

SPECTRAL ESTIMATION OF SEISMIC DATA USING YULE-WALKER METHOD

D.Mukesh Kumar Reddy¹, U.Krishna kishore², K.S.Ramesh³,
S.Koteswara Rao⁴, T.Vaishnavi Chandra⁵

Department of ECE, K L University, Vaddeswaram, Guntur

rao.sk9@gmail.com, mukesh.donthireddy0101@gmail.com,
dr.ramesh@kluniversity.in, vaishnavichandra.dalu999@gmail.com

Abstract

Seismic events involves a lot of data, so these are to be subjected to signal processing techniques in order to obtain better estimates for analysing the seismic signals. Yule-Walker method always produces a stable model for spectral estimation. By processing the synthetic signal using various signal analysis methods along with Yule-Walker method and additionally the tonal frequency of the signal is analysed.

Key words: Seismology, Adaptive signal processing, Stochastic signal processing, Applied statistics, Estimation theory.

1. INTRODUCTION

Study of seismic data helps in developing a warning system for prediction of earthquakes. When an earthquake occurs, seismic waves move on the surface of the earth. After the occurrence of earthquake, different kinds of waves are released, out of all these waves P and S waves penetrate deeper into the surface of the earth and are merely sufficient to study the mechanism of earthquakes. [2]. The change in behaviour of animals a few days before the occurrence of earthquake also enables us to predict the earthquake. [3]. Change in the content of precursors in ionosphere prior to earthquake occurrence also can be analysed for earthquake prediction [11].

The non-parametric methods are limited by the reason that they are not designed to integrate data that is made available regarding the process into the estimation procedure. In some applications especially where little knowledge is available about how the data samples are produced. Therefore one would hope that if it was possible to use a model for processing directly into spectrum estimation algorithm, outcome of a more accurate and higher resolution estimates to be obtained [1]. This may easily be done by using parametric approach to spectrum estimation.

Among all the parametric methods that estimate PSD, Yule-Walker is the most commonly used one [8]. The autoregressive (AR) parameters are computed by estimation of autocorrelation function, solving the error of forward prediction in the sense of least square prediction. In autoregressive methods the signal's amplitude at a specified interval is formed by adding up the various amplitudes of previous signals along with the error of estimation. [10].

In this analysis, Yule-Walker method which is one of the parametric method for estimation of PSD is used. The Yule-Walker method as well as other parametric methods perform spectral estimation for data records .Even though the Yule-Walker method applies window to data, it always produces a stable model. Seismic signal spectral analysis using Yule-Walker method may be used a method for developing a prior earthquake prediction system.

The section-2 of this paper, discusses in detail of the Yule-Walker method mathematical modelling and the section-3 describes and presents the simulation and results of seismic data analysis Yule walker method

2. MATHEMATICAL MODELLING

The parametric is based on making use of a model for the process so that to obtain the power spectrum estimation [4]. For e.g., if $x(n)$ is the path order auto regressive process, then $x(n)$'s measured values may be used to estimate the parameters of all pole model, $\hat{a}_p$ and these, $\hat{a}_p(k)$ which are model parameters estimated may in turn be used in power spectrum estimation as following.

An Auto regressive spectrum estimate process can be considered as output of all pole filter that is carried forward by unit white noise.

where $r_x(k)$ is related by filter coefficients $b_q(k)$ using the Yule-Walker equation.

$$r_x(k) = \sum_{i=0}^{q-k} b_q(1+i)b_q(1+i-k); k=0, 1, 2, \dots, q \quad (1)$$

With $r_x(-k) = r_x^*(k)$ and $r_x(k) = 0$ for $|k| > q$

The power spectrum of path-order AR process is,

$$p_x(e^{j\omega}) = \frac{|b(o)|^2}{|1 + \sum_{k=1}^p \hat{a}_p(k)e^{-jk\omega}|^2} \quad (2)$$

