Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 3, Issue 7; April-June, 2016, pp. 605-608

http://www.krishisanskriti.org/Publication.html

# Survey Paper on Different Techniques of DOA Estimation

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**Abstract—***This paper presents different tool for the Direction of arrival (DOA) estimation such as Barlett Method, Linear prediction Method, Music Algorithm and Esprit Method. The comparative study is presented with pros and cons of each technique and procedures to implement them and the result oriented study to find a best technique to minimise the error noise which enables users to be located and this information can be useful for both the, user and service provider antenna element.*

**Keywords***: DOA, Barlett Method, Linear prediction Method Music Algorithm Esprit Method.*

## 1. INTRODUCTION

Smart antenna can be defined as antenna whose performance is controlled by computer .Smart antennas helpful in improving radar systems, Improving system capacities with mobile wireless, and improved wireless communications through the implementation of space division multiple access (SDMA).these smart antennas are governed by an algorithm which control its action and its nature by systematic implementation of rules according to algorithm. By the application of these SIR (signal interference ratio) can be maximised and MSE (mean square error) can be minimised. The algorithms are accomplished electronically by analog devices but easy to accomplish by digital signal processing which require array output be digitized using analog to digital converter digitization performed either at IF or baseband frequencies.

The term smart antenna system syndicates multiple antenna elements with a signal processing capability to optimize its radiation and reception pattern automatically in response to the signal environment. There is difficulty in localization of sources radiating energy by observing their signal received at spatially divided sensors is of considerable significance, occurring in many fields, including radar, sonar, mobile communications, radio astronomy, and seismology. In this paper an estimation of the direction of arrival (DOA) using different technique is considered, and various DOA estimation methods are described, compared, and understanding to various worries. The DOA estimation methods considered include Barlett method, linear prediction method. Various Eigen structure methods including many versions of MUSIC algorithms and ESPRIT method is analysed.

## 2. BASIC PRINCIPLE OF DOA ESTIMATION IN SMART ANTENNA

DOA can be defined as the point where the transmitting wave reaches the technique associated to beamforming which estimates the direction of the transmitted wave. It is used to localize the direction of radiating source. Smart antenna designed to adapt to a varying signal surroundings in order to optimize a given algorithm. An optimizing criterion, or cost function, is normally defined based upon the requirements at hand

DOA is for the direction of array antenna of the radio wave. If the radio wave received meets the condition of far field narrowband, it can take the front of the radio wave as a plane. The angle between the array normal and the direction vector of the plane wave is the Direction of arrival (DOA)

The estimated target of DOA gives N snapshots data: X (1)…X (N), using an algorithm to estimate the value of multiple signals' DOA (θ).

For generally far and wide signals, a wave-way difference exists when the same signal reaches different array elements. This wave-way difference leads to a phase difference between the arrival array elements. Using the phase difference between the array elements of the signal one can estimate the signal azimuth, which is the basic principle of DOA estimation

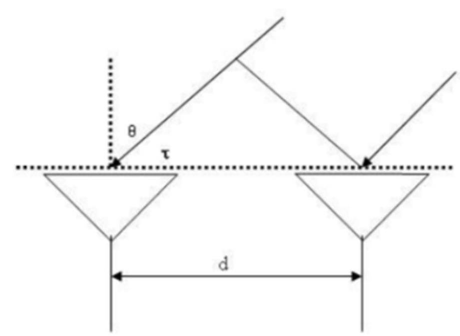


**Fig. 1: The basic principle of DOA estimation**

considering two array elements where d is the distance between the array elements, c is the speed of light, θ is the incident angle of the far field signal, τ is the time delay of the array element, then The signal received by the antenna due to the path difference is

$$\tau = \frac{d \sin\theta}{c},$$

To obtain the phase difference between the array elements

$$\varphi = e^{-j\omega\tau} = e^{-j\omega \frac{d \sin\theta}{c}} = e^{-j2\pi \frac{d \sin\theta}{\lambda f_0} f},$$

Here $f_o$ is the centre frequency. For narrow band signals, the phase difference is

$$\varphi = e^{-j2\pi \frac{d \sin\theta}{\lambda}},$$

Here λ is the wavelength of the signal. Therefore, if the time delay of the signal is known, the direction of the signal can be gained according to

$$\tau = \frac{d \sin\theta}{c}$$

This is the basic principle of spatial spectrum estimation techniques.

