Detecting the Occurrence of Ground ULF Electromagnetic Signal Prior to the Earthquake Events

MOHD SYAKIRAN BIN SAMSUDIN
Faculty of Electrical Engineering, Universiti Teknologi MARA,
40450 Shah Alam, Selangor, Malaysia.
Email: mohdsyakiran@gmail.com

Abstract **– This project is emphasizing on detecting the occurrence of ground Ultra Low Frequency (ULF) signal prior to the earthquake events. In recent years many publications have appeared indicating that electromagnetic observations in low frequency ranges may be used as precursors to earthquakes. The ULF frequency band is considered as most promising frequency range in ground base observation where electromagnetic earthquake precursors may be found. This project used three set of real time data from California region which is on 06.08.2010 at Yucaipa-607 station, 11.10.2010 at OcotilloWells-606 station and 08.01.2011 at EastMilpitas-609 station. The data was taken from Quakefinder websites which owned magnetometer station along the California fault region. The observation was made several days before and on the day of the earthquake event occurred. The software used in this project to analyze data is using Matlab. From the results obtained, it shows strong correlation between ULF signal and determination of earthquake precursors.**

Keyword - Earthquake, Electromagnetic, Magnetometer, Ultra Low Frequency (ULF)

I. INTRODUCTION

An earthquake is a trembling of the ground those results from the sudden shifting of rock beneath the Earth's crust that creates seismic waves. When the crust moves abruptly, the sudden release of stored force in the crust sends waves of energy radiating outward from the fault. Internal waves quickly form surface waves, and these surface waves cause the ground to shake and sometimes displacing the gorund [1]. Earthquakes occur along faults, which are fractures or fracture zones in the earth across which there may be relative motion. Geologists locate these faults and determine which are active and inactive. This helps identify where the greatest earthquake potential exists. [2]

This project deals with ULF anomalies associated with medium earthquake occurred along California fault region. An anomaly is defined as any occurrence or object that is strange, unusual, or unique. It can also mean a discrepancy or deviation from an established rule, trend, or pattern [3]. The anomaly of ground ULF signal is detected by using magnetometer that is connected to the computer to process data. It measures the strength or direction of the magnetic filed in the vicinity of instrument used in ground-based electromagnetic geographical structures. ULF phenomena provide a promising tool for earthquake electromagnetic studies as such emissions come from the crust of the source region [4].

It is focus on the ULF part of the EM spectrum 0.001 Hz – 10 Hz because these are the highest frequency signals that can reach the Earth's surface with little attenuation. The generation of seismo-electric anomalies is another interesting aspect constituting to the seismo-electromagnetic phenomena that may be observed effectively as perturbations in the magnetospehere and on the ground, varying from a few days to a few hours before the seismic shock [5]. This paper present a case study where seismo-electromanetic phenomena have been observed in the ULF range a few hour before earthquake occurred at Yucaipa-607 station on 06.08.2010, OcotilloWells-606 station on 11.10.2010 and EastMilpitas-609 on 08.01.2011 with the help of data analysis from Quakefinder.

II. ULTRA LOW FREQUENCY (ULF)

The ULF-oscillations, also called 'geomagnetic pulsations' or 'micropulsations', occupy the 10^{-3}–10^{0} Hz range. The intensity of these pulsations is measured in thousandths (0.001) of 1% of the basic geomagnetic field value. Pulsations are classified, according to their morphological properties, into continuous pulsations (Pc) and irregular pulsations (Pi); within each of these two groups they are further divided according to their period. Pc is composed of many wave packets and these wave packets are separated by phase skips. Phase skips are sudden changes in the phase of wave signals, while frequency remains nearly constant. This classification was proposed by IAGA (International Association for Geomagnetism and Aeronomy) in 1964 as shown in Table 1. [6]

Table 1: IAGA Classification of Geomagnetic Pulsations

Continuous Pulsations			Irregular Pulsations		
Notation	Period (s)	Freq (mHz)	Notation	Period (s)	Freq (mHz)
Pc1	0.2 - 5	200 - 5000	Pi1	1 - 40	25 - 1000
Pc2	5 - 10	100 - 200	Pi2	40 - 150	7 - 25
Pc3	10 - 45	22 - 100			
Pc4	45 - 150	7 - 22			
Pc5	150 - 600	2 - 7			

