DOA Estimation using MUSIC Algorithm and Biological Inspired Optimization Technique for Array Geometrics

Suprith Kumar K S[1], S. Akhila [2],
[1, 2] Department of ECE, BMS College of Engineering,
Bangalore, India

***Abstract*-- Navigation systems and location technologies are seeing rapid progress in many fields such as military sonar, satellite communication and radar systems. The received signal is very weak due to various environmental conditions that change dynamically. So, in order to increase the strength of the received signal and to improvise the radiation pattern, the signals have to be processed using adaptive Array Signal Processing (ASP) technique. An adaptive smart antenna system consists of a set of antenna elements and a signal processor that adapt its radiation pattern to focus the reception of array signals in the required direction and reject the signals from interfering direction. Techniques used to produce such radiation pattern by calculating the excitation weights is called Adaptive Beam Forming (ABF) technique. The performance of this technique largely depends on Direction of Arrival (DOA) of the signal and Signal to Noise Ratio (SNR). This calls for development of a robust ABF technique. In this work, Particle Swarm Optimization (PSO) technique is used to achieve ABF and suppression of side lobes.**

Key words-- Adaptive Beam Forming (ABF), Array Factor (AF), Array Signal Processing (ASP), Direction of Arrival (DOA), Multiple Signal Classification (MUSIC), Particle Swarm Optimization (PSO).

I. INTRODUCTION

End to end communication requires highly directive beam of radiation [1].This is achieved by placing several antennas in the form of an array. Research on DOA estimation [2] is done as a part of array processing. Over few decades, wireless communication has gained the momentum due to its flexibility and convenience. For advanced services, a high-speed data rate is the need of the hour which requires higher frequency bands.But at higher frequencies cross interference and multipath fading becomes a major problem. Smart antenna systems can be used to overcome such problems. These smart antennas [7] have signal processing capability which are used to identify direction of arrival of the signal. Once the direction is identified, beam forming vectors are calculated which helps in tracking the target. There are several algorithms available to estimate the DOA of the signal such as Multiple Signal Classification (MUSIC), Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) algorithm. These techniques are useful in finding the DOA from the peaks of the spectrum. DOA estimation is still an evolving and active field of research. Whereas Beam forming is a technology used in arrays to get directional radiation pattern at specified angles. The main lobe [8] is the lobe with maximum magnitude. This means the array can transmit more energy in

the direction of main lobe when it is used as a transmitter or on the other hand, the signal from that direction will be received better if the array works as a receiver. Often the radiation pattern of the array needs to be adjusted to satisfy various requirements. The radiation pattern is determined by several parameters such as nature of elements in the array, geometry of the array, the excitation coefficients of each element etc. An array consisting of multiple elements is used for improving the radiation pattern without changing the characteristics of individual elements. Compared to individual elements, an array can achieve higher directivity, higher gain and a lower SLL. The most common geometry for arrays are linear, rectangular and circular. This paper is organized as follows- Section 2 gives the related work, section 3 gives the method used for adaptive beamforming using the PSO technique, Section 4 gives the simulated results followed by the analysis. The paper concludes with section V.

II. RELATED WORK

2.1 DOA Estimation using MUSIC Algorithm

The principle of MUSIC algorithm [4] is to perform characteristic decomposition on an array output data to obtain a covariance matrix, resulting in signal and noise subspaces which are orthogonal to each other. The noise and signal subspaces are then used to constitute a spectrum function by performing spectral peak search method. This gives the DOA of signal. This algorithm has high resolution, accuracy and stability when compare to other techniques [1].

Modelling this mathematically,

1) Consider the narrow band signal sources with center frequency ω_0. Let us assume D number of testing signal sources.
2) Consider a uniformly spaced antenna array which consists of M isotropic array elements having same responses. Such that M is greater than D.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

3) Let inter-elemental spacing be'd' and interval not greater than half the wavelength of the highest frequency.
4) Each element is considered to be in the far field and received signals are coming from the signal source are as a plane wave.
5) Both noise and signal are uncorrelated.