Thus, if $b(o)$ and $\hat{a}_p(k)$ can be estimated using the data, then an estimate formed can be represented using,

$$\hat{p}_{per}(e^{j\omega}) = |X_N(e^{j\omega})|^2 = \sum_{k=-N}^N \hat{r}_x(k)e^{-jk\omega} \quad (3)$$

If $\hat{a}_p(k)$ and $\hat{b}_q(q)$ are the model parameters of spectrum estimate would be

$$\hat{p}_x(e^{j\omega}) = \frac{\left| \sum_{k=0}^q \hat{b}_q(k) e^{-jk\omega} \right|^2}{\left| 1 + \sum_{k=1}^p \hat{a}_p(k) e^{-jk\omega} \right|^2} \quad (4)$$

The AR coefficients are obtained by solving the matrix,

$$\begin{bmatrix} r_x(0) & r_x^*(1) & r_x^*(2) & \dots & r_x^*(p) \\ r_x(1) & r_x(0) & r_x^*(1) & \dots & r_x^*(p-1) \\ r_x(2) & r_x(1) & r_x(0) & \dots & r_x^*(p-2) \\ \dots & \dots & \dots & \dots & \dots \\ r_x(p) & r_x(p-1) & r_x(p-2) & \dots & r_x(0) \end{bmatrix} \begin{bmatrix} 1 \\ a_p(1) \\ a_p(2) \\ \dots \\ a_p(p) \end{bmatrix} = \varepsilon_p \begin{bmatrix} 1 \\ 0 \\ 0 \\ \dots \\ 0 \end{bmatrix} \quad (5)$$

Where,

$$r_x(k) = \frac{1}{N} \sum_{n=0}^{N-1-k} x(n+k) x^*(n) \quad (6)$$

; k=0, 1, ..., p

Solving the above matrix,

$$|b(0)|^2 = \varepsilon_p = r_x(0) + \sum_{k=1}^p a_p(k) r_x^*(k) \quad (7)$$

A variation used to find the unbiased estimate,

$$\hat{r}_x(k) = \frac{1}{N-k} \sum_{n=0}^{N-1-k} x(n+k) x^*(n) \quad (8)$$

; k=0, 1, ..., p

3.SIMULATION AND RESULTS

Step1: The signals used for analysis in this work are obtained from synthetic data taken from [9] in which 33 traces are recorded and divided into 1500 samples at a sampling frequency of 0.002s is collected with the help of a geophone by using explosives placed at about 100feet under the surface of the earth. The synthetic signal is shown in Fig.1.

Step2: The power spectral density estimate obtained from synthetic seismic is represented in Fig.2.

Step3: The raw seismic signal taken from shot 13 in the book seismic data [9] can be observed in Fig.3, represented using sample number vs amplitude of the signal

Step4: In order to remove bias of the seismic signal, the raw seismic signal is detrended and shown in Fig.4.

Step5: The spectral estimate of raw seismic signal using Yule-Walker method is represented in Fig.5, by using normalized frequency and power spectrum density in dB representation.

Step6: The frequency range of the synthetic signal is between 15 and 60 Hz. The realized spectrum of finite impulse response band pass filter is shown in Fig.6.

Step7: The filtered signal is obtained from FIR band pass filter application is represented in Fig.7, using sample number vs magnitude of the signal representation.

Step8: The fast Fourier transform spectrum seismic estimate after BPF is shown in Fig.8. It is represented in normalized frequency vs. magnitude representation.

$$f_s = \frac{1}{0.002} = 500\text{Hz} \quad \omega = \frac{2\pi f}{f_s} = 0.1134 \pi$$

We get the total frequency, $f = \frac{500}{2} * 0.1134$ therefore, $f = 28.35$ Hz if $f_s = 500$

Step 9: The signal spectral analysis after band pass filter using the parametric, Yule-Walker method is represented in Fig.9.

