ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Exploration of Enormousness for Tremor Discovery Using Major Waves and Minor Waves

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Abstract:

An earthquake (also known as a quake, tremor or temblor) is the perceptible shaking of the surface of the Earth, which can be violent enough to destroy major buildings and kill thousands of people. The severity of the shaking can range from barely felt to violent enough to toss people around. Earthquakes have destroyed whole cities. They result from the sudden release of energy in the Earth's crust that creates seismic waves. The seismicity, seismism or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time. Each event is associated with some waves such as primary waves, secondary waves, Rayleigh waves, Stoneley waves and Love waves. As these waves travels from interior of earth to surface they degrades in magnitude and intensity, only a part of the original waves reach the earth surface originated in earth's crust which are recorded as seismograph. Till to date, many of the researchers applied different techniques like prediction based on radon emissions, prediction using extraction of instantaneous frequency from underground water. As the earthquake occurs due to transmission of waves, hence feature extraction from the seismic signal is the efficient approach to predict the earthquake. The parameters of seismic signal are analyzed by using fast fourier transform spectrum analysis. The magnitude which forms the base of analysis is used for the detection of earthquake. The minor quakes are neglected and the surface wave magnitude of the quakes that show impact on earth's surface is calculated and found it as 4.0. Hence, the occurrence of earthquake can be predicted if the magnitude exceeds 4.0.

*Keywords - **Primary waves; Secondary waves; Intelligent methods; Surface wave magnitude; FFT spectrum.***

INTRODUCTION

Earth is said to be the only planet in the solar system know to nurture, cherish and shelter the entire mankind. All the things required for the survival is provided beneath a thin layer of atmosphere that separates us from the decrepit space. As earth is made up of obscure and interactive systems hence it is quite unpredictable. Air, water, land, and life including humans combine forces to create a constantly changing world that we are striving to understand. The formation of earth is believed to be took place around 4.54 billion years ago and there are many theories that support this formation. The Big Bang theory is one among such theories where a star collapsed forming earth's core which is at temperature equal to surface of the sun i.e., 60000C. From space earth looks like a big blue blob with white swirls, the lush land in green, the deserts in brown and the cloud, ice and snow in white. As one third i.e. 71 percent of the earth's surface is covered with water hence it is also called a blue planet. After some millions of years the earth's core cooled down due to continuous loss of energy which resulted formation of several layers, apart from core, such as crust and mantle. Earth's crust is the topmost layer and supports life due to various geographical divisions such as biosphere, lithosphere, atmosphere and hydrosphere.

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Earthquakes are usually caused when the rock underground suddenly breaks along the fault and due to the stresses and pressure among the rocks and the outer layer push the sides of the fault together. Due to this stress the rock slips suddenly, with a release of energy in the form of waves through the earth's crust and these results in the vibrations and shaking over the earth surface. Usually large earthquakes usually begin with slight tremors but within no time would form in to a violent shock and ends with a vibration of gradually diminishing force called aftershock. The subterranean point of origin of an earthquake is called its focus; the point on the surface directly above the focus is the epicentre. Due to the sudden release of energy in the earth crust, it creates seismic waves which make the ground shake.

Volcanic eruptions, rock falls, landslides, and explosions can also cause a quake, but most of these are of only local extent. Earth's activity can be categorised into three events specifically foreshock, the energy released from earth's core which is weak and due to their weak strength they cannot reach earth surface. Main Shock, here the strength in energy is much stronger enough to hit the earth surface and causes damage. Aftershock, the event which occurs after the main shock i.e. the earthquake has finally eventualized. Shock waves from a powerful earthquake can trigger smaller earthquakes in a distant location hundreds of miles away if the geologic conditions are favorable. The surface of the Earth is made up of a collection of large plates that does not reside in fixed positions, they move, and they frequently press up against one another with great force. When two plates push against each other, it creates a convergent plate boundary. At this convergent boundary, one plate will usually slide underneath the other and melt into the magma. If neither plate can slide underneath the other, the two plates sometimes create a mountain range. When plates slide in opposite directions while pressed against each other, this is called a transform boundary. A lot of tension builds at the seismic faults around these boundaries, which can lead to earthquakes.