Consider number of signal sources to be k and varying from 1 to D and the signal be $S_k(t)$ where, $S_k(t)$ is a narrowband signal which can be expressed as:

$$S_k(t) = s_k(t)e^{j\omega_k t}$$

Where $s_k(t)$ is the complex envelope of $S_k(t)$ and $\omega_k(t)$ is the angular frequency of $S_k(t)$.

According to the assumptions made, all signals are at same center frequency. So

$$\omega_k = \omega_0 = \frac{2\pi c}{\lambda}$$

Where, c is speed of sound wave, lambda is wave length of the signal.

The m-th element output signal is given by,

$$x_m(t) = \sum_{k=1}^{D} s_k(t)e^{-j(m-1)2\pi d \sin\theta_k/\lambda} + n_m(t)$$

Where, $n_m(t)$ is the noise.

The response function is given as-

$$a_m(\theta_k) = e^{-j(m-1)2\pi d \sin\theta_k/\lambda}$$

And the output signal as-

$$x_m(t) = \sum_{k=1}^{D} a_m(\theta_k)s_k(t) + n_m(t)$$

Performing Eigen decomposition on the received signal and separating noise from the signal, a noise matrix E_n is constructed with the help of noise characteristic value:

$$E_n = [V_{D+1}, V_{D+2}, \dots\dots, V_M]$$

The spatial spectrum $P_{mu}(\theta)$ can be defined as,

$$P_{mu}(\theta) = \frac{1}{a^H(\theta)E_n E_n^H a(\theta)} = \frac{1}{\| E_n^H a(\theta) \|^2}$$

When $a(\theta)$ is orthogonal with each column of E_n, due to presence of noise the value of the denominator will be minimum. Therefore, $P_{mu}(\theta)$ has a peak. By changing the arriving angle spectrum function is calculated and the direction of arrival of the signal is estimated by searching the peak.

2.2 Improved MUSIC Algorithm

Suppose the received signal is a coherent signal then the MUSIC algorithm fails to successfully receive the signals as shown in the fig 7. The MUSIC algorithm is restricted to uncorrelated signals. This section discusses about improved MUSIC algorithm which overcome problems encountered when correlated signals are received. In this algorithm, conjugate reconstruction of the data matrix of the MUSIC algorithm is possible helping in obtaining better results for correlated signals. The algorithm is as follows:

Let, $Y = JX^*$, such that X^* is the complex conjugate of X.

The resultant matrix Y is given by

$$R_y = E[YY^H] = JRX^*J$$

The reconstructed matrix is obtained as-

$$R = R_x + R_y = AR_sA^H + J[AR_sA^H]^* + 2\sigma^2 I$$

Where R_x, R_y and R matrices have the same noise subspace. By performing characteristic decomposition of R it is possible to obtain the eigenvalue and eigen vector. Separating the noise subspace and using this new noise subspace to construct spatial spectrum, the direction of arrival of the signal can be estimated by finding the peak.

III. ADAPTIVE BEAMFORMING USING PSO TECHNIQUE

The efficiency of an antenna array system decreases due to the various atmospheric conditions [6]. In order to improve the efficiency of the system, optimization of the design becomes essential. In Particle Swarm Optimization [7] (PSO), the solutions are considered as the particle and population is termed as swarm size. The particles are in motion around the search space. Personal best and global best positions will guide the movement of particles in the search space and movement of entire swarm is based on the best possible position discovered. PSO technique optimizes a given problem by iterative process and it tries to obtain a better solution. PSO can be used on optimization problems that are partially irregular, noisy and which change over time.

Modelling this PSO technique mathematically-

Assuming [9] there are I birds in each flock, each bird can be seen as one particle in the algorithm, and the space is extended to J dimensions, the total number of the particles is J*I. The movement of each particle will be updated by the following two equations:

1. The velocity of the particle is updated by the equation
$$V_{ij}^{t+1} = w * v_{ij}^t + c_1 * rand(i)\left(P_{best,i}^t - x_{ij}^t\right) + c_2 * rand(i)(G_{best}^t - x_{ij}^t)$$
2. The next position of the particle is given by
$$x_{ij}^{t+1} = x_{ij}^t + V_{ij}^{t+1}$$

Where, v_{ij}^t is the velocity vector of particle 'i' in dimension 'j' at time t, w is the array weight, x_{ij}^t is the position vector of particle, $P_{best,i}^t$ is the personal best position of particle, G_{best}^t is the global best position of particle, c_1 and c_2 are acceleration constants which are used as cognitive and social components,
$rand(i)$ are random numbers ranging 0 to 1, V_{ij}^{t+1} denotes the velocity of i^{th} particle in j^{th} dimension at $(t+1)^{th}$ time.

