Estimation of Location and Separation Between Acoustic Emitting Sources : A Comparison Between Classical and Modern Methods

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ABSTRACT

 A mathematical model for localization of acoustical sources with separation between them is derived and presented. A classical (Fourier transform) method and a modern, parametric, (Burg) method are used. The results show the capability of Burg method to resolve the adjacent sources when compared with Fourier transform method, as well as the localization of the sources. The performance is studies with varying some parameters relating to the problem.

KEY WORDS

Burg method, spectral estimation, location of sources.

1. INTRODUCTION

The magnitudes and frequencies estimation of signal's harmonics with their number from measurement represent a problem in some applications of signal processing such as radio communication, direction of arrival estimation, and so on.

A synthetic aperture scanning of antenna (acoustic receiver) is used to collect the data and then extract the information from it. The non-parametric _Fourier transform , (FT) ,technique , known also as "traditional spectral estimation " technique is efficient in computation .However , it has two main disadvantages : high sidelobes , and moreover low resolution [1]. A long data records (long aperture) is required to overcome such problem. Resolution refers to the ability of the technique to detect the least separation between the points that the object consists of. Hence the aim of the work is to find another method of better resolution and smaller sidelobes. The parametric, "Modern" methods play big role in solving such problems .one of such methods is a Burg technique .it is high resolution and stable method [2, 3]. It uses a linear prediction model and minimizes the backward and forward errors of linear prediction to estimate frequency components of the signal. The received acoustic wave is recorded as amplitude and phase. The wave is sampled, i.e. is recorded as discrete values.

The auto –regressive process (AR) is used to model the recorded data for localization problem. A Burg technique is used to calculate the coefficients of AR process.

The recording of data, and then, the reconstruction of the sources parameters both represent the process of localization and separation of the problem under consideration.

The contribution given by this paper is to use Burg method, as high resolution technique, to model the object's localization and separations between the objects.

1.1. Related work.

As given in [2, 3], the Burg method has other applications in medicine, radar, and so on. This work is categorized within spectral estimation problem. Some other related spectral estimation work can be found in long wavelength imaging, as acoustical holographic imaging [4], direction of arrival estimation [5] problems.

2. FIELD ANALYSIS AT FRESNEL REGION [6,7,8].

The problem under consideration (the two acoustic sources, also we called them as object) has a field distribution $D_1(p_1)$. The propagation of this field $S_1(x)$ toward the axis of recording x_1 is represented by

$$S_1(x) = \frac{\beta}{z_{o1}\lambda} \int_{p1} D_1(p_1) \exp\big(j\Upsilon r_1(p_1,x_1)\big) dp_1 \qquad (1)$$

This represents an approximate to Fresnel principle. Υ Is a wave number, and β is a constant. The distance between the recoding plane and the object's plane is Z_{o1} . The distance between a certain point on α recording axis x_1 and a certain point on the object 'p1' is r_1 , and is given by

$$r_1(p_1,x_1) = \sqrt{z_{o1}^2 + (x_1 - p_1)^2} \qquad (2)$$

Using a paraxial approximation,

$$((x_1 - p_1)^2/z_{o1}^2) \ll 1 \qquad (3)$$

The r1 (p_1,x_1) is given as

$$r_1(p_1,x_1) = z_{o1} + \frac{(x_1 - p_1)^2}{2\,z_{o1}} - \frac{(x_1 - p_1)^4}{8z_{o1}^3} + - - - - - \qquad (4)$$

r1 , in Fresnel region , could be approximated using only two terms of equation (4) , i.e.

$$r_1(p_1,x_1) = z_{o1} + \frac{x_1^2}{2z_{O1}} + \frac{p_1^2}{2z_{o1}} - \frac{p_1 x_1}{z_{o1}} \qquad (5)$$

Substituting (5) in (1) yields

$$S_1(x) = \beta_1 \exp\left(\frac{j\Upsilon x_1^2}{2z_{o1}}\right) \int_{p1} D_1(p_1) \exp\left(\frac{j\Upsilon p_1^2}{2z_{o1}}\right) exp\left(\frac{-j\Upsilon x_1 p_1}{2z_{o1}}\right) dp_1 \qquad (6)$$

$\beta 1$: Complex constant resulting from substitution of (5) in (1)