When there is an earthquake there will be moment of waves on the earth surface called seismic waves. The study of such waves is called as seismology. There are different types of waves released after the earthquake had occurred which include primary waves, secondary waves, Love waves, Rayleigh waves, stoneley waves; among these p-waves and s-waves travels inside the earth called as body waves and are stronger enough to study the earthquake activities. The remaining waves travel along earth surface they are called as Surface waves.

As earthquake is among the most damaging events caused by the earth itself, in order to reduce the risk it is necessary to predict where and when a future large earthquake may occur. As urbanization advances rapidly worldwide, earthquakes causes a serious threat to lives and properties. The mitigation of the seismic risk is a complex task, which requires the cooperation of scientists, engineers and decision makers, and that has to be approached at different time scales.

Earthquake prediction is the branch of seismology, which can be done by the following prediction methods.

Animal Behavior:

Abnormal behavior in animals can be helpful to predict the forthcoming disaster, as they behave in unusual manner and disappear from the region where the earthquake occurs.

Radon Emissions:

There are different rocky materials inside the earth which emits certain gases, the amount of such emission is extremely concentrated and yields spikes when recorded on the graph during the earthquake.

Study of Waves:

Study of p-waves and s-waves helps in predicting earthquake, as these waves carries earthquake energy. Various parameters can be extracted from these waves and are to be analysed. When earthquake occurs over a region these waves are emerged from earth's core and reaches the earth's surface. The two different surface waves; p-waves - travels inside earth in both liquid and solid interfaces and they are the faster among all waves and s-waves - travels in both solid and liquid interfaces but are slow than p-waves. These surface waves are recorded to measure the earthquake intensity using a device called seismogram. Seismogram records response of these waves in a visual form called seismographs. Seismic parameters [4] such as frequency, wavelength, energy, magnitude can be extracted from the seismographs.

Earthquake has caused the greatest loss of life, causing a powerful and deadliest loss at heavily populated areas or the oceans; earthquake which occurs in the form of tsunami in the ocean areas causes the greatest loss by devastating the communities thousands of kilometres away. It is estimated that around 500,000 earthquakes occur each year among them only 100,000 of earthquakes can be felt. Table I gives the census of the drastic death toll that took place at various locations due to the heinous earthquake. Table II gives the property damages that occurred due to earthquakes. This motivates to present a prediction methodology for earthquake so as to reduce the risk and to control the live and property loss to the possible extent.

RELEVANT WORK

Research and experimental development comprises of creative work undertaken on a systematic basis in order to increase the stock of knowledge, culture and society and the usage of this stock of knowledge is to devise new applications. The purpose of research is to describe, explain, predict and expand the knowledge. The research comprises of series activities they are: Identify and formulating the problems, extensive literature review, developing the hypothesis, objectives or research questions, preparing the research design, determining the sample, collection of data, analysis and interpretation of data.

