Time Domain Feature Extraction Technique for earth's electric field signal prior to the Earthquake

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Time Domain Feature Extraction Technique for earth's electric field signal prior to the Earthquake

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Abstract. Earthquake is one of the most destructive of natural disasters that killed many people and destroyed a lot of properties. By considering these catastrophic effects, it is highly important of knowing ahead of earthquakes in order to reduce the number of victims and material losses. Earth's electric field is one of the features that can be used to predict earthquakes (EQs), since it has significant changes in the amplitude of the signal prior to the earthquake. This paper presents a detailed analysis of the earth's electric field due to earthquakes which occurred in Greece, between January 1, 2008 and June 30, 2008. In that period of time, 13 earthquakes had occurred. 6 of them were recorded with magnitudes greater than Ms=5R (5R), while 7 of them were recorded with magnitudes greater than Ms=6R (6R). Time domain feature extraction technique is applied to analyze the 1st significant changes in the earth's electric field prior to the earthquake. Two different time domain feature extraction techniques are applied in this work, namely Simple Square Integral (SSI) and Root Mean Square (RMS). The 1st significant change of the earth's electric field signal in each of monitoring sites is extracted using those two techniques. The feature extraction result can be used as input parameter for an earthquake prediction system.

1. Introduction

One of the major earthquakes in the world after an Alaskan earthquake with a magnitude of 9.2R in 1964 is the Northern Sumatra earthquake with a magnitude of 9.1R on December 26, 2004. The Northern Sumatra earthquake killed over 230.000 people [1]. The most recent giant earthquake with a magnitude of 9R on March 11, 2011 occurred in Tohoku, Japan [2]. This earthquake was followed by a tsunami that killed 18,000 people [3]. Considering these disastrous effects of an earthquake, it is highly important of knowing ahead of earthquakes in order to reduce the number of victims and material losses.

Geophysical phenomena that can be observed prior to the earthquake, such as seismological, geodetic, geochemical, hydrological or electro field [5], can be used as input for short term earthquake prediction system. One of the methods is the VAN method, which is named after the initials of the researchers' initials, P. Varotsos, K. Alexopoulos, and K. Nomicos [6]. This method was carried out by continuously monitoring the earth's electric field potential changes and their East-West (E-W) and North-South (N-S) polarity gradients.

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In this work, two difference time domain feature extraction techniques are applied for extracting the 1st significant change of the earth's electric field signal prior to the earthquake (EQ). This feature can be used as the input parameter to the earthquake prediction system.

This paper is organized as follows; Section II describes the earth's electric field. Section III discussed the proposed feature extraction method which is based on the SSI and RMS techniques of the earth's electric field signal. The experimental results are presented in Section IV. Finally, the conclusion is presented in Section V.

2. Earth's Electric Field

When a strong earthquake is in the preparation, the activity of tectonic stress load change of the lithosphere specifically in the seismogenic area is increasing [6, 7]. There are a great number of geophysical and geochemical phenomena changes prior to the earthquake. The implementation of the earth's electric field to predict the earthquake has been widely used in Greece. There are three monitoring sites in different areas, i.e. Athens (ATH), Pyrgos (PYR) and Hios (HIO).

Based on the measurements of ground surface earth's electric field, it is assumed that the x- and y-components of the electric field, i.e. E_x and E_y, are registered by horizontal dipoles. The z component, contains the same quality of information as the x- and y- components. However, due to technical difficulties, the measurement of the z-component required a vertical dipole with 150-200 m depth in the ground. Because of this, the z-component has been ignored [11]. The total magnitude of the measurement electric field is given by

$$|\vec{E}| = \sqrt{E_x^{\ 2} + E_y^{\ 2}} \tag{1}$$

Earth's electric field data used in this work was collected from the database three different monitoring sites in Greece available at www.earthquakeprediction.gr [9]. These monitoring sites are located in areas shown in Figure 1:

- Athens (ATH) monitoring site, installed on May 23, 2003, operating up to now.
- Pyrgos (PYR) monitoring site, installed on April 15, 2003, operating up to now.
- Hios (HIO) monitoring site, installed on March 18, 2006, operating up to 2010.

