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The Main Shock of Earthquake Detection Using Signal Processing

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Abstract:
The earthquakes are catastrophic events that must be studied and predicted. In this research, signal processing based method is used to detect the location of earthquake and the main shock time. The correlation coefficients and the total correlation coefficients used to detect the earthquake time. The results show that the use of the correlation coefficients in general is effective to find the main shock. The correlation coefficient among six stations are given a higher accuracy of 100% than two stations only, the data took from Iraqi seismic monitoring stations for date 2017-2018.

Keywords: Earthquake, Signal Processing, Main Shock, Correlation Coefficient.

1.Introduction:

An earthquake is the expression of the natural phenomenon that causes ulcer, or fear and instability of people and their characteristic is the sudden release of energy, which travels by waves from the Earth's interior**.** By recording seismic ground motion, seismologists are trying to obtain information about physical processes within the earth. A central target of attention has historically been the earthquake source. However, ground motion recorded at a seismic station on the earth's surface differs considerably from seismic signals originated at the earthquake source. [1]

The earthquake events have larger separation of primary and secondary-waves than in the case of local mining blasts (Shearer 1999; Malovichko 2012). As the blast spread through the layers of the earth a produce seismic signals using a transmitter. Thus, seismic signals are highly staining with noise. Signal to noise ratio of seismic signal is so low. Pre-processing techniques like FIR band "Finite Impulse Response" and other types of filters are used in order to increase its Signal to noise ratio (SNR) and to reduce the noise. [2]

Earthquake is the shaking of the surface of the Earth, coming about because of the abrupt arrival of energy in the Earth's lithosphere that creates seismic waves, an earthquake is a reason of a sudden slip on a fault, the tectonic plates are in every case gradually moving, but they get stuck at their edges because of friction. At the point when the stress on the edge overcomes the friction, there is a quake that releases energy in waves that travel through the earth's crust and rise the shaking that we feel. **Seismic waves** are waves of energy that movement through the Earth's layers, and are an aftereffect of tremors, volcanic eruptions, magma movement, large landslides and large man-made blasts that give out low-frequency acoustic energy. Numerous other natural and anthropogenic sources create low-amplitude waves regularly referred to as ambient vibrations. Seismic waves are studied by geophysicists called seismologists. Seismic wave fields are recorded by a seismometer, hydrophone (in water), or accelerometer.

There are a wide range of kinds of quake: tectonic, volcanic, and explosion. The type of earthquake relies upon the region where it happens and the geological make-up of that region. The most well-known are tectonic earthquakes. These happen when rocks in the earth's crust break because of geological forces made by movement of tectonic plates. Another type, volcanic earthquakes, happen related to with volcanic activity. Collapse earthquakes are little quakes in underground caverns and mines, and blast quakes result from the blast of nuclear and chemical devices. We can measure movement from enormous tectonic earthquakes utilizing GPS because rocks on either side of a fault are offset during this kind of quake. [3]

Types of earthquake waves:

Body waves: Body waves travel through the inside of the Earth along ways controlled by the material properties in terms of density and modulus (stiffness). The density and modulus, thus, shift as indicated by temperature, composition, and material phase. This impact looks like the refraction of light waves. Two kinds of particle motion result in two kinds of body waves: Primary and Secondary waves.

Primary waves (P-waves) are compressional waves that are longitudinal in nature. P-waves are squeeze waves that movement quicker than different waves through the earth to touch base at seismograph stations first, hence the name "Primary". These waves can go through any type of material, including liquids, and can travel about 1.7 times faster than the S-waves. In air, they appear as sound waves, subsequently they travel at the speed of sound. Ordinary velocities are 330 m/s in air, 1450 m/s in water and about 5000 m/s in granite.