Earthquake predictions (may be short-term, long-term) are being the research domain for several years. Several researchers contributed their related work in the field of earth sciences to predict the earthquake. P. Shebalin, V. Keilis-Borok, A. Gabrielov, I. Zaliapin, D. Turcotte [1], used an data mining approach to predict earthquake using a technique called RTP(Reverse Tracing of Precursors) in which they observe and analyze the premonitory patterns of seismicity and the RTP method is applied to reconstruct those patterns. Neeti Bhargava, V. K. Katiyar, M. L. Sharma and P. Pradhan [2], used an analytical approach to predict the earthquake based on the study on anonymous behaviour of animals before the earthquake occurs. Sajjad Mohsin Faisal Azam and G. Molchan and L. Romashkova [3], characterized the prediction of earthquake using a two-dimensional error diagram approach in the field of data mining using M8 algorithm. Sajjad Mohsin, and Faisal Azam [4], compared different seismic algorithmic approaches for earthquake prediction to predict true occurrence of earthquake. Chieh-Hung Chen, Chung-Ho Wang, Jann-Yenq Liu, Chen Liu, Wen-Tzong Liang, Horng-Yuan Yen, Yih-Hsiung Yeh, Yee-Ping Chia, and Yetmen Wang [5], identified the earthquake signals which can cause earthquake using an image processing technique called HHT transform (Hilbert-Huang Transform). Claudio Satriano, Yih-Min Wu, Aldo Zollo, Hiroo Kanamori and W. H. K. Lee [11], worked on the concept called EEW (Early Earthquake Warning system) based on the waves analysis, they suggested that prediction of earthquake is much stronger when ground motion is analyzed based on study of Waves (p-waves and s-waves). Lynn R. Sykes, Bruce E. Shawet [18], introduced different time scales in earthquake prediction. Robert J. Geller [19], discussed the probability of correct prediction rate of earthquakes. Stefan Wiemer [20], done his research on worldwide earthquakes and collected statistical data and tried to predict the upcoming quake with his calculated statistics. Hiroo Kanamori [21], worked on real time quakes occurred and tried to forecast in same area based on previous disaster. Toshi Asada [22], discussed the types of quakes occurred in Japan and tried to predict the quakes using precursors technique. C. G. Sammis and D. Sornette [23] came forward with the new concept of Positive feedback and memory for predicting the earthquakes et al.

All previous researches done predictions based on data mining, radon emission and other methods. In this paper a contemporary approach is introduced to detect the earthquake using wavelet transform.

FORMATION OF EARTHQUAKES

An earthquake is the result of primary waves which get pass through the earth's crust. The innermost layer of the earth called core is at a temperature equal to the surface of the sun and hence the metals are in molten state as they easily attain their melting points. Hence, core can be described as a hot mass of molten metal. This molten metal easily moves in the core and in this movement among the plates of rock in the crust tends to jam, break apart or get stuck as they move past each other. If these plates are unable to move in their free motion stress builds up between them and they start to bend.

As these plates move one over the other, vibrations are produced due to friction between them. Vibrations are set up in solid bodies by a sudden blow or sliding together of two rough surfaces. The main cause of earthquakes in the earth's crust is volcanic explosion. Perceptible tremors are set up by the passage of trains and tanks, avalanches and landslides, rock falls in mines and caverns and explosions. These tremors act as a passage to the strain energy developed in the earth's crust.

Tectonic earthquakes are generated by the rapid release of strain energy that is stored within the rocks of the crust; on which continents are build about 22 miles (35 kilometers) thick. A small proportion of earthquakes are associated with human activities, such as drilling for the fossil fuels and underground water. Dynamite or atomic explosions sometimes can cause mild quakes. The injection of liquid wastes deep into the earth and the pressures resulting from holding vast amount of water in reservoirs behind large dams can also trigger minor earthquakes. Recently, collapse of underground old coal mine in England caused sporadic small earthquakes.

It is estimated that around 500,000 earthquakes occur each year detectable with current instrumentation, among them only 100,000 of earthquakes can be felt. Minor earthquakes occur nearly constantly around the world in places like California and Alaska in the U.S., as well as in Mexico, Guatemala, Peru, Indonesia, Iran, Pakistan, Italy Portugal, Turkey, Greece, India and Japan. Larger quakes occur less frequently compared to minor quakes i.e. in an exponential manner; for example, roughly ten times as many earthquakes of larger than the magnitude of 4 occur in a particular time period rather than earthquakes larger than magnitude of 5.

Today the number of seismic stations has rapidly increased from about 350 in 1931 to many thousands. As a result, many more earthquakes felt are reported than in the past, this due to the vast improvement in instrumentation, rather than an increase in the number of earthquakes. The United States Geological Survey (USGS) estimates that, since 1900, there have been an average of 18 major earthquakes (magnitude 7.0–7.9) and one great earthquake (magnitude 8.0 or greater) per year, and that this average has been relatively stable. In recent years, the number of major earthquakes per year has decreased, though this is probably a statistical fluctuation rather than a systematic.

EXPERIMENTATION METHODOLGY

The experimentation methodology adopted for the detection of earthquakes is shown in Fig.1. Seismic signal is provided as input to this research. As the signal may contain some noise, the wave is subjected to a process called denoising, where the noisy data is removed. In this research, denoising is carried out using haar wavelet.