Pulsation are known to occur in the 0.005 – 0.1 Hz (period = 10 sec-150 sec) portion of the geomagnetic spectrum as a strong signal. Pc 3-4 characteristics have held long interest for seismologists, as they are a form of contamination when using magnetometer to attempt measurements of long-period motion. The Quakefinder data plot use Pc3/4 characteristic to show the anomaly of ULF signal because it is used as a diagnostic for determine magnetic pulsations along fault line throughout California region. The method of ground-based monitoring of the near-Earth space, relying on explorations of geomagnetic pulsations, has been designated as 'ground-based Magnetohydrodynamic (MHD) diagnostics'. It provides a realistic foundation for timely reception of regular information on the solar wind and the magnetosphere. [7]

The Pi1 and Pi2 pulsation recorded at low latitudes can indicate the occurrence of magnetic substorm. The pulsations result from complicated plasma processes taking place in the solar wind, in the Earth's magnetosphere or ionosphere. Expanding to the Earth's surface, these oscillations undergo a number of changes, which enabled us, assuming a certain hypothesis of their origin, to get a definite insight into the medium they have passed through [8].

III. METHODOLOGY

Figure 1 shown the method used to accomplish this project.

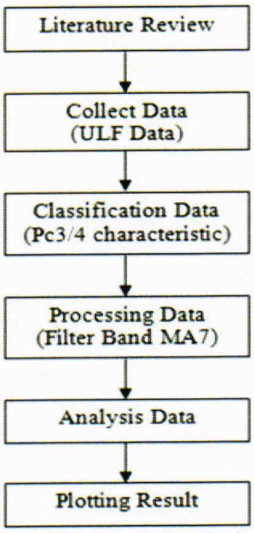

Figure 1: Flowchart of method used

In this project, the data have been chosen to analyzed is from 1st July 2010 to 31st January 2011. These dates have been chosen as a study case because it shows a great regularity of earthquake in California based on list of recent earthquake from Quakefinder data resources prepared by the California Magnetic Network (CalMagNet) [9]. The data is analyzed by using Matlab and the result shows the graph of Amplitude (V) vs. Time (H). The data have analysed for one day from Universal Time Clock, UTC 00:00 to 24:00. The infomation of the earthquake event (date, time, station and magnitude) from Quakefinder data resources is summarized in Table 2.

Table 2: Some charactericties of Earthquake

Set	Date	Time, UTC	Station	M
A	06-08-2010	17:39	Yucaipa-607	4.05
B	11-10-2010	03:00	OcotilloWells-606	4.27
C	08-01-2011	00:10	EastMilpitas-609	4.10

The Quakefinder established that there is dramatic increase in ULF magnetic pulses in term of amplitude (unit Volts) near the locations of the earthquake. The location of an earthquake is commonly described by the geographic position of its epicentre and by its focal depth [10]. Figure 2 shown the map for the observation data taken from the fault line and the station placed along the California region.

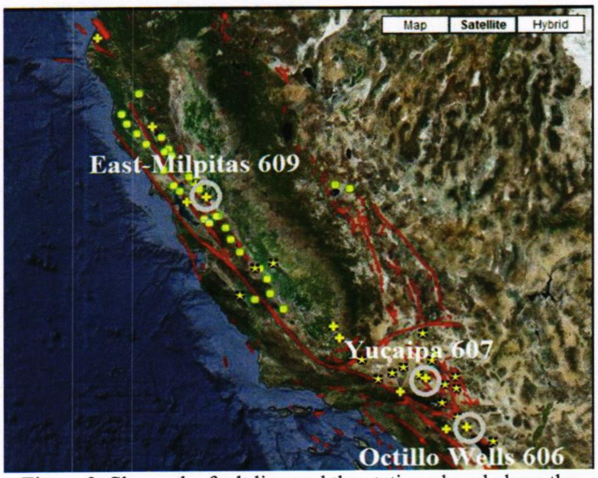

Figure 2: Shows the fault line and the station placed along the California region. [9]

The range frequencies of the continuous pulsation of Pc3/4 are 7-100 mHz and these frequency are converted into amplitude after the data have been analyzed. The data obtained has been filtered a few times to get the best reading of the waveform by using Filter Band MA7 and the result were the graph of amplitude [11]. Furthermore, the other data that supported or proved the occurrence of ground ULF prior to the earthquake event is the time series pulse counting plot. This pulse shown that there is anomaly of ULF signal due to the number of 'uni-polar pulses' which is high and low pulse waveform and bipolar pulse waveform. The 'uni-polar pulses' is the discriminator that ties the pattern to an impending quake is that the amplitude and the frequency of occurrence of the pulse increase in each 3 or more adjacent days. It will detect the present or possibility of earthquake around more than 15 pulses per day. Bipolar pulse considered as any pulse that exceeds both green and red colour horizontal line without changing slope direction in between the two pulses.

