

Review Paper on Adaptive Antenna for Direction of Arrival Estimation & Beam Forming

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Abstract— This paper gives an overview of design and development of adaptive antenna for direction of arrival estimation and beam forming. There are various techniques available now days for DOA estimation using FPGA or DSP processors, by the use of various algorithms which are MUSIC, ESPRIT and Capon etc. Use of FPGA or DSP is more costly, bulky and complex. To resolve these problems a system which is more cost effective and less complex as compared to others is used. In comparison with FPGA or DSP processors the use of Phase detector AD8302 is more reliable, which can compare phase of two received antennas signals and give voltage output. This output is used to compute the angle of arrival of signal on computer, following the use of phase shifter to direct the signal to the desired direction only. This method is more efficient in RADAR as well as in communication technology.

Key words: Beam Forming, Direction of Arrival, Micro Strip Patch Antenna, MUSIC Algorithm, Phase Detector, Phase Shifter

I. INTRODUCTION

As the demand of wireless services is increasing drastically over the years. To provide voice and data services with higher data rate along with the need of more number of subscribers per base station to reduce overall network cost is important. Due to which the wireless technology is getting updated from first, second, third and now up to the fourth generation. But due to limitations of broadcasting spectrum, there is increase in traffic. Therefore as there is increase in traffic per channel the interference also increases. Hence we need to develop a system, which would provide higher data rate and can be cost effective, which are then used in applications of PL (position location) services, for fraud detection and emergency call in military rescue application, along with reduction in the interference.

DOA estimation using fixed antennas has many limitations because of its resolution. Antenna resolution is mainly dependent on the main lobe beam width, which is inversely proportional to the physical size of antenna. Increasing size of antenna to improve accuracy of measurement of angle is not good solution of this problem, because in aircrafts, missile seekers or in communication, antenna has limitation for physical size. Hence in that case, main lobe beam width is wide due to which it is not possible to distinguish multiple signals coming from different directions. Instead of using single antenna, an array antenna is more efficient in this way to determine the angle of arrival of signals. Array antennas have also various advantages as they are used to avoid interference and also to form multiple beam patterns. Now days the term smart antenna has come into existence which is more likely used in DOA estimation methods. The term smart antenna generally refers to any

antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize SOI (signal of interest) and to minimize interfering signals [12].

In order to determine an appropriate attitude of three-axis stabilized communication satellites novel attitude determination method using direction of arrival (DOA) estimation of a ground signal source. The method is characterized by taking the ground signal source as the attitude reference and acquiring attitude information from DOA estimation. A developing low Earth orbit (LEO) satellite which tests mobile communication technology with smart antennas can be stabilized in three axes by corporately using a magnetometer, reaction wheels, and three-axis magnetorquer rods. Based on the communication satellite, simulation results demonstrate the effectiveness of the method. The method could be a backup of attitude determination to prevent a system failure on the satellite. Its precision depends on the number of snapshots and the input signal-to-noise ratio (SNR) with DOA estimation [17].

There are various applications of DOA estimation in communication as well as in RADAR. Where DOA method is used to detect the enemy aircraft, by using network jammer circuit the RADAR signals can be blocked, due to which enemy cannot detect our aircraft. So in communication technology to avoid such multiple signal interference and to direct the signals in desired direction the aforesaid method can be used effectively.

This paper discusses various DOA estimation techniques and their comparisons in section II, whereas section III defines the MUSIC and ESPRIT algorithm's mathematical model. Section IV describes the Various Signal Processing Circuitries for DOA estimation and beam forming methods using phase detector AD8302, and finally section V gives overall conclusion.

II. VARIOUS DOA ESTIMATION TECHNIQUES

There are various methods for finding angle of arrival, that are divided into two main parts such as quadratic type and subspace based type, which are explained as follows.