As shown in Figure 1, the distances between each of the monitoring are sited as follow:

- PYR monitoring site to ATH monitoring site is 216.6 km.
- ATH monitoring site to HIO monitoring site is 209.5 km.
- PYR monitoring site to HIO monitoring site is 425.6 km.

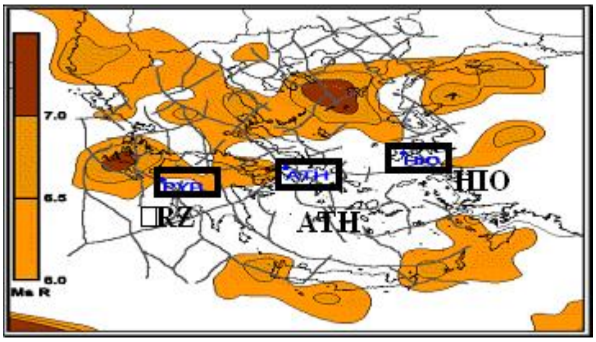


Figure 1. Location of the monitoring sites PYR (A), ATH (B), and HIO (C) [9]

3. Proposed Feature Extraction Technique

The proposed technique in this work is based on time domain feature extraction technique; SSI and RMS. Figure 2 shows the flowchart of the proposed technique. The raw data of the earth's electric field are read properly. The differencing technique is then applied to the earth's electric field signal. The peak detection technique is used to find the 1st significant change in the Earth's electric field. SSI and RMS feature extraction are applied to extract the earth's electric field signal.

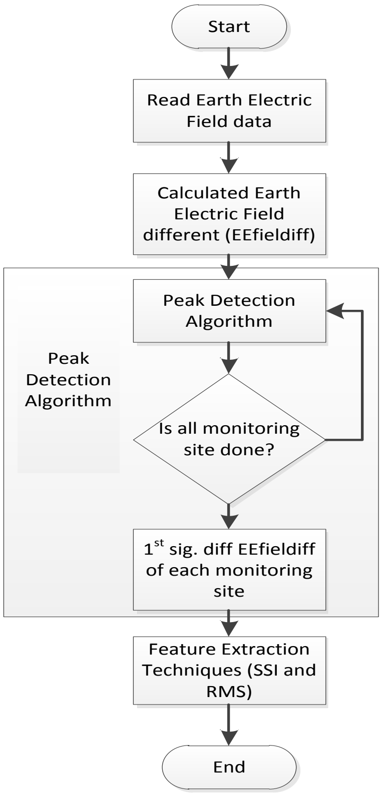


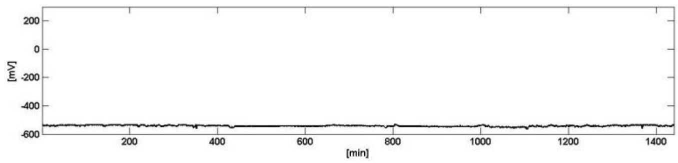
Figure 2. Flowchart of the proposed feature extraction technique

3.1. Reading of earth's electric field data

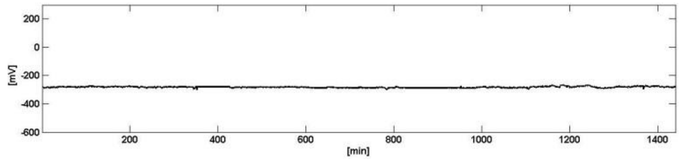
This stage involves the process of reading and interpreting data extracted from the earth electric field database. The raw data of the earth's electric field consists of two pairs of polarities, i.e. East-West (E-W) and North-South (N-S) polarities. The total amplitude of the earth's electric field can be found by using the following expression;

$$\left|\vec{E}\right| = \sqrt{E_{EW}{}^{2} + E_{NS}{}^{2}} \tag{2}$$

Examples of earth's electric field data from two polarities E-W and N-S are plotted in Figure 3. The first row (a) contains data from E-W polarity. The second row (b) contains data from N-S polarity. This sample of data was taken on February 6, 2008 prior to the 6.7R EQ on February 14, 2008. The differencing technique is then applied to the earth's electric field as shown in Figure 3.



