Source localization for underwater acoustics using esprit algorithm

N.Kasthuri1, S.Balambigai2* &S.Yuvashree3
1Professor, Department of ECE, Kongu Engineering College, Perundurai
2Associate Professor, Department of ECE, Kongu Engineering College, Perundurai
3PG student, Department of ECE, Kongu Engineering College, Perundurai

*Email: sbalambigai@gmail.com

Abstract. In order to perform the underwater source localization, vector sensors play a major role. If vector sensors are used as an array, the gain can be improved and the accuracy can also be improved. In furtherance of finding the direction of arrival (DOA) of the sound signal which is nothing but the source localization, there are several algorithms like MVM, MUSIC, etc., are used. These algorithms have some computational complexity and also the resolution performance is not good. In encouragement of accomplishing superior determination and to decrease the computational complexity, the Estimation of Signal Parameters through Rotational Invariance Transform (ESPRIT) algorithm is utilized in this paper. This paper gives the details about ESPRIT algorithm and the azimuth angle obtained from the experimental data.

1. Introduction

Vector sensor is used for the source localization which can find the angle of the source in the three dimensional direction. Vector sensor array consists of three uniformly spaced elements [1]. Hydrophone is a device which can find pressure of the source coming from all the directions inside each element. In order to measure the speed of the particle, there is an accelerometer which is tri axial inside the vector sensor. The non-subspace methods like capon method and the sub-space method like ESPRIT and MUSIC methods are used for finding the direction [2]. The direction of arrival is nothing but the direction in which the sound signal is propagating from transmitter to the receiver. The type of non-subspace method is conventional method or classical methods. Among all these algorithms, better resolution can be achieved by ESPRIT algorithm. The main principle behind this algorithm is that it uses the rotational operator which is otherwise known as phase shift operator for determining the direction of the source.

2. Methodology

The various steps for the generation of the signals before pre-processing is shown in Figure 1. First the signal is generated from the signal generator and they are amplified using power amplifier as the input signal. The output of the power amplifier will be fed to the transmitter. Here vector sensor array act like a receiver. This vector sensor will detect the direction of the sound which is coming in different directions [3]. Vector sensor array output is acquired by the data acquisition system which is controlled by the PC. The main principle of the proposed ESPRIT algorithm is that the elements present in the vector sensor array are to be considered as sub-arrays in order to improve the resolution of the signal [4].
2.1. Pre-processing steps for converting time domain to frequency domain

In order to convert the data from time domain to frequency domain, First, the time domain data should be loaded and particular channels should be chopped. In order to attain the proper DC offset the chopped channels should be detrended. Then power spectrum is taken for the detrended data for converting the data from time domain to frequency domain. After converting the data from time domain to frequency domain, the channels should be processed by using the ESPRIT Algorithm. The lower computational cost makes the ESPRIT algorithm an intuitive solution to various parameter determination problems. Applying a constraint on the array structure, ESPRIT reduces the computational complexity. ESPRIT algorithm assumes P element antenna array which later decomposes to for two identical sub-arrays of M element each. The determination of rotation operator \( \Psi \) in the ESPRIT algorithm is used to detect the signal angle of arrival. For overlap condition that an antenna array element may be a part of both sub-arrays \( P = 2M \) and non-overlap implies \( P = 2M \). The two sub-arrays are separated by \( -d \) distance.

After converting the data from time domain to frequency domain, two sub arrays are formed. Each array consists of two vectors namely, \( V_1 \) and \( V_2 \), \( V_2 \) and \( V_3 \). The flow chart which is given in Figure 2 describes the procedure to find the direction of arrival using the ESPRIT algorithm [5].

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**Figure 1** Steps for the generation of signals before preprocessing

**Figure 2** Flow chart for finding the Direction of Arrival using the ESPRIT procedure
3 ESPRIT algorithm

Estimation of signal parameters via rotational invariant techniques (ESPRIT) is a technique to determine parameters of a mixture of sinusoids in a background noise. It is similar to MUSIC algorithm, in that it exploits the underlying signal and noise models and generates estimates that are asymptotically exact and efficient. This technique is first proposed for frequency estimation, however, with the introduction of phased array systems, it is also used for Angle of arrival estimations as well. By exploiting a property known as the shift invariance, ESPRIT can overcome problems with the drastic reduction in storage and computational requirements. ESPRIT does not require precise knowledge about the array manifold steering vectors, thereby not requiring array calibration. Application of ESPRIT algorithm lies in a particular class of shift invariant geometry of sensor arrays.

ESPRIT algorithm consists of the array of antennas which are divided as two sub-arrays [6]. These sub-arrays consist of the data of the two array elements of the vector sensor in the frequency domain and also it is added with some noise. Hence it can be written as,

\[ A_1 = [V_1, V_2] \text{ and } A_2 = [V_3, V_4], \] (1)

where,

\[ V_1, V_2 = A \ast (\text{Signal vector of 1st & 2nd array elements}) + \text{noise} \]
\[ V_3, V_4 = A \ast \Psi \ast (\text{Signal vector of 2nd & 3rd array elements}) + \text{noise} \]

Here, A is called the steering vector and it can be written as,

\[ A = e^{-j\theta_i}, \quad \text{where } \theta_i = -(2 \ast \pi \ast d \ast \sin \theta_i) \]
\[ \text{where, } L = 1 \text{ to } N \]

The point to be noted in ESPRIT algorithm is that the rotational operator which is denoted as \( \Psi \) is multiplied with the signal vector and it is used to determine the DOA.