IV. RESULTS AND DISCUSSION

The result will be presented and broken down by the sets of data shown from previous chapter which is Set A (Yucaipa-607 station), Set B (OcotilloWells-606 station) and Set C (EastMilpitas-609 station). These three set data plot are graphical representations of ULF magnetometer reading collected from various stations throughout California region. These data consist of ten stations which are representing in different colours. The grey colour signal, the dark green colour signal and the black colours signal represent data for Yucaipa-607 station, OcotilloWells-606 station and EastMilpitas-609 station respectively in all set of Pc3/4 waveform. These data have been chosen because it shown ULF anomalies associated with medium earthquake (M: 4.0 to M: 6.0) occurred along California fault region. These three set data also include the data before and after filtered on the day of the earthquake event. Filter is used to reject attenuates frequencies outside the range needed and to get the origin EM emission that mix with other signal.

In addition, two days data before the earthquake event is analyzed in order to make comparison. The frequency ranges of the Pc3/4 are 7 mHz – 100 mHz and these frequency are converted into amplitude range of 0V - 0.8V after the data have been filtered. The unusual spark occurred shows the anomaly of ULF signal before the earthquake event. Unusual spark defined as the signal that is increasing drastically from the normal view of the waveform until it is reach at certain value.

Furthermore, the bar graph represents Kp (Solar) Activity Graph. The Kp graph is a geomagnetic index of solar magnetic activity for a given time period. This magnetic energy is associated with strong fields on the sun. The planetary or Kp index has values that range between 0 and 9. The values of the index give a good indication of geomagnetic activity. Table 2 shows Kp index description using three different colour regarding the bar graph data.

Table 2: Kp Index Description

Kp Index	Description	Colour
Kp < 4.0	Quiet or Calm	Green
Kp = 4.0	Minor Storm	Yellow
Kp > 4.0	Major Storm	Red

Knowing to the fact that the magnetic field varies in different ways around the globe dependent upon the way in which the magnetosphere is affected, it is not possible to have a simple relationship between one station and a global Kp index.

A. 1st Set Data – 06.08.2010, Yucaipa-607

Two days before earthquake event:

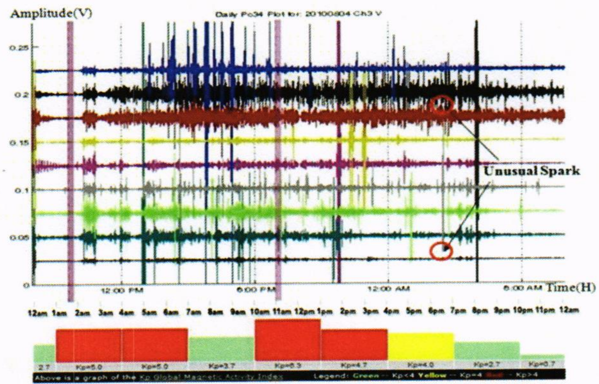

Figure 4: Daily Pc3/4 channel 3 data plot for 04.08.2010

Figure 4 shows unusual spark appeared on 4th August 2010 at 02:35 UTC (06:35 LT) which is two days before the earthquake events on Yucaipa-607. The Kp index value at that time is 4.0 which means quiet day. This data also show **(grey colour)** unstable signal occurred few hours before the ULF signal appeared and the highest value of Kp index detected is 6.3. Then, the signal is back to normal after the unusual spark appeared. The scale for Y-axis (amplitude) for this data is 0.05V. The maximum value for this data is 0.18V and the minimum value is 0.04V. The other data show the increasing signal due to the man-made activity nearby the station or that place.