3. BURG METHOD PRINCIPLE

Estimating [1, 9] the AR parameters is achieved by using Burg method. Based on minimization of backward and forward error of linear predictors, the above method can be regarded as order recursive least squares lattice technique. The auto regressive parameters should satisfy the levinson-Durbin recursion. It is supposed that the data $S_1(n_1)$, $n_1 = 0,1, ..., $ N-1, is given. In order the estimator to be derived, the backward and forward linear predicting estimation of order i, is given by

$$\hat{S}_1(n_1) = -\sum_{\ell=1}^{i} a_{1i}(\ell)S_1(n_1 - \ell) \tag{7}$$

$$\hat{S}_1(n_1 - i) = -\sum_{\ell=1}^{i} a^*_{1i}(\ell)S_1(n_1 + \ell - i) \tag{8}$$

with the corresponding backward and forward errors $f1i(n_1)$ and $g_{1i}(n_1)$ defined as $f_{1i}(n_1) = S_1(n_1) - \hat{S}_1(n_1)$ and $g_{1i} = S_1(n_1 - i) - \hat{S}_1(n_1 - i)$ where $a_{1i}(\ell), 0 \le \ell \le i - 1, i = 1,2, ..., c,$ represent the coefficients of prediction. $\varepsilon 1i$ represents a least square error and is given as

$$\varepsilon_{1i} = \sum_{n_1=i}^{N_1-1} [|f_{1i}(n_1)|^2 + |g_{1i}(n_1)|^2] \tag{9}$$

The above error should be minimized by taking the coefficients of prediction process according to the limitation of the recursion of Levnsion-Durbin which is given by

$$a_{1i}(\ell) = a_{1(i-1)}(\ell) + K_{1i}a^*_{1(i-1)}(i-\ell) \quad 1 \le \ell \le i - 1 \quad , 1 \le i \le c \tag{10}$$

With $K_{1i} = a_{1i}(\ell)$ is the ith coefficient of reflection in the realization of lattice filter for the predictor. Substituting (10) in expression for f_{1i} (n1) and $g_{1i}(n_1)$ will result in the pair of order recursion equations for backward and forward prediction errors which is given by

$$f_{1i}(n_1) = f_{1(i-1)}(n_1) + K_{1i}\, g_{1(i-1)}(n_1 - 1), \quad i = 1,2, ..., c$$

$$\tag{11}$$

$$g_{1i}(n_1) = K^*_{1i}\, f_{1(i-1)}(n_1) + g_{1(i-1)}(n_1 - 1) \quad i = 1,2, ..., c$$

Substitution from (11) into (10) and minimizing ε_{1i} with respect to K1i , the result will be

$$\hat{K}_{1i} = \frac{-\sum_{n_1=i}^{N_1-1} f_{1(i-1)}(n_1)g^*_{1(i-1)}(n_1 - 1)}{\frac{1}{2}\sum_{n_1=i}^{N_1-1}\left[\left|f_{1(i-1)}(n_1)\right|^2 + \left|g_{1(i-1)}(n_1 - 1)\right|^2\right]} i = 1,2, ..., c \tag{12}$$

The cross correlation estimation between the backward and forward prediction errors is given in the numerator of equation 12. From the normalized. Factors of the denominator in equation 12, it is clear that $\left|K_{1i}\right|$ is less than one, hence the model of all – pole gained from the obtained data is stable. The denominator in (12) represents the least squares estimation of the backward and forward errors $E^b_{1(i-1)}$ and $E^f_{1(i-1)}$ respectively [1]. Hence $\hat{K}_{1i}$ in (12) is given as

$$\widehat{K}_{1i} = \frac{-\sum_{n_1=i}^{N_1-1} f_{1(i-1)}(n_1)g_{1(i-1)}^*(n_1-1)}{\frac{1}{2}\sum_{n_1-i}^{N_1-1}\left[\widehat{E}_{1(i-1)}^f + \widehat{E}_{1(i-1)}^b\right]} \quad i = 1, 2, ..., c \tag{13}$$

Where $\widehat{E}_{1(i-1)}^f + \widehat{E}_{1(i-1)}^b$ represents the estimation of a least- squared error E1i: The denominator in equation (13) can be calculated according to an order-recursion as given by relation [1]

$$\widehat{E}_{1i} = \left(1 - \left|\widehat{K}_{1i}\right|^2\right)\widehat{E}_{1(i-1)} - \left|f_{1(i-1)}(i-1)\right|^2 - \left|g_{1(i-1)}(i-2)\right|^2 \tag{14}$$

Where $\widehat{E}_{1i} = \widehat{E}_{1i}^f + \widehat{E}_{1i}^b$ represents the total-squared error [1, 9].