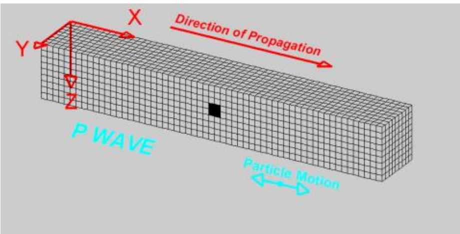


Figure 1: The P-Waves Shape

These are shear waves, which arrive after the P-waves. They’re additionally body waves but they only propagate through a solid medium. They likewise rarely do any huge damage. [4]

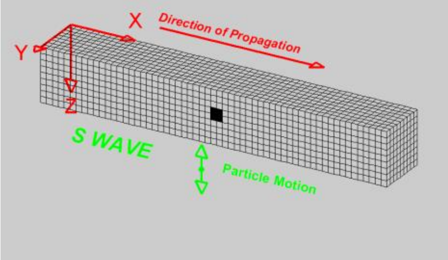


Figure 2: The S-Waves Shape

Surface waves: Seismic surface waves travel along the Earth's surface. They can be delegated a type of mechanical surface waves. They are called surface waves, as they decrease as they get further from the surface. They travel more gradually than seismic body waves (P and S). In large quakes, surface waves can have an amplitude of a few centimeters.

Surface waves (Rayleigh and Love) do by a long shot the most harm. Instead of body waves (S and P waves), they spread on the surface and convey by the vast majority of the energy felt on the surface — in other words, these are what you feel when you experience an tremor. This happens due to although they travel slower than body waves, their molecule movement is significantly more pronounced. In the case of Rayleigh waves, the movement is of a rolling nature, like to an ocean surface wave.

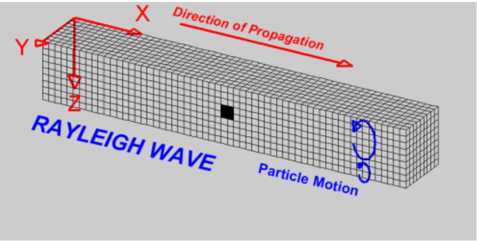


FIGURE 3 : THE RAYLEIGH WAVES SHAPE

In spite to their name, there's nothing extremely lovable about the Love waves — they were named subsequently after Augustus Edward Hough Love, a Professor for Natural Philosophy at Oxford University who previously depicted the movement of the waves named after him. Love waves have a transversal (perpendicular) movement and are the most damaging outside the prompt area of the epicenter. Love waves can be annihilating**.** [6] [7].

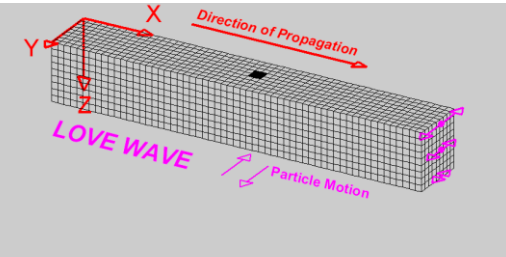


FIGURE 4: THE LOVE WAVES SHAPE

Seismic signal measurement: (Sources) indicated that, Earthquakes are registered by a seismographic network. Each seismic station in the system estimates the movement of the earth at that site. The slip of one block of rock over another in an earthquake discharges energy that causes the ground vibrate. That vibration pushes the abutting bit of ground and makes it vibrate, and in this way the energy goes out from the tremor in a wave. [8][9]

There are wide ranges of approaches to quantify various parts of a quake:

- **Magnitude**
- **Intensity**

1. Related works:

In the prior literature, this area was essential because it concentrates on the sensitive issues that be crucial for the decision making and the economy. Therefore, different scholars focused on this phenomenon from various viewpoint, based on the certain purposes. Below we highlighted most of the researchers who studied seismic signals and the findings of each study.