The initial velocity and position of each particle are generated randomly. In this technique, all the particles will be initialized randomly and they are evaluated and then fitness is computed by finding the p_{best} (best value which is obtained by each particle) and g_{best} (best value which is obtained in the entire swarm) values. Further, the iteration process continues to find best optimum solution. Initially, particles' velocity is updated with the p_{best} and g_{best} values. Further, individual particle's

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

position is updated with respect to the current velocity. This process continues until predefined value is met.

In the PSO technique the phases are considered as particles which represent the candidate solution to the problem being addressed. Initially, the population size, solution space, fitness function and number of iterations are defined.

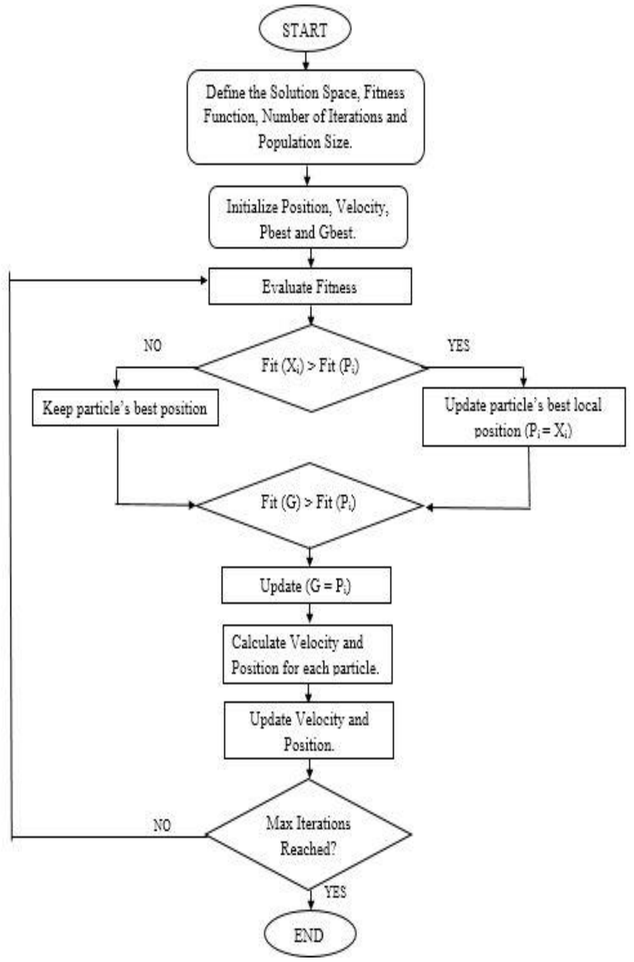

Fig.1: Flowchart for Adaptive Beamforming using PSO Technique.

Each particle [11] is considered as a single entity in the problem space. Initialize the particle local best, particle global best, it's position and velocity. The i^{th} particle is represented as $X_{ij} = x_{i1}, x_{i2}, \dots \dots \dots, x_{iD}$. The best previous position of the i^{th} particle is given by $P_{ij} = p_{i1}, p_{i2}, \dots \dots \dots, p_{iD}$. The rate of position change for the i^{th} particle is given as

$$V_{ij} = v_{i1}, v_{i2}, \dots \dots \dots, v_{iD}.$$

Fitness function for beam forming is defined as

$$AF(\theta_{s1}) - [AF(\theta_{i1}) + AF(\theta_{i2})]$$

Where, $AF(\theta_{s1})$ is the magnitude of radiation pattern in desired direction and $AF(\theta_{i1})$, $AF(\theta_{i2})$ are in the interfering direction. The aim is to amplify the array factor gain of the desired user and attenuate the array factor gain of the interferer. Equations for array factor in user and interfering direction is as given below.

