

Direction-Of-Arrival Estimation for Adaptive Antenna Systems

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Abstract : Adaptive smart antenna system manipulates the signal impinging on various antenna elements in such a way that, the main beam is directed towards the desired signal and a null is formed in the direction of interferers. Such smart antenna systems play a very important role in wireless and military applications as they can increase capacity, coverage range and resolution. To locate the desired signal, in smart antenna system direction of arrival (DOA) estimation algorithms MUSIC and ESPRIT are considered. This paper evaluates and compares MUSIC and ESPRIT DOA estimation algorithms which are mostly used in design of adaptive antenna system. MUSIC and ESPRIT provide a higher resolution and accuracy hence, are explored much in detail. Implementation of MUSIC and ESPRIT shows that, MUSIC is more stable and accurate than ESPRIT therefore, MUSIC is widely used to detect DOA of incoming signals.

Keywords: DOA, ESPRIT, MUSIC, Smart Antenna

I. Introduction

One of the most assured technique for increasing the capacity of cellular wireless communication and accuracy related to military applications is the adaptive array antenna. The smart antenna working basically deals with an array of antenna elements whose radiation pattern is controlled by adjusting the amplitude and phase of different antenna elements in the array. Signals impinging on various antenna elements at the transmitter, whose time delay information is used by the adaptive smart antenna system to produce its output. Hence, this time delay must be appropriately combined at transmitter to be deciphered by the receiver. This information itself is used by the smart antennas to combine signals with greater fidelity or produce a null for the interfering signals and hence, improving the capacity for communication and accuracy for military purpose. The various DOA estimation algorithms are Bartlett, Capon, Min-norm, MUSIC and ESPRIT [3] [6] [8] [10]. But, MUSIC and ESPRIT algorithms are high resolution and accurate methods which has a huge response in the design of smart antennas and hence, their performance is evaluated in following sections.

II. DOA Estimation Algorithms

The purpose of DOA estimation is to get the direction of arrival of the incoming signals by using the estimate of data received by the array of antenna elements. As shown in Fig. 1, these results of DOA estimation are further used by the adaptive beam forming to locate the desired signal and produce a null for signals not of interest. Hence, the successful design of adaptive system block basically depends on, how well the DOA block estimates the incoming signals direction of arrival. The performance of DOA estimation algorithm depends on parameters like the number of antenna elements, their spacing, the number of signal samples and SNR. The DOA estimation algorithms have been evaluated and categorized into two methods viz. Conventional and subspace methods. Conventional methods also called as classical methods first compute a spatial spectrum and then estimate the DOA by local maxima of the spectrum [3] [4] [6] [8]. The methods that fall under this are the Bartlett, Capon methods but, these methods suffer from lack of angular resolution. Subspace based methods show a higher angular resolution and the methods that come under this is MUSIC and ESPRIT algorithms which are mostly used [1] [2] [5] [6] [9].

III. MUSIC DOA Estimation Algorithm

MUSIC is an acronym which stands for Multiple Signal Classification. It is high resolution technique based on exploiting the Eigen structure of input covariance matrix. MUSIC makes assumption that noise in each channel is uncorrelated making correlation matrix diagonal but, the incident signals are somewhat correlated creating non diagonal signal correlation matrix. Since, multiple signals direction of arrival (DOA) obtained at its output, this method of estimation is termed as the MUSIC method [2] [5] [8]. MUSIC method outputs a spectrum with certain peaks, present in the spectrum. The location of these peaks on x-axis is nothing but, the direction of arrival for each of the incoming signals. MUSIC requires Eigen values and vectors for its working.

