COMPARISON BETWEEN CLASSICAL AND MODERN METHODS OF DIRECTION OF ARRIVAL (DOA) ESTIMATION

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ABSTRACT

In this paper, a comparison between the classical method; Fast Fourier Transform (FFT), and modern methods; MUltiple SIgnal Classification (MUSIC) method and EigenVector method (EV) for direction of arrival estimation are investigated. The simulation results of single source and two sources DOA estimation are realized for three methods (FFT, MUSIC, and EV). After DOA estimation is realized an investigation is making to show the performance of the (FFT, MUSIC, and EV) methods for DOA estimation of min. difference between angles of sources versus SNR at fixed number of elements. The experimental results are achieved for single source DOA estimation using set of ultrasonic transducers.

KEYWORDS: *Array Signal Processing, DOA, MUSIC, EV.*

I. INTRODUCTION

Increase of demand for the wireless technology service have spread into many areas such as, sensor network, public security, environmental monitoring, mobile in smart antenna, and search and rescues. All these applications can be counted the main reason for determine the direction of arrival (DOA) estimation of incoming signal in wireless systems. The DOA also, used in other applications such as radar, sonar, seismology, and strategy of defense operation. In smart antenna technology, a DOA estimation algorithm is usually incorporated to develop systems that provide accurate location information for wireless services [1]. The DOA technique one branch of array signal processing [2]. This paper based on uniform linear array (ULA) of multiple sensors that deals with array receiving antenna to extract a useful information from it.

Many algorithms are founded to solve the problem of DOA [3]. Initially Beam forming, ESPRIT, Maximum likelihood algorithm, subspace methods (Pisarenko Harmonic Decomposition (PHD)[4], MUltiple SIgnal Classification (MUSIC)[5], and Eigenvector method (EV) [6]) and other algorithms. We are used in this paper classical method (FFT) [7] and modern methods (MUSIC and EV) and compare between them. This paper include the problem formulation of DOA estimation. After that the theoretical and mathematical expression for MUSIC and EV methods are introduced. Then the simulation and experimental results has been realized. The conclusions and suggestion for future work are the last sections of this paper.

II. PROBLEM FORMULATION

We assume that a system consist of uniform linear array (ULA) with N-elements and M-sources and the distance between elements is d. The first element of the array consider as a reference element. The scenario for this system is the sources in the far field and the incoming data is plane wave. This system are shown in figure (1).

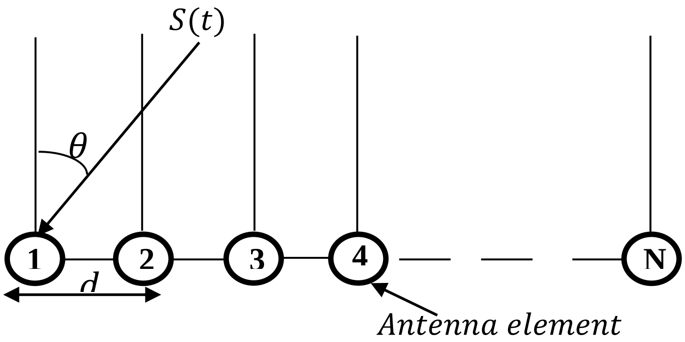

Fig. 1. Uniform Linear Array (ULA) and the Direction of Arrival (DOA).

The data received at the array antenna is

$$X = As + n \tag{1}$$

Where

$A = [a(\theta_1), a(\theta_2), \ldots\ a(\theta_M)]$ Array steering vector.

s: Signal source.

n: is an additive noise term whose mean is 0 and variance is σ^2I.

The algorithms will be using in this paper are based on the autocorrelation matrix of the received data [8]. These algorithms are MUltiple SIgnal Classification (MUSIC) and EigenVector method (EV), and compare these with classical Method Fourier Transform (FT).