- Quadratic Type – The Bartlett and capon (minimum variance distortion less response) are quadratic types. Both these methods are highly dependent on physical size of array aperture which results in poor resolution and accuracy [1] [4].
- Subspace Based Type – This method of DOA estimation is based on the Eigen decomposition. The subspace based DOA estimation algorithms MUSIC and ESPRIT provide high resolution. They are more accurate and not limited to physical size of array aperture. The performance of ESPRIT and MUSIC algorithm is analyzed based on number of snapshots,

number of users, user space distribution, number of array elements & SNR [1][4].

- MUSIC Algorithm – In music algorithm the decomposition of covariance matrix into two orthogonal matrices takes place which are signal and noise subspace. By using one of the above methods of DOA estimation MUSIC algorithm is used in highly non-coherent signals. To use this method in correlated signals we use improved music algorithm. Music algorithm uses Eigen values and Eigen vectors of the signal and noise. Noise and signal’s Eigen vectors are orthogonal to each other and it is very easy to separate the signals from each other. Hence MUSIC is most likely used method for DOA estimation [4].
- ESPRIT Algorithm – ESPRIT stands for estimation of signal parameter via rotational invariance technique. This method does not require searching all steering vectors to estimate DOA, due to which this method has less computational complexity and less storage requirement as compared to MUSIC algorithm [5].

All these methods mentioned above are only applicable when,

- 1) Numbers of snapshots are sufficiently large for estimation of covariance matrix data.
- 2) The overall incident signals are less than the number of receiving antenna elements.

There are also few methods which are applicable when there is less number of snapshots or a single snapshot. Matrix pencil (MP) method is one of them. In this method Cyclostationarity [15] is used, in which it can accept signal having same cycle frequency and reject all other signals which are nothing but the noise signals. This method extracts SOI (signal of interest). This method combines temporal and spatial processing techniques, and used for both coherent as well as non-coherent signals. Cyclostationarity is achieved by using blind method.

The various DOA estimation techniques are analyzed and compared to find the best suitable method for different applications. From the comparison table it can be said that MUSIC and ESPRIT are the most suitable and more accurate methods for direction finding applications [13].

Method	Advantages	Disadvantages
Barlett	Simple to implement, Robust to element perturbations, not need for a prior knowledge of specific statistical property	Depends on array size, Ability to resolve angles limited by array HPBW
Capon	Better resolution than Barlett, no need for a prior knowledge of specific statistical property	Limited by sensor noise power, Competing sources are highly correlated, gives worse result
Linear prediction	Based upon prediction error	Choice can affect the final solution, depends on array element chosen
Maximum entropy	Gives the same pseudo spectra as linear prediction	Choice of inverse Correlation matrix Dramatically affects the resolution achieved
Pisarenko harmonic decomposition (PHD)	Peaks are indication of roots of the polynomial in the denominator	Based on minimizing the mean squared error of the array output under the constraint that normal of weight vector be equal to 1.
Min norm	Only relevant for Uniform Linear arrays(ULA)	It’s Pseudo spectrum is almost same as PHD Pseudo spectrum
MUSIC	Good Resolution	Lower performance than ESPRIT, sensitive to gain and phase errors, sensitive to coherent multipath
Root MUSIC	Applied only on uniform Linear array(ULA)	S/N ratio is relatively low, root finding suffers a loss in accuracy
ESPRIT	High resolution , non-critical Array calibration	Computationally complex limited by Array geometries, Requires multiple snapshots.

Table 1 various DOA estimation methods and there comparisons.

III. MUSIC AND ESPRIT ALGORITHM MATHEMATICAL MODEL

A. Signal Model

The following signal model is applicable for both MUSIC and ESPRIT algorithms. The data model assumes that the signals impinging upon an array of sensors are narrow-band and emitted from a point source in the far field. Consider number of plane waves from M narrow-band sources, impinging from different angles θ_i , $i=1, 2, \dots, M$, impinging into a uniform linear array (ULA) of N equi-spaced sensors, as shown in Fig. 1. At a particular instant of time t, $t=1, 2, \dots, K$, where K is the total number of snapshots taken, the array

output will consist of the signal plus noise components. For the signal model, correlation matrix will be as given below.

$$R_{xx} = \sum_{m=1}^M \lambda_m k_m k_m^H = E_S E_S^H + \sigma_n^2 E_S E_S^H$$

In real array measurements, the covariance matrices are unknown and they can be estimated from a finite amount of measurements called snapshots. Therefore the natural estimate of the correlation matrix or the sample covariance matrix is given by,

$$R'_{xx} = \sum_{k=1}^{K-1} X(K). X(K)^H$$

$$R'_{xx} = (1/K) \sum_{k=0}^{K-1} X_k \cdot X_k^H$$

Where K is the number of samples or observation vectors, and x is the K×M complex envelopes matrix of M measured signals [1].

