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PERFORMANCE ANALYSIS OF AN ARRAY OF SENSORS BASED ON THE DIRECTION OF ARRIVAL ALGORITHM

Maria (Stan) Necula[1,2], Dorin Bibicu[3,4], Simona Moldovanu[5,6], Luminita Moraru[1,*]

1,* Faculty of Sciences and Environment, Physics Department, “Dunarea de Jos” University of Galati, 47 Domneasca St., 800008, Romania
2 Tehnical College ”Radu Negru”, 119 Stiintei Street, 800170, Galati, Romania
3 Faculty of Economics and Business Administration, Business Adminstration Department, “Dunarea de Jos” University of Galati, 59-61 Nicolae Balcescu St., Romania
4 “Dunarea”High School 24 Oltului St., Galati, Romania
5 Faculty of Control Systems, Computers, “Dunarea de Jos” University of Galati, Romania
6 “Dumitru Motoc” High School, 15 Milcov St., 800509, Galati, Romania
** Corresponding author: luminita.moraru@ugal.ro*

Abstract
In this paper, we investigate a system of spatial multiple sensor arrays in an acoustic field in order to evaluate the parameters of the spatial signal and the location of the signal source. A uniform linear array and a periodic scanning system is considered. The spatial spectrum that expresses the signal distribution in the space from all directions to the receiver is determined. We evaluate the efficacy of direction of arrival (DOA) based on Multiple Signal Classification (MUSIC) algorithm estimation method for low frequency range when the number of array elements, the number of snapshots (i.e. the number of samples), SNR and element spacing are parameters in numerical simulation. The simulation results review all factor affecting the accuracy of estimation.

Keywords: acoustic field, sensor array, MUSIC algorithm, numerical simulation

1. INTRODUCTION

The first mention of Direction of Arrival Estimation DOA was related to the linear spectrum estimation based on the method of Fourier transform or on the statistical analysis of maximum likelihood spectrum estimation [1-3]. However, several authors indicated that a wrong estimation of the DOA severely degrades the beamformer performance [4, 5].

Let us consider a uniform array (UA) of N receivers receiving K narrow band signals (i.e. all array elements in the array can capture a signal at the same time) produced by some correlated sources. Spatial spectrum estimation method uses a space array to achieve a space signal parameter.

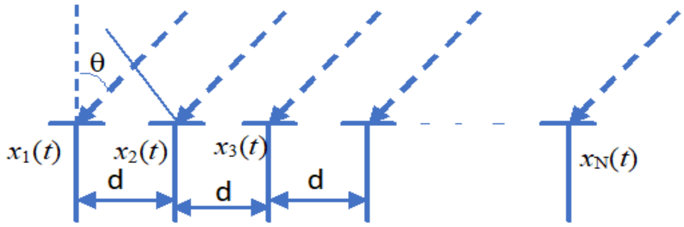

Fig. 1. Uniform linear array having N array cells, for DOA estimation

Let S(t) be a wave with speed of propagation c and frequency ω_0 incident at an incident angle θ on the array. To meet the hypothesis of planar wave the incident source has to be paced at a distance higher than d, the distance between array cells. The received signal in the cell 1 is denoted as $x_1(t)$. The time delay of the signal between cells due to the path difference is $\tau=\frac{d\sin\theta}{c}$. The received signal in cell 2 is [6, 7]:

$$x_2(t)=s(t)e^{i\omega_0(t+\tau)}=s(t)e^{i(\omega_0 t+\frac{2\pi d}{\lambda}\sin\theta)}$$

Generally, for an array having N receivers, the wave incident on the UA is as follows:

$$X(t)=s(t)e^{i\omega_0 t}\left[1,\ e^{i\frac{2\pi d}{\lambda}\sin\theta},\dots,\ e^{i(N-1)\frac{2\pi d}{\lambda}\sin\theta}\right]^T=s(t)e^{i\omega_0 t}A(\theta)$$

Where the input array $X(t)$ and the direction $A(\theta)$ vectors are as follows:

$$X(t)=[x_1(t),\ x_2(t),\ \dots,\ x_N(t)]^T$$

$$A(\theta)=\left[1,\ e^{i\frac{2\pi d}{\lambda}\sin\theta},\dots,\ e^{i(N-1)\frac{2\pi d}{\lambda}\sin\theta}\right]^T$$

The received signal is described as:

$$X(n)=s(n)A(n) \qquad n=1,\ 2,\dots N$$

In the hypothesis of the K narrowband signals, we have to consider an approximation as follow:

$$S_j(t-t_1)\cong S(t),\quad j=1,\dots,K$$

and the wave front signal is delayed as:

$$s_k(t-t_1)\cong s_k(t)e^{i(N-1)\frac{2\pi d}{\lambda}\sin\theta}$$

If the impact of an array element n on the j^{th} signal source is considered, the output signal $x_N(t)$ of the n^{th} element is as follows:

$$x_N(t)=\sum_{j=1}^{K}s_j(t)e^{i(N-1)\frac{2\pi d}{\lambda}\sin\theta}+n(t)$$

where $n(t)$ is the Gaussian additive noise.

