Application Of Covariance Method On Geophone Signals And Their Spectral Analysis During An Earthquake

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Abstract: Seismic waves are emanated due to the occurrence of earth. The seismic waves thus generated are sensed by geo phones. The seismic data thus acquired is subjected to refined methods of signal processing and is effectively analyzed spectral estimation of seismic signals using parametric methods gives greater accuracy and r resolution. To resolve power spectrum and investigate the alterations in the spectrum during their presence and absence of disturbances, covariance method can be used which is one among the parametric methods. These studies will be useful for developing and early warning systems for the earthquake prediction.

Index Terms: Advanced statistical signal processing, Adaptive signal processing, Seismology, Geophone, Autoregression

1 INTRODUCTION

The dynamical behavior from tectonic plates beneath the earth during an earthquake generates seismic waves. Analysis of seismic signals in terms of magnitude, frequency and energy is a challenging task. Deployment of geophone is a versatile technique to sense the movement of earth's surface due to an earthquake. The fundamental concept of geophone is as follows

$$\frac{\partial^2 d}{\partial t^2} + 2\lambda\omega_0 \frac{\partial d}{\partial t} + {\omega_0}^2 d = \frac{\partial^2 g}{\partial t^2} \quad (1)$$

Where 'd' denotes displacement of the mass, resonant frequency is denoted by 'ω_0', 'g' is for ground displacement, 'λ' denotes damping factor. By rearranging, the resulted transfer function is:

$$Y(\omega) = T(\omega).X(\omega) \quad (2)$$

Here, Y denotes output and T denotes transfer function in input. Geo phone requirement obtained by arranging after subjecting to Fourier transform is as follows:

$$V_a = s_c \frac{\partial d}{\partial t} \quad (3)$$

$$V_a = s_c \frac{j\omega}{-\omega^2 + 2j\lambda\omega\omega_0 + {\omega^2}_0} \frac{\partial^2 g}{\partial t^2} \quad (4)$$

Where 's_c' is used to denote geophone sensitivity constant (in V.s/m) and 'V_a' indicates analog voltage

In order to obtain better estimates and resolution, parametric methods such as covariance is implemented for deriving spectral estimates and analyzes the acquired seismic data during an earthquake event using geo phone. The advantage of this method is to avoid windowing process of the data and spectral splitting, which results in higher resolution in identifying exact dominant frequency components in the spectrum.

2 METHODOLOGY

To derive the estimates of power spectrum, a model is proposed using parametric method. Considering a signal x[n] of autoregressive process with p^{th} order, wherein, x[n] computed values are used for processing the estimate's parameters with pole model of all $\alpha_p(k)$ and $a_p(k)$, which in turn useful for deriving spectral estimates :

$$\hat{P}_x(ej\omega) = \frac{1}{\left| \sum_{k=0}^{P} a\wedge_p(k) e^{-jk\omega} \right|^2} \quad (5)$$

A spectral estimate yielded by all auto regressive method is given by,

$$\hat{P}_{AR}(f) = \frac{1}{f_s} \frac{\sum p}{\left| 1 + \sum_{k=1}^{p} a\wedge_p(k) e^{-2\pi jkf/f_s} \right|^2} \quad (6)$$

The normalized auto correlation functions are to be solved to estimate AR coefficients.

$$\begin{bmatrix} r_x(0) & r^*_x(1) & r^*_x(2).... & r^*_x(p) \\ r_x(1) & r_x(0) & r^*_x(1).... & r^*_x(p-1) \\ r_x(2) & r_x(1) & r_x(0).... & r^*_x(p-2) \\ ..... & ..... & .... & ...... \\ r_x(p) & r_x(p-1) & r_x(p-2).... & r_x(0) \end{bmatrix} \begin{bmatrix} 1 \\ a_p(1) \\ a_p(2) \\ ..... \\ a_p(p) \end{bmatrix}$$

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$$= \sum p \begin{bmatrix} 1 \\ 0 \\ 0 \\ .... \\ 0 \end{bmatrix} \quad (7)$$

Here, $r_x(k) = \frac{1}{N} \sum_{n=0}^{N-1-k} x(n+k)x^*(n); k = 0,1,..., p$ (8)

It is a way of approach to estimate the AR constants by assuming the method used is the covariance. The equations set in covariance process's solution needs to solve,

$$\begin{bmatrix} r_x(1,1) & r_x(2,1).... & r_x(p,1) \\ r_x(1,2) & r_x(2,2).... & r_x(p,2) \\ .... & .... & .... \\ r_x(1,p) & r_x(2,p).... & r_x(p,p) \end{bmatrix} \begin{bmatrix} a_p(1) \\ a_p(2) \\ .... \\ a_p(p) \end{bmatrix} = - \begin{bmatrix} r_x(0,1) \\ r_x(0,2) \\ ...... \\ r_x(0,p) \end{bmatrix} \quad (9)$$

where, $r_x(k,l) = \sum_{n=p}^{N-1} x(n-1)x^*(n-k)$ (10)

3 SIMULATION AND RESULTS

Step-1: Covariance method is applied on a synthesized signal to obtain the desired output of geophone signals and spectral analysis. From book_seismic_data.mat [9] the data is acquired. At the depth of 80-100 feet, the recorded traces of synthetic signal are obtained which can be shown in fig.1

Step-2: The results of covariance method are observed in terms of their PSD's as depicted in fig.2

Step-3: Fig.3 represents the seismic raw data.