During earthquake event (before filter):

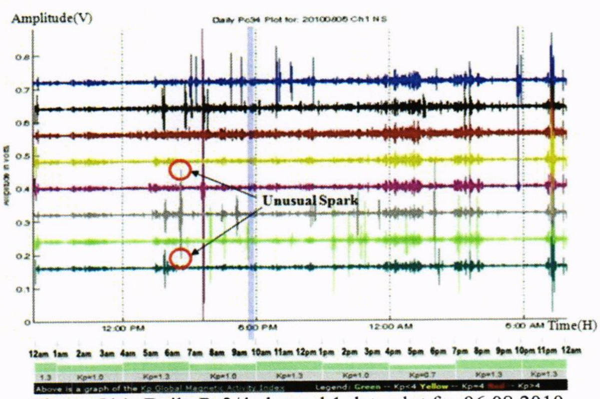

Figure 5(a): Daily Pc3/4 channel 1 data plot for 06.08.2010

Figure 5(a) shows the unusual spark appeared at 14:40 UTC (06:40 LT) which are few hours before the earthquake event occurred at Yucaipa-607 station. A few hours before the unusual spark, the signal **(grey colour)** are stable or in normal condition same with other data. The scale for Y-axis (amplitude) for this data is 0.1V. The maximum value for this data is 0.46V and the minimum value is exceeding 0.19V. These values are not the exact data for ULF signal due to the interference and attenuation of the frequency from other data.

During earthquake event (after filter):

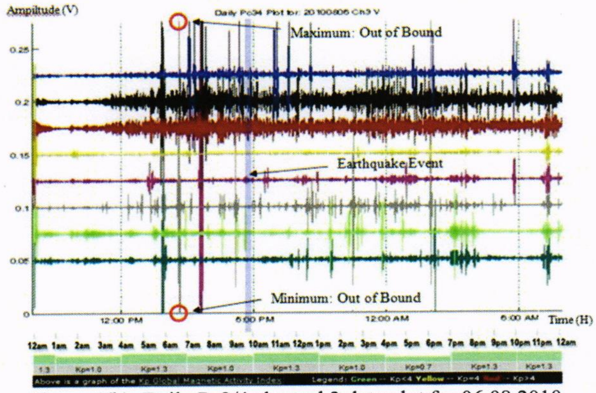

Figure 5(b): Daily Pc3/4 channel 3 data plot for 06.08.2010

Figure 5(b) shows a large anomaly of ULF signal appeared **(grey colour)** at 14:40 UTC (06:40 LT) on Yucaipa-607 after being filtered for a few times. The Kp index value at that time is 1.3. The scale for Y-axis (amplitude) for this data is 0.05V. The maximum amplitude cannot be determined because ULF signal is exceeding maximum value which is 0.8V. The same case goes to minimum amplitude which is the minimum value exceeding 0V value. The light blue vertical bar shows the earthquake event occurred on 6th August 2010 at 17:39 UTC (09:39 LT) with magnitude of 4.05 and the Kp index value is 1.0 which means no geomagnetic activity. The geographic position of its epicenter is at Latitude: 33.979 N, Longitude: -116.443 W and its focal depth is 7.66 km. A few hours after the earthquake event, it can be seen that the ULF signal is unstable due to the geomagnetic activity.

Daily pulse during earthquake:

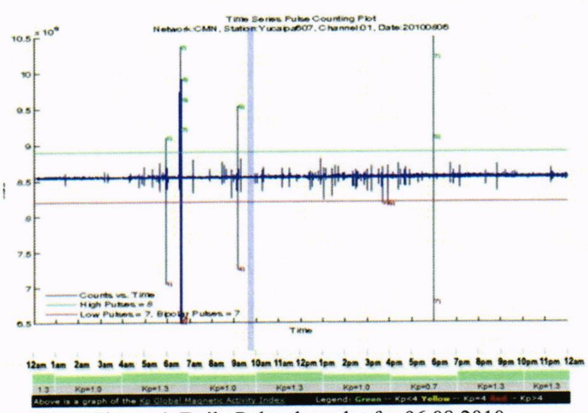

Figure 6: Daily Pulse data plot for 06.08.2010

Figure 6 show that there are several uni-polar pulses and bipolar pulses apperead on the day of event occurred. The light blue vertical bar shows the earthquake event on Yucaipa-607 at 17:39 UTC (09:39 LT). The total of high pulses, low pulses and bipolar pulse obtained are 8, 7 and 7 respectively.

