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Analysis of Seismic Waves Using Pisarenko Harmonic Decomposition Algorithm

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Abstract: Seismic signal is a combination of complex exponentials and noise recorded in multiple traces using multiple array elements. The major problem in seismic signal is to extract the uncorrelated sinusoidal signals from the noise. Estimating sinusoidal signals from noise measurements can be obtained by the Pisarenko Harmonic Decomposition method. The resolution of frequencies that are closely spaced and estimating the frequencies of a seismic signal which consists of complex exponentials and white noise is proposed in this paper by using the above technique. This algorithm is based on the frequency of the complex exponentials and variance methods for spectrum estimation.

Keywords: Seismology, Stochastic signal processing, Adaptive signal processing, Spectrum Estimation, Pisarenko Harmonic Decomposition.

1. INTRODUCTION

1.1. Seismology

Around the globe, on an average there are fifty earthquakes occur and damage the structures. Each earthquake radiates seismic waves that propagate along the earth. Seismology is the science that studies the earthquakes and seismic waves which travel along the earth gives information about the structure and the behaviour of the earth. Seismology is the study of the elastic waves passing through the earth [1]. Seismograms detect and record the presence of seismic waves. They measure and also amplify the motion of the ground.

1.2. Seismic Waves

Seismic waves are the waves which emanate from the earth's surface. The seismic earthquakes create two sorts of waves and they are body waves and surface waves. The body waves propagate through the earth, whereas the surface waves travel along the earth's surface. Particle motion of the body waves is smaller than that of the surface waves [1]. Because of its particle motion, surface waves tend to cause severe damage. Primary and Secondary waves are the two types of the waves which result in the particle motion of body waves. Seismometer sensors record the motion of the earth and detect the seismic waves that arise from earth. Seismometers can be placed at the earth's surface, underwater, in bore holes etc. Seismograph is the instrument that records the intensity of the seismic signals [2]. Seismograph also records non-earthquake source signals like noise from wind, nuclear and chemical explosions etc. Seismic waves travel faster than Tsunami waves. The global seismographic monitoring systems are used to detect and to study the nuclear testing.

1.3. Spectrum Estimation

The power spectrum is the Fourier transform of the autocorrelation sequence. So, estimating the power spectrum is same as estimating the autocorrelation function. For an autocorrelation ergodic process it is known that

$$r_x(k) = \underset{M \to \infty}{\text{Lt}} \left[\frac{1}{2M+1} \sum_{m=-M}^{M} x(m+k)x^*(m) \right] \quad (1)$$

So, if $x(m)$ is known for all 'm', estimating the power spectrum is easy. There are two complications in this method. The quality of data that one has to work is unlimited in several cases in the first complication. This limitation is a natural characteristic of the data collection process. For an example, the analysis of seismic data from an earthquake in which signal is present only for a short period of time. The second complication is that the data is frequently corrupted by noise with an interfering signal. The spectrum estimation involves $p_x(e^{j\omega})$ from an infinite number of noisy measurements of $x(m)$.

The methods for spectrum estimation may be divided into two categories. The first method is the classical or non-parametric method which starts by estimating the autocorrelation sequence of $r_x(k)$ from a given set of data. The power spectrum is estimated by Fourier transforming that autocorrelation sequence [3]. The second method includes the parametric approach which is described in the following section.

1.4. Parametric Method

The drawback of non-parametric technique for range estimation is that it is not intended to incorporate the information that is accessible about the estimation procedure. In parametric strategy it is conceivable to incorporate a model for the procedure specifically into the range estimation calculation. In the parametric approach the initial step is to choose a suitable model for the procedure. This determination depends on priori information about how the procedure is produced. The regularly utilized models are ARMA, AR, MA and harmonic models [4]. Once a model is chosen, the following step is to assess the model parameters from the given information. The last step is to assess the power range by including the evaluated parameters into the parametric form for the range.

1.5. Pisarenko Harmonic Decomposition

V. Pisarenko considered the issue of assessing the frequencies of a whole of complex exponentials in noise. In view of Carathedory hypothesis he exhibited that the frequencies could be gotten from Eigen vector comparing to the base Eigen estimations of the autocorrelation matrix [5, 6].

In Pisarenko harmonic decomposition $x(m)$ is a total of "n" known complex exponentials in noise. It is likewise accepted that $(n + 1)$ estimations of the autocorrelation matrix are known (or) evaluated. With a $(n + 1) \times (n + 1)$ autocorrelation matrix, the measurements of noise subspace is equivalent to one [9]. The calculation strategy for the Pisarenko harmonic decomposition is given in the ensuing area.