Step-4: Fig.4. represents the detrended data.

Step-5: Fig.5 shows the results of covariance methods applied on the raw data.

Step-6: It shows the band pass filter results

Step-7: In Fig.7, we can observe the FIR band passed signal

$$\omega = \frac{2\pi f}{500} = 0.08407\pi$$

If $f_{s=500}$, the resultant tonal frequency is f=21.0175 Hz

Step-8: As a part of the spectral analysis, FFT is implemented on the signal and is plotted which is shown in Fig.8.

Step-9: By subjecting to covariance method after band pass filter, the final spectral analysis is observed in Fig.9.

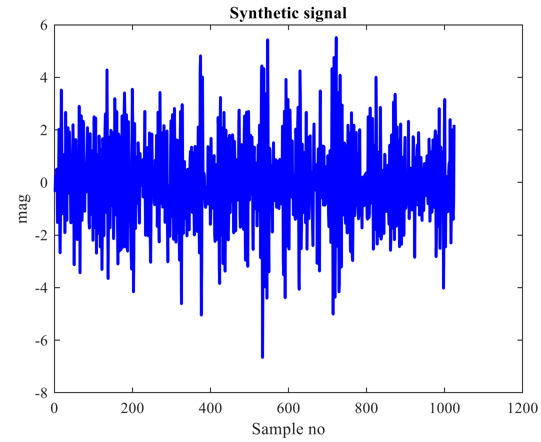

Fig 1. *Signal in synthetic form*

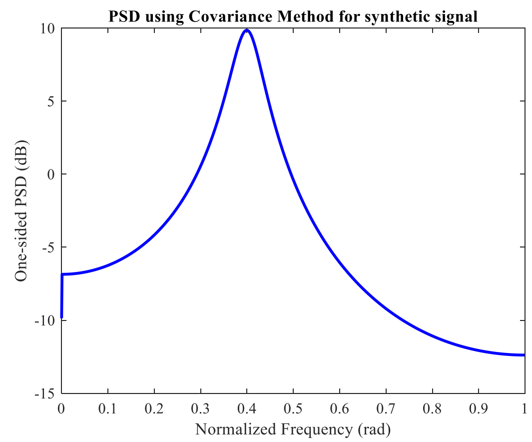

Fig 2.*PSD using covariance Method*

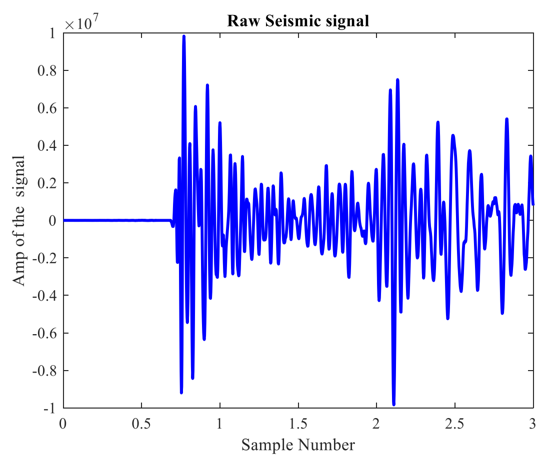

Fig 3*. Seismic signal in raw form*

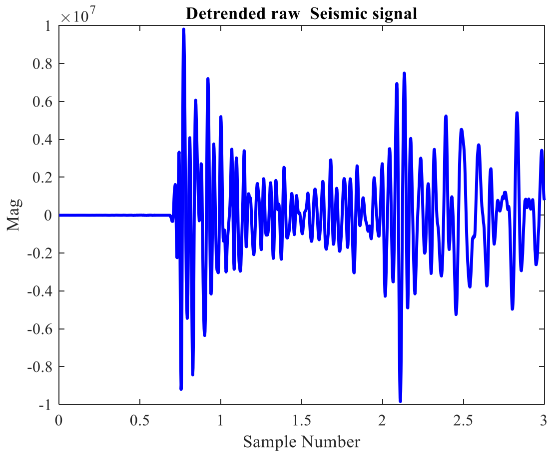