$$AF(\theta_{s1}) = \sum_{n=1}^{N} e^{jb_n} * e^{j(n-1)(kdsin\theta_{s1})}$$

And

$$AF(\theta_{i1}) = \sum_{n=1}^{N} e^{jb_n} * e^{j(n-1)(kdsin\theta_{i1})}$$

$$AF(\theta_{i2}) = \sum_{n=1}^{N} e^{jb_n} * e^{j(n-1)(kdsin\theta_{i2})}$$

Where, N is the number of array elements, $k = \frac{2\pi}{\lambda}$ is the wave number, λ is wavelength of the signal, d is the elemental-spacing, b_n is the phase shift weight at element n, θ is the angle of incidence.

PSO technique is used to obtain the optimized radiation pattern. In each iteration, the array factor gain will be varied based on the desired user and the interferer with respect to the past iteration. Then the converged values provides an optimized radiation pattern.

IV. SIMULATION RESULTS

4.1 The basic direction of arrival estimation:

Fig. 2 shows two independent narrow band signals that are incident at an angle 30^0 and 60^0. The following assumptions are made: two signals are not inter related, ideal AWGN channel is considered, the SNR is 20dB, number of array elements is 16 and the frequency considered is 10 KHz.

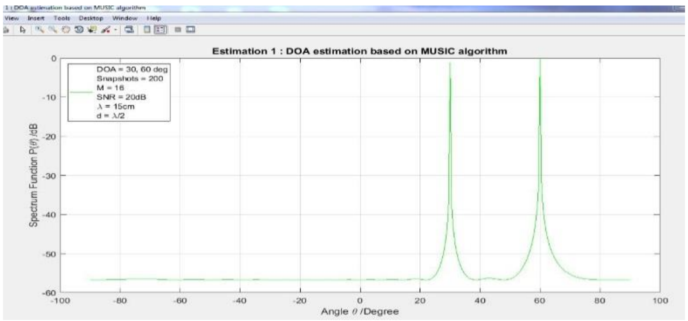

Fig.2: Basic DOA estimation using MUSIC algorithm.

Best results for DOA of signals has been obtained with the help of MUSIC algorithm.

4.2 DOA estimation with respect to array elemental spacing:

In this simulation, total array element considered is 16, inter elemental spacing are lambda by 6, lambda by 2 and lambda. The result is as shown below.

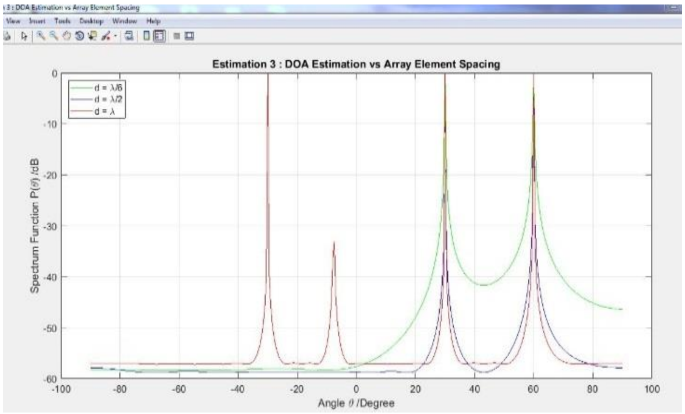

Fig.3: DOA estimation with change in array elemental spacing.

From the results (Fig.3) it can be seen that as the inter-elemental spacing between the elements increases, beam width of the estimated received signal becomes narrow. As the spacing between elements increased, the accuracy and resolution also increased. But, when spacing is greater than $\lambda/2$ false peaks have been detected along with signal. Therefore in real time, inter elemental spacing becomes a major factor in DOA estimation.

4.3 DOA estimation with respect to number of elements:

Fig. 4 shows the simulation for 10, 50 and 100 number of array elements with remaining parameters remaining unchanged.