III. MULTIPLE SIGNAL CLASSIFICATION (MUSIC)

MUSIC method is a high-resolution algorithm that based on eigen-decompostion of the autocorrelation matrix. This method is decompose the covariance matrix into two subspaces, signal subspace and noise subspace. Estimation the direction of arrival of incoming signal is determined from steering vectors that orthogonal to the noise subspace, which is by finding the peak in spatial power spectrum.

Suppose that there are *M* sources, the receiving signal of *N* elements uniform linear antenna array is given by

$$X = \sum_{i=1}^{M} a(\theta_i)s_i + n = \ \ AS\ + n \tag{2}$$

The signal auto covariance matrix can be written as the average of *N* array output samples:

$R = E\{XX^H\}$ The eigen-decomposition is

$$R = Q\Lambda Q^H = \sum_{i=1}^{N} \lambda_i q_i q_i^H \tag{3}$$

Where $\Lambda = diag\ (\lambda_1, \lambda_2, \ldots, \lambda_N)$ it is eigenvalues and sorting in ascending sequence: $\lambda_1 \geq \lambda_2, \ldots, \geq \lambda_M > \lambda_{M+1} = \ldots = \lambda_N$. That is the first *M* eigenvalues are in connection with the signal and their numeric value are all more than σ^2. The signal divided into two subspace signal subspace and noise subspace. The signal subspace is the eigenvector $(q_1, q_2, \ldots, q_M)$ corresponding to the largest eigenvalues (λ_1, λ_2,…, λ_M), so the signal subspace is: $Q_s = [q_1, q_2, \ldots, q_M]$. $\Lambda_s$is the diagonal matrix consist of the m larger eigenvalues. The later N-P eigenvalues are totally depended on the noise and their numeric value are σ^2 . The noise subspace is the eigenvector corresponding to the remaining eigenvalues (λ_{M+1}, λ_{M+2},…, λ_N), so the noise subspace $Q_n = [q_{M+1}, q_{M+2}, \ldots, q_N]$. $\Lambda_n$is the diagonal matrix consist of the m larger eigenvalues. So R could be divided into:

$$R = Q_s\Lambda_s Q_s^H + Q_n\Lambda_n Q_n^H \tag{4}$$

Duo to each column vector is orthogonal to noise subspace: $Q_n^H a(\theta_i)$, $i = 1,2, \ldots M$, the spectrum of the MUSIC are derived:

$$P(\theta)_{MUSIC} = \frac{1}{\boldsymbol{a}^H(\theta)\boldsymbol{Q}_n\boldsymbol{Q}_n^H\ \boldsymbol{a}(\theta)} \tag{5}$$

From eq. (5), we can estimating the DOA by searching the peak value [9].

IV. EIGEN VECTOR METHOD (EV)

In addition to the MUSIC algorithm, a number of other eigenvector methods have been proposed for estimation the DOA. One of these, the EigenVector (EV) method. The EigenVector is closely relate to the MUSIC algorithm. Specifically, the EV method estimates the exponential frequencies from the peaks of the eigenspectrum:

$$P(\theta)_{EV} = \frac{1}{\sum_{i=p+1}^{M} \frac{1}{\lambda_i} \left| \boldsymbol{a}^H(\theta) Q_n \right|^2} \quad (6)$$

Where λ_i is the eigenvalue associated with eigenvector Q_n.
$a(\theta)$: Array steering victor
The only difference between the EV method and MUSIC is the use of inverse eigenvalue (the $\lambda_i$are the noise subspace eigenvalues of R) weighting in EV and unity weighting in MUSIC, which causes EV to yield fewer spurious peaks than MUSIC. The EV Method is also claimed to shape the noise spectrum better than MUSIC [9].

V. SIMULATION RESULTS

The DFT, MUSIC, and EV are simulated for estimation the (DOA) using software MATLAB program. We are using in this paper ULA 10 elements, the distance between the elements is half wavelength (0.5λ), and SNR is (30 dB), and snapshot 1000. The figures (2, 3, and 4) shows the estimation of angle of arrival for single source for three methods.