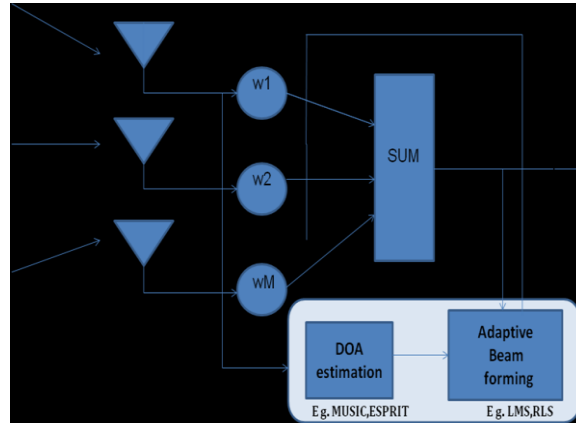


Fig.1 D Signals Impinging on M Antenna Elements

If the number of signals impinging on M element array is D, the number of signal Eigen values and Eigen vector is D and the number of noise Eigen values and Eigen vectors is M-D then the Array Correlation Matrix with equal variances is given by,

$$R_{xx} = A^H R_{ss} A + \sigma_n^2 I \quad (1)$$

Where, $A = [a(\theta_1) \ a(\theta_2) \ \dots \ a(\theta_D)]$: Array Steering Matrix
 $R_{ss} = [s_1(k) \ s_2(k) \ \dots \ s_D(k)]$: Source Correlation Matrix

R_{xx} has ‘D’ Eigen Vectors related to signals and M-D Eigen Vectors related with noise. So, we can construct the M-D subspace spanned by noise Eigen vectors such that,
 $V_n = [V_1 \ V_2 \ \dots \ V_{M-D}]$ (2)

The noise subspace Eigen Vectors are orthogonal to array steering vectors at the angles of arrivals $\theta_1, \theta_2 \ \dots \ \theta_D$ and the MUSIC power spectrum is given as,

$$P_{MUSIC}(\theta) = 1 / \text{abs}((a(\theta)^H V_n V_n^H a(\theta))) \quad (3)$$

IV. ESPRIT DOA Estimation Algorithm

ESPRIT stands for Estimation of Signal Parameters via Rotational Invariance Techniques which is another subspace based DOA estimation algorithm. It does not involve an exhaustive search through all possible steering vectors to estimate DOA and hence, reduces the computational and storage requirements as compared to MUSIC. ESPRIT scans two arrays called doublets at a time in a translational way. ESPRIT assumes $D < M$ sources centered at frequency f_0 . Fig. 2 shows four element linear array composed of two doublets [3] [4] [6] [8].

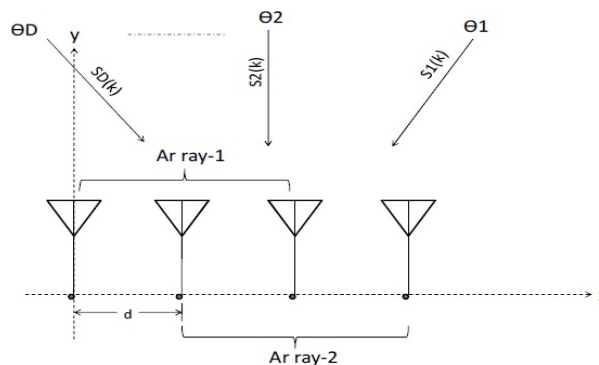


Fig. 2 Four element linear array with two doublets

The two sub arrays, Array-1 and Array-2 are displaced by distance ‘d’. The signals induced on each of the arrays are given by,
 $x_1(k) = A^H s(k) + n_1(k)$ (1)

$$x_2(k) = A \Lambda s(k) + n_2(k) \quad (2)$$

where, $\Lambda = \text{diag} \{ e^{jk d \sin(\theta_1)}, e^{jk d \sin(\theta_2)}, e^{jk d \sin(\theta_3)} \}$
 = diagonal unitary matrix with phase shifts between doublets for each DOA

Creating a signal subspace for the two sub arrays results in two matrices V_1 & V_2 . Since, the arrays are translationally related, the subspaces of Eigen vectors are related by a unique non-singular transformation matrix φ such that,

$$V_1 \varphi = V_2 \quad (3)$$

There must also exist a unique non-singular transformation matrix T such that,

$$V_1 = AT \quad \text{and} \quad V_2 = A \Lambda T \quad (4)$$

and finally we can derive, $T \varphi T^{-1} = \Lambda$

Thus, the Eigen values of φ must be equal to the diagonal elements of Λ such that,

$$\lambda_1 = e^{jk d \sin(\theta_1)}, \lambda_2 = e^{jk d \sin(\theta_2)}, \dots, \lambda_D = e^{jk d \sin(\theta_D)} \quad (5)$$