The first study was conducted by Chen in 1984. Chen utilize for a seismic signal analysis algorithm called segmentation algorithm. An activity sequential algorithm is produced that employs a regression modeling of the data and a popularize probability ratio test to detect the considerable statistical changes in the waveform. The algorithm does not require previously knowledge of the data. (C.H., 1984)

In the same context, **Alperovich et al. (2001)** suggested an algorithm for solution the problem of recognizing the presence of signals produced by an earthquake by analysis of its signature against the existing database of magnetic signals. To accomplish this reason, they developed the magnetic signature of specific seismic tremors utilizing the distribution of the energies among blocks, which join wavelet packet coefficients. (L. & et, 2001)

Nina Castov A, et al. (2006) utilized three essential points are related with this technique: Choice of optimal wavelet and optimal wavelet premise B_{opt} for chose data set based on minimal entropy: $B_{opt}=\arg \min BE(X, B)$. The best results were come to by symmetric complex wavelets with scaling Wavelet packet decomposition and filtration of data information utilizing general of thresholding of the form $\lambda = \sigma p2 \ln(n)$, where σ is minimal variance of the sum of packet decomposition of chosen level, Cluster analysis of decomposed data.

Lin et al. (2017) Using FM modulation signal encoding and taking the peak of WVD of analytic signal, the TFPF is applied to recover seismic event embedded in additive random noise. Reduced window length pseudo WVD is utilized to get a fair estimation of seismic reflect signal. Testing on synthetic seismic data and normal shot point information shows better execution in recovery of seismic events by eliminate noise and improve signal. The improved SNR, progression of seismic event can got in filtered seismic information, which leads the clear recovery seismic events.

1. *Background:*

Seismic noise: Random noise exists widely in seismic data. Common method of removing random noise is mainly based on enhancing signal energy or suppressing random interference. Because effective signal in seismic data has strong correlation but random noise has no correlation, we can strengthen the energy of effective signal to suppress that of noise.

There are many factors that cause seismic noise that range from solar and lunar tides within the solid Earth and atmospheric pressure fluctuations to human activities and temperature ocean waves and storms (Zhang et al., 2009). Since these factors are constantly acting on the Earth the crust is continually reverberating. Investigations showed that noise mainly occurs at periods between 1 s and 10 s. The associated seismic waves are called microseism.

These seismic signals are poorly localized in space and cannot be fixed to a specific origin time. Thus, in most cases noise sources give rise to more or less permanently proceeding no coherent interfering signals.

Filtering: The most common signal processing operation is to filter the signals to enhance certain features and suppress others. A filter has the purpose of removing part of the signal in a particular frequency range (Andrea's widmann), in this work

2. Methodology:

The proposed algorithm

Step 1. Signals reading
Step 2. Signals normalization
Step 3. Signals segmentation
Step 4. correlation coefficient calculation
Step 5. detect maximum time of correlation to find the main shock

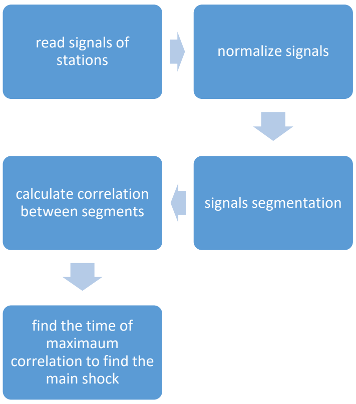


FIGURE 5: FLOW CHART OF THE PROPOSED ALGORITHM

Step 1. Read station signals:
When read the digital signal it contains two lines the first one represents the time and the second represents the signal value. Since the seismic signal is an acoustic signal, it is a longitudinal wave consisting of the inertia and compression. When measured, it becomes a voltage in which the value of the signal Compression and negative value are permeable. The reference reading also includes other values, such as information about the seismic station, monitoring time, sample time and the time between each reading
.