Fig.2 shows the result of using FFT algorithm. It is estimation the DOA for single source at 20° degree. A high sidelobe is clear and this is one of the disadvantages of using the FFT method. The peak of main beam at 20° and it's very wide (5°) to(38°). The wide beam causes an ambiguity in estimation the DOA. This ambiguity causes problem in locate the accurate angle, especially in military application that need accurate angle. Another disadvantage for the wide beam is causes loss power.

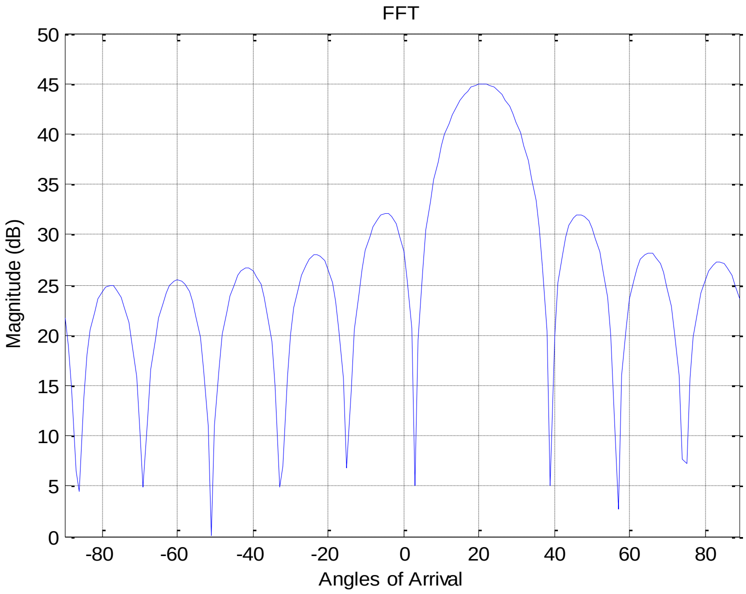

Figure 2. DOA Estimation for one source (20) degree using FFT method. (SNR=30dB, N=10, d=0.5λ)

The result shown in fig.3 is that of using MUSIC algorithm. It is able to estimation the DOA for single source at 20° degree. There is very small (negligible) sidelobe and these are the advantages of MUSIC method. The main beam of MUSIC method narrow than the main beam in FFT method so it is overcome the ambiguity in estimation the DOA and loss of the power.

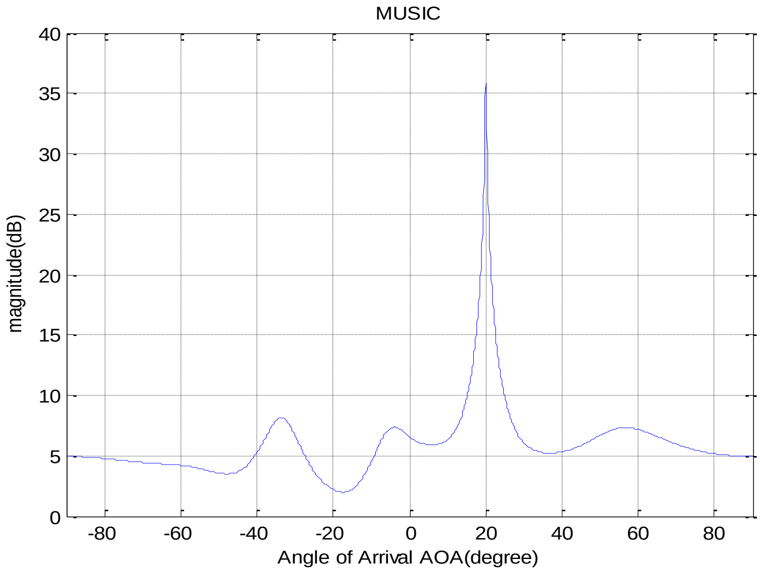

Figure 3. DOA Estimation for one source (20) degree using MUSIC method. (SNR=30dB, N=10, d=0.5λ)

The result shown in fig.4 is that of using EV algorithm. It is capable to estimation the DOA for single source at 20° degree. There is very small (negligible) sidelobe and these are the advantages of EV method. The main beam of EV method is very sharp and narrow than the beams in FFT and MUSIC method so it is overcome the ambiguity in estimation the DOA and give accurate estimation.

