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A Novel Design Algorithm for DOA Estimation of Target Source Localization

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Abstract: Underwater target detection in oceanic environment has attracted considerable interest in both military and civilian applications. MUSIC is considered better than other algorithms for direction findings. With the increasing demand of near perfect target localization, and less interference at higher noise levels, coupled with ability to differentiate closely spaced apart sources, MUSIC algorithm provides us with the scope of modification. MUSIC is inappropriate to give proper DOA of signals when the noise level is higher. It also fails to differentiate sources which are very nearby. A novel algorithm is proposed using SVD of the covariance matrix discussed. A ULA antenna array configuration is taken for both the algorithm calculations. Simulations results show that proposed method gives better performance than basic MUSIC algorithm.

Keywords: DOA, MUSIC, SVD, Covariance Matrix, ULA, Array Configuration

I. Introduction

Direction finding and angle of arrival estimation has been an active area of research for a long time. DOA of signals has found vast and wide area of applications. Whether it may be in RADAR, wireless communication, speech processing, underwater target localization, estimating DOA of signals have found importance in signal localization and target acquisition. Here are at present different algorithms and techniques available for estimating DOA. But almost all of these techniques can be grouped into subspace and spectral techniques in broad. MUSIC, ESPRIT, Maximum Likelihood, Matrix Pencil and so on is some of the widely used ones. Each of these techniques is found to have various limitations. Traditionally, MUSIC is found to give better performance than all the other available algorithms. And as such, most of the research works are carried out in this technique. With the increasing demand of near perfect target localization, and less interference at higher noise regions, coupled with ability to differentiate closely spaced sources, MUSIC algorithm provides us with the scope of improvements. Being a subspace technique, it needs to know the type of signal to be detected so that the required modifications and conditions can be processed to the algorithm [1].

Moreover, MUSIC algorithm requires that the number of sensors used in the antenna array be more than the number of the signals to be detected, failing which the technique fails. There are coherent signal and related signal in the actual communication environment. If the condition does not meet, there will be bias occurred and even failure in the use of MUSIC algorithm for signal DOA estimation. In order to solve the problem of the DOA estimation of coherent signals, an improved algorithm is presented in this section by processing the covariance matrix of the array output signal, which can effectively estimate the signal DOA and identify the coherent signal source. In this paper, we have developed a traditional MUSIC architecture and analyzed its outputs using ULA antenna configuration. The proposed algorithm is also analyzed and its simulation results are compared with that of MUSIC [1]-[2].

II. Proposed Design Model

For direction of arrival (DOA) estimation, A structure of uniform linear array (ULA) composed of M sensors and d narrowband signals of the different DOAs [a(θ_1) a(θ_2) a(θ_3).....a(θ_d)] was considered. Then, the array output is given by

$$x(t) = a(\theta)\, s(t) \qquad (1)$$

Here s(t) is the signal arriving from the source and the steering controlling vector and s(t) = exp($j\omega t$) and x(t) is the array output. a(θ) = $[1, \exp(j\emptyset), \ldots, \exp(j(L-1)\emptyset)]^T$ and the phase delay difference between the sensors, $\emptyset = -\omega d \cos\theta / c$. A single signal at the DOA θ, thus results in a scalar multiple of the steering vector. The output equation can be put in a more rigid form by defining a steering matrix and a vector of signal waveforms [3].

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$$A(\theta) = [a(\theta_1)\ a(\theta_2)\ a(\theta_3)\ldots..a(\theta_d)] \quad (2)$$

$$S(t) = [s_1(t), s_2(t), s_3(t), \ldots\ldots.s_d(t)]^T \quad (3)$$

In the presence of an additive white Gaussian noise v(t), an observed a no. snapshot from the M array elements was modeled as,

$$x_K(t) = A(\theta)\ S(t) + v(t) \quad (3)$$

The array covariance matrix R of the received signal vector in the positive forward direction can be written as

$$Rxx = E[X(t)X(t)^H] = \frac{1}{L}\sum_L^K[X(t)X(t)^H] \quad (4)$$

Then the DOAs of the several incident signals can be estimated by finding the peaks of the MUSIC spectrum given by

$$P_{MUSIC}(\theta) = \frac{1}{a(\theta)^H E_N E_N^H a(\theta)} \quad (5)$$

Where $E_N = [e_{d+1} e_{d+2} \ldots\ldots\ldots e_{M-1}]$ is subspace noise.

Once obtained a MUSIC algorithm, we update the steps so as to improve its performance.