B. Music Algorithm

MUSIC algorithm uses following steps to determine Direction of arrival.

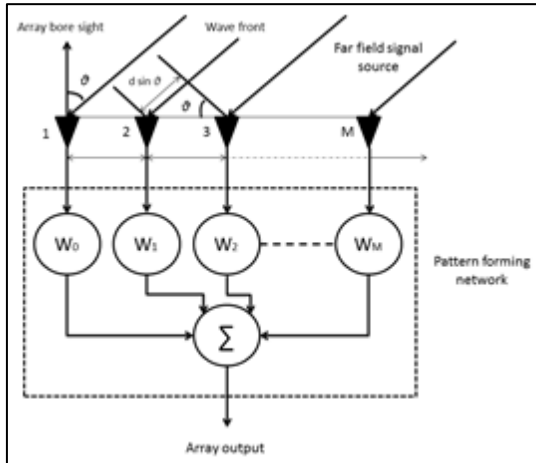


Fig. 1: MUSIC Algorithm Model [1]

1) Step 1

Collect input samples $X_k, k=0...N-1$ and estimate the input covariance matrix

$$R'_{xx} = (1/K) \sum_{k=0}^{K-1} X_k \cdot X_k^H$$

2) Step 2

Perform Eigen decomposition on R'_{xx}

$$R'_{xx} E = E \Lambda$$

Where $\Lambda = \text{diag}\{\lambda_0, \lambda_1, \dots, \lambda_{M-1}\}$ are the Eigen values and $E = \text{diag}\{q_0, q_1, \dots, q_{M-1}\}$ are the corresponding eigen vectors of R'_{xx} .

3) Step 3

Estimate the number of signals L' from the multiplicity K , of the smallest Eigen value λ_{\min} as equation $L' = M - K$

4) Step 4

To compute music spectrum by following eq

$$P_{\min}(\theta) = A^H(\theta) A(\theta) / A^H(\theta) E_n E_n^H A(\theta)$$

5) Step 5

Find the L' largest peaks of estimates $P_{\min}(\theta)$ to obtain the Direction -Of- Arrival [1].

C. Esprit Algorithm

ESPRIT algorithm uses following steps to determine direction of arrival.

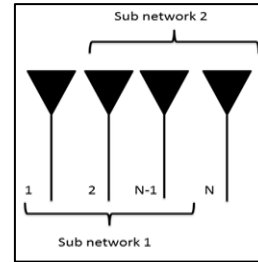


Fig. 2: ESPRIT Algorithm Model [1]

1) Step 1

Obtain an estimate R'_{xx} of R_{xx} from the measurements X

2) Step 2

Perform Eigen decomposition on R'_{xx} .

$$R'_{xx} = V \Lambda V^H$$

Where $\Lambda = \text{diag}\{\lambda_0, \lambda_1, \dots, \lambda_{M-1}\}$ are the Eigen values

And $E = \text{diag}\{q_0, q_1, \dots, q_{M-1}\}$ are the Eigen vectors

3) Step 3

Using the multiplicity, K , of the smallest Eigen value λ_{\min} , estimate the number of signals L' , as

$$L' = M - K.$$

4) Step 4

Obtain the signal subspace $V_s = [V_0 \dots V_{L-1}]$ and decompose it into sub-array matrices

$$V_s = [v_0/v_1]$$

5) Step 5

Compute the Eigen decomposition.

6) Step 6

Calculate the Eigen values.