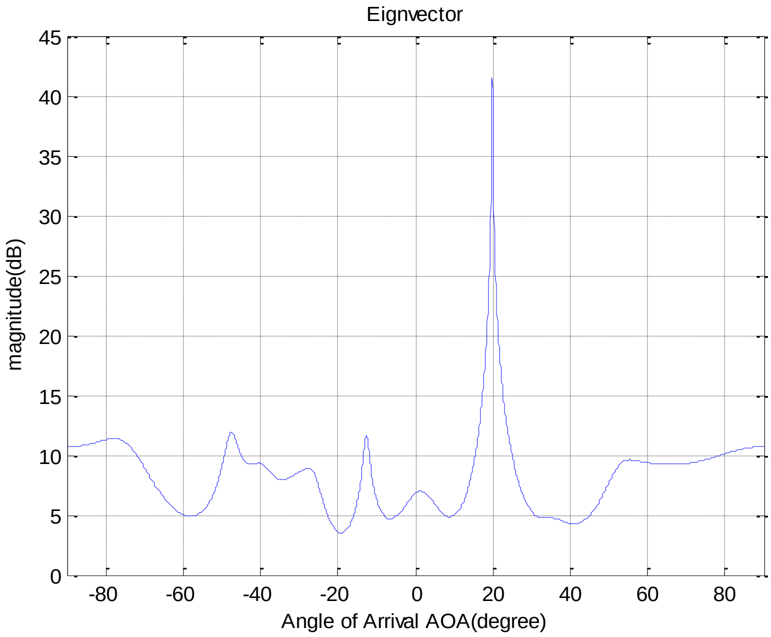

Figure 4. DOA Estimation for one source (20) degree using EV method. (SNR=30dB, N=10, d=0.5λ)

The figures (5, 6, and 7) shows the estimation of angle of arrival for two sources for three methods. We are using the same parameters of the single source. Fig.5 shows the result of using FFT algorithm. It is able to resolve between two adjacent sources but the difference between them is high more than (20°) degree. Additionally, a high side lobe is clear and this is one of the disadvantage of the FFT method. The falling between peak and vale of two sources not enough and equal to about 5dB because the wider beam of the FFT method.

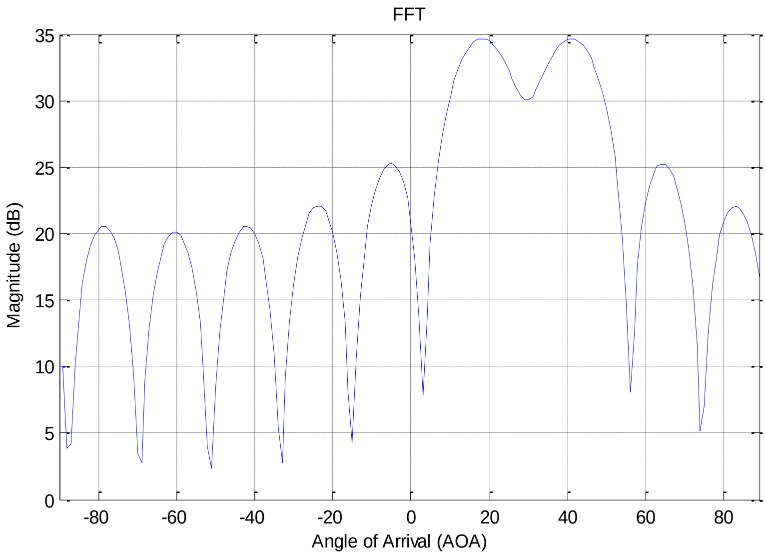

Fig.5 DOA Estimation for two sources (20, 40) degree using FFT method. (SNR=30dB, N=10, d=0.5λ)