Step 2. Normalize signals:
Normalizing the signal means that the digital signal with positive and negative values is converted to a positive digital signal and with limits starting from zero. This is done by calculating the local average value for each set of readings and calculating the absolute value of the difference between the readings and the local mean.

$$\hat{x} = |x - \bar{x}_{local}| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Where $\hat{x}$ is the normalized signal, x is the non-normalized signal and $\bar{x}_{local}$ is the local average of the non-normalized signal.
In this work the noise was relatively removed using normalization and can't remove all noise for not knowing the earthquake from noise only after comparison.

Step 3. • Segmentation of signals:
The segmentation of the signal is done by taking a window for each set of readings and considering it as one part of the signal to be compared with other parts of the signal or with other parts of the other signals.

Step 4.• Calculation of correlation coefficient:

The correlation coefficient is calculated by calculating the correlation coefficient between each part of the signal and the corresponding part of the signal of the other station so that we can know how closely these two parts are related to each other. Of course, the readings that are read at each station are noise from the outside of the station so the correlation coefficient is slightly between the different parts of the stations because the noise is random. When the coefficient of correlation is high, it means that the force in the two stations is a single source power and this source is very likely to be a seismic signal.

$$\rho_{x,y} = \frac{cov(x,y)}{\sigma_x \sigma_y} \quad \text{...} 0.1$$

Where:

σ_x Is the covariance is the standard deviation of x

σ_y Is the standard deviation of y

Step 5.• Look for the maximum relationship time to find the main shock:

After calculating the correlation coefficient for all parts of the signal with the corresponding parts in the other station, a matrix of values is produced. This is a fluctuating value. It is recommended to introduce it to the intermediate filter to handle this oscillation and then to find the largest correlation coefficient and find the corresponding time because it will represent the time that occurred in the main shock of the earthquake.

3. *Data:*

Iraqi Broadband Seismic Network symbolized by (MP) is a +11 broadband station, distributed in many governorates of Iraq. This network was established in 2014 by the University of Arkansas at Little Rock (UA Little Rock) with Lawrence Livermore National Lab (LLNL) from the United States of America, in cooperation with Iraqi universities Dhi Qar, Sumer and Basra. Nowadays, the Seismological Laboratory of University of Basra (SLUB) archives waveforms (time-series) data of network MP. The location of these stations are marked by red triangles in Figure (1-1) and listed in Table (1-1). The data collected from the network MP was in the GCF format. For the purpose of using on Matlab platforms, it is required to convert it to a format called SAC. So we used the Seismometer Configuration Real-time Acquisition and Monitoring (Scream) version 4.4 to converts GCF data format to SAC data format. A SAC data file includes essential information of the station components (ENZ) called header. The ENZ means the three components that record movement of the earth, (E) east-west, (N) north-south and (Z) top-down. In this study, we used the Z component.

Table 1: Broadband seismic stations in Iraq that are belong to the MP network

NO	Station Code	Latitude	Longitude	Begin Y/M/D	End Y/M/D
١	AMR2	31.9899	47.1902	2015/11/07	--
٢	BSR2	30.2927	47.6191	2015/09/05	--
٣	DHK1	36.8606	42.8665	2007/01/03	--
٤	KAR2	32.5398	44.0224	2017/01/15	--
٥	NSR1	31.7416	46.1151	2014/08/01	2017/09/30
٦	SLY1	35.5784	45.3667	2015/09/15	--

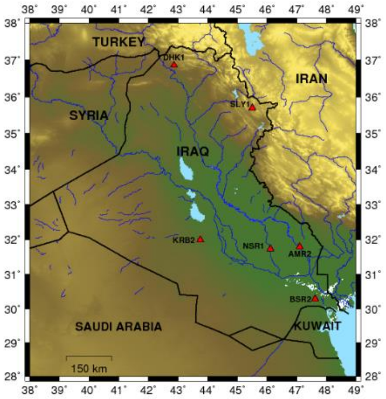


Figure 6: Location of the broadband seismic stations of the MP network that are used in this study

4. Results:

Figure (6) and (7) shows the seismic signal of a station within a three-hour period. The x-axis represents time in clock units and the y-axis represents the amount and direction of the earthquake. With an estimated time, rate of 100 readings per second.