## 3. TRADITIONAL AND SMART ANTENNA

The traditional, fixed beam array where the main lobe can be steered, by defining the fixed array weights. However, this configuration is neither smart nor adaptive. The second array in the Fig. is a smart antenna designed to adapt to a changing signal environment in order to optimize a given algorithm.

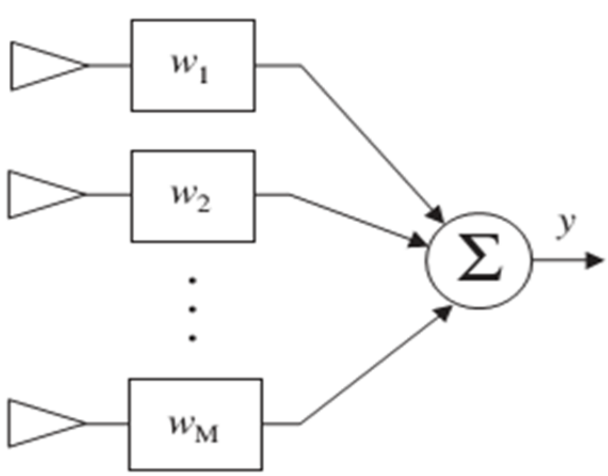


**Fig. 2: Traditional Array or Antenna**

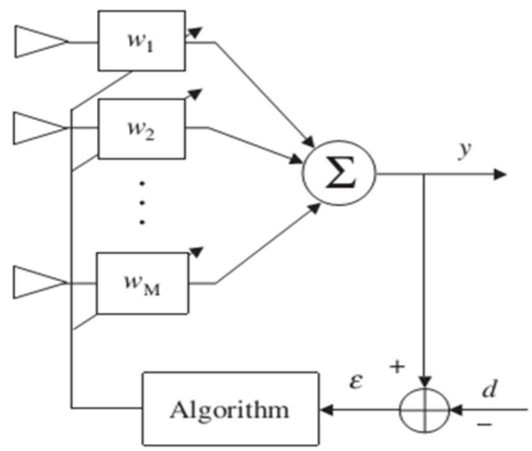


**Fig. 3: Smart Antenna**

In the above Fig. the cost function is defined as the magnitude of the error squared, $|\varepsilon|^2$, between the desired signal d and the array output y. The array weights w¯ are adjusted until the output matches the desired signal and the cost function is minimized.

## 4. FACTORS AFFECTING THE DOA ESTIMATION

Many factors influence the results of DOA estimation these factors are related to the source of incoming signal as well as the actual application environment where the DOA estimation is performed. Some of the important factors affecting the DOA estimation are listed below

I. **Number of array elements**: The no of array elements affects the estimation performance more the no of array better the estimation performance.
II. **The coherence of the signal source:** If there is a coherent signal in the signal source, the signal covariance matrix is no longer for the non-singular matrix. In this case, the original super-resolution algorithm will fail. Therefore, it will greatly affect the performance of DOA estimation.
III. **Snapshots**: It is defined as the no of samples in the time domain in case of frequency domain it is defined as the number of time sub-segments of discrete Fourier transform (DFT).
IV. **SNR:** Signal to noise ratio(SNR) can be defined as the comparison between the desired signal and background noise it is expressed in decibels. It directly affects the DOA estimation performance at low SNR the DOA estimation drops dramatically.