1.6. Flow Chart

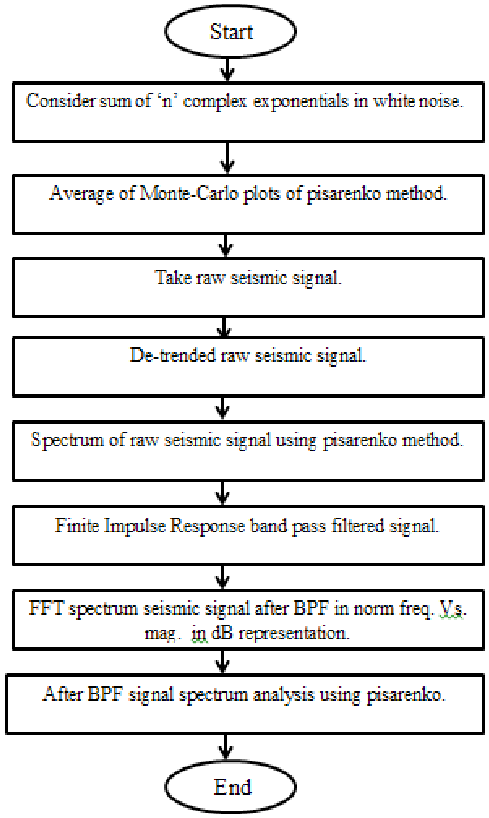

Figure 1: Flow chart of PHD Algorithm

1.7. Mathematical Modelling of Pisarenko Estimation

Step 1: Given that a signal includes '*n*' complex exponentials [7] in white Gaussian noise.

Step 2: Determine the minimum Eigen value $\lambda_{\min}$ and the corresponding Eigen vector $V_{\min}$ of the $(n+1)\times(n+1)$ of autocorrelation matrix R_x.

Step 3: Choose the white noise power equal to minimum Eigen value $\lambda_{\min} = \sigma_\omega^2$ and Set the frequencies equal to the angles of the roots of the Eigen filter. Along these lines,

$$V_{\min}(z) = \sum_{k=0}^{n} v_{\min}(k) z^{-K} \tag{2}$$

Or the location of the peaks in the frequency estimation functions.

$$\hat{p}_{\mathrm{PHD}}(e^{j\omega}) = \frac{1}{\left| e^{H} V_{\min} \right|^2} \tag{3}$$

Step 4: Solve the complex exponential powers by computing the linear equations given below [7].

$$\begin{bmatrix} \left|V_1(e^{jw_1})\right|^2 & \cdots & \left|V_1(e^{jw_n})\right|^2 \\ \vdots & \ddots & \vdots \\ \left|V_n(e^{jw_1})\right|^2 & \cdots & \left|V_n(e^{jw_n})\right|^2 \end{bmatrix} \times \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} \lambda_1 - \sigma w^2 \\ \vdots \\ \lambda_n - \sigma w^2 \end{bmatrix} \tag{4}$$

2. SIMULATION AND RESULTS

Step 1: The input signal x is consists of n complex exponentials in white noise. The white noise with variance 0.5 is generating for 10 times as shown in Figure 1. The signal buried in noise is obtained for a Monte-Carlo runs of 10. The Figure 1 shows the calculation of the spectrum using the Pisarenko harmonic decomposition.

Step2: After plotting of the Eigen spectrum using Pisarenko harmonic decomposition method and normalizing the frequency, and the next step is to calculate average of the Monte-Carlo scenarios. The Figure 2 shows the plotting of average Monte-Carlo of Pisarenko method.

Step 3: Determining the 'P' largest peaks taken from local maxima and estimating the frequencies using PHD method. Calculating and initializing mean and variance of FFT to zero. The Figure 3 shows the input raw seismic signal obtained from Mat lab file present in signal obtained from Mat lab file present in Book_Seismic Data. Mat [8] raw seismic signal is recorded during man-made blasting dynamite and is loaded to MATLAB.

Step 4: The Figure 4 shows the de- trended raw seismic signal. To remove the general drift in the random signal of the raw seismic signal by using PHD is as shown in Figure 4.

