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Time-Frequency Spectral Analysis of Single - Channel Earthquake Data for P-Wave Detection.

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Abstract — **Sudden occurrence of an earthquake and its harmful consequences is very well known phenomenon to all of us. It is an abrupt and severe natural disaster across the world, resulting in the loss of immense wealth and population. Therefore, there is an urgent need of earthquake detection system. P-wave arrival time estimation in earthquake warning system is the basic problem that the geologists and seismologists face around the world. In earlier days, P-wave arrival time identification and detection was very time consuming and only skilled and efficient seismologists could perform this work. But in the era of information and communication technology, this work is done with the help of consistently improving technology and better analysis techniques. The decision of the exact arrival time of P wave in earthquake warning system can be used to determine the epicenter, magnitude, etc. of an earthquake in real time. This paper describes the comparative analysis of different time-frequency spectral techniques i.e. short time fourier transform, continuous wavelet transform and discrete wavelet transform on earthquake data for P-Wave detection.**

Index Terms— **Data Analysis, P-Wave arrival time detection, Short Time Fourier transform, Continuous Wavelet Transform, Discrete Wavelet Transform.**

1. INTRODUCTION

Earthquake and its terrible consequences are worldwide known phenomena and are totally unpredictable. Man, being a part of nature, is created and destroyed by nature through its natural calamities and disasters which are impossible to control. A huge loss of human life and property are the consequences such natural calamities. Tsunami is also a form of an earthquake occurring at sea. There are several examples in history regarding devastation caused by earthquakes and tsunami. 26 January, 2001 Gujarat earthquake, December 26, 2004 Indian Ocean Earthquake, October 8, 2005 Kashmir Earthquake, August 10, 2009 Andaman Islands Earthquake, April 25, 2015 North East India Earthquake etc. are just few examples of major earthquakes occurred in India in recent past. And the list is quite big if we consider world-wide earthquakes. Basically earthquakes occurred almost daily but their affects cannot be sensed due to their lower magnitude. Higher magnitude earthquakes which are build up due to internal movement of earth plates with time causes major devastation. The tectonic shift has caused a series of recent earthquakes in the region of Northern India which has led to the conditions that might trigger multiple earthquakes which may go up to 8.0 in magnitude. Our earth is mainly comprised of four layers. These four layers are the inner core, outer core, mantle and crust. The upper crust and mantle are known as lithosphere. The layer is 50 meters thick and is divided into sections known as tectonics plates. Intense shaking of tectonics plates lead to the occurrence of earthquake. Scales used to measure the intensity of an earthquake is Richter Scale and revised Mercalli Magnitude Intensity scale [1].

2. LITERATURE SURVEY

Seismographs [2] record earthquake events. At convergent boundaries, focal depth increases along a dipping seismic zone called a Benioff zone. Seismographs generally consist of two parts, a sensor of ground motion which we call a seismometer, and a seismic recording system. Modern seismometers are sensitive electromechanical devices but the basic idea behind measuring ground movement can be illustrated using a simpler physical system that is actually quite similar to some of the earliest seismograph systems.

Today, most seismic data are recorded digitally, which facilitates quick interpretations of the signals using computers. Digital seismograms are "sampled" at an even time interval that depends on the type of seismic instrument and the interest of the people who deploy the seismometer. A digital seismogram is a record of the ground movement stored as an array of numbers which indicate the time and the movement of the ground for a range of times and are easily analysed using computers. The principle is the same as that used for digital audio signals that are stored on Music CD's. Also, since with active in a three-dimensional space, to record the complete ground motion, we must record the motion in three directions. Usually, we usually choose Up-down, East-West and North-South Component.

Location of India is at the north-western end of the Indo-Australian Plate. It encompasses India, Australia, a major portion of the Indian Ocean and other smaller countries. This plate is colliding against the huge Eurasian Plate and going under the Eurasian Plate. The process of one tectonic plate getting under another is called subduction. A sea, Tethys, separated these plates before they collided. Part of the lithosphere, the Earth's Crust, is covered by oceans and the rest by the continents. The former can undergo subduction at greater depths when it converges against another plate, but the latter is buoyant and so tends to remain close to the surface. When continents converge, large amounts of shortening and thickening takes place, like at the Himalayas and the Tibet. Three chief tectonic sub-regions of India are the mighty Himalayas along the north, the plains of the Ganges and other rivers, and the peninsula. The Himalayas consist primarily of sediments accumulated over long geological time in the Tethys. The Indo- Gangetic basin with deep alluvium is a great depression caused by the load of the Himalayas on the continent. The peninsular part of the country consists of ancient rocks deformed in the past Himalayan-like collisions. Erosion has exposed the roots of the old mountains and removed most of the topography. The rocks are very hard, but are softened by weathering near the surface. Before the Himalayan collision, several tens of millions of years ago, lava flowed across the central part of peninsular India leaving layers of basalt rock. Coastal areas like Kachchh show marine deposits testifying to submergence under the sea millions of years ago [3]. Earthquake risk in the Indian subcontinent is different everywhere. India on the basis of the four parts of the quake zone [4] i.e. Zone 2, Zone 3, Zone 4 and Zone 5 respectively from lower to higher risk of earthquake occurrence. Seismic waves [5] are basically of three types i.e. the primary wave (P wave), secondary wave (S wave) and surface waves (surface waves). The surface waves are the most severe and damaging waves. Earthquake detection system which is sensor based detects P-wave first and the time lag between the later arriving damaging surface waves can be used as alert time for earthquake warning system. Smart phones have accelerometers which can also be used as warning system as sudden change in acceleration is sensed in the surrounding environment.

