of the MUSIC algorithm [7].

Make a transformation matrix J, J is an Mth-order anti-matrix, known as the transition matrix, i.e.

$$J = \begin{bmatrix} 0 & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \cdots & 0 \end{bmatrix}$$

Let Y=JX*, where X* is the complex conjugate of X, then the covariance of data matrix Y is

$$R_y=E[YY^H]=JRX^*J. \quad (7)$$

From the sum of Rx and Ry, the reconstructed conjugate matrix can be obtained.

$$R= R_x+ R_y=AR_sA^H+J[AR_sA^H]^*J+2\sigma^2 I. \quad (8)$$

The formula shows derivation process, the essence of the modified music algorithm is the special situation of the spatial before and after smoothing algorithm, which the length of sub-array equals with the number of array element [8].

- Spatial Smoothing Techniques

A spatial smoothing preprocessing method for resolving issue of encountered in direction-of-arrival estimation of fully correlated signals is analyzed. Simulation results gives, which illustrate this technique in comparison with the ordinary MUSIC technique. Modified spatial smoothing algorithm is given which has the ability to detect more coherent signals.

There are many methods presents for estimation of DOA of a signal using an antenna array. The MUSIC algorithm, works on the premise that the signals impinging on the array are not fully correlated. Only under uncorrelated conditions the source covariance matrix S satisfies the full rank condition, which is the basis of the MUSIC eigen-decomposition. The performance of MUSIC decreases severely in a highly correlated signal environment as encountered in multipath propagation. Some techniques have been proposed to make MUSIC work in the presence of coherent signals, which usually involve modification of the covariance matrix through a preprocessing scheme called spatial smoothing [9]. One method of spatial smoothing is based on averaging the covariance matrix of identical overlapping arrays and requires an array of identical elements built with some form of periodic structure, such as the uniform linear array.

The signal covariance matrix R_{xx} is a full-rank matrix as long as the incident signals on the sensor array are uncorrelated, which is the key to the MUSIC eigenvalues decomposition. If the incoming signals become highly correlated then the matrix R_{xx} will lose its non-singularity property and performance of MUSIC will reduce. In this case, spatial smoothing must be used to overcome the correlation between the incoming signals by dividing the main sensor array into forward overlapping subarrays and introducing phase shifts between these subarray [10].

The vector of received signals at the k^{th} forward subarray is given by:

$$x_k^F(t) = AD^{(k-1)}S(t) + n_k(t) \quad (9)$$

Where (k-1) is k^{th} power of the diagonal matrix D is expressed as:

$$D = diag\{e^{-\frac{2\pi}{\lambda}sin\theta_1}, \ldots\ldots, e^{-\frac{2\pi}{\lambda}sin\theta_m}\} \quad (10)$$

The spatial correlation matrix R is given by:

$$R = \frac{1}{L}\sum_{k=0}^{L-1} R_k^F \quad (11)$$

L is number of overlapping subarrays. When applying forward spatial smoothing the N-element array can detect up to N/2 correlated signals [11].

- Toeplitz approximation method

S.Y.Kung et al. gives Toeplitz approximation method, TAM based on a reduced order Toepitz approxmation of an estimated spatal conariance matrix. When source are uncorrelated and statistically stationary then the estimated covariance matrix is Toeplitz. In a multipath environment, where the source paths are fully correlated then covariance matrix is not Toeplitz. The Toeplize structure can he guaranteed by employing spatial smoothing, which destroys cross correlation between directional components. The TAM is designed for robustness in an arbitrary ambient noise environment [12].

When the signals are coherent with each other, the value of R matrix's rank is rank-deficient, and then correlation matrix will be no longer Toeplitz. We can structure a Toeplitz matrix:

$$R_T(-n) = \frac{1}{M-n}\sum_{i=1}^{M-n} R_{t(t+n)}\,,\ n = 0,1,\ldots\ldots, M-1$$

$$R_T(n) = R_T^*(-n) \quad (13)$$

Toeplitz approximation method can well distinguish and estimate DOA of the coherent signals. Comparing with the spatial smoothing technology, Toeplitz approximation method does not reduce the correlated matrix dimensions [13].

IV. DIRECTION OF ARRIVAL SIMULATION

This section compound the MATLAB simulation by studying and changing various parameters are M number elements used in array, each element spaced by d and number of iterations used for computations.

The simulations are carried out to analyze the various features of estimation. It illustrates that how it will affect on the digital beam forming by changing the parameters. In the adaptive array antenna desired signal is phase modulated, those four signals are not correlated, ideal Gaussian white noise is used and the SNR is assumed to be 30dB.