Seismic parameters such as energy and frequency are computed using FFT spectrum analysis. Based on these extracted parameters other parameters such as wavelength, magnitude of the signal are computed and are explained in section IV. Since, the magnitude itself is sufficient for deciding the earthquake occurrence; a

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
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decision is made based on the computed surface wave magnitude. After computing training set of signals a threshold value for magnitude is fixed, later a test set of signals are computed and magnitude is analyzed and if their magnitude value exceeds the threshold value the earthquake may occur, if the threshold value is not exceeded there is no earthquake.

Seismic waveform in wave signal format (.wav extension) is considered as input parameter to the research, and is analyzed in the FFT spectrum in haar wavelet. Input seismic signal is shown in Fig 2. The input signal is read into haar wavelet and is analyzed using FFT Spectrum with level 5 and the decomposition in the signal is observed with 5 different variations, Fig 3.

The wavelet transform [13] acts as a tool for signal and image processing that have been successfully used in many scientific applications such as image and signal processing, image compression, computer graphics, and pattern recognition method [15].

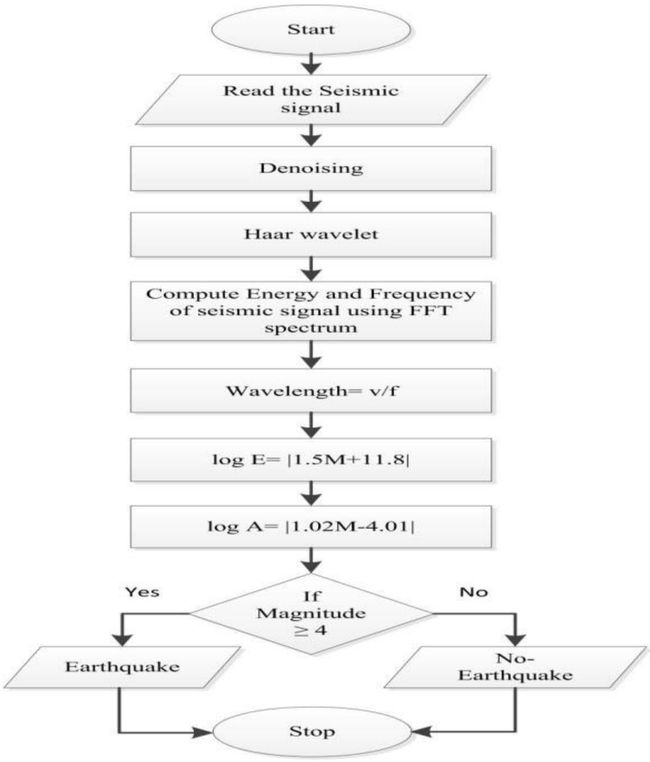

Figure 1. Flow chart diagram representing experimentation methodology

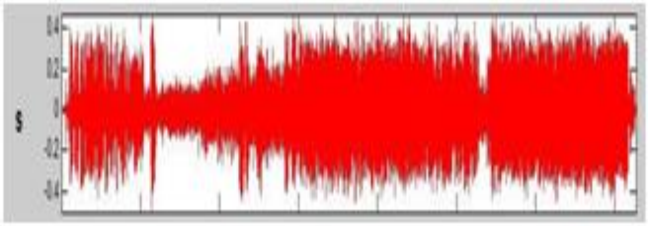

Figure 2: Seismic Signal

Fourier transform is mostly suitable for the applications of non-stationary signals which may vary instantaneously in time [7]. It is critical to analyze the time-frequency characteristics of the signal, which are non-stationary signals, in order to understand the exact features of the signals. For this reason, researchers has concentrated more on continuous wavelet transform (CWT) that gives more reliable and detailed time-scale representation rather than the short time fourier transform (STFT) giving a time- frequency relation.

The CWT technique [13][14] expands the signal onto basis functions created by expanding, shrinking and shifting a single prototype function, which is named as mother wavelet. This transformation decomposes the signal into different scales with different levels of resolution. Since a scale parameter shrinking or expanding the mother wavelet in CWT, the result of the transform is time-scale representation. This scale parameter is indirectly related to frequency, when considered the central frequency of mother wavelet.