The rotational operator can be represented as,

\[ \Psi = \text{diagonal} (e^{j\omega_L}) \] (2)

The next step after forming sub-arrays is to find the covariance matrix for equation (1). It can be obtained by multiplying the \( A_1 \) with its conjugate Hermitian transpose \( A_1^H \) and similarly for \( A_2 \). Thus the covariance matrix can be represented as,

\[ R_{xx1} = E\{A_1 \ast A_1^H\} \] (3)
\[ R_{xx2} = E\{A_2 \ast A_2^H\} \] (4)

The Eigen decomposition is performed for the obtained covariance matrices to produce two Eigen vectors \( Q_1 \) and \( Q_2 \) of (N x N) dimension and it can be represented as,

\[ Q_1 = \text{eig} (R_{xx1}) \] (5)
\[ Q_2 = \text{eig} (R_{xx2}) \] (6)

Then the Eigen values \( \lambda_i \) are obtained from the diagonal values of the Eigen vectors. This includes the following step.

\[ H = \begin{pmatrix} Q_1^T \\ Q_2^T \end{pmatrix} \ast (Q_1 \ast Q_2) \] (7)

From the equation (7), 2N x 2N matrix are obtained which is derived from the equation (6). Thus from the Eigen values the direction of arrival of the signal can be calculated. Here the azimuth angle of the source signal can be obtained from the following expression,

\[ \text{ESPRIT\_doas} = \text{asin}(\text{angle}(H)/(2 \ast \pi \ast d)) \ast \pi / 180 \]
4. Results and discussion
The experimental specifications for the given data are as follows. The amplitude of the input loaded data is 6mv, the signal frequency ranges from 4kHz to 6kHz. The dataset required for this simulation is obtained from National Institute of Ocean Technology (NIOT), Pallikaranai consists of sound signals in underwater. The experiment was simulated in the MATLAB for finding the Azimuth angle of the signal and the results are discussed below. The imported data was analyzed and the required channel range has been chopped. The chopped channels are represented in the Figure 3.1.

![Figure 3.1. Chopped channels from the input data](image1)

In order to remove the DC offset the chopped channels have been detrended and the detrended data re represented in Figure 3.2.

![Figure 3.2. Detrended Data from the chopped channels](image2)

After Detrending the data the time domain data is converted into frequency domain data by using the power spectral plot. The frequency range where the signal peak is obtained is around 4 kHz to 6 kHz. This power spectral data are represented in Figure 3.3.

![Figure 3.3. Power spectral data from the detrended values](image3)

The main difference between MUSIC and ESPRIT algorithm is the computational complexity and resolution. In order to know the ability of the ESPRIT algorithm, the comparison is made between these two algorithms. Figure 3.4 shows the Estimation result using MUSIC algorithm.
Figure 3.4 Estimation result using MUSIC algorithm

Figure 3.5 shows the Estimation result using ESPRIT Algorithm. Same angle 30° is obtained as like MUSIC algorithm. But the only difference is that there is some accuracy in ESPRIT algorithm when compared with the MUSIC algorithm.

Figure 3.5 Estimation result using ESPRIT algorithm
Figure 3.6 shows the comparison between the MUSIC algorithm and the ESPRIT Algorithm together. This figure proves that ESPRIT Algorithm has high resolution and it also has high accuracy than the MUSIC Algorithm.

Figure 3.6 Comparison plot of the estimation of coherent signals using MUSIC and ESPRIT algorithm

After converting the data to the frequency domain, the calculation steps of the ESPRIT algorithm are performed and the azimuth angle is calculated from the Eigen values and the results are represented in Figure 4.6
From Figure 4.6, it is concluded that the input angles given was almost similar to the calculated Direction of arrival. Here, three samples were tested and the angle given was 100°, 65° and 180° and the calculated angles were 97°, 68° and 179° respectively. Hence from the calculated azimuth angles it is concluded that the ESPRIT algorithm has better resolution compared to other algorithms.

5 Conclusion
From the obtained results, it is concluded that the angle obtained from the calculations are of the point of source in which it is located. Also it is concluded that the ESPRIT algorithm gives better results when compared with the other subspace method like MUSIC algorithm [7]. This proves that this algorithm gives more accuracy which means that it gives high resolution [8]. Here the steps are not more complex and as it is proved that it does not require any definite array geometry, this algorithm may be proven to be the best algorithm for finding the DOA of the signal source [9] in underwater communication. Based on the three samples that are tested with the angle of 100°, 65° and 180° it is found that the calculated angles are 97°, 68° and 179° respectively for the ESPRIT algorithm. Hence from the calculated azimuth angles it is concluded that the ESPRIT algorithm has better resolution when compared to other algorithms.

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