POWER SPECTRUM ANALYSIS OF SEISMIC DATA FOR AN EARTHQUAKE USING BARTLETT ALGORITHM

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Abstract

Earthquakes are the unforeseeable disasters in nature. During earthquake energy is released suddenly into earth’s lithosphere and creates seismic waves. Explosion that propagates through earth layers produce seismic signals using a transmitter. Hence, seismic signals are highly contaminated with noise. Signal to noise ratio of seismic signal is very low. Pre-processing techniques like FIR band filter is used in order to increase its SNR and to reduce the noise. In this paper Bartlett’s method is implemented in frequency domain to analyse power spectrum of the seismic signal.
Keywords: Stochastic signal processing, Adaptive signal processing, Seismology, Applied statistics, Seismic signal processing.

1. Introduction

1.1 Seismic signals

Study of earthquakes and related incidents is known as seismology. Due to sudden transference of tectonic plates earthquakes are caused which results in great destruction to mankind. A seismogram is used to predict the seismic signals which are generated using a source[1]. As these signals contain noise, various signal processing techniques are used. Signal processing is an authorized technology used to implement and transform the information obtained. Seismic signal processing processes the seismic data for the purpose of suppressing noise and enhances the signal. So, signal processing is attuned for this purpose.

1.2 Types of seismic waves

Seismic waves are of different types. They are body waves and surface waves. The waves that travel through the earth layers are called body waves whereas surface waves travel through the surfaces. The earth quakes cause both body waves and surface waves and radiates seismic energy. Based on the properties of pressure and shear wave’s, body waves are classified into love waves and Rayleigh waves which are detected by using seismogram. There are many seismic devices in the world which collects the seismic reflection data and used for the analysis and future prediction [10]. All these waves arrive at different time and different speed due to the disturbances in the travelling path like noise and origin of the signal at various time intervals.

1.3 Signal processing

The ground movements are monitored continuously by the seismic recording systems during the destruction. Various signal processing techniques are used on the collected seismic data to analyze
the geological features of the earth. The collected data consists of noise waves which are of low velocity and low frequency. The SNR ratio of these noises is very low so seismic trace also become low [9]. Thus various processing techniques are used to increase the SNR. Here power spectrum analysis is used to determine the seismic trace by using various algorithms of both parametric and non-parametric methods. To produce the image of earth crust the numerical algorithms are used to process the exploration of seismic data. In order to increase the SNR and to reduce the noise non parametric technique using FIR band pass filter is used. Bartlett algorithm is implemented in the frequency domain to analyze the spectrum of seismic signal [8,11]. Section 2 deals with Mathematical modelling. Section 3 deals with Simulation and results. Section 4 deals with conclusion.

2. Mathematical Modelling

In Power spectrum estimation, periodogram is not a consistent estimate of power spectrum. So non parametric methods are used for the power spectrum estimation by smoothing and averaging operations which are directly implied on the periodogram or on the auto correlation [3,5]. Auto correlation is used for estimating the time domain signals and to find the noise in the data.

Non parametric methods are used for spectrum estimation. Repetition of the data is not found in this method. These methods are used for estimating the power spectrum for a measured data. Fourier transform is used for estimating the power spectrum. The non-parametric methods are periodogram, Bartlett’s method, Welch method, Blackman Tuckey method. To reduce the variance in the power spectrum all the techniques used here decrease the frequency resolution [2]. By using Bartlett method we are estimate the power spectrum for the detrended band pass filter seismic signal [8].

The periodogram averaging of Bartlett method is discussed it produces estimation of power spectrum. As the data length N goes to infinity the expected value of periodogram converges up to $P_x(e^{jw})$.

$$\lim_{n \to \infty} E\{P_{per}(e^{jw})\} = P_x(e^{jw})$$

(1)
If the consistent estimate of the mean is determined, E\{P\_per(e\_jw)\}, will be the consistent estimate for the P\_x(e\_jw)[7]. The power spectrum is estimated by random process of periodogram averaging x\_i.

\[ P\_\text{per} (e\_jw) = \frac{1}{L} | \sum_{n=0}^{L-1} x(n)e^{-jnw} |^2 \]  

(2)

The average of periodograms is

\[ P\_x (e\_jw) = \frac{1}{K} \sum_{i=1}^{k} (P\_\text{per} (e\_jw)) \]

(3)