The covariance matrix is decomposed using Singular Value Decomposition technique given as

$$SVD\ (R_{xx}) = USV^H \quad (6)$$

A matrix *RA* can be calculated as

$$RA = E_s B E_s^H \quad (7)$$

Where $E_s = [e_1 e_{d+2} \ldots\ldots\ldots e_{d-1}]$ is signal subspace where

B= diagonal (1/SS – sigma*I) (8)

SS = diagonal (S_s) and SN = diagonal (S_N)

sigma = trce (S_N)/(M – D) (9)

The new modified MUSIC algorithm is given by

$$P_{MUSIC}(\theta) = \frac{a(\theta)^H * RA * a(\theta)}{a(\theta)^H E_N E_N^H a(\theta)} \quad (10)$$

It indicates from the denominator, the orthogonality between a(θ) and UO will make it reduce, and hence will increase $f_{MUSIC}(\theta)$. Hence the D largest sharp peaks of the MUSIC spectrum correspond to the DOAs of the signals impinging on the array [4]-[5].

III. RESULTS & DISCUSSION

In this paper, we analyzed the performance of DOA estimation with various source positions and different noise levels where MUSIC algorithm was implemented. As demonstrated earlier, the last step of MUSIC is scanning all the angles in equation 11, have been discussed and sharp peaks observed in a graph. In this section, we tried to show the peak graph of array geometries mentioned above, and gained a general view of the graph which will be used in further data analysis. In all the analysis, it is assumed that the same number of sensors used is unless mentioned otherwise [6].

- **Simulation Result for MUSIC**
- **Source positions (-40°,30°,60°), at SNR=30dB**

A coded simulation has been carried out to evaluate this method. In the simulation, we assume that three uncorrelated narrow band signals strikes on a linear array antenna at angles of arrivals $-40°$, 30° and 60°. The three signals are assumed to have equal signal to noise ratio (SNR=30 dB), the number of snapshots taken from the array is N= 128.

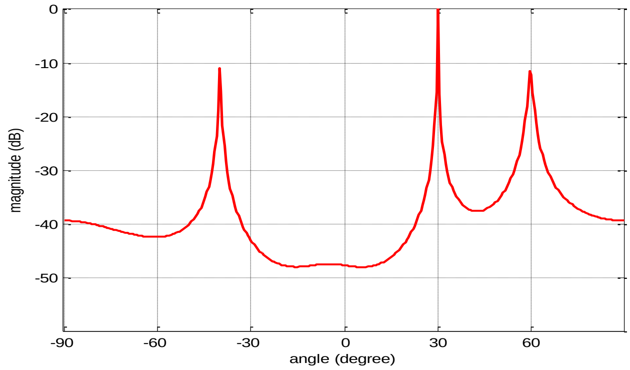

Fig. 1: MUSIC Spectrum for Source positions (-40°, 30°, 60°) at Low SNR

The detected signals computed using MUSIC algorithm against angles is shown in above Fig. 1. It is obvious that the detected peaks indicating the DOAs of the three signals typically agree with the incident signals.

- **Source positions (40°, 0°, 30°) and SNR =10dB**

In this simulation we assume same uncorrelated signals impinging on antenna array at angle of -40°, 0°, 30° with a higher noise level with SNR = 10dB.

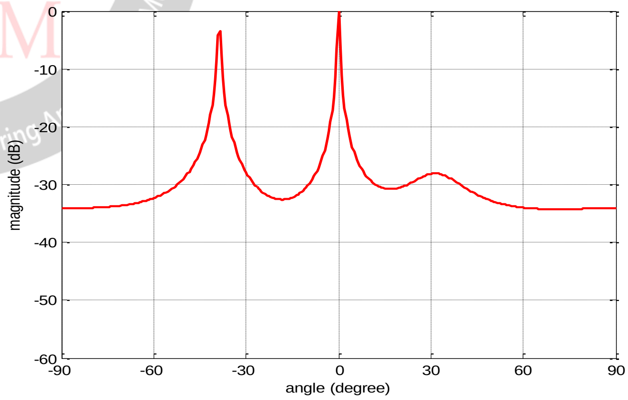

Fig. 2: MUSIC Spectrum for Source Positions (40°, 0°, 30°) at Low SNR

It is observed from Fig. 2, peaks of the spectrum can be found at -40°, 0° only. For incident angle 30°, no peaks can be found at the same position on the spectrum plot. The reason can be attributed to the increase in noise levels accompanying the signals. And as such, the MUSIC algorithm neglected the signal as a noise while plotting the spectrum. Thus, MUSIC spectrum fails to give proper outputs at higher noise level.