7) Step 7

Estimate the Angle-of-Arrival as [1].

$$\theta_k = \cos^{-1} [\arg(\hat{\theta}_k) / \beta d]$$

As seen from the above discussion, ESPRIT eliminates the search procedure inherent in most DOA estimation methods; ESPRIT produces the DOA estimate directly in terms of the Eigen values [1].

Comparison of MUSIC and ESPRIT algorithm by varying various parameters [1].

Sr. no.	Parameters	Music	Esprit
1	SNR	Output peaks are sharper. For SNR=25 db and angle 35° we get pseudo spectrum 75 db.	Output peak increases. For SNR=25 db and angle 35° we get pseudo spectrum 73 db.
2	Angular Separation	Better results. For angular separation of 5° - 20° and angle of 35° we get pseudo spectrum 60 db.	Poor results. For angular separation of 5° to 20° and angle of 35° we get pseudo spectrum 57 db.
3	No of Snapshots	Peaks are increased and efficiency is also more. For varying no of snapshots k = 1000 and angle is 35° we get pseudo spectrum 64 db.	Sharper peaks. For varying no of snapshots k = 1000 and angle is 35° we get pseudo spectrum 65 db.
4	No of Sensing Element	Better resolution obtained. For varying no of sensors M = 14 element and angle of 35° we get pseudo spectrum 58 db.	Performance is better. For varying no of sensors M = 14 element and angle of 35° we get pseudo spectrum 59 db.
5	Element Spacing	Output peaks are accurate and inadequate. For varying element spacing d = 0.75 lambda and angle of 35° we get pseudo spectrum 55 db.	Accuracy is not much better as compared to music. For varying element spacing d = 0.75 lambda and angle of 35° we get pseudo spectrum 53 db.

Table 2: Results of varying various parameters of antenna arrays

Different DOA estimation methods are compared and results are obtained for selecting best suitable method. The comparison table is given above [1]. By observing below results, it is clear that by varying no of sensing elements, angular distance, element spacing, SNR, no of snapshot there is variation in output values and results becomes more accurate and efficient.

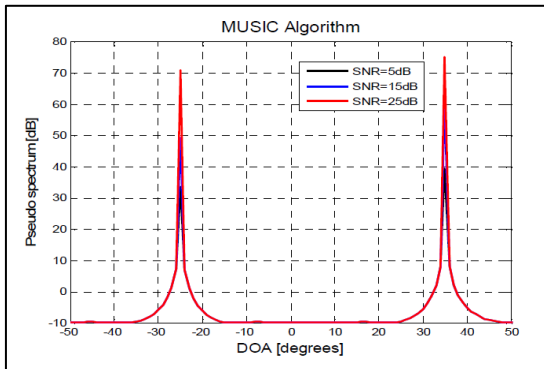


Fig. 3: The effect of varying the SNR.

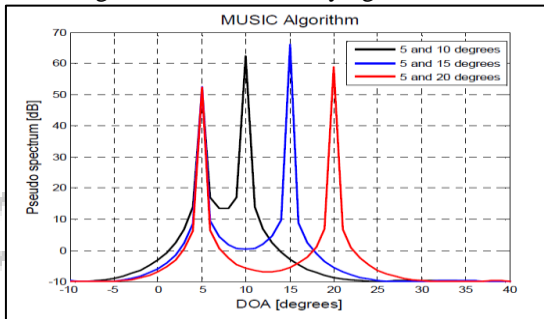


Fig. 4: The effect of varying the angular separation [1].

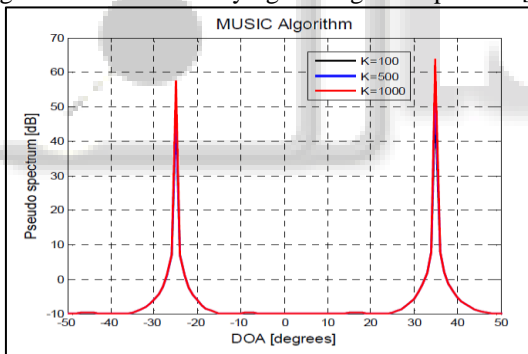


Fig. 5: The effect of varying the number of snapshot.