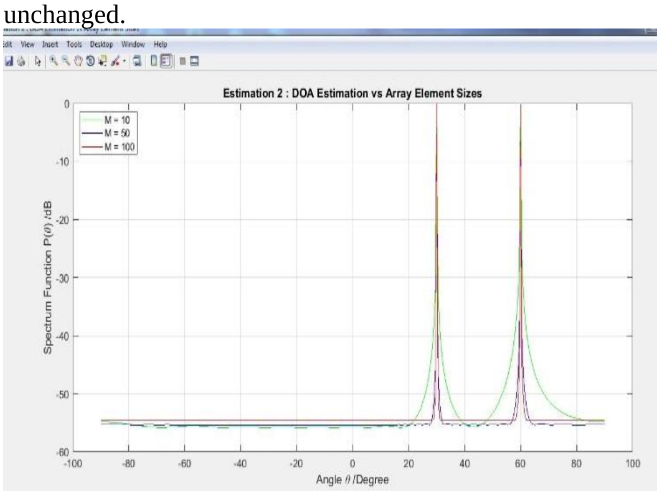

Fig.4: DOA estimation with increase in array elements.

It is seen that with increase in number of elements, the beam width becomes narrower and directivity becomes higher. Thus it has been possible to distinguish spatial signals, but the flip side is that the data processing speed decreases.

4.4 DOA estimation with respect to number of snapshots:

The number of snapshots taken are 5, 50 and 200 which is done by retaining the same simulation parameters.

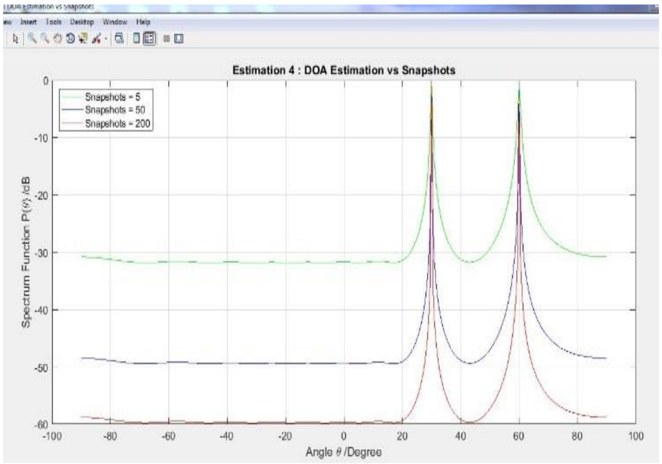

Fig.5: DOA estimation with increase in number of snapshots.

With increase in snapshots, the beam width becomes narrow, highly directive beam is obtained and efficiency of estimation also increases. But with more snapshots more data needs to be processed and reducing the speed. Hence in real time applications, optimal selection is necessary for better results.

4.5 DOA estimation with respect to SNR:

Here again, the assumed parameters are kept unchanged and SNR is varied between -20dB, 0dB and 20dB. Increase in SNR results in a narrow and highly directive beam and thus the accuracy increases. This is seen in Fig.6. The performance declines sharply at low SNR.

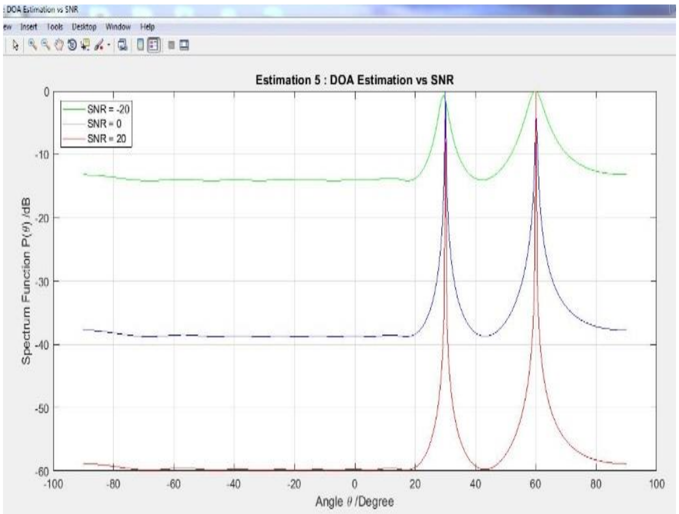

Fig.6: DOA estimation with respect to change in SNR.

4.6 Detection of coherent signals using improved MUSIC Algorithm:

Let us consider an AWGN noise channel through which we are receiving two signals incidenting at an angle 30° and 60^0 respectively and these signals are coherent and uncorrelated to each other. Other parameters remains unchanged.