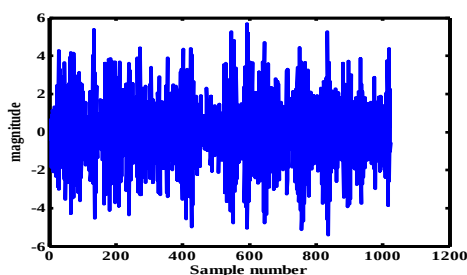


Fig1.Synthetic signal.

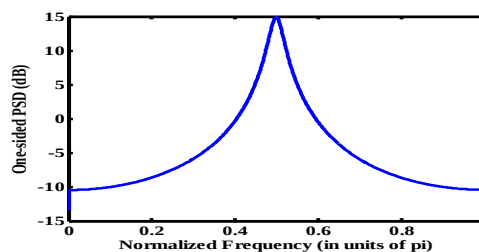


Fig 2.PSD using Yule-Walker Method

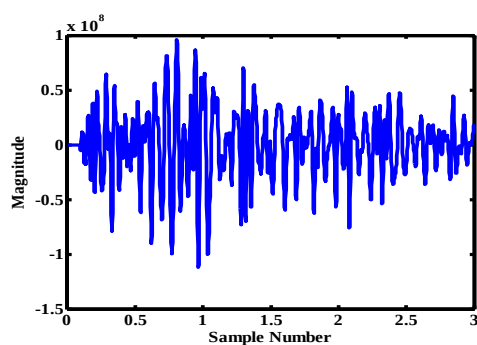


Fig 3. Raw seismic signal.

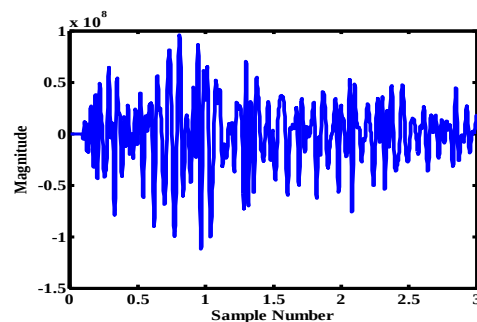


Fig 4. Detrended raw Seismic signal.

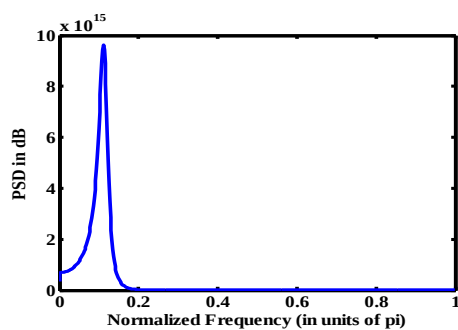


Fig5. Raw signal spectrum.