Once, the Eigen values of φ , $\lambda_1, \lambda_2, \dots, \lambda_D$ are calculated, we can estimate the angles of arrival as,

$$\theta_i = \sin^{-1} (\arg (\lambda_i) / kd) \quad (6)$$

From above equations it becomes clear that, ESPRIT eliminates the search procedure and produces the DOA estimation directly in terms of Eigen values without much computational and storage requirements. This Eigen structure shows excellent accuracy and resolution in many applications [3] [4] [7] [10].

V. Results And Discussions

The simulation results are obtained for MUSIC and ESPRIT method of DOA Estimation by varying the number of antenna elements (N), number of signal sources (K), angles of arrival (AOA) and signal to noise ratio for incoming signals in MatlabR2008a software. Results for MUSIC Fig.3 shows, the graph for angle of arrival (x-axis) Vs directional spectrum (y-axis) for N=10 and K=4; Fig.4 depicts graph for N=20 and K=4. Similarly, Fig.5 and 6 show graphs for K=3, N=20 and K=5, N=20 respectively. Fig. 7 and 8 accurately detects angles of arrival for 10°, 30°, 50°, 70°, 90°, 100°, 120°, 150°, 240°, 360° respectively. Results obtained for ESPRIT fig.9 and fig.10 depicts the graph for varying the number of antenna elements (N) on x-axis from 2 to 3 Vs AOA on y-axis; Fig. 11, 12 shows graph for varying the signal to noise from 10 to 20 respectively and Fig.13 refers to graph that detects all the incoming signals in an accurate manner.

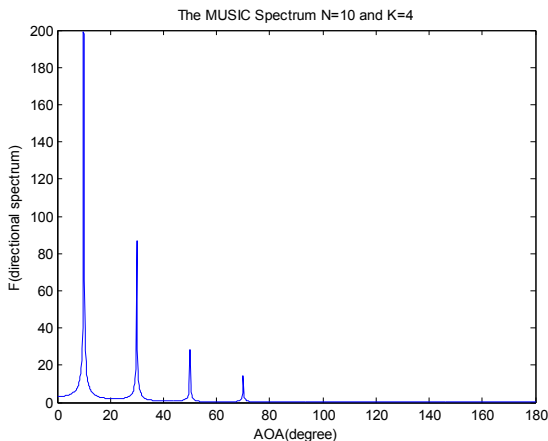


Fig. 3: Effect of varying number of antenna elements (N=10)

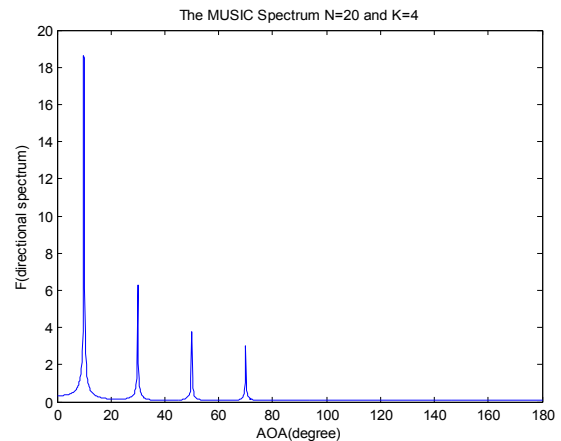


Fig. 4: Varying the number of antenna elements (N=20)

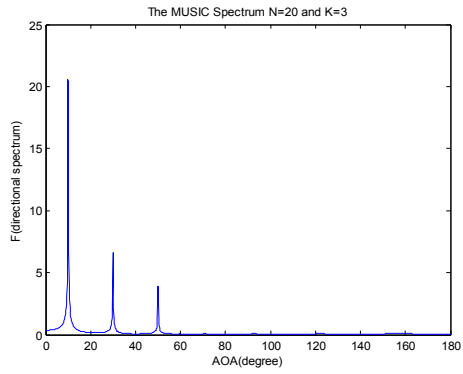


Fig. 5: Effect of varying number of incoming signals ($K=3$)