Figure (8) and (9) shows the seismic signal of the same previous station after processing in the form of normalization. The x-axis represents the time in hours and the y-axis is the amount of vibration. The mean of each group of readings was calculated and the value of each reading was subtracted from that arithmetic mean and the absolute value of the difference between them was taken to eliminate the change in the arithmetic average of the signal over the period of time and to eliminate the repeated noise in the signal to obtain a signal representing the amount of vibration regardless of its direction, by using matlab code.

Figure (10) shows the correlation coefficient per second between the seismic signals of two stations. The X-axis is the time in hours and the y-axis is the absolute value of the correlation coefficient of 0 to 1. The figure also shows the highest correlation coefficient and the time when the main shock occurred.

Figure (11) shows the total correlation coefficient per second between the seismic signals of 6 stations. Where the x-axis represents time in hours and the y-axis represents the correlation coefficient between all these stations. The highest correlation coefficient and the time when the earthquake was recorded indicate more than two stations.

Table (1) represents the main shock time of the earthquake using two stations only. The column represents the number of the two stations. The time of the quake was calculated using the second column, and the second column represents the calculated time.

Table (2) represents another view of the previous table, where each row and each column represents one of the six stations and each value at the junction of the line represents the time of the earthquake using the two stations representing that line and column.

5. Discussion:

From the previous findings, we observed that the seismic signal is not a single mean medium, since the average signal may change over time due to the problems in the earthquake measuring instruments and surrounding noise, as we have already seen in Figure (7) and (8). Therefore, the signal needs to be processed before extracting its properties. The process of processing is the nominalization process, which subtracts the arithmetic average of the signal by subtracting each reading from the arithmetic mean of a small set of readings. Eliminate negative values using absolute value to study quake intensity regardless of quake direction as shown previously in Figure (9) and (10). A comparison of the two stations that were treated by comparing the correlation coefficient for each set of readings and the corresponding one at the other station is then made. And take the absolute value of the correlation coefficient to find the largest correlation coefficient during the time period of the signal, which will represent the time when the main shock occurred as shown in Figure (11). It is also possible to compare more than two stations to obtain the most accurate results, and then take 6 stations and calculate the coefficient of correlation for each station and then collect all the correlation coefficients, which is called the cumulative or cumulative correlation coefficient and then divided by the number of possibilities (15) All stations, which gave more precise results and better since some of the stations diverge does not produce the correct results in the case of using only two stations as shown in Figure (12) and Tables (2) and (3) , The time of signal record (14:00-17:00) in date 2/6/2017.