Fig.6 shows the result of using MUSIC algorithm. It is able to recognize between two adjacent sources $(20^{\circ}, 26^{\circ})$ the deference between them more small than FFT about $(6)^{\circ}$ degree. There is very small (negligible) sidelobe and these are the advantages of MUSIC method. The falling between peak and vale of two sources better than FFT and equal to about 10dB.

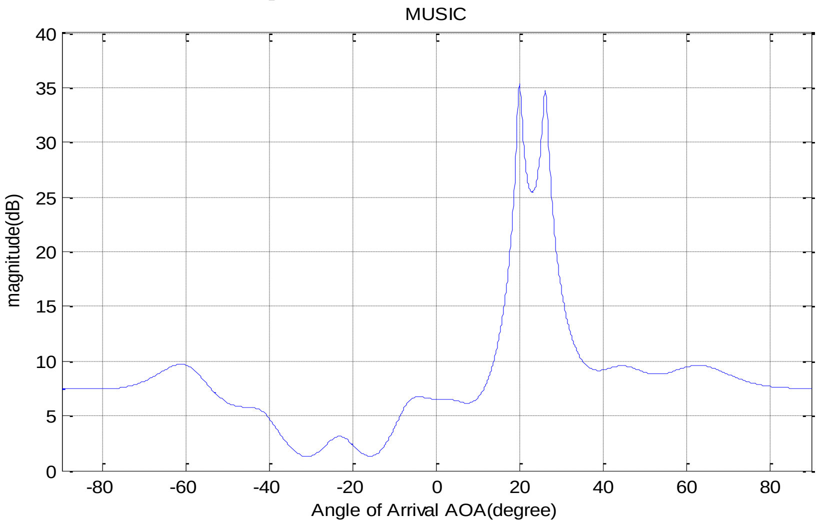

Fig.6 DOA Estimation for two sources (20, 26) degree using MUSIC method. (SNR=30dB, N=10, d=0.5λ)

Fig.7 shows the result of using EV algorithm. It is able to recognize between two adjacent sources $(20^{\circ}, 24^{\circ})$ the deference between them smaller than FFT and MUSIC about $(4)^{\circ}$ degree. There is very small (negligible) sidelobe and these are the advantages of EV method. The falling between peak and vale of two sources the best over than FFT and MUSIC methods and equal to about 18dB because it is very narrow beamwidth.

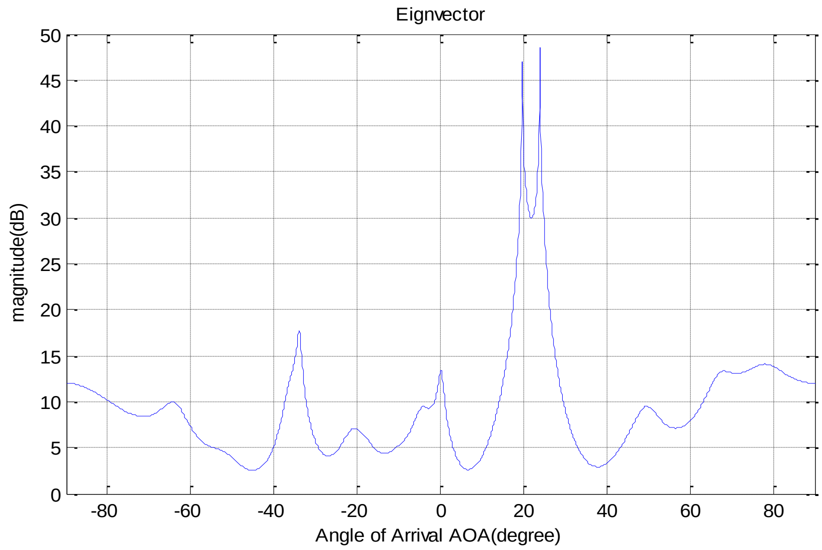

Fig.7 DOA Estimation for two sources (20, 24) degree using EV method. (SNR=30dB, N=10, d=0.5λ)