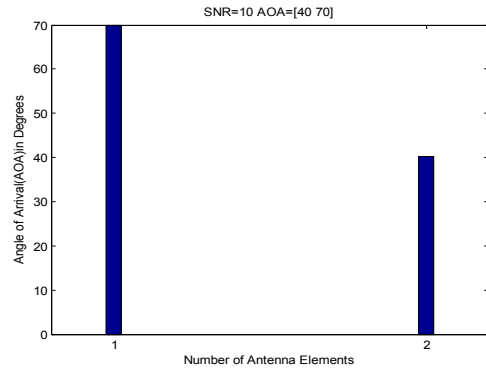


Fig.9: Varying the number of antenna elements ($N=2$)

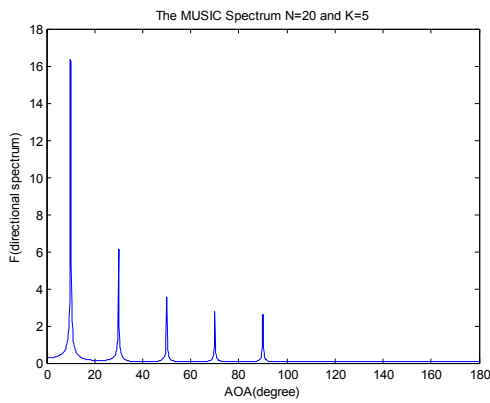


Fig. 6 : Varying the number of incoming signals ($K=5$)

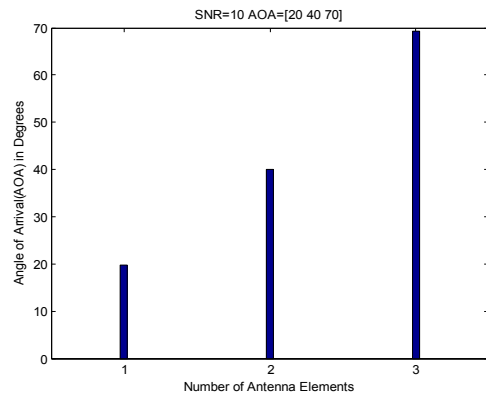


Fig.10: Varying the number of antenna elements ($N=3$)

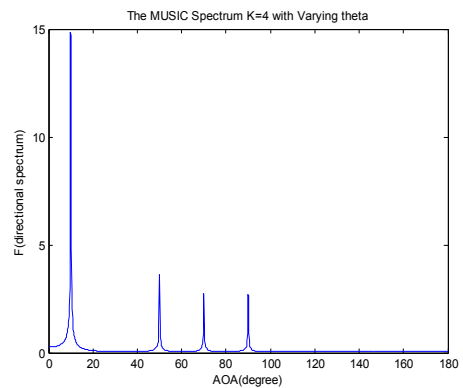


Fig.7: Detection of Incoming signals at 10° , 50° , 70° , 90° , 120°

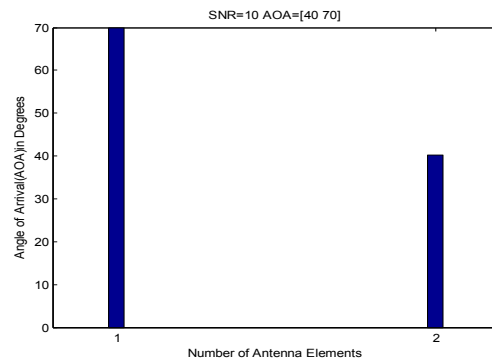


Fig.11: Varying the signal-to-noise ratio ($SNR=10$)