B. 2nd Set Data – 11.10.2010, OcotilloWells-606

Two days before earthquake event:

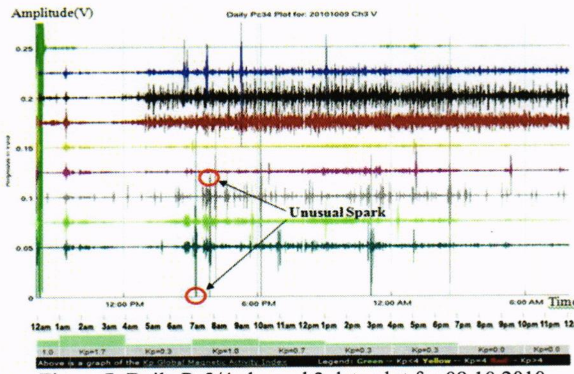

Figure 7: Daily Pc3/4 channel 3 data plot for 09.10.2010

Figure 7 shows unusual spark occurred on 9th October 2010 at 15:10 UTC (07:10 LT) which is two days before the earthquake events on OcotilloWells-606. The Kp index value at that time is 1.0. This data also show **(dark green colour)** unstable signal occurred few hours after the ULF signal appeared and the highest value of Kp index detected is 1.7 which means no geomagnetic activity. Then, the signal is back to normal after 10 hours the unusual spark appeared. The scale for Y-axis (amplitude) for this data is 0.05V. The ULF signal occurred at maximum value which is 0.12V and exceeding minimum value which is 0V.

During earthquake event (before filter):

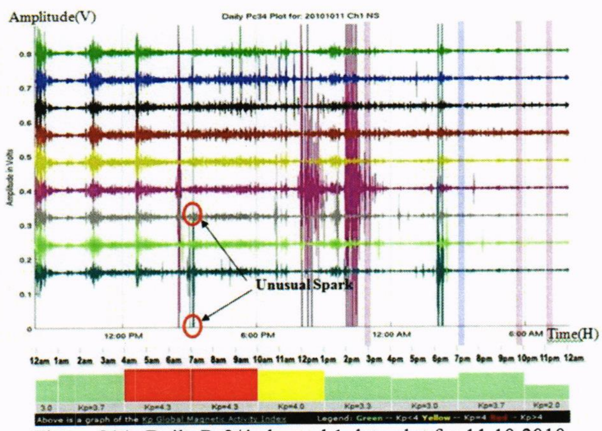

Figure 8(a): Daily Pc3/4 channel 1 data plot for 11.10.2010

Figure 8(a) shows the unusual spark appeared at 15:05 UTC (07:05 LT) which are few hours before the earthquake event occurred at OcotilloWells-606 station. A few hours before the unusual spark, the signal **(dark green colour)** are stable or in normal condition same with other data. The scale for Y-axis (amplitude) for this data is 0.1V. The maximum value for this data is 0.33V and the minimum value is exceeding 0V. These values are not the exact data for ULF signal due to the interference and attenuation of the frequency from other data. The purple colour signal show the man-made activity occurred at that place or station.

During earthquake event (after filter):

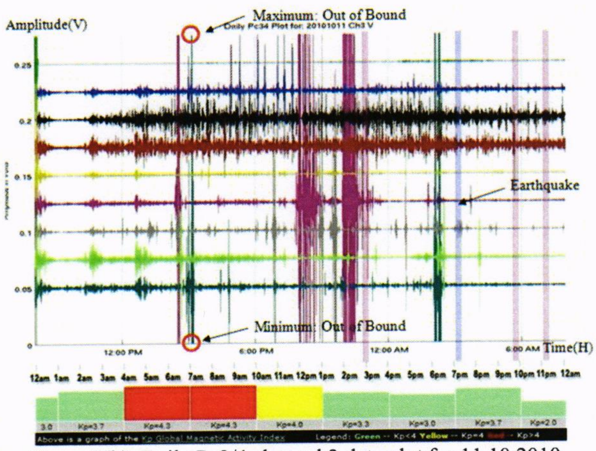

Figure 8(b): Daily Pc3/4 channel 3 data plot for 11.10.2010

Figure 8(b) shows a large anomaly of ULF signal appeared **(dark green colour)** at 15:05 UTC (07:05 LT) on OcotilloWells-606 after being filtered for a few times. The Kp index value at that time is 4.3. The scale for Y-axis (amplitude) for this data is 0.05V. The maximum amplitude cannot be determined because ULF signal is exceeding maximum value which is 0.8V. The same case goes to minimum amplitude which is the minimum value exceeding 0V value. The light blue vertical bar shows the earthquake event occurred on 11th October 2010 at 03:00 UTC (19:00 LT) with magnitude of 4.27 and the Kp index value is 3.7 which means quiet day. The geographic position of its epicenter is at Latitude: 32.158 N, Longitude: -115.289 W and its focal depth is 5.58 km. A few hours after the earthquake event, it can be seen that the ULF signal is back to normal condition. The purple colour signal show the man-made activity occurred at that place or station.