Fig.8 shows the performance of the (FFT, MUSIC, and EV) to recognize between sources when the SNR was changed at fixed number of elements (10 elements). In FFT, method for low SNR needs high difference between angles to resolve between sources because of low resolution for this method, but when SNR high it needs small difference to resolve between sources. For the same parameters, the result of the MUSIC method is the best when compared with FFT methods. The result of EV, method is the best when compared with both MUSIC and FFT methods.

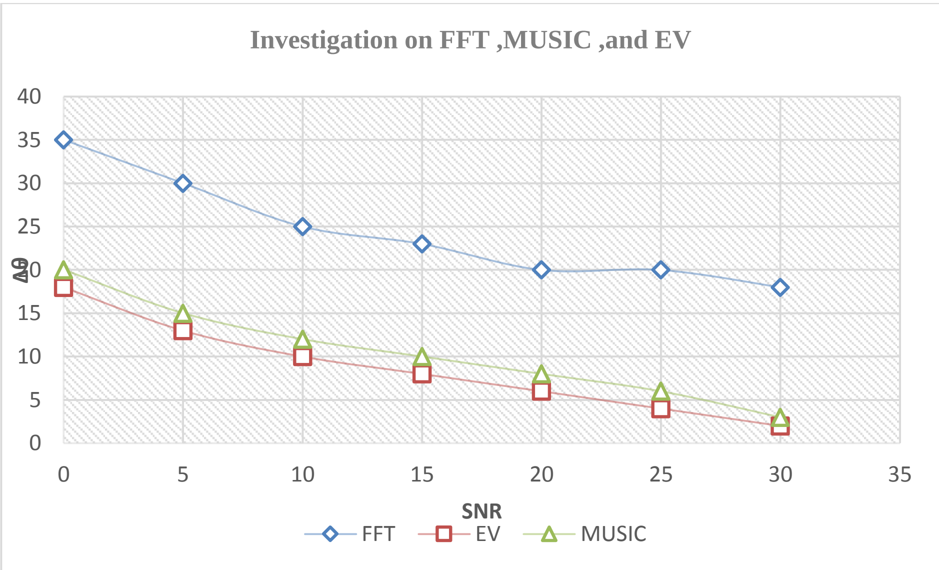

Fig.8. DOA Estimation for minimum difference between angles versus SNR.

VI. Experimental Results

The ultrasonic transducers are used in DOA estimation experiment set for single source. The FFT, MUSIC, and EV methods are used for DOA estimation. Then a comparison is made between high-resolution and classical methods for different values of the system parameter. The system parameters are N (number of samples), Δx (distance between samples and equal to d in equation), Z_o (distance between transmitter and receiver).

In this experiment, the parameters used are N=20 samples Z_o=72 cm, Δx=0.2cm, f=40 MHz, λ= 0.8 cm, θ=22^0 (Direction of arrival).

The results shown in figures (9, 10, 11)