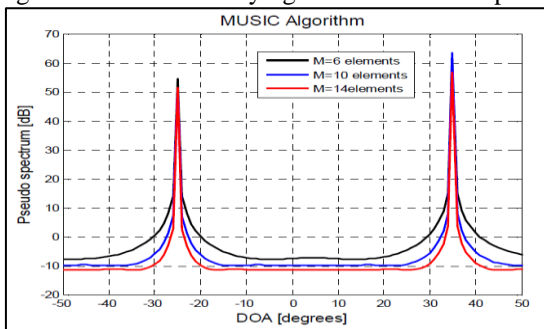


Fig. 6: The effect of varying the number of sensors [1].

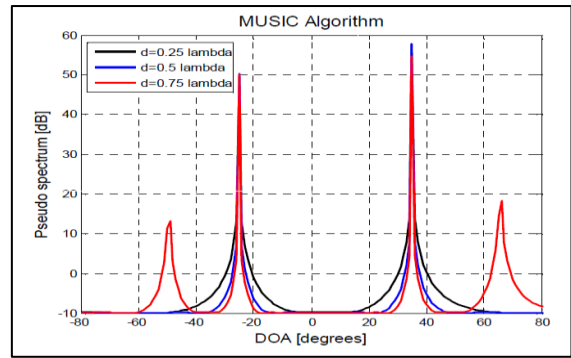


Fig. 7: The effect of element spacing d.

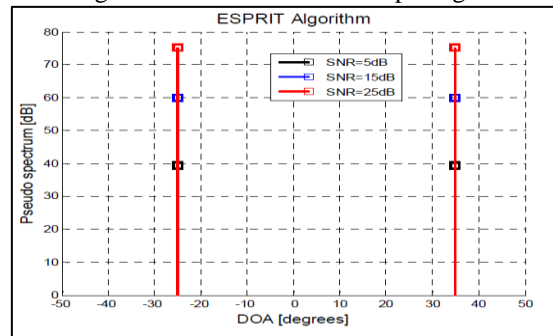


Fig. 8: The effect of SNR in ESPRIT algorithm.

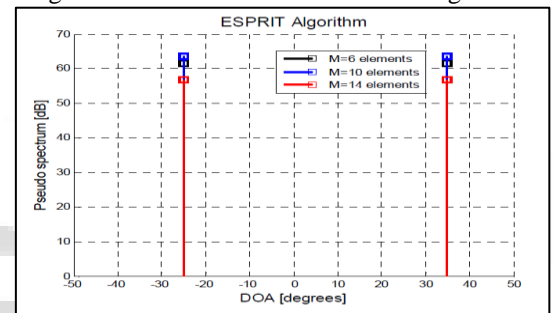


Fig. 9: The effect of varying number of elements.

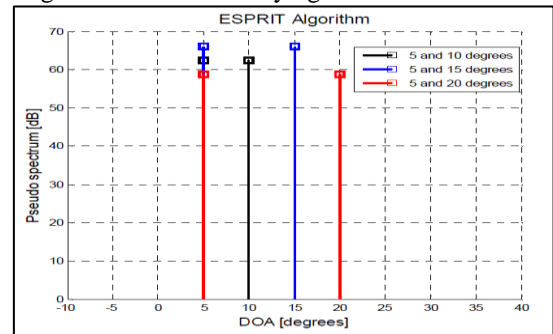


Fig. 10: The effect of varying the horizontal angular separation [1].

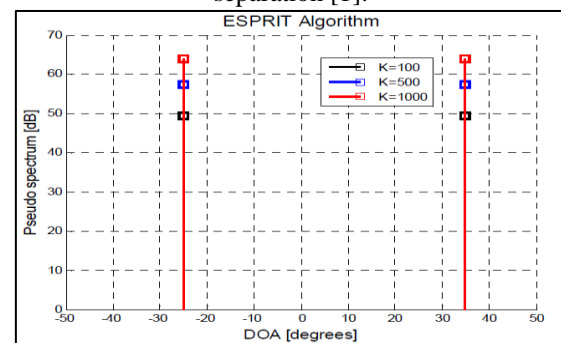


Fig. 11: The effect of varying the number of snapshot on the algorithm.