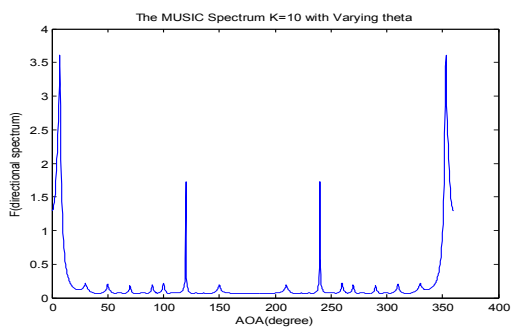


Fig. 8: Detection of incoming signals at $10,30,50,70,90,120,240,360^\circ$

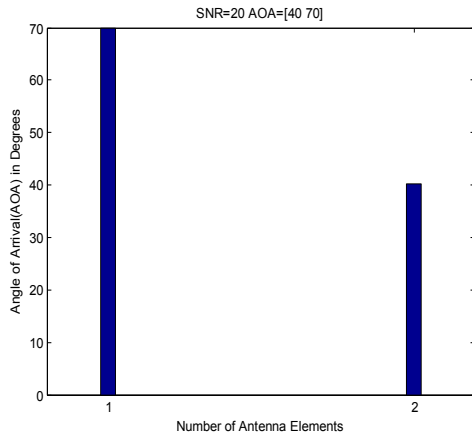


Fig.12: Varying the signal-to-noise ratio (SNR=20)

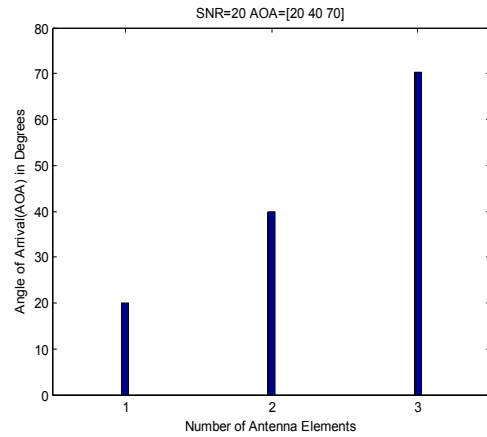


Fig.13: Detection of incoming signals at 20°, 40°, 70°

VI. Conclusions

This paper presents the simulation results for MUSIC and ESPRIT method of DOA Estimation. Since, MUSIC and ESPRIT methods have greater resolution and accuracy hence, are evaluated in detail. Table 1 shows performance of MUSIC that improves as the number of elements in the array and for greater angular separation between the signals. These improvements are seen in the form of sharper peaks in MUSIC spectrum. Table 2 shows the performance of ESPRIT algorithm which improves when SNR and number of antenna elements are increased. These improvements are seen in form of smaller angle detection for ESPRIT DOA Estimation technique.

Table 1: Simulation Results for MUSIC Algorithm

Varying Parameters (DOA Estimation)	Observed Output	Conditions
[a] Number of antenna elements (N) increased from 10 to 20	- Peaks of spectrum become sharper	(a) Output observed for AOA=(10°,30°,50°, 90°,120°) (b) K=4 (c) Spacing between elements is 0.5
[b] Number of snapshots (p) increased	- Precise detection of incoming signals - Resolution capacity increases	(a) K=4 (b) N=20
[c] AOA Detection	- Incoming signals very accurately detected using MUSIC DOA Estimation process	(a) Values considered: (10,30,50,70,90,120,150,240,360°) (b) K=4,10 (c) N=20

Table 2: Simulation Results for ESPRIT Algorithm

Varying Parameters (DOA Estimation)	Observed Output	Conditions
[a] Number of antenna elements (N) increased from 2 to 3	-More precise detection of incoming signal angle	(a) Output observed for AOA=(20°,40°,70°) (b) K=2,3 (c) SNR=10
[b] SNR increased from 10 to 20	-Less errors in angle detection at output	(a) Output observed for AOA=(40°,70°) (b) N=2
[c] AOA Detection	-All incoming signals very accurately detected using ESPRIT DOA Estimation Process	(a) Values considered: (20°,40°,70°) (b) K=3 (c) N=20

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