Haar functions [15][16] have been used from 1910 when they were introduced by the Hungarian mathematician, Alfred Haar characterized complete orthogonal system of functions Lp[0,1], [0, 1], p □ [0, 8] which take values from the set {0, 2j: j □ N}. The functions of this scheme has a property that each function is continuous over the interval [0, 1] which may be represented by a uniformly and convergent series in terms of elements of this system.

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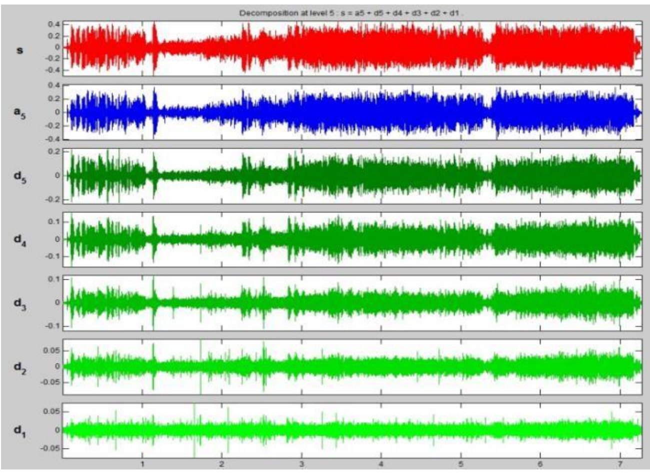

Figure 3 Decomposition levels (d1, d2, d3, d4, d5) in Haar

Wavelet original signal (S) = d1+ d2+ d3+ d4+ d5(1)
Where d1, d2, d3, d4, d5 are decomposed signals and S is the original signal.

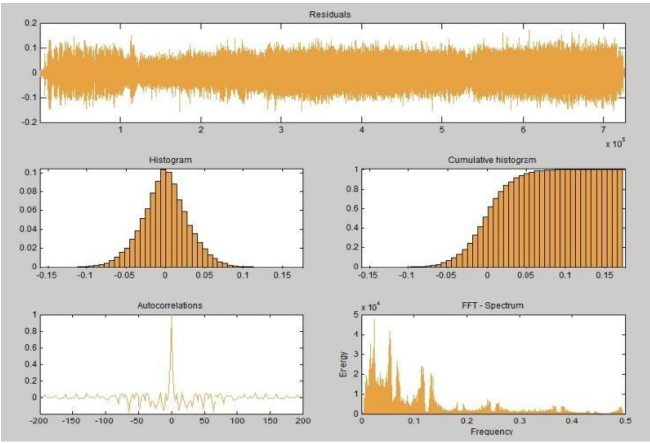

Figure 4 Analytical methods

In order to extract the parameters, the decomposed signal Equation (1) is compressed and its residual is analyzed, this analysis produces analytical methods like histograms, cumulative histograms, autocorrelations, FFT spectrum, Fig 4. Among the analysis, FFT spectrum is extracted which contains the graph that correlates energy and frequency of the seismic signal, shown in Fig 5.

Frequency analysis, the method to extract an estimate of frequency components which are not known prior, such process is known as discrete fourier transform (DFT). DFT plays imperative role in frequency analysis because it takes discrete signal in the time domain and converts it into discrete signal in frequency domain.

There is a procedure for computing DFT, using FFT function. The FFT does not directly extract the spectrum of a signal, the FFT can vary depending on the number of points (N) of the FFT function, and the number of periods of the signal that are represented.

The time taken to evaluate a DFT on a computer depends principally on the number of multiplications involved. DFT needs N2 multiplications but FFT only needs Nlog2 (N).

Y = fft(X) is the function that returns a discrete fourier transform of vector variable X, when computed with fast fourier transform algorithm. If the input X is a matrix, Y = fft(X) function returns the fourier transform of each column of the matrix. If the input X is a multidimensional array, fft operates on the first non-singleton dimension array. The function fft(X) is equivalent to fft(X, n), where n is the size of variable X in the first non-singleton dimensional array. If the length of X is less than n, X is padded with trailing zeros to the length n. If the length of X is greater than n, the sequence X is deficient. When X is a matrix, the lengths of the columns are adjusted in the same manner.