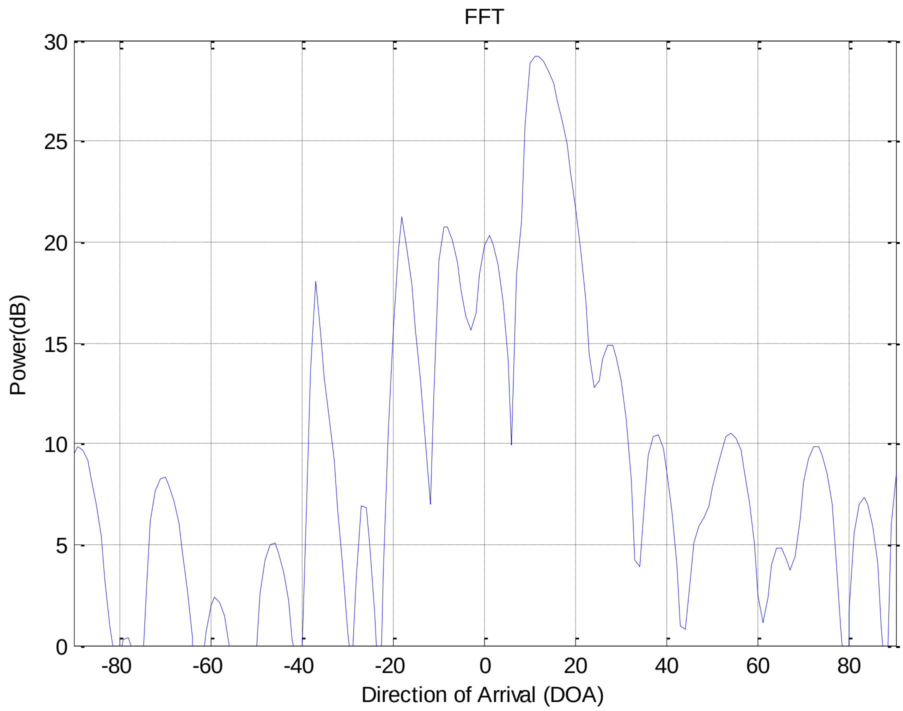

Fig.9 DOA estimation for single source using FFT method

Figure (9) demonstrate the FFT method. It can estimation the DOA. High sidelobe level is clear about -8 dB. In addition, the error in resolution is high and equal to 45 %. The beamwidth of the main beam are wide compared to other methods and equal to (8^0). The wide beamwidth give error in estimation and if there is two sources in this range it is difficult to distinguish between them and consider as one source.