## 5. TECHNIQUES OF DOA ESTIMATION

### 5.1 Bartlett Method

Bartlett method is one of the earliest methods of spectral analysis. In Bartlett method a rectangular window of identical weighting is applied to the time series data to be analysed. This is equivalent to applying equal weighting on each element. In Barlett Method plan is to scan across the angular region of interest (usually in discrete steps), and whichever direction produces the largest output power is the estimate of the desired signal's direction. More specifically, as the look direction θ is varied incrementally across the space of access. For bearing estimation problems using an array Thus, by steering the array in θ direction this method estimates the mean power $P_B(\theta)$, an expression for which is given by

$$P_B(\theta) = \frac{\mathbf{S}_\theta^H\ R\ \mathbf{S}_\theta}{L^2}$$

here $S_\theta$ denotes the steering vector associated with the direction θ, L denotes the number of elements in the array, and R is the array correlation matrix. A set of steering vectors $\{S_\theta\}$ associated with various direction θ is often referred to as the array manifold in DOA estimation literature. In practice, it may be measured at the time of array calibration. From the array manifold and an estimate of the array correlation matrix, $P_B(\theta)$ is computed Peaks in $P_B(\theta)$ are then taken as the directions of the radiating sources. The process is similar to that of mechanically steering the array in this direction and measuring the output power. Due to the resulting side-lobes, output power is not only contributed from the direction in which the array is steered but from the directions where the side-lobes are pointing. The processor is also known as the conventional beamformer and the resolving power of the processor depends on the aperture of the array or the beamwidth of the main lobe.

### 5.2 Linear Prediction Method

The linear prediction (LP) method estimates the output of one sensor using linear combinations of the remaining sensor outputs and minimizes the mean square prediction error, that is, the error between the estimate and the actual output Thus, it obtains the array weights by minimizing the mean output power of the array subject to the constraint that the weight on the selected sensor is unity. Expressions for the array weightsˆ wand the power spectrum $P_{LP}(\theta)$, respectively, are

$$\hat{\mathbf{w}} = \frac{R^{-1}\mathbf{u}_1}{\mathbf{u}_1^H\ R^{-1}\ \mathbf{u}_1}$$

$$P_{LP}(\theta) = \frac{\mathbf{u}_1^H\ R^{-1}\ \mathbf{u}_1}{\left|\mathbf{u}_1^H\ R^{-1}\ \mathbf{S}_\theta\right|^2}$$

where $u_1$ is a column vector such that one of its elements is unity and the remaining elements are zero. The position of 1 in the column vector corresponds to the position of the selected element in the array for predicting its output. There is no criterion for proper choice of this element; however, choice of this element affects the resolution capability and bias in the estimate.

### 5.3 Music Algorithm

In 1979 Schmidt and its colleagues proposed Multiple Signal Classification algorithm which is popularly known as MUSIC algorithm. Due to its generality this algorithm popularised largely. This generality is accompanied with the expense that the array response must be known for all possible combinations of source parameters The promotion of the structure algorithm characterized rise and development, and it has become a crucial algorithm for theoretical system of spatial spectrum. Characteristic decomposition for the covariance matrix of any array output data, resulting in a signal subspace orthogonal with a noise subspace corresponding to the signal components is the basic idea of MUSIC algorithm .Then these two orthogonal subspaces are used to constitute a spectrum function, be got though by spectral peak search and detect DOA signals.

### 5.4 Spectral MUSIC

Commonly known as spectral MUSIC, in this method by eigen value decomposition of the estimated array correlation matrix or singular value decomposition of the data matrix with its N columns being the N array signal vector samples estimates the noise subspace from available samples. N array signal vector samples, also known as snapshots. First the noise subspace has been estimated, then a search for M directions is made by looking for steering vectors that are as orthogonal to the noise subspace as possible. This is normally accomplished by searching for peaks in the MUSIC spectrum given by

$$P_{MU}(\theta) = \frac{1}{\left|\mathbf{S}_\theta^H U_N\right|^2}$$

Here $U_N$ denotes an L by L – M dimensional matrix, with L–M columns being the eigen vectors corresponding to the LM smallest eigen values of the array correlation matrix and $S_\theta$ denoting the steering vector that corresponds to direction θ.