By evaluating we get

\[ E\{P\_x (e\_jw)\} = E\{P\_\text{per} (e\_jw)\} = \frac{1}{2\pi} P\_x (e\_jw) \ast W\_b (e\_jw) \]

(4)

\( W\_b (e\_jw) \) is the Fourier transform of the Bartlett window W\_b(K). P\_x(e\_jw) is unbiased in additions to our assumptions data records are uncorrelated. The variance of P\_x(e\_jw) is given as:

\[ \text{Var}\{p\_x (e\_jw)\} = \frac{1}{k} \text{Var}\{p\_\text{per} (e\_jw)\} \]

(5)

K and L goes to the infinity as the P\_x(e\_jw) is the estimation of the power spectrum. In Bartlett method x(n) is partitioned into K non overlapping sequences which consists of the length L. Here N=KL.

\[ x(n) = x(n+iL) \quad \text{where} \quad n=0,1,\ldots,L-1. \]

(6)

\[ i=0,1,\ldots,K-1. \]

Thus we get the Bartlett estimate as

\[ P\_b (e\_jw) = \frac{1}{N} \sum_{i=0}^{N-1} \frac{1}{\sum_{n=0}^{L-1} x(n+iL)e^{-jnw}} |^2 \]

(7)

P\_b(e\_jw) is asymptotically unbiased, periodogram used in this are computed using length L then the resolution can be determined as

\[ \text{Res}[P\_b (e\_jw)] = 0.89\left(\frac{2\pi}{L}\right) \]

(8)

As the variance is inversely proportional to K,

\[ (\text{Var} [P\_b (e\_jw)] = \frac{1}{k} \text{Var} P\_\text{per} (e\_jw)) \]

(9)
3. Simulation and Results

As the seismic signal is random, the power spectrum is used where FFT is not used, as it is stochastic and deterministic. Seismic signal consists of more noise because it is caused by the earthquake. Here, raw seismic data is considered as it consists of more noise. By using band pass filter, the noise of raw seismic data signal is removed. In this Bartlett estimation, it is considered as 50. Uniform noise is added and the variance is 12.

Step1: The input signal is considered for checking the Bartlett algorithm. Synthetic signal is considered as the input signal and is plotted in Fig. 1 by considering the sample number and the magnitude.

Step2: The overlay plot of 50 Bartlett estimates for the synthetic signal is determined and plotted in Fig. 2.

Step3: The actual data is loaded, here the actual data is nothing but the seismic data. The loaded seismic data is plotted and is shown in Fig. 3.

Step4: Due to any mean, which regards shift or bias, is present in any random signal. To remove that mean, signal has to be de-trended. The de-trended signal is plotted which removes the mean in Fig. 4.

Step5: At different frequency components, power spectrum is estimated by distributing energy among the waveform. For raw seismic signal power spectrum is applied. The estimated Bartlett power spectrum of raw seismic data is plotted in Fig. 5.

Step6: The band pass filter frequency spectrum is plotted in Fig. 6. The main function of BPF is to limit the output signal bandwidth and it conveys the data in required form at the desired and required speed. When band pass filter is applied, we get normalized frequency at the range of 0.03-0.269Hz.

Step7: The convolution is performed between FIR band pass filter signal and de-trended signal. The band pass filter removes the noise in the particular frequency. FIR signal of 8th order which has 8 filters is used for the detrended seismic signal and thus graph is plotted as shown in Fig. 7.
Step 8: Fast Fourier transform of seismic signal after band pass filter is plotted in Fig.8. The Bartlett power spectrum of the de-trended seismic signal is estimated and plotted as shown in Fig.9. Here 0.078 normalized frequency is obtained.

\[ w = \frac{2\pi}{f_s} f = 0.078\pi = \frac{2\pi}{500} f = 0.078\pi \]

Total frequency \( f = 0.078 \times \frac{500}{2} \)

\[ = 19.5 \text{Hz} \]
Fig. 5. Bartlett power spectrum of a seismic signal.

Fig. 6. FIR band pass filter of raw seismic signal.

Fig. 7. FIR band pass filter of a detrended signal.

Fig. 8. FFT spectrum of seismic signal after band pass signal filtering.

Fig. 9. Bartlett power spectrum of BP filtered detrended seismic signal.
4. Conclusion

In Bartlett algorithm, large fluctuations of the periodogram are reduced. Using FIR, band noise is reduced as the SNR ratio is increased. The power spectrum of seismic signal is analysed using Bartlett method in the frequency domain.

5. References