- **Source positions (0°, 30°, 34°) and SNR= 30dB**

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In this simulation we take the source positions to be $0°, 30°, 34°$ with respect to the antenna array. The noise level is considered low at SNR = 30dB.

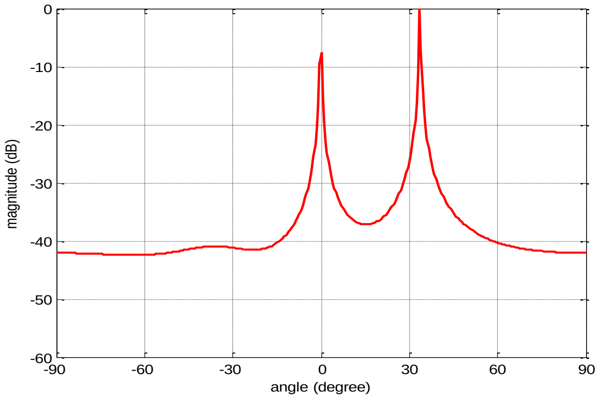

Fig. 3: MUSIC Spectrum for Source Positions (0°, 30°, 34°) at nearby Sources

In plotting the output spectrum of MUSIC in Fig 3.we can find only two peaks at 0° and 34° as shown in the fig. Thought the noise level is low, the algorithm still could not give peaks at 30°. it is due to the fact that since the two signals at 30° and 34° are very close, the algorithm mistook it as only one signal after overlapping the two signals. Thus it can be concluded that MUSIC again fails to give proper DOAs for closely spaced sources [7].

- **Simulation result for Modified MUSIC**
- **Source positions (-40°,30°,60°), at SNR=30dB**

To evaluate the Modified algorithm, a coded simulation has been carried out. In the simulation, here we have taken three uncorrelated narrow band signals. The signals are assumed to impinge on a linear array antenna with respect to its axis at angles −40° , 30° and 60°. The three signals are assumed to have equal signal to noise ratio (SNR=30 dB), the number of snapshots taken from the array is N= 128. The signal is detected by the algorithm and is given out as peaks on the spectrum graph obtained in above Fig. 4. It can be seen that the detected peaks indicating the DOAs of the three signals typically agree with the incident signals

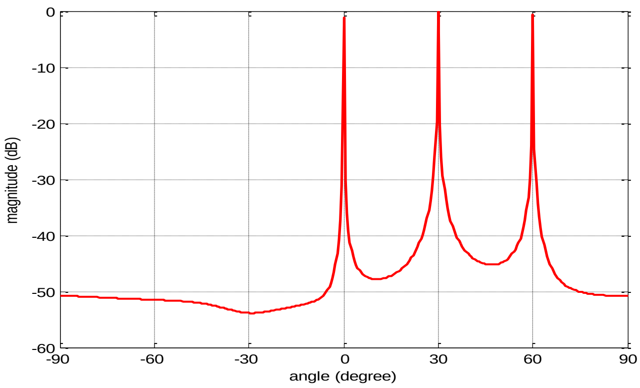

Fig.4: Modified MUSIC Spectrum for Source positions (-40°, 30°, 60°) at Low SNR

It is observed that in this output spectrum the peaks are sharper since the peaks lie between 0dB and -50 dB for all the three signals, hence one can easily differentiate between the signals. The resolution of the signals detected is high

- **Source positions (-40°, 0°, 30°) and SNR = 10dB**

In this simulation condition, we take three different signals with incident angles -40°, 0°, 30° on the axis of the antenna array. The number of sensors taken is 5. The noise accompanying the signal is increased as given by the SNR = 10dB. The output spectrum is plotted and is given by the Fig. 5. The peaks of the spectrum give the signal detected and the angle corresponding it gives the DOAs. It can be seen that the all the three signals are detected properly correctly with proper DOAs.

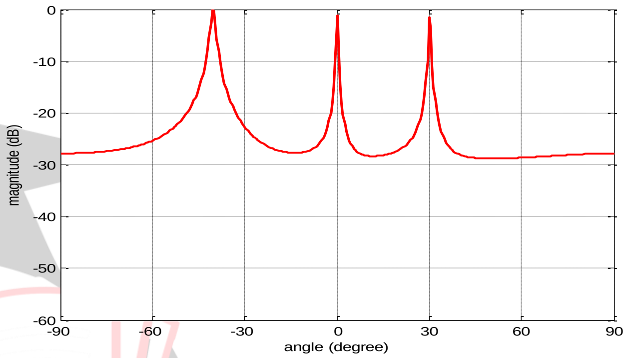

Fig. 5: Modified MUSIC Spectrum for Source positions (-40°, 0°, 30°) at High SNR

With regard to the previous MUSIC algorithm, this new algorithm doesn't consider one of the signals to be noise and hence not neglected.