### 5.5 Root-MUSIC

The root-MUSIC method is based on the eigenvectors of the sensor array correlation matrix. It obtains the signal estimation by examining the roots of the spectrum polynomial. The peaks in the spectrum space correspond to the roots of the polynomial lying close to the unit circle.

It is applicable to ULA (Uni Linear Array)

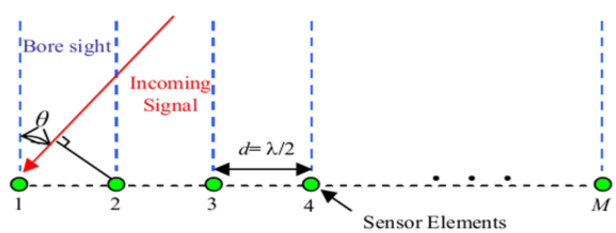


**Fig. 3: Uni Linear Array**

Here m elements arranged in straight line where d= λ/2,

Here λ is wavelength of incoming signal.

### 5.6 Esprit Method

ESPRIT method is termed as Estimation of signal parameters via rotational invariance techniques (ESPRIT) is a computationally efficient and robust method of DOA estimation. It uses two identical arrays in the sense that array elements need to form matched pairs with an identical displacement vector, that is, the second element of each pair ought to be displaced by the same distance and in the same direction relative to the first element. However, this does not mean that one has to have two separate arrays. The array geometry should be such that the elements could be selected to have this property.

Now lets us consider the four element linear array is composed of two identical three-element sub arrays or two doublets. They are arranged transitionally named as 1 and 2

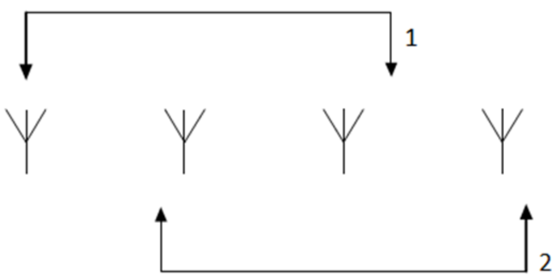


**Fig. 4: Two identical arranged and displaced arrays**

Induced signal on each array is expressed as

$$\overline{x_1}(k)=[\overline{a_1}(\theta_1)\ \overline{a_1}(\theta_2)\ ..\ \overline{a_1}(\theta_D)].\begin{bmatrix} s_1(k) \\ s_2(k) \\ s_D(k) \end{bmatrix}+\overline{n_1}(k)$$

**Table 1: Pros and Cons of different algorithm of DOA estimation**

| Algorithm | Pros | Cons |
|---|---|---|
| Barlett | Easy to realize, Robust to element, Perturbations, Prior knowledge is not needed of specific statistical property | Array size Dependent<br><br>Angle resolving capability Limited |
| Linear Prediction | Prediction Error based | Depends on Array element Chosen final solution based on choice |
| Music | Works for other array shapes, need to know sensor positions Very sensitive to sensor position, gain, and phase errors, need careful calibration to make it work well | Searching through all could be computation - ally expensive |
| Esprit | High resolution, non critical array Calibration Much less computation | Twice the no sensors |

## 6. CONCLUSION

Barlett method is simple to implement and no prior knowledge is needed. LP methods perform well in moderately low SNR environments and are good compromises in situations where sources are of approximately equal strength and are nearly Coherent. If sensors are expensive and few, and if computation is not of concern, MUSIC is suitable. If there are plenty of sensors compared with the number of sources to detect, and if computational power is limited, ESPRIT is suitable

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