Fig.7: DOA estimation using MUSIC algorithm for Coherent signals.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

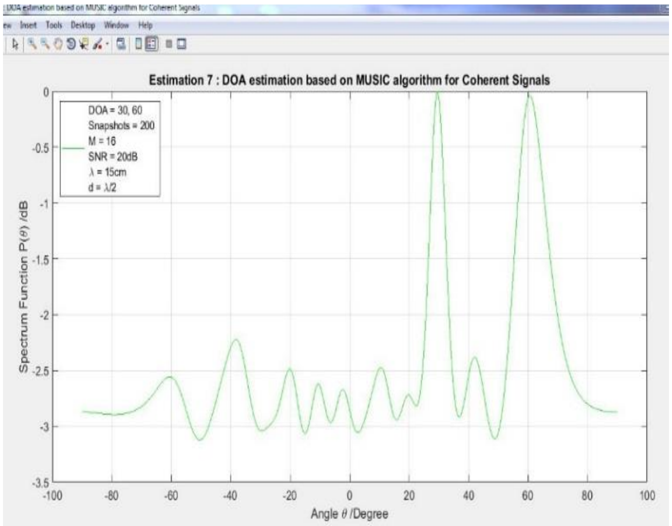

Fig.7 shows that MUSIC algorithm loses its effectiveness for coherent signals. Whereas improved MUSIC algorithm is able to remove the signal correlation feature and thereby it is possible to estimate direction of arrival of signal more accurately as shown in fig 8.

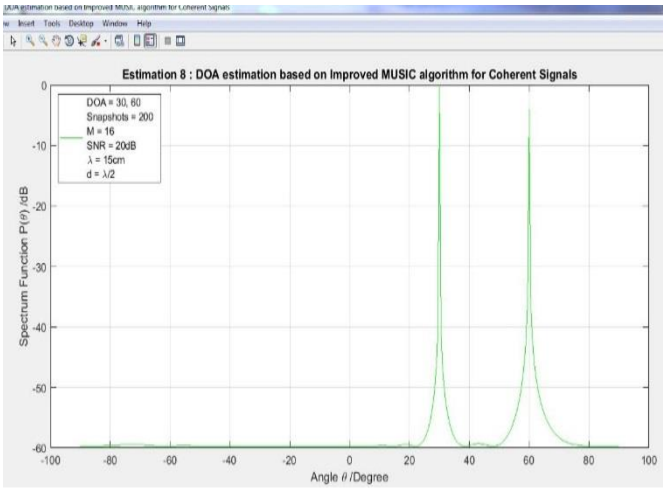

Fig.8: DOA estimation using Improved MUSIC algorithm.

Thus improved MUSIC algorithm provides better results for the DOA estimation for coherent signals.

4.7 Adaptive Beam forming using PSO:

To demonstrate the performance of the PSO technique, a uniform linear array with N elements, inter elemental spacing of lambda/2 is considered. The amplitude of the received signals is considered as 1V for simulation purpose. The additional system noise to all antenna elements is white noise with zero mean and a noise variance of $\sigma_n{}^2$. PSO is done for 100 iterations with a population size of 50, c_1 *and* c_2 set to 2. Phase excitation b_n is taken in the range [-2π, 2π]. Initially the p_{best} and g_{best} and their velocities are taken to be random.

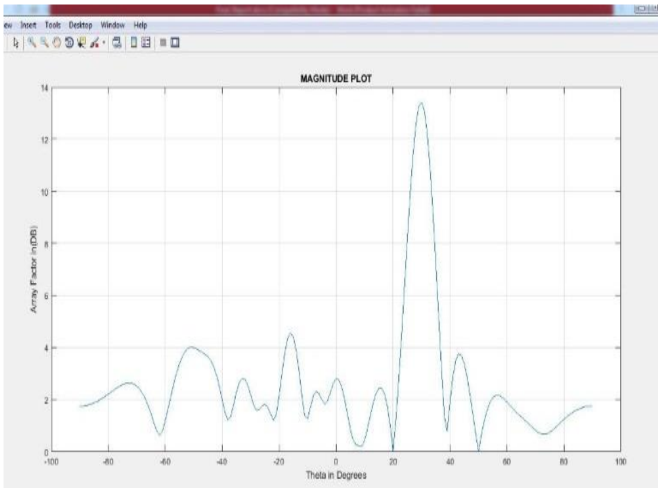

Fig.9: Magnitude plot with respect to array factor and theta at 30 degree.