Daily pulse during earthquake:

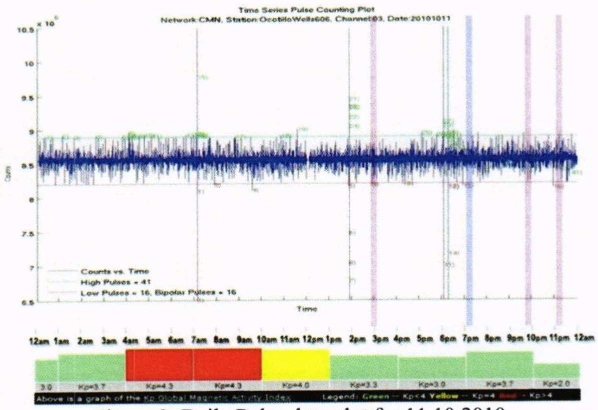

Figure 9: Daily Pulse data plot for 11.10.2010

Figure 9 show that there are lot of uni-polar pulses and bipolar pulses occurred on the day of event occurred. The light blue vertical bar shows the earthquake event on OcotilloWells-606 at 03:00 UTC (19:00 LT). The total of high pulses, low pulses and bipolar pulse obtained are 41, 16 and 16 respectively.

C. 3rd Set Data – 08.01.2011, EastMilpitas-609

Two days before earthquake event:

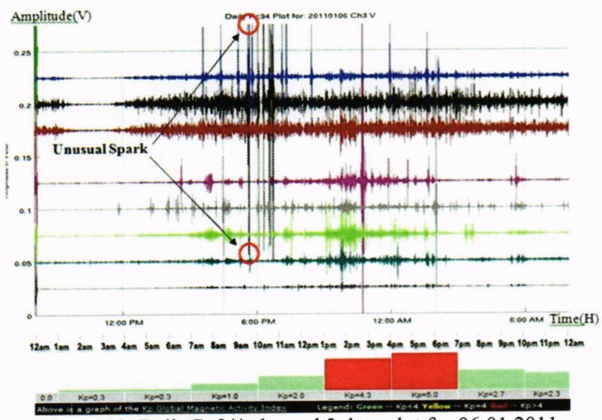

Figure 10: Daily Pc3/4 channel 3 data plot for 06.01.2011

Figure 10 shows unusual spark occurred on 6th January 2011 at 17:30 UTC (09:30 LT) which is two days before the earthquake events on EastMilpitas-609. The Kp index value at that time is 1.0 which means no geomagnetic activity.

This data also show **(black colour)** unstable signal occurred few hours before and after the ULF signal appeared and the highest value of Kp index detected is 5.0 which mean major storm occurred from 00:00 UTC until 03:00 UTC . The scale for Y-axis (amplitude) for this data is 0.05V. The ULF signal occurred at exceeding maximum value which is 0.8V and the minimum value is 0.06V. The other data show the increasing signal due to the man-made activity nearby the station or that place.

During earthquake event (before filter):

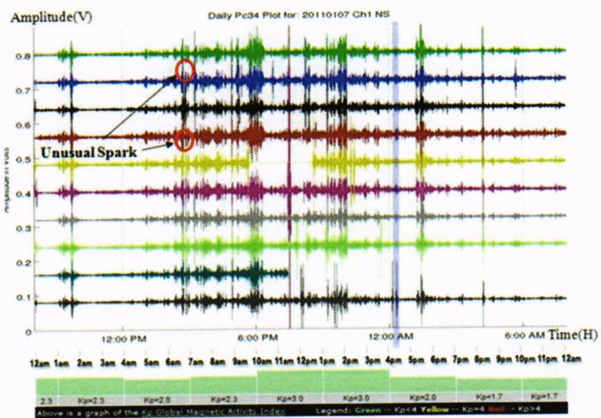

Figure 11(a): Daily Pc3/4 channel 1data plot for 08.01.2011

Figure 11(a) shows the unusual spark appeared at 14:50 UTC (06:50 LT) which are few hours before the earthquake event occurred at EastMilpitas-609 sation. A few hours before the unusual spark, the signal **(black colour)** are stable or in normal condition same with other data.The scale for Y-axis (amplitude) for this data is 0.1V. The maximum and minimum value cannot be determined due to the interference and attenuation of the frequency from other data. The missing signal or data (yellow signal) from 18:00 UTC until 21:00 UTC is because of the lost connection (power system shutdown) between magnetometer and computer.