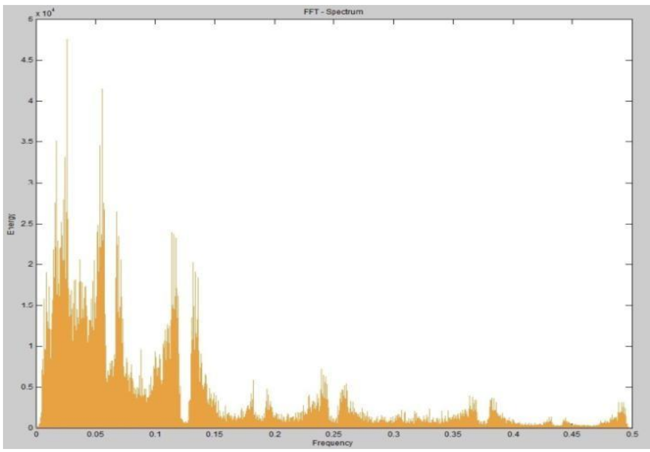

Figure 5 Energy versus Frequency

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
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Y = fft(X, [], dim) and Y = fft(X, n, dim) applies the FFT operation across the dimension dim. The FFT functions (fft, fft2, fftn, ifft, ifft2, ifftn) are based on a library called FFTW, FFT library. To compute an N-point DFT when N is composite i.e., when N = N1N2, the FFTW library decomposes the problem by means of Cooley-Tukey algorithm, which first computes N1 transforms of size N2, and then computes N2 transforms of size N1. The decomposition is applied recursively to the both N1 and N2 point DFTs until the problem can be solved using machine- generated fixed-size codelets. The codelets in turn use several algorithms in combination, including a modified Cooley-Tukey, a prime factor algorithm, and a split-radix algorithm, the particular factorization of N is chosen heuristically.

When N is a prime number, the FFTW library first decomposes an N-point problem into three (N–1) point problems using Rader's algorithm. It then uses the Cooley- Tukey decomposition method described above to compute the (N–1) point DFTs. For most N, real input DFTs require approximately half of the computation time of complex- input DFTs. However, when N has large prime factors, there may be a little speed variation.

Fig 5 describes the relation between the energy and frequency distribution from which the highest peak energy and peak frequency is extracted with their related values. As the basic parametric values are obtained, these values are further used to derive other seismic parametric values.

The empirical associations (by John Stockwell and Hiroo Kanamori) between seismic parameters, in CGS system, from earthquake seismology are classified in the subsequent manner.

Wavelength Vs Velocity Vs Frequency

$$\lambda = v / f \qquad (2)$$

Where λ is wavelength in meters, v is the velocity of wave and f is the frequency of wave in Hz.

Magnitude Vs Energy

$$\log_{10} E = |1.5M_s + 11.8| \qquad (3)$$

where E is the energy in ergs and Ms is the surface wave magnitude

Magnitude Vs Rupurture Area [8]

$$\log_{10} A = |1.02M_s - 4.01| \qquad (4)$$

where A is the Rupture area and Ms is the surface wave magnitude

EXPERIMENTATION RESULTS

Prediction of earthquake is one of the challenging field, several researchers are working on various methodologies to predict the earthquake. In spite of all their efforts most of them failed to produce an accurate model to predict the earthquake. It can be predicted by analyzing the seismic signals

Table 1 shows the preliminary results forming a data set of the parameters which are extracted using FFT spectrum. The attribute that detects the occurrence of earthquake is surface wave magnitude (Ms).