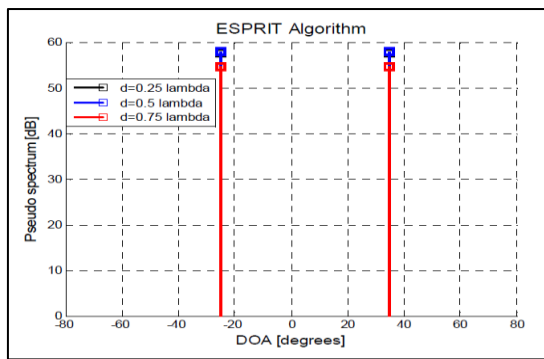


Fig. 12: The effect of element spacing d .

IV. VARIOUS SIGNAL PROCESSING CIRCUITRIES

In DOA estimation process the two receiving antenna signals are used and the phase difference between those two signals is used to find angle of radiating signals. There are various signal processing circuitries used in DOA estimation. In which, use of FPGA or DSP is most popular method, that can process signals to find angle between two receiving antenna signals. The results obtained from those methods are more reliable and accurate. But the major issue is the increased cost of circuitry. Also in some cases DAQ (data acquisition controller) is used for signal processing, but this method is also having huge investment. Third method is using phase detector circuitry which can take two receiving antenna signals as inputs and calculate the phase difference between these two signals to give digital output. This output is nothing but the error signal, which is used for beam forming process when connected to the phase shifter input. This method of finding direction of arrival is most suitable, cost effective and reliable. This method is less complex as compared to other methods.

Use of DSP processor in DOA estimation is common method [14]. Where 2-D DOA estimation method is used in which two computational cores in MUSIC are identified and parallelized. Vectorization of multiple single precision floating point operations is proposed to make good use of the 128-bit vectors on DSP C6678. Then, the parallel DOA estimation algorithm is implemented on one of the cores of DSP C6678.

In some methods such as commercial-off-the-shelf (COTS) software-defined radios (SDRs) [10] is used to find the receiving signals, in which Universal Software Radio Peripherals (USRPs) is used to receive signals.

Use of data acquisition controller is rear case in DOA estimation for signal processing [11]. DAQ is used for signal processing for DOA estimation. In which PCI6052E DAQ is used.

FPGA's are used for signal processing [12], Where Xtreme DSP Spartan 3A 1800 board is used for DOA estimation.

All the above methods are not much reliable. Hence newly adopted method is the use of phase detector AD8302 for signal processing [16]. This phase detector Measures

- Gain/Loss and Phase up to 2.7 GHz.
- Dual Demodulating Log Amps and Phase Detector Input Range is -60 dBm to 0 dBm.
- Typical Nonlinearity < 0.5 dB.
- Accurate Phase Measurement Scaling (10 mV/Degree).

- Typical Nonlinearity $< 1^0$.
- Measurement/ Controller/ Level Comparator Modes Operates from Supply Voltages of 2.7 V to 5.5 V.
- Stable 1.8 V Reference Voltage Output.
- Small Signal Envelope Bandwidth from DC to 30 MHz.

Hence this is best suitable for DOA estimation.

V. CONCLUSIONS

From the above results it can be concluded that direction of arriving signal is determined by using subspace based method like MUSIC and ESPRIT, because they are best suitable, accurate, efficient method in all applications of DOA estimation. however there are various parameters such as no of snapshots, no of sensing antenna arrays, angular separation between two array antenna elements, distance between two antenna elements etc. by varying which we can improve performance of the system. it can also be concluded from above discussion that the use of FPGA, DSP, or DAQ in signal processing can be avoided by the use of phase detector circuit. Due to use of phase detector circuit the cost is reduced by a scale factor of 97% along with reduction in complexity.

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