- **Source positions (0°, 30°, 34°) and SNR= 30dB**

In the simulation case considered here, we take the source positions to be 0°, 30°, 34° with respect to the antenna array so that two sources are very nearby, differentiated only by a mere 4°. The noise surrounding the signal sources are assumed to be low as given by the SNR = 30dB.

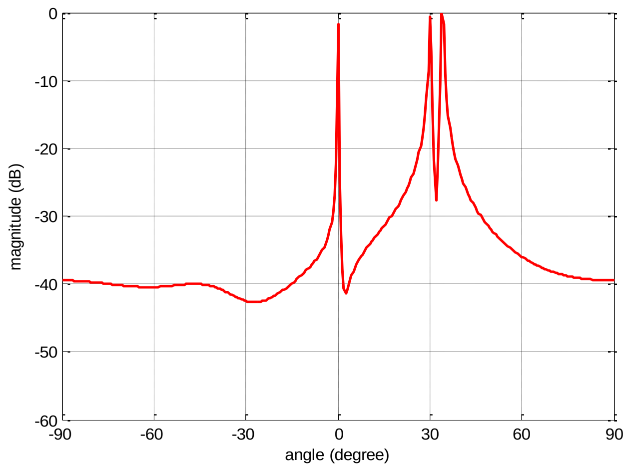

Fig. 6: Modified MUSIC Spectrum for Source Positions (0°, 30°, 34°) at nearby Sources

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The algorithm spectrum is plotted as shown in Fig. 6. It can be seen that the spectrum contains three peaks denoting the detection of three signals at $0^\circ, 30^\circ, 34^\circ$ which agrees with our assumption.

➢ **Source positions ($0^\circ, 30^\circ, 34^\circ$) and SNR= 10dB**

In this case, we assumed three signals of interest incident at angles $0^\circ, 30^\circ, 34^\circ$ with respect to the antenna axis. The entire antenna placed in a uniform linear array fashion. The distance between the antennas that's placed near to each other should be minimum for proper angle of arrival estimation. The noise level around the signals is increased as SNR = 10 dB. The output spectrum is plotted as shown in the Fig 7. It is observed that, we listed three peaks but not at desired positions.

Though we found peaks at 30° and 34° , we could not find peaks at 0°, from which it can be concluded that the algorithm fails to detect a third signal.

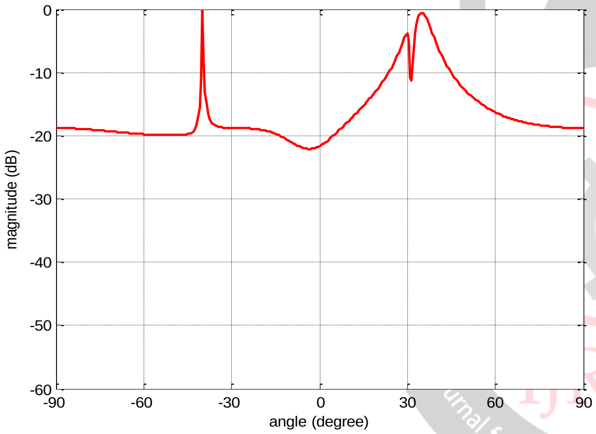

Fig. 7: Modified MUSIC Spectrum for Source Positions ($0^\circ, 30^\circ, 34^\circ$) at Higher SNR

The modified MUSIC algorithm provides better performance for nearer angles with minimum signal to noise ratio.

IV. Conclusion

The proposed design algorithm for finding of direction of arrival was developed after carrying out certain modifications in MUSIC algorithm by processing the covariance matrix of the array output signal. MUSIC algorithm works well for low level noise regions, but when the noise level is increased, its performance degrades severely.. MUSIC also fails to detect signals which are very close by. As such, it cannot differentiate two signals separated by AOA s of 4°, under normal conditions. The proposed algorithm was able to detect signals under a certain degree of high noise levels and also for close by sources the modified algorithm fails when the noise level is increased to a certain level. At such levels, it starts to detect noise signals as the desired signals. So we tend to get more peaks in signal spectrum graph, making it difficult to find out the real signals. In both the algorithms that we have analyzed, both can only give azimuth angles, not the elevation angle also, since we have used ULA and not UCA.

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