Step 5: After de-trending the raw seismic signal the next step is applying the PHD algorithm to the de-trended seismic signal to obtain the spectrum of raw seismic signal as shown in Figure 5. The maximum peak value is determined in this Figure is 0.08008π normalised frequency. The sampling frequency is calculated using the sampling interval 0.002s as,

$$fs = 1/0.002 = 500 \text{ Hz}$$

$$w = \frac{2\pi f}{fs} = 0.08008\pi$$

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

$$= \frac{2\pi}{fs} f = 0.\ 08008\pi$$

Therefore, f is the frequency of the signal and is given by

$$\text{Tonal Frequency } f = \frac{500}{2} \times 0.08008$$

$$= 250 \times 0.08008$$

$$= 25 \times 0.8008$$

$$= 20.02 \text{ Hz}$$

Step 6: The Figure 6 shows the Finite Impulse Response band pass filter spectrum frequency in which the normalised frequency is along X-axis and the gain in dB on Y-axis.

Step 7: By removing the noise in a particular frequency, to obtain Finite Impulse Response band pass filtered signal as shown in Figure 7.

Step 8: For obtaining spectrum of band pass filtered raw seismic signal by applying Fast Fourier Transform and taking normalised frequency to analysis the signal shown in Figure 8.

Step 9: The Figure 9 shows the estimation of spectrum after filtering with band pass filter and plotting the Eigen spectrum to determine the peak values and analysing the signal spectrum using PHD method. The maximum peak value is estimated at 0.0957π.