2. EXPERIMENTAL

Based on the above model, we will now discuss on the parameters that can affect the direction of arrival DOA estimation. The performance of the system is analyzed in interaction with the following parameters: number of array elements, the number of snapshots (i.e. the number of samples), SNR and element spacing.

All the simulations were performed in MATLAB environment.

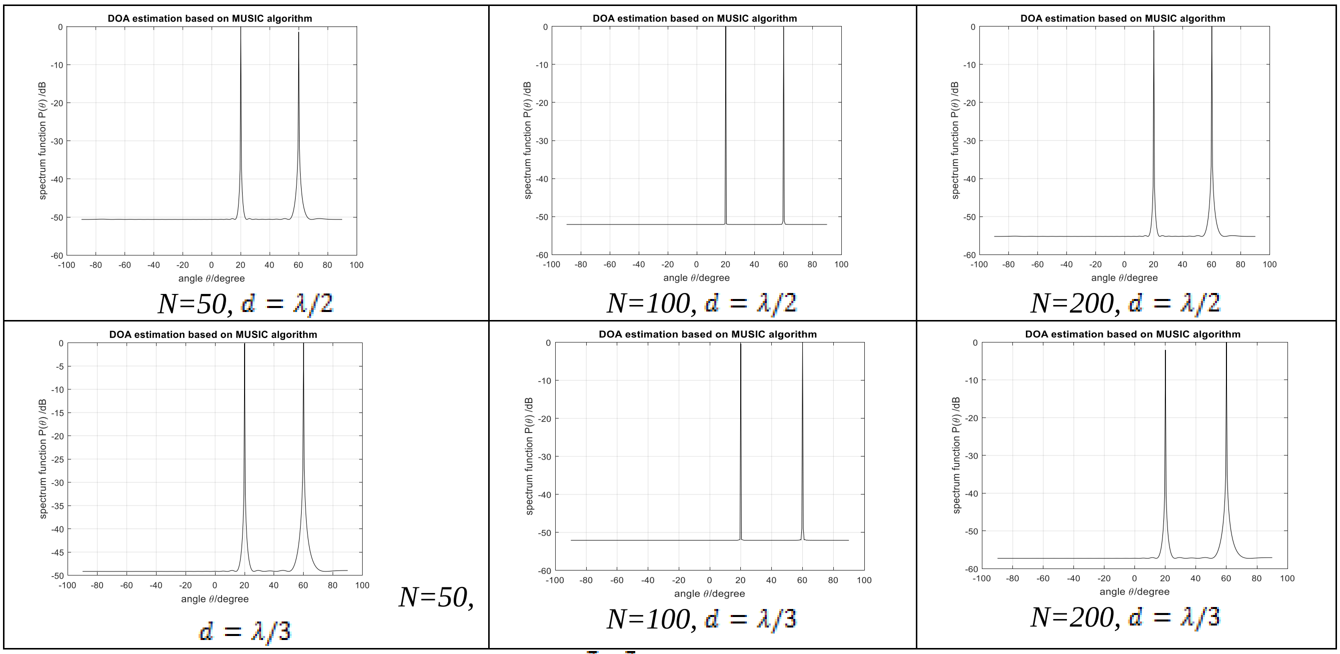

Fig. 2. Estimation spectrum for frequency $=\frac{\pi}{4}, \frac{\pi}{3}$*, when the snapshots number varies as N=50, 100, 200, number of array elements M=30, wavelength* λ *=150, element spacing is* $\lambda/2$ *and* $\lambda/3$*, and noise SNR=20[dB].*