During earthquake event (after filter):

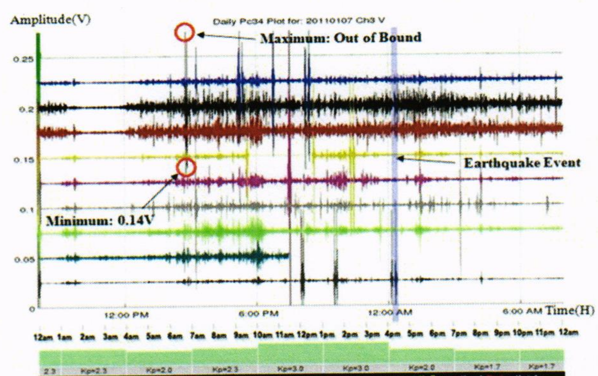

Figure 11(b): Daily Pc3/4 channel 3 data plot for 08.01.2011

Figure 11(b) shows a large anomaly of ULF signal **(black colour)** appeared at 14:50 UTC (06:50 LT) on EastMilpitas-609 after being filtered for a few times. The Kp index value at that time is 2.0. The scale for Y-axis (amplitude) for this data is 0.05V. The maximum amplitude cannot be determined because ULF signal is exceeding maximum value which is 0.8V. The minimum amplitude for this data is 0.14V. The light blue vertical bar shows the earthquake event occurred on 8th January 2011 at 00:10 UTC (16:10 LT on 7th January 2011) with magnitude of 4.10 and the Kp index value is 2.0 which means no geomagnetic activity. The geographic position of its epicenter is at Latitude: 37.289 N, Longitude: -121.662 W and its focal depth is 7.08 km. A few hours after the earthquake event, it can be seen that the ULF signal is unstable due to the geomagnetic activity.

Daily pulse during earthquake:

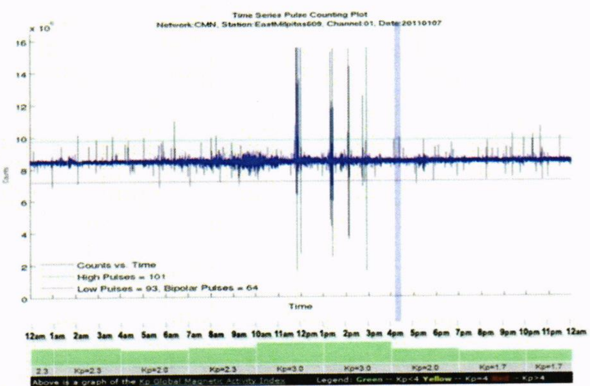

Figure 12: Daily Pulse data plot for 08.01.2011

Figure 12 show that there are lot of uni-polar pulses and bipolar pulses occurred on the day of event occurred. The light blue vertical bar shows the earthquake event on EastMilpitas-609. The total of high pulses, low pulses and bipolar pulse obtained are 101, 93 and 64 respectively.

In all set of data, it can be clearly view that at least a few hours before earthquake event occurs there will be an anomaly in the ULF data. This anomaly can be view by unusual spark in the ULF data [12]. This happen because the changing in rock stresses can cause electromagnetic disturbances that generate ULF magnetic signals. The basis of this theory is that rocks near the hypocenter of the impending quake are stressed to their elastic limit and begin to crack without actually displacing (rupturing) yet. This cracking process releases a flood of charged particles. These moving charges form huge underground currents which disturb the Earth's normal magnetic field. These disturbances can be detected at ULF due to the signal's ability to penetrate kilometers of solid rock only at low frequencies using magnetometers [13]. The data that exceed the maximum and minimum values show the great ULF pulse occurred. However, all these data sets have noise. Magnetic pulsations must be screened for lightning and man-made activities [14].

V. CONCLUSION

In general, this project have achieves its objective which mean it is possible to use ULF data to determine the earthquake. From analysis of graph obtained, the result showed that ULF signal appears a few hours before the earthquake event. Besides, it is also proved that there are anomalies of ground ULF occurred for two days before the earthquake event. Therefore, this finding is useful to give early information of the occurrence of earthquake. This project is only a preliminary analysis; more data must be collected and further analysis must be performed for improvement of this project.

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