Using (13) and (14), the Burg method determine (estimate) the parameters of auto regressive process. Than the power spectrum estimation is found, by using the AR parameters, as following [1, 9]

$$P_{1xx}^{Bu}(f) = \frac{\widehat{E}_{1p}}{\left|1 + \sum_{\ell=1}^{P}\widehat{a}_{1p}(\ell)e^{-j2\pi f\ell}\right|^2} \tag{15}$$

The advantages of the Burg method are (1) it is computationally efficient, (2) it results in high frequency resolution, (3) it yields a stable AR model [2,3]. The limitation of Burg method is that it may exhibit spectral line splitting in sometimes.

4. SOURCES LOCALIZATION

Multiplication of the recorded data S1(x) by the quadratic phase factor $\left(\frac{\gamma x_1^2}{2Z_{o1}}\right)$ and then applying one of the spectral resolution methods: either a Fourier transform method, or a high resolution Burg method.

5. RESULTS

Two acoustic transmitting sources (regarded as two points) are used. The computer is used to simulate the problem under consideration. The first source is positioned at lateral distance p1=2cm from a supposed vertical reference axis at which the receiving acoustic transducer begins from. The second transmitting source is positioned at a lateral distance p2 from the vertical reference axis .The received waveform from the two sources at the receiving (recording) axis is sampled , according to synthetic aperture scanning , by N1 samples .

The axial distance between transmitting and receiving axis is zo1. The wavelength is λ , the sampling interval is ΔX, and the position difference between the two sources is Δp , i.e. p2-p1 .Different value of zo1 , ΔX , λ and p2 are used as given in the following results (figures) .Two spectral estimation methods are used :Fourier transform (FT) and Burg method .

The minimum separation (resolution) that the Fourier transform could resolve is given by the following formula [10]

$$\sigma_1 = \frac{\lambda z_{o1}}{a_2} \tag{16}$$

a_2 : half of the aperture length.

$$a_2 = \frac{(N_1 - 1)}{2}\Delta X \tag{17}$$

A percentage errors (P.E) of Δp,i.e. p2 –p1 are shown in figures 1,2,3. We assumed that when P.E< 20% is an acceptable value.

5.1. Results without Noisy Data.

Figure (1) shown the results (performance) when both methods are used. it is clear from the parameter and equation (16) and (17) that σ1 > 5cm .Hence   (FT) could not resolve the separation , Δp , for acceptable P.E. , for values less than σ_1=5 , while Burg method could resolve less thanσ_1 ,and up to p2=3cm , i.e. Δp =1 cm . Moreover, the percentage error, P.E, is too much less than that for (FT) method.

Figure (2) shows also the enhanced performance of Burg method when compared with (FT) method, with σ_1 > 2.1 cm. P.E. for Burg method is less than 7% while for when P.E. is small, the P.E. is between 20% to 40%.

Figure (3) shows that (FT) could not resolve the two sources until Δp = 3 cm since σ_1 > 5 cm while Burg method resolve the two sources with Δp=2 cm.

5.2. Results with Noisy Data

For more investigation of the problem, a white noise is added to the data, and its effect on the parameters of the problem is noticed in the following figures. Figure (4) shows the two thin peaks that correspond to the two acoustic source with Δp=2 cm when Burg method is used , While (FT) method is used , while (FT) method failed to resolve the two peaks since σ_1 > 3.4 and the result seems to be a single source .
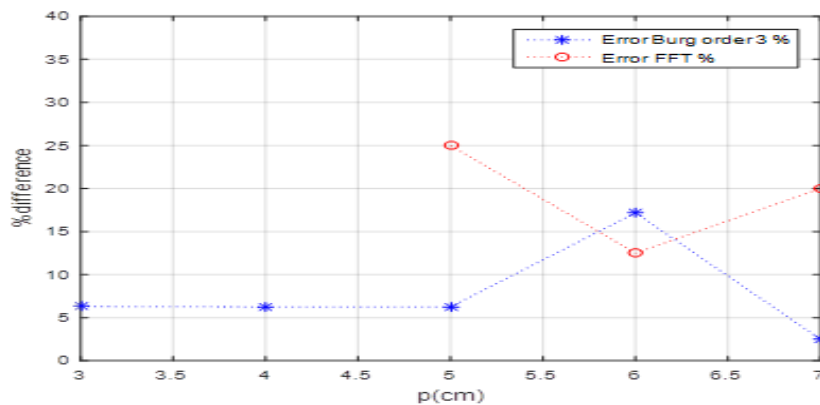