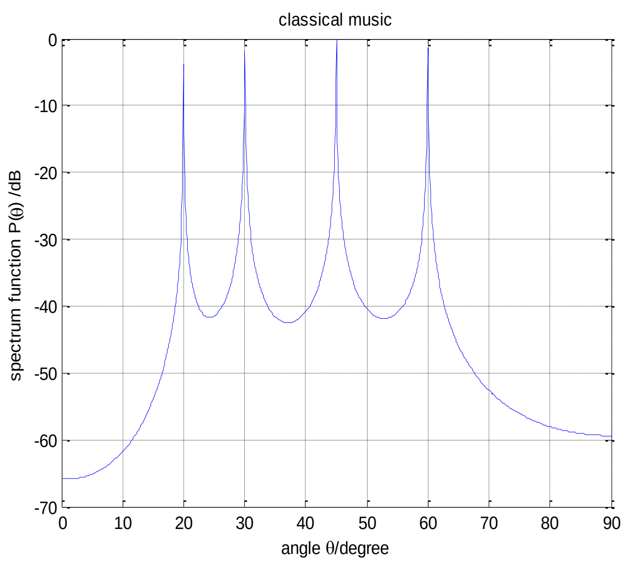

Fig.1: Simulation of classical MUSIC algorithm

The first simulation shows how four signals are recognized by the classical MUSIC algorithm. There are four independent narrow band signals, the incident angle is 20, 30, 45 and 60 degrees respectively, the SNR is 30dB, the element spacing is half of the input signal wavelength, array element number is 8, the number of snapshots is 100.

- MUSIC algorithm and modified MUSIC algorithm for coherent signals

The simulations show how four signals are recognized by the MUSIC algorithm and modified MUSIC algorithm. When the signals are coherent, let the incident angle is 20, 30, 45 and 60 degrees respectively, those four signals are not correlated, ideal Gaussian white noise is used, the SNR is 30dB, the element spacing is half of the input signal wavelength, array element number is 8, and the number of snapshots is 100. The simulation results are shown in Figure 2 and Figure 3.

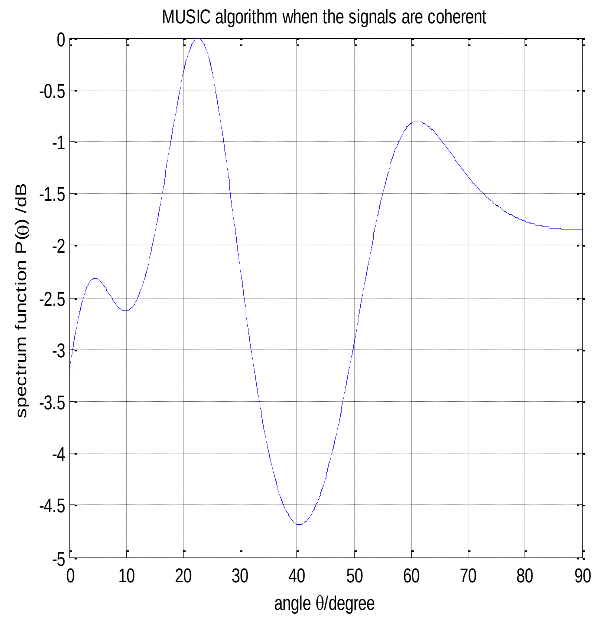

Fig.2: Simulation for MUSIC algorithm when the signals are coherent

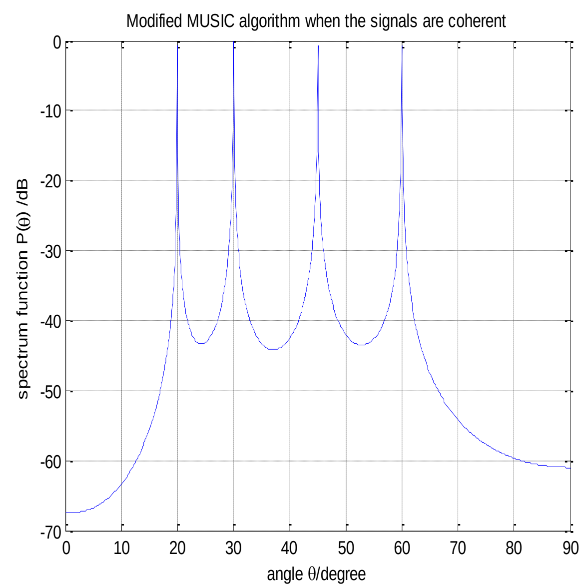

Fig.3: Simulation for the modified MUSIC algorithm when the signals are coherent

As can be seen from Figure 2 and Figure 3, for coherent signals, classical MUSIC algorithm has lost effectiveness, while modified MUSIC algorithm can be better applied to remove the signal correlation feature, which can distinguish the coherent signals, and estimate the angle of arrival more accurately. Under the right model, using MUSIC algorithm to estimate DOA can get any high resolution. But MUSIC algorithm only focuses on uncorrelated signals; when the signal source is correlation signal, the MUSIC algorithm estimation performance deteriorates or fails completely. This modified MUSIC algorithm can make DOA estimation more complete, and have a marked effect both on theoretical and practical study.