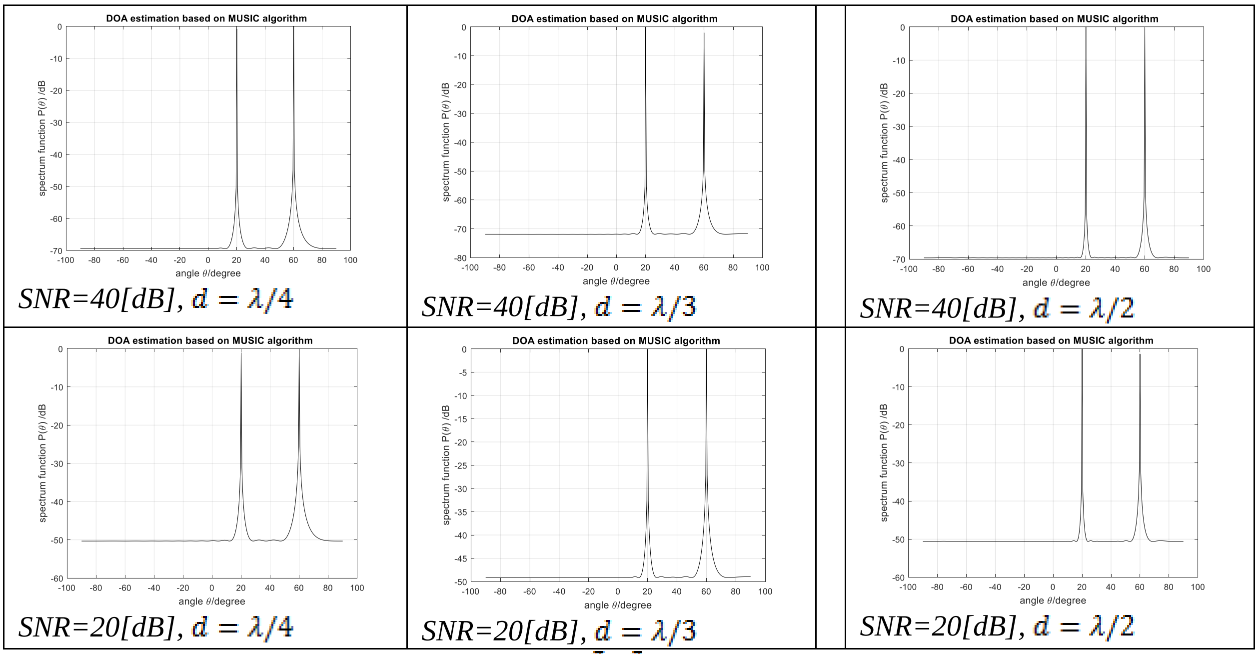

Fig. 3. Estimation spectrum for frequency $=\frac{\pi}{4}, \frac{\pi}{3}$*, snapshots N=50, number of array elements M=30, wavelength* λ *=150, element spacing is* $\lambda/2$ *,* $\lambda/3$ *and* $\lambda/4$*, and noise SNR=20 and 40[dB].*

Figure 2(a) and (b) present the simulation results when the number of snapshots varies as 50, 100 and 200. In fig. 2(a), the element spacing is $\lambda/2$ and in fig 2(b) it is $\lambda/3$. A needle spectrum peak appearance i.e. DOA estimation spectral beam width becomes narrow and a very good spatial separation exists for the case N=100 and both $\lambda/2$ and $\lambda/3$. In this case, the ability to distinguish spatial signals is enhanced. When the number of the snapshots N increases estimation performance decreases.

Figure 3 displays the effects of the signal to noise ratio and of the element spacing on the estimation. Two simulation results when low SNR and higher SNR are considered. The analysis of the spectra indicates that signal to SNR values influence the estimation performance, namely as the value of SNR increases we found out that the estimation performance increases. When we analyze the DOA estimation spectra from the point of view of array element spacing, we found out that for a smaller than $\lambda/2$ DOA estimation falls within the broader spectrum.

Figure 4 indicates the influence of the number of the array elements over the DOA estimation spectrum. A more accurate estimation of DOA is obtained when the number of array elements increases. For larger numbers of the array elements, the spectral beam width becomes narrow, the directivity of the array is improved and DOA estimation performance increases.

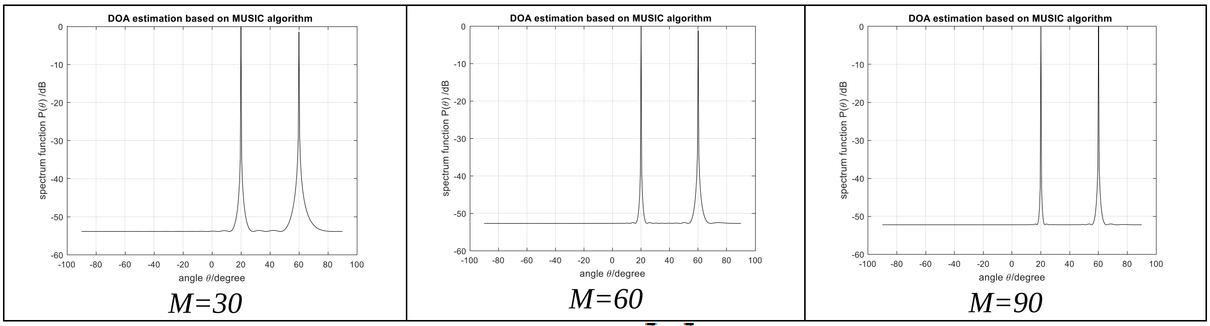

Fig. 4. Estimation spectrum for frequency = $\frac{\pi}{4}$, $\frac{\pi}{3}$ *, snapshots N=100, number of array elements varies as M=30, 60, 90, wavelength* λ *=150, element spacing is* $\lambda/4$*, and noise SNR=20[dB].*

3.CONCLUSIONS

The simulation results indicate that depending on the number of array elements, the number of snapshots, SNR and element spacing, the performances of DOA based MUSIC algorithm estimation method for low frequency range change. Thus, when the number of the snapshots increases estimation performance decreases; when element spacing is smaller than $\lambda/2$ DOA estimation falls within the broader spectrum; when SNR increases we found out that the estimation performance increases; and when the number of array elements increases the directivity of the array is improved and DOA estimation performance increases.

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