$$\text{Tonal Frequency } f = \frac{500}{2} \times 0.0957$$

$$= 250 \times 0.0957$$

$$= 25 \times 0.957$$

$$= 24.375 \text{ Hz}$$

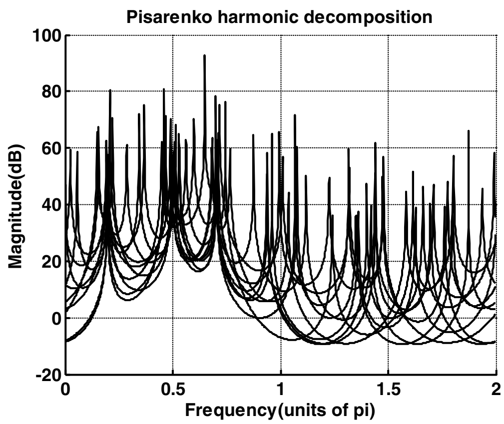

Figure 1: Pisarenko Harmonic decomposition

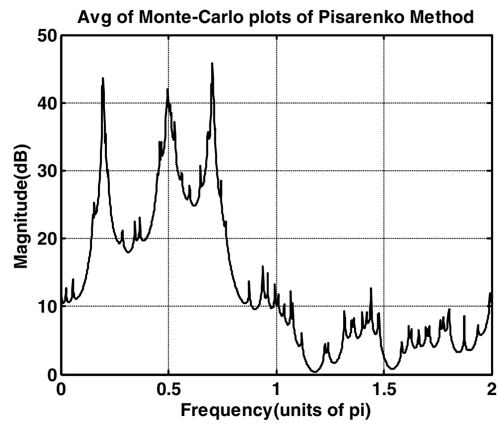

Figure 2: Avg. of Monte-Carlo plots of Pisarenko Method

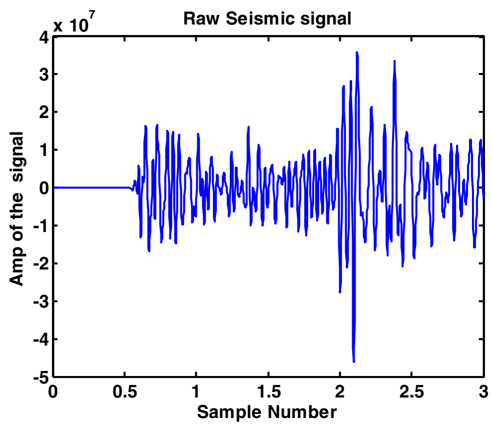

Figure 3: Raw seismic signal

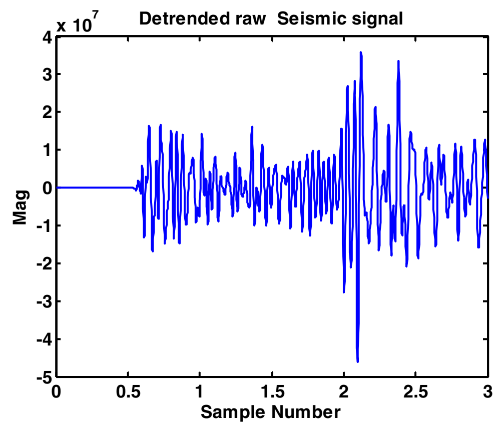

Figure 4: Detrended raw seismic signal

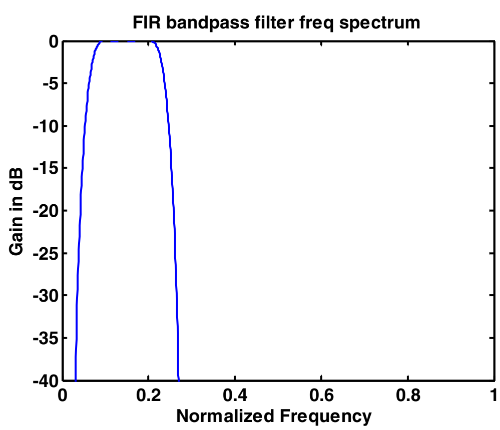

Figure 5: FIR band pass filter freq. spectrum

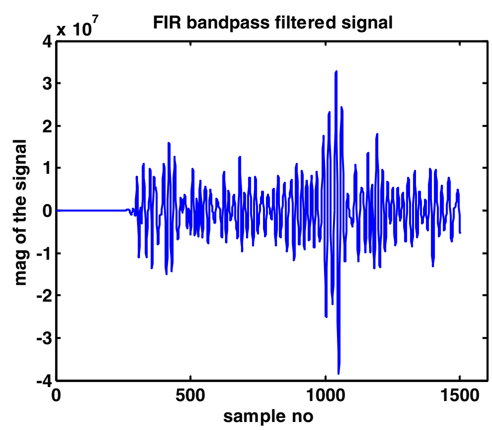

Figure 6: FIR band pass filtered signal

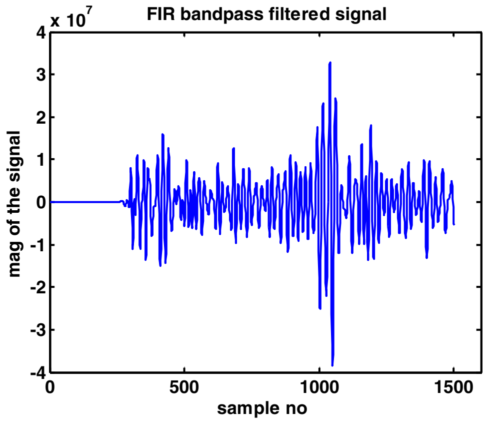

Figure 7: FIR band pass filtered signal

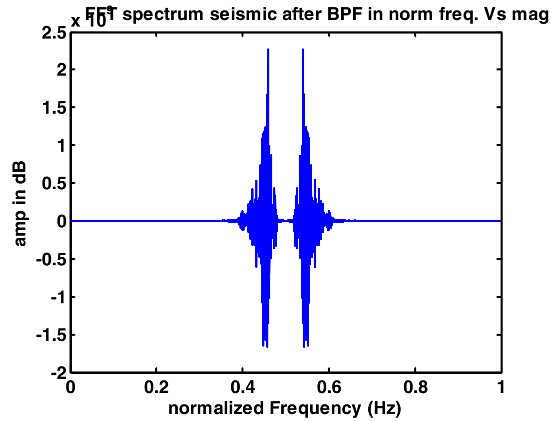

Figure 8: FFT spectrum signal

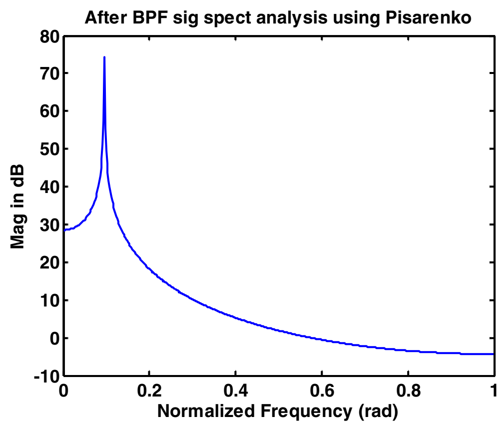

Figure 9: Signal spectral analysis using Pisarenko

3. CONCLUSION

In this paper, a procedure for estimating the frequencies of one original seismic signal which present in a white noise is proposed. The procedure is based on parametric method for spectral estimation. By applying a suitable method to auto correlation coefficients and noise of the seismic signal power spectral density can be estimated. The proposed method is accurate in estimating the frequencies and improves the resolution of peak values which occur at complex exponentials.

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