In this scenario 16 elements linear array is considered with one desired user direction along 30° and 2 undesired interferes at 20° and 50°. The aim is to obtain an optimal phase shift that configures the adaptive antenna in such a way that the resulting AF along the desired user should be maximized and the AF along interferer should be minimized.

Each particle consists of a set of randomly generated shift weights, which are optimized at each iteration, until their values produce the desired radiation pattern as shown below.

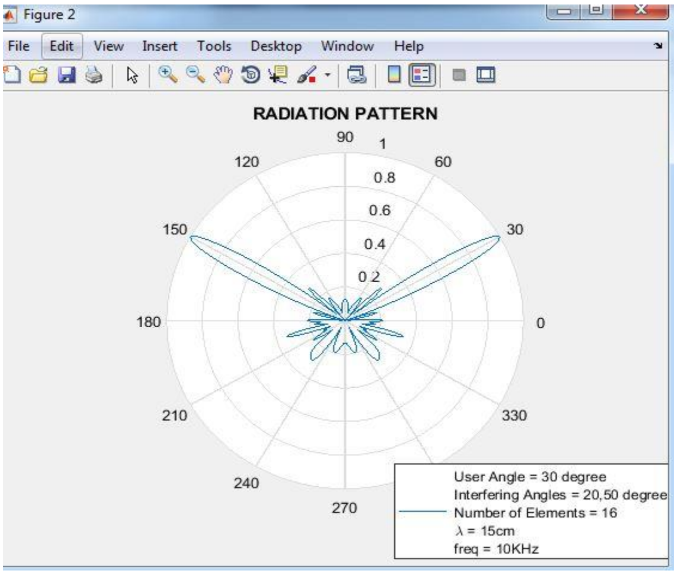

Fig.10: Radiation Pattern at 30 degrees.

From the Fig.10 the radiation pattern shows that the main lobe is obtained in the user direction and nulls in the interfering directions. Convergence plot for the best possible phase shift values with respect to change in weights and iterations is shown in Fig.11.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

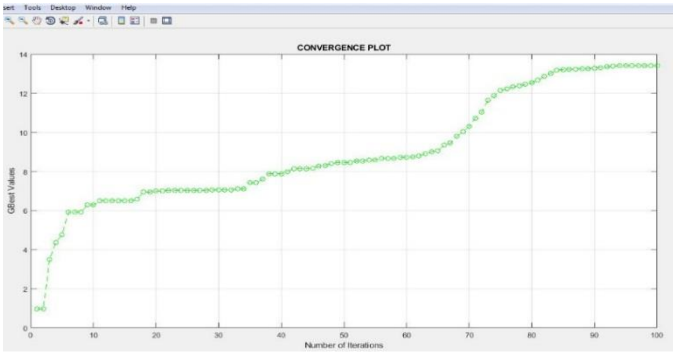

Fig.11: Convergence plot with respect to Global best values and iterations at 30 degrees.

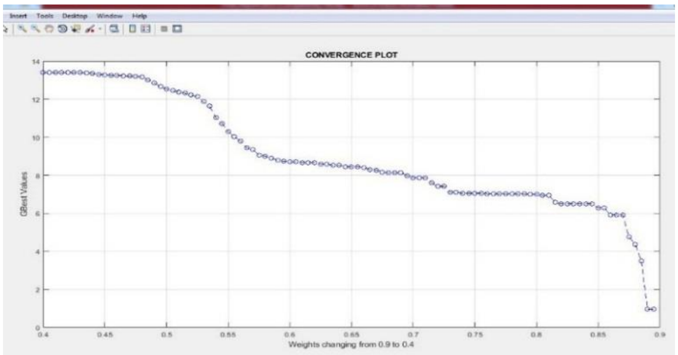

Fig.12: Convergence plot with respect to Global best values and weights at 30 degrees.