- Forward Smoothness Music Algorithm

The simulation shows how four signals are recognized by the classical MUSIC algorithm. The SNR is 30dB, the element spacing is half of the input signal wavelength, array element number is 8, the number of snapshots is 100.

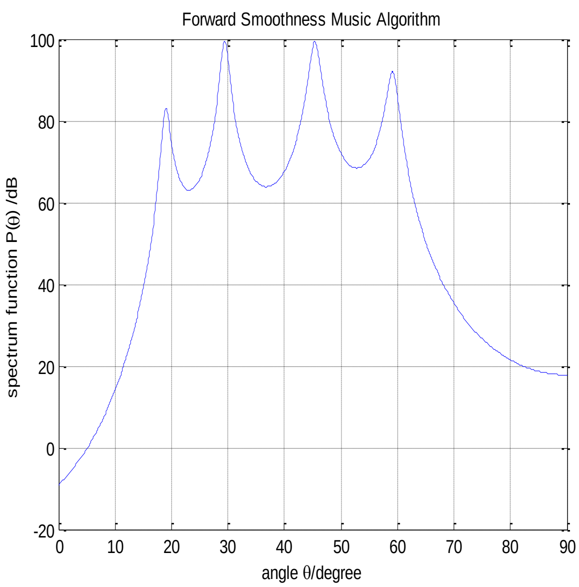

Fig.4: Forward Smoothness Music Algorithm

Smooth music is better that music. The performance can be improved with more elements in the array, with higher number of snapshots of signals and greater angular separation between the signals. These are responsible for the form of sharper peaks in MUSIC spectrum and smaller errors in angle detection.

- Toeplitz approximation Music Algorithm

The simulation shows how four signals are recognized by the classical MUSIC algorithm. The SNR is 30dB, the element spacing is half of the input signal wavelength, array element number is 8, the number of snapshots is 100.

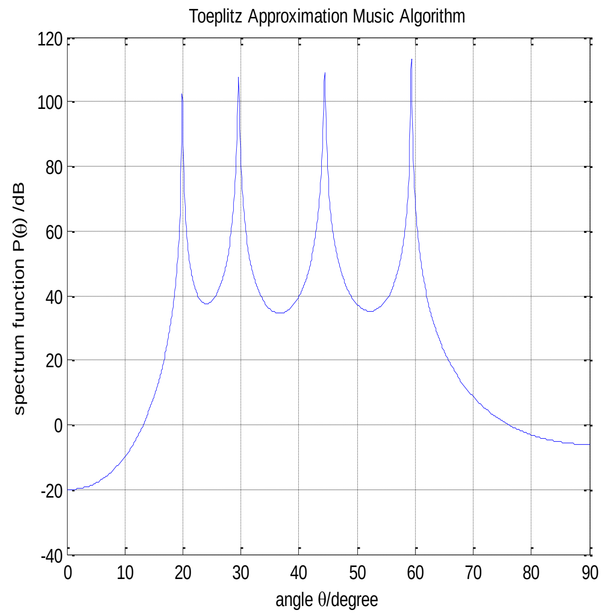

Fig.5: Toeplitz approximation Music Algorithm

Toeplitz music is better that smooth music. The performance can be improved with more elements in the array, with higher number of snapshots of signals and greater angular separation between the signals. These are responsible for the form of sharper peaks in MUSIC spectrum and smaller errors in angle detection.

V. CONCLUSIONS

MUSIC method algorithm also have some problems like channel mismatch and coherent interface for overcome these problems different techniques are used like A spatial smoothing preprocessing scheme for solving problems encountered in direction-of-arrival estimation of fully correlated signals is analyzed. When the signal is coherent, classical MUSIC algorithm has lost effectiveness, and modified MUSIC algorithm is able to effectively distinguish their DOA. we implemented the modified MUSIC algorithm for coherent signals. The Toeplitz structure can he guaranteed by employing spatial smoothing, which destroys cross correlation between directional components. The TAM is designed for robustness in an arbitrary ambient noise environment.

VI. REFERENCES

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