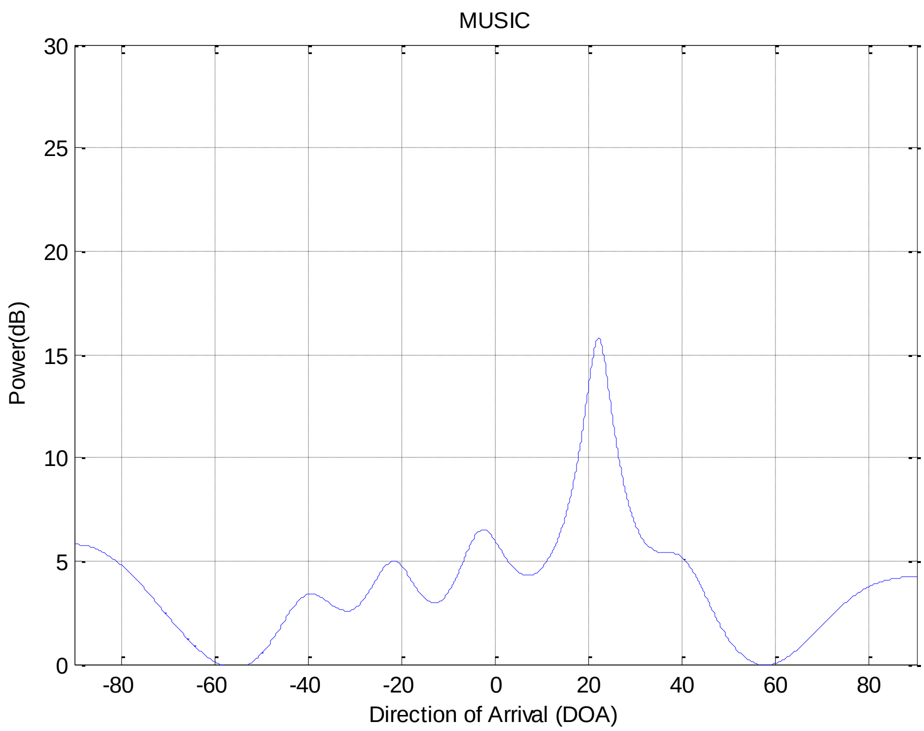

Fig.10 DOA estimation for single source using MUSIC method

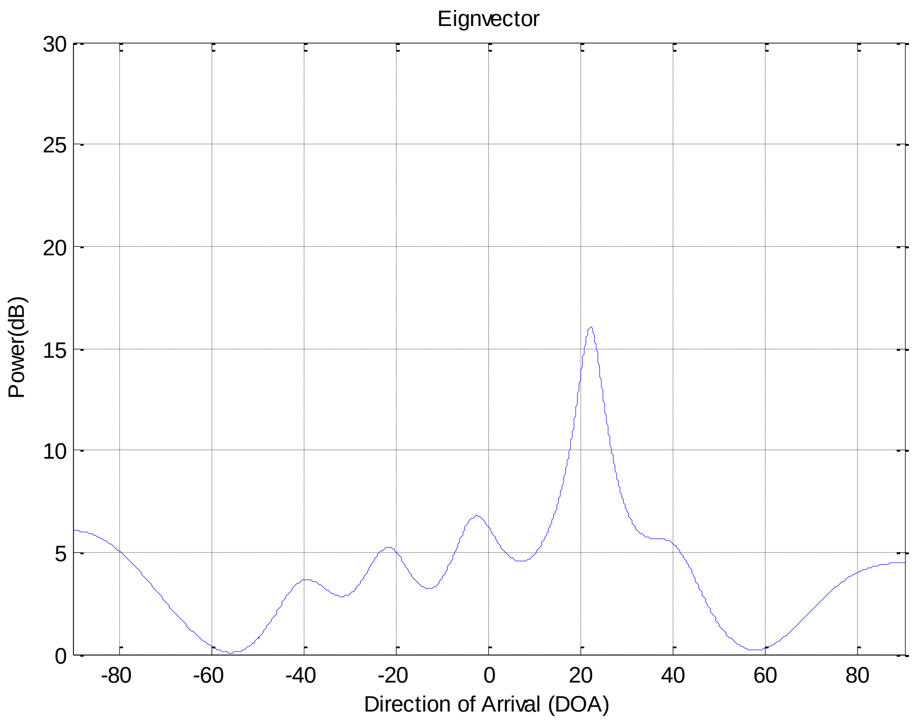

Fig.11 DOA estimation for single source using EV method

Figures (10& 11) are shows the results for using MUSIC and EV methods. It is capable to estimate the DOA with small sidelobe equal to -9.3 dB in MUSIC and -9.5 dB in EV. there is no error in resolution of estimation. These methods are the best. The performance for the above method can be indicated using the table (1).

Table (1) comparison between the performances of the DOA estimation methods for single source

Method	Estimation	Error	SLL
FFT	12^0	45%	-8 dB
MUSIC	22^0	0%	-9.3 dB
EV	22^0	0%	-9.5 dB

VII. CONCLUSIONS

From the simulation results and experimental results about the performance of classical method (FFT) and modern method (MUSIC, and EV). We can conclude that the classical method is work properly at high SNR and long data but this work began falling when the data or the SNR is decreasing. In short data the (FFT) method need high difference between angles of sources to resolve between them because it is low resolution and high sidelobe level. The modern method (MUSIC and EV) is better than (FFT) method. For same parameter that used in (FFT) method the (MUSIC and EV) need much smaller difference between angles of sources to resolve between them and negligible sidelobe because it high resolution algorithms and the beam width of the main is very narrow and this beam give accurate estimation of DOA.

VIII. SUGGESTION FOR FUTURE WORK

We are suggestion for future work to realize the experimental results of two sources DOA estimation. Make investigation performance of three methods for two sources DOA estimation. Compare between the simulation and experimental results.

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