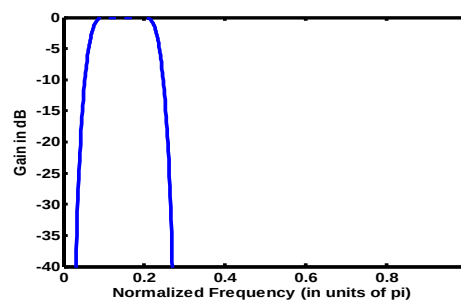


Fig 6. FIR band pass filter frequency using Yule-Walker

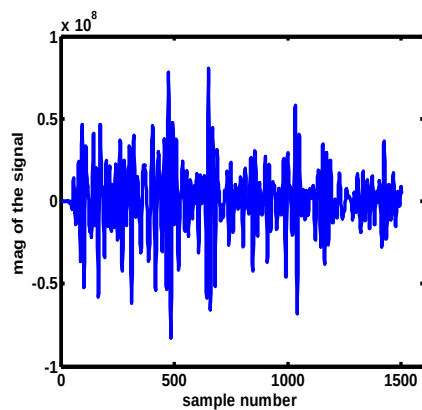


Fig 7. FIR band pass signal spectrum

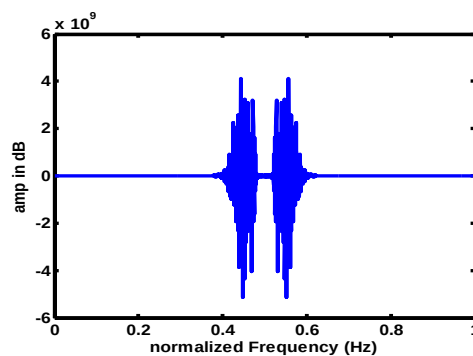


Fig 8. FFT spectrum seismic after BPF

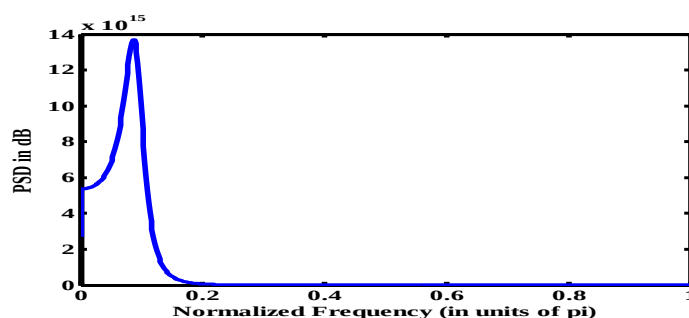


Fig.9.After BPF sig spectral analysis Using Yule-Walker.

4. CONCLUSION

The synthetic seismic signal which is collected from geophone and subjected to adequate amounts of signal processing and implemented using Yule-Walker method. The results are obtained and analysed. These results may be set as reference and it can be used as possibility in developing prior warning system for earthquake prediction.

5. REFERENCES

- [1] Sanjit K. Mitra, "Digital Signal Processing - Computer Based Approach", second edition, McGraw-Hill Publication.
- [2] Raju.G.V.S, Kishore, Kumar Reddy.C, Narsimha Prasad.L.V, "Revealing of Earthquake Magnitude using Seismic signals and Wavelet transforms", the fifth international conference on soft computing and Software engineering, pp.619-627, 2015.
- [3] Neeti Bhargava, V. K. Katiyar, M. L. Sharma, P. Pradhan, "Earthquake Prediction through Animal Behavior: A Review", Indian Journal of Biomechanics, pp.159-170, Mar. 2009.
- [4] Monson H. Hayes, "Statistical Digital Signal Processing and modelling", John Wiley & Sons.inc.

- [5] R Revathi, S Lakshminarayana, S Koteswara Rao, K S Ramesh, K.Uday Kiran. "Application of Maximum Entropy Method for Earthquake Signatures using GPSTEC".
- [6] Dr.N.Purnachandra Rao, "Earthquakes", Andhra Pradesh Akademi of Sciences (APAS) publishers.
- [7] S. K. Baji, R. Revathi, S. Lakshminarayana, S. Koteswara Rao and K. S. Ramesh, "Application of Multiple Signal Classification Algorithm on GPS TEC for Earthquakes", Indian Journal of Science and Technology, Vol 9(17), May 2016.
- [8] K.Umamaheswari, P.Sushma chowdary and P.Rajesh, "Estimation of Random Signals using Nonparametric and Parametric methods", Vol 5, pp.25-33, Jul.2013.
- [9] Wail A.Mousa and Abdullatif A.Al-Shuhail, "Processing of Seismic Reflection data using MATLAB", 2011.
- [10] Ahmet alkan, Ahmet S.Yilmaz, "Frequency domain analysis of power system transients using welch and yule walker methods", pp.2129-2135, Mar.2007.
- [11] Mohamad Huzaimy Jusoh, Norsuzila Ya'acob, Hasnida Saad, Ahmad Asari Sulaiman, Noor Hasimah Baba, Robi'atun Adayiah Awang and Zuhani Ismail Khan, "Earthquake Prediction Technique Based on GPS Dual Frequency System in Equatorial Region", IEE International RF and microwave proceedings, pp.372-376, Dec.2008.