Signal amplitude

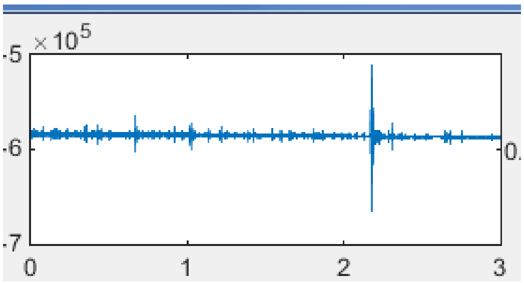


FIGURE 7 THE SIGNAL OF EARTHQUAKE FOR AMR2, DATE 2/6/2017

Signal magnitude

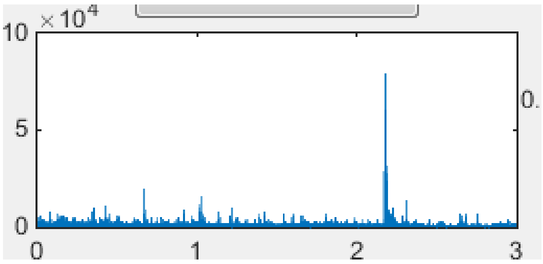


FIGURE 8 THE NORMALIZED SIGNAL OF EARTHQUAKE FOR AMR2, DATE 2/6/2017

Signal amplitude

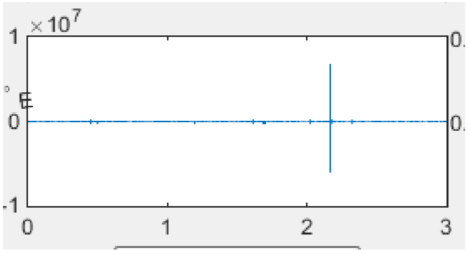
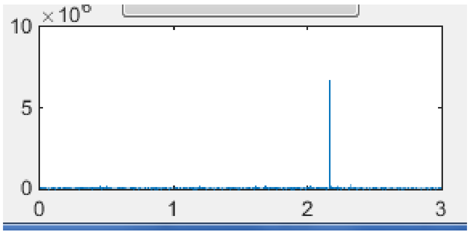


FIGURE 9 THE SIGNAL OF EARTHQUAKE FOR NSY1, DATE 2/6/2017



Signal magnitude

FIGURE10 THE NORMALIZATION SIGNAL OF EARTHQUAKE FOR NSY1, DATE 2/6/2017

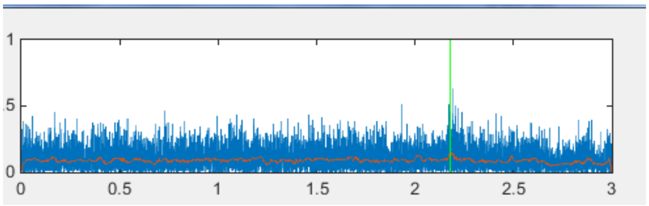


FIGURE 11: THE CORRELATION COEFFICIENTS BETWEEN PAIR (AMR2, NSY1)

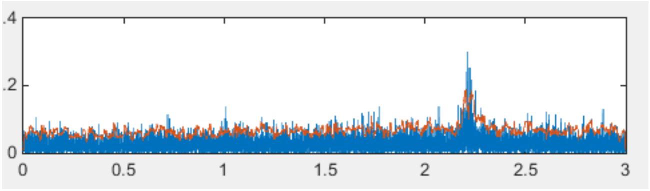


FIGURE 12: THE SUMMATION OF CORRELATION COEFFICIENTS FOR ALL STATIONS, DATE 2/6/2017

TABLE 2: THE TIME OF MAIN SHOCK FROM USING TWO STATION ONLY, DATE 2/6/2017

The two stations	Time of main shock
1-2	131.65
1-3	132.5833
1-4	134.0333
1-5	131.6833
1-6	134.0333
2-3	132.5333
2-4	132.4333
2-5	116.9167
2-6	132.6167
3-4	132.2
3-5	124.65
3-6	133.8167
4-5	8.3667
4-6	133.35
5-6	16.05

Station name	AMR2	BSR2	DHK1	KAR2	NSY1	SLY1
AMR2		131.65	132.5833	134.0333	131.68334	134.0333
BSR2	131.65		132.5333	132.4333	116.9167	132.6167
DHK1	132.5833	132.5333		132.2	124.65	133.8167
KAR2	134.0333	132.4333	132.2		8.3667	133.35
NSY1	131.68334	116.9167	124.65	8.3667		16.05
SLY1	134.0333	132.6167	133.8167	133.35	16.05	

TABLE3: THE TIME OF MAIN SHOCK FROM USING TWO STATION ONLY, DATE 2/6/2017

6. *Conclusions:*

From the results presented above, we conclude the following:

1. The use of the correlation coefficient to find the main shock is very effective.

2 - The total correlation coefficient between a groups of stations gives more accurate results than the use of two stations only

3. Reduce the distance makes the detection of earthquake time easier.

4. Increase the distance between the stations makes detect the location easier.

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