The seismic signals are obtained from USGS (United States Geological Survey), SSA (Seismological Society of America), SCEDC (Sothern California Earthquake Data Center), and JMA (Japan Metrological Agency). These signals are analyzed and seismic parameters are extracted. Theoretical observations on earthquake yielded that the magnitude is the deciding factor for the detection of earthquake. Experimental results concluded that the extracted parameter i.e. surface wave magnitude is the substantial attribute to detect the earthquake. Based on the experimental analysis over 140 seismic signals the minimum surface wave magnitude for the detection of earthquake is chosen as 4. Consider signal 1, the computed magnitude is 5.9 since it exceeded established value there is an earthquake. Similarly

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International Journal & Magazine of Engineering, Technology, Management and Research
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consider signal 3 the computed magnitude is zero which didn't exceeded the established value, hence there is no earthquake.

CONCLUSION

Earthquake is a natural calamity effecting human and wild life. Knowing the earthquake disaster earlier helps the mankind to protect their life. Predicting the earthquake before it strikes is helpful to reduce its negative impact on human life. Prediction is done previously based on animal behavior, radon emissions, pattern recognition methodologies, but they couldn't predict the perfect occurrence of the earthquake and produced false alarms. So, in this research, seismic signal parameters such as energy, frequency, wavelength, surface wave magnitude and rupture area are extracted using FFT Spectrum analysis in haar wavelet and these parametric values are considered as data set which are analyzed and the earthquake is detected based on the surface wave magnitude of the seismic signal.

TABLE 1. Features extracted using FFT Spectrum

Signal No.	Energy (ergs)	Frequency (Hz)	Wavelength (mts)	Magnitude of surface Wave	Rupture Area (cm^2)	Earthquake detection
1	659	27.1	17.71	5.9	0.32	Yes
2	11306	25.5	18.82	5.1	0.10	Yes
3	11370	129.4	00.03	0.0	0.00	No
4	4197	61.2	07.84	5.4	0.19	Yes
5	1535	42.1	11.40	5.5	0.22	Yes
6	78000	80	00.41	0.0	0.00	No
7	191200	21.8	22.02	4.3	0.37	Yes
8	6700	104.9	00.32	0.0	0.00	No
9	195100	80	00.42	0.0	0.00	No
10	3212	24.5	19.59	5.5	0.21	Yes
11	1524	28.6	01.17	0.0	0.00	No
12	28770	16.5	29.09	4.8	0.01	Yes
13	19444	31.6	15.19	5.0	0.04	Yes
14	630	116.4	00.28	0.0	0.00	No
15	3348	24.45	01.37	0.0	0.00	No
16	2490	117.6	04.08	5.6	0.23	Yes
17	53400	333	00.01	0.0	0.00	No
18	196	144	00.23	0.0	0.00	No
19	602000	152.70	03.14	4.0	1.08	Yes
20	27497	25.6	18.75	4.9	0.00	Yes
21	75660	29.7	16.16	4.6	3.31	Yes
22	1070	78	00.40	0.0	0.00	No
23	972	128	00.20	0.0	0.00	No
24	405	277	00.20	0.0	0.00	No
25	171620	30	16.00	4.3	0.35	Yes
26	150680	29.3	17.17	4.4	0.31	Yes
27	485	30	01.11	0.0	0.00	No
28	790	118	00.20	0.0	0.00	No
29	215000	30	16.00	4.3	0.39	Yes
30	203200	29.5	16.27	4.1	0.22	Yes
31	4350	8	00.40	0.0	0.00	No
32	8500	23.8	20.16	5.0	0.36	Yes
33	2250	23	01.90	0.0	0.00	No
34	13650	26	18.28	5.1	1.24	Yes
35	75700	30	16.11	4.6	8.72	Yes
36	1925	45	00.70	0.0	0.00	No
37	3450	11	00.20	0.0	0.00	No
38	68200	32.6	15.10	4.6	0.15	Yes
39	3260	23	01.45	0.0	0.00	No
40	218800	29.7	16.10	4.3	0.92	Yes

FUTURE ENHACEMENTS

The magnitude extracted from seismic signal here is surface wave magnitude. Richter magnitude of seismic waves raised below the earth's crust is calculated in near future to increase the accuracy of magnitude based prediction. The other parameters that mainly affect the earthquake like surface pollution rate, volcanic eruption rates etc are to be considered as a factor to predict earthquake.

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