3. Problem Formulation

The seismic waves observed in earthquake records manifest clearly non-stationary characteristics, as well as wide frequency content. Those characteristics are twofold.

1. The first characteristic involves variations with time of the intensity of the ground motion (acceleration, velocity or displacement). That is, with the arrival of the first seismic wave, its intensity builds up rapidly to a maximum value for a certain time and then decreases slowly until it vanishes [6].

2. The second characteristic involves variations with time of the frequency content, with a tendency to shift to lower frequencies as time increases. This behavior is well known as a frequency dependent dispersive effect. This phenomenon is very complex and involves the arrival of the different seismic phases (P, S and Surface waves), the intensity of the ground motion, the magnitude of the earthquake, source and path effects [7].

Hence, the analysis should either be made on the basis of intensity of earthquake for P-Wave detection where we can obtain a peak for P-Wave arrival time estimation or, it should be made on the basis of change in frequency content of signal. We are primarily focused on the algorithm for P-Wave arrival time estimation of earthquake data and check its consistency with respect to large scale data.

The short-time Fourier transform (STFT) is a standard method for analyzing time-varying signals. However, the method assumes that the spectral components varying so slowly that the signal can be regarded as stationary in the analyzing time window. Therefore, the STFT does not allow the calculation of the dominant frequency, the center frequency, or the change spectral contents if they are rapidly changing with time. The time-frequency distribution ideally describes how the energy is distributed, and allows us to estimate the fraction of the total energy of the signal at time t and at frequency ω. The above statement states that the energy should be positive. In order to achieve fine simultaneous time-frequency resolution in a non-stationary time series, we must deal with the uncertainty principle. The uncertainty principle restricts us from achieving arbitrarily fine resolution simultaneously in both the time and the frequency domain. The condition to satisfy the uncertainty principle [8] is given by the inequality

$$t.\Delta\,\omega \geq 1/4\Pi \simeq 0.08 \text{ cycles}$$

in which the selection of Δt (time resolution) and Δω (frequency resolution) are not arbitrary parameters. A trade-off between them should be considered in order to reach the desired "good" resolution. In the majority of the cases, it is dependent on the signal characteristics [6].

Conventionally, the Fourier transform is used to analyze the frequency content of seismic signals. Fourier analysis gives a global representation of the data but cannot analyze its local frequency content or its regularity (If the mth derivative of the signal resembles |x -x0|r locally around x0, then the regularity p = m + r with 0 <r <1. The signal is more regular with greater p). Hence the Fourier Transform is not always the best tool to analyze real life signals, which are usually of relatively shorter and limited duration. Common example includes speech signal. Frequency content of most signals changes with time, the classical Fourier theory is useful for analyzing a signal in the time domain or in the frequency domain. To overcome this problem many alternatives such as time dependent spectrum has been developed and widely studied. These new technique is known as Joint Time Frequency Analysis transform is used to analyze non stationary signals, that their spectra varying with time. For signals whose spectra varying with time (non-stationary), such as speech signals, seismic signals etc. joint time frequency analysis must be used. Joint Time-Frequency Analysis methods include the Short time Fourier transform (STFT), Wigner-Ville distribution (WVD) and Wavelet transform (WT) [9].

Time –Frequency localization and distribution can be understood from the Figure 1 where signal is represented in time domain, frequency domain and time –frequency domain i.e. STFT spectrogram and Wavelet spectrogram where frequency is represented by its inverse and is known as its scale.

4. Analysis of various time-frequency techniques

Benchmark Earthquake data of Japan's Kyoshin Network is analyzed to test various time-frequency techniques for P-wave detection and a comparative analysis for spectral resolution is observed. Figure 2 shows de-noised single channel i.e. up-down data of Kyoshin Network of Japan to test our algorithms.

Figure 3 shows stft power spectral density spectrogram to analyze P-Wave arrival time estimation. Figure 4 shows the comparative analysis of spectrogram of Discrete Wavelet transform using haar wavelet at scale 3 and Continuous Wavelet Transform. The analysis is performed using MATLAB 2015a as a preprocessing and analysis tool.