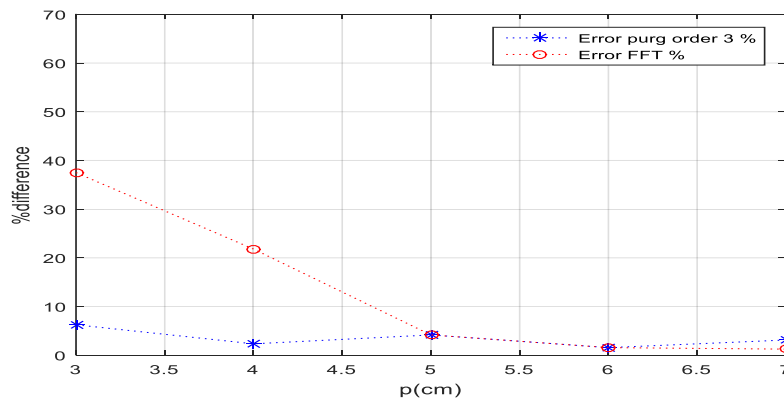Figure 1.   Two points without noise (Z=30, N=20 , ΔX=0.5, λ=0.8, p1=2)

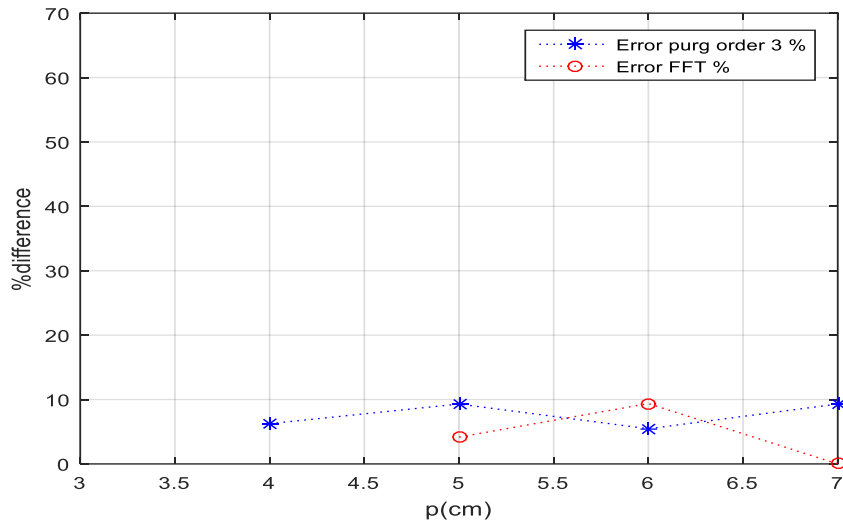Figure 2. Two points without noise (Z=25, N=20 , ΔX=0.5, y=0.4, p1=2)

Figure 3.   Two points without noise (Z=25, N=20 , ΔX =0.5, λ =0.8, p1=2)
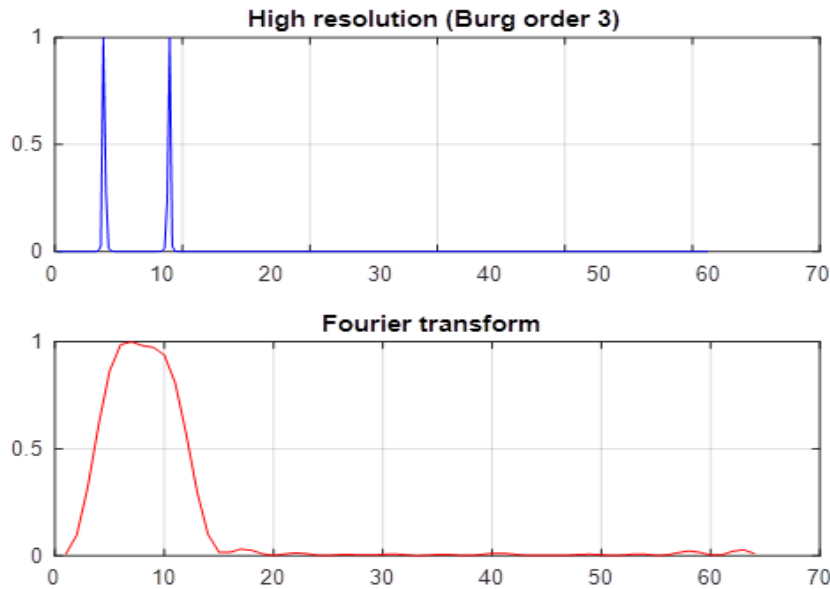

Figure 4.   Two points with noise (Z=30, N=15 , ΔX =0.5, λ =0.4, p1=2,p2=4)

6.   CONCLUSIONS

It is proved that Burg method can be used to find the locations of, and separation between the objects and to find other parameter, the amplitude, and to decrease the effect of sidelobes. So it has better performance than (FT) method since it has high resolution performance for small Δp and has less P.E. For a future work, a practical data is used and compared with simulation results.

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