Fig 4. *Raw seismic signal after detrending*

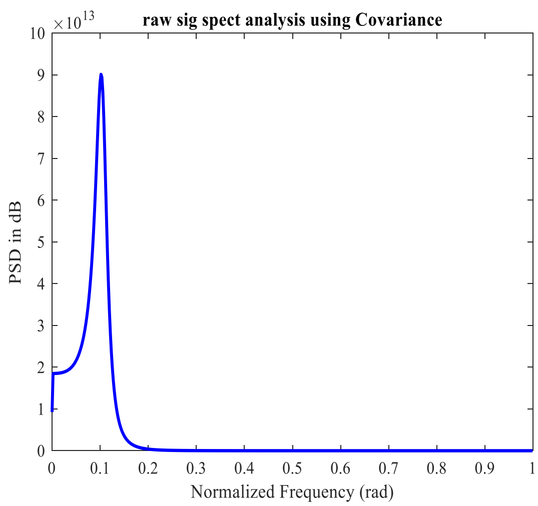

Fig 5. *Spectral analysis of raw signal*

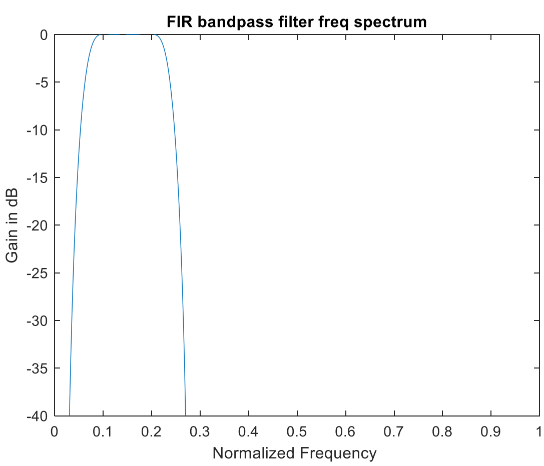

Fig 6. *Using covariance spectrum, Frequency of FIR BPF*

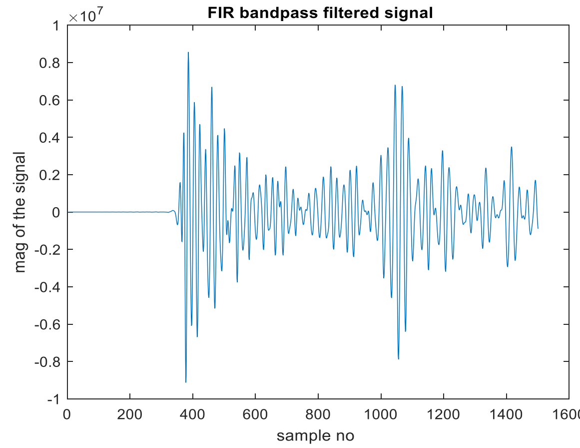

Fig 7. *Bandpass FIR*

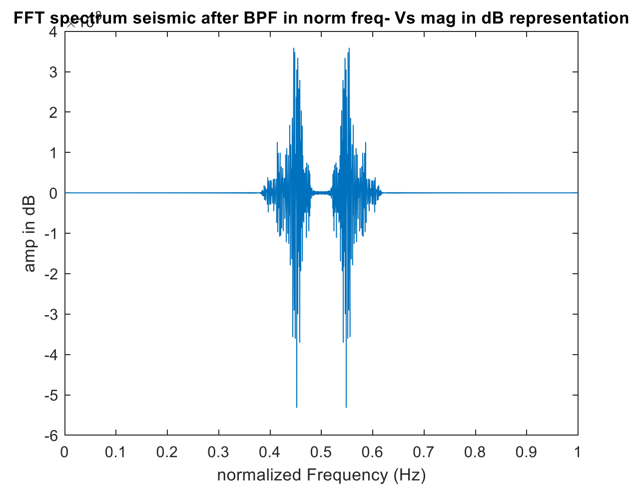

Fig 8. *Seismic signal FFT spectrum after Band pass filter in normfreqVs mag in dB*

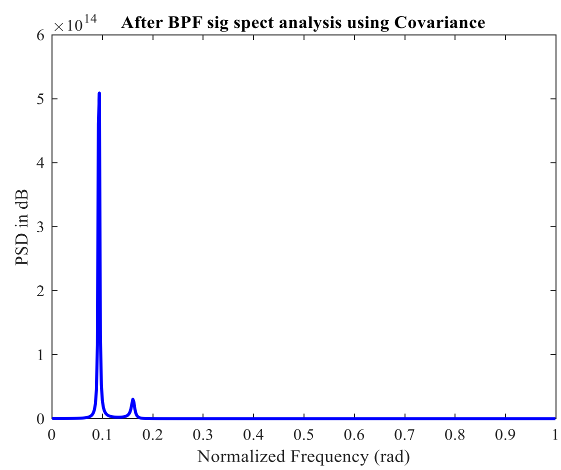

Fig.9. *Spectral analysis using Covariance of Band pass signal*

4 CONCLUSIONS

Implementing covariance method on geophone synthesized signals. The results are spectral analyzed for better estimates and high resolution. The spectral estimates are useful for the prediction of earthquakes events having similar observation during an earthquake which are well correlated.

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