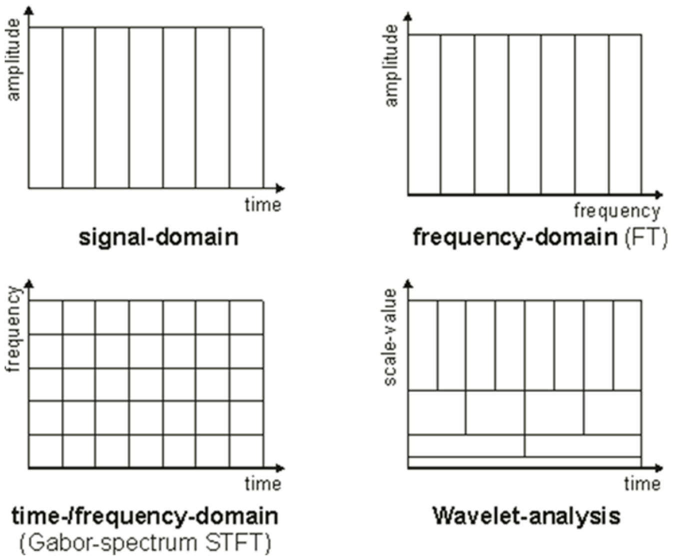

Figure 1 Various time-frequency resolution techniques used in P-Wave detection of Earthquake data

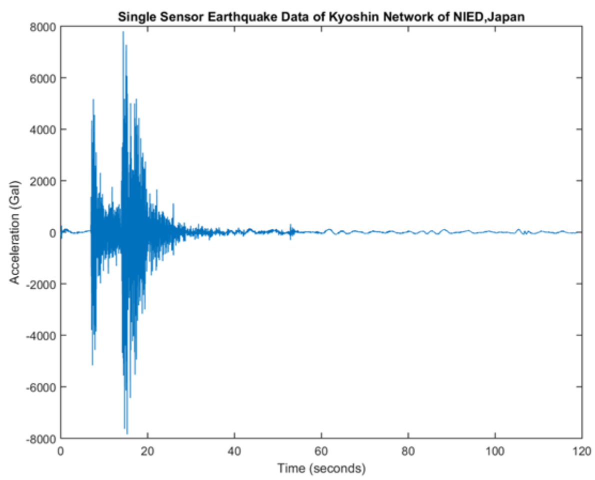

Figure 2 De-noised single channel (Up-Down) data of K-Net

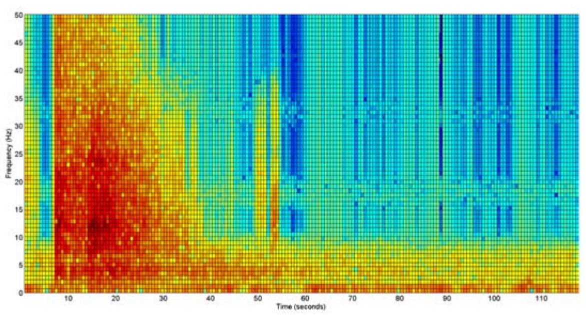

Figure 3 Short time Fourier transform power spectral density spectrogram of test data

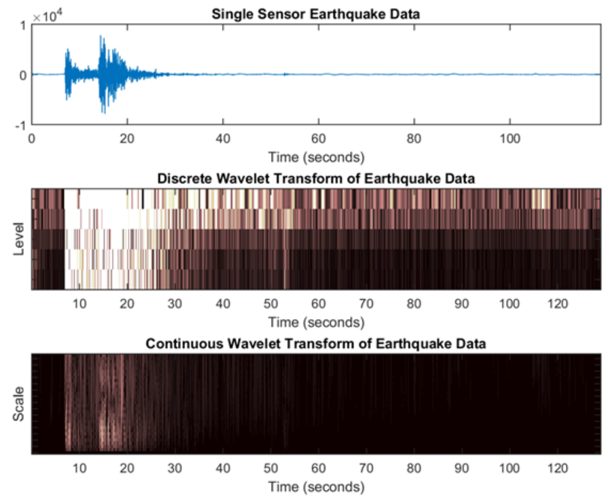

Figure 4 DWT and CWT applied on test data to check time-frequency spectral resolution.

5. FUTURE SCOPE

With the recent development and the growth of personal computers technology, analysis for P-wave arrival time has been eased to far extent for implementation for an earthquake detection mechanism. Out of three time-frequency spectral techniques, DWT has best resolution due to its inherent scaling features for better resolution. The analysis is to be performed on large scale earthquake data to check its consistency with that of seismological recorded data. Features extracted from time-frequency method on large scale data is to be used as training and testing data set in supervised learning algorithms i.e. artificial neural networks, linear regression etc. to fit our results for real time earthquake warning mechanism.

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