In Fig.12, the convergence graph shows how the phase value is attaining the best optimal value with respect to number of iterations and change in weights.

V. CONCLUSION

DOA estimation plays a key role in array signal processing and is applied in wide variety of applications. The signals are received from various signal sources from different directions. By applying the DOA estimation algorithm, accurate direction of the signal is obtained. There might exist various kinds of noise and disturbances which affects the receiving signal. Though there are many estimation algorithms to obtain the DOA of a signal, MUSIC algorithm has an ability to detect multiple signals, has higher precision and requires less sensors. The simulation results shows that DOA estimation accuracy can be enhanced through either inter elemental spacing, number of elements, number of snapshots and SNR. The snapshots and SNR needed to be high enough to improve accuracy and resolution of the DOA estimation. The computational complexity of the algorithm to estimate DOA depended on obtaining the covariance matrix and its disintegration to compute the power spectrum. PSO technique is used to optimize the radiation pattern of linear antenna array. Fitness function is used to increase the signal strength in the user direction and reduce the signal strength in the interferer direction. It was also used to obtain an optimal set of phase shift weights that configured the adaptive antenna in such a way that the resulting AF along user could be maximized and AF along interferer could be minimized. It was observed that the PSO was able to achieve optimized radiation pattern for a different directions of user and interfering angles. Several variables like acceleration coefficient, swarm size, iterations and velocity components can be used to achieve the optimized radiation pattern according to user requirements.

VI. REFERENCES

[1] Ali Massoud, “Direction of Arrival Estimation in Passive Sonar System”, Department of Electrical and Computer Engineering, Queen’s University, Kingston, Canada, 2012.

[2] Pooja Gupta and S.P. Kar, “MUSIC and Improved MUSIC Algorithm to Estimate Direction of Arrival”, IEEE International Conference on Communications and Signal Processing, 2015, Melmaruvathur, India.

[3] S. Ashwin Srinath, C.P. Harihar Prasad and Valarmathi J, “Direction of arrival Estimation for Narrowband and Wideband Underwater Targets”, IEEE Conference on Microelectronic Devices, Circuit Systems, 2017, Vellore, India.

[4] Iqroop Kaur and Sanjeev Kumar,“Linear Antenna Array Optimization Techniques”, International Journal of Engineering Trends and Technology, May to June 2011, India.

[5] Pawan Kumar and Manjeet Singh Patterh, “Linear Antenna Array Optimization Using Genetic Algorithm”, International Journal For Technological Research in Engineering, Volume 2, Issue 11 July 2015, Patiala, Punjab.

[6] Russell C Eberhart and Yuhui Shi, “Comparison between Genetic Algorithm and Particle Swarm Optimization”, International Conference on Evolutionary Programming, Dept. Electrical Engineering, Indiana University Indianapolis, 2005.

[7] Harshanjali S and Priyalakshmi S, “Geometrical Optimization of Antenna Array using PSO”, International Journal of Engineering Research and Reviews, Vol. 3, page (102-109), Issue July to September 2015, India.

[8] S.S.Saleem, M.M. Ahmed, U. Rafique and U.F. Ahmed, “Optimization of Linear Antenna Array for Low SLL and High Directivity”, Department of Electrical Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2016.

[9] Prerana Saxena and A.G.Kothari, “Performance Analysis of Adaptive Beamforming Algorithms for Smart Antennas”, International Conference on Future Information Engineering, Dept. Electronics Engineering, VNIT, Nagpur, 2014.

[10] Shaobing Huang, Li Yu, Wenxia Ding and Fang-jian Han, “Adaptive Beamforming Algorithm for Interference Suppression Based on Partition PSO”, IEEE Conference on Electronics and Mobile Communication, Vancouver, Canada, 2016.

[11] Mohammad K. Khawaldeh and Saed Khawaldeh, “Design of Optimal beam forming Using Particle Swarm Optimization”, International Journal of Computer Applications, 2017, Spain.

[12] O. Aboderin, L. M. Pessoa and H. M. Salgado, “Performance Evaluation of Antennas for Underwater Applications”, IEEE OCEANS MTS, Dec 2016, USA Monterey.