(a)



(b)

Figure 3. Raw earth's electric field data: (a) E-W and (b) N-S polarity prior to 6.7R EQ on Febuary 14, 2008.

3.2. The differencing technique of the earth electric field (EEFieldiff) signal

The differencing method is implemented to the earth's electric field. This method is used to observe the change in the earth's electric field over a certain period of time. *E [n]* denotes the value of the amplitude of the earth's electric field at discrete time *[n]*, and *E [n-1]* at discrete time *[n-1]*. The differencing of the earth's electric field, also called earth's electric field difference (EEfieldiff), is given by

$$\Delta E = E[n] - E[n-1] \tag{3}$$

where ΔE is the resulting EEfieldiff. An example of the EEfieldiff is shown in Figure 4.

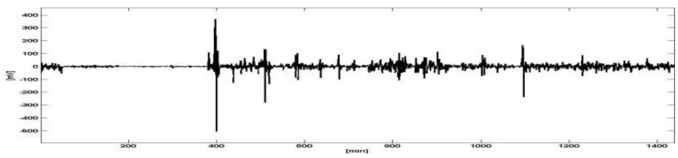


Figure 4. EEfieldiff prior to 6.7R EQ on Febuary 14, 2008.

3.3. Peak Detection Algorithm

The idea of peak detection algorithm is finding the 1st maximum amplitude of EEfieldiff prior to the earthquake. This first maximum amplitude of EEfieldiff is called the signal's peak. The time when the peak of EEfieldiff occurred is referred to as the peak time. As illustrated in Figure 4, the 1st significant change of the earth's electric field with the amplitude of 368 [mV/min] is found at the peak time of 397 minutes. The peak detection of EEfieldiff is shown in Figure 5. The maximum amplitude is detected by segmenting EEfieldiff per day. The calculated slope of the maximum amplitude of the segmented signal and the next segmented signal is assigned as the 1st significant change of EEfieldiff as shown in Figure 6. Once the 1stsignificant change of the SES is detected in one of the monitoring sites, the same procedure would be applied to the rest data from other monitoring sites. This procedure begins at the point where the 1stsignificant change from the previous monitoring sites is detected.

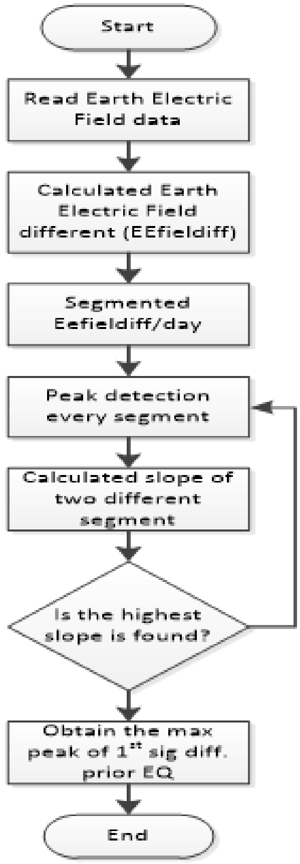


Figure 5. Algorithm of the determination of the 1st significant change of earth electric field prior to the earthquake.

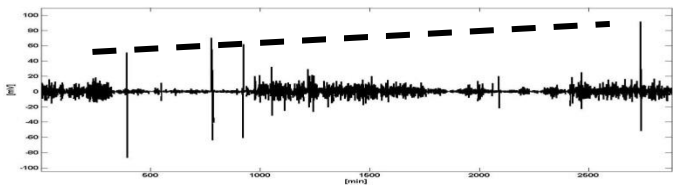


Figure 6. Slope between February 5, 2008 and February 6, 2008.

3.4. Time domain features extraction technique

Feature extraction is a process of extracting the 1st significant change of the earth's electric field to the feature vector that can be used as input to the identification/classification system. Simple Square Integral (SSI) and Root Mean Square (RMS) techniques are implemented in this work [10].

Simple Square Integral (SSI). This technique applied the absolute square of the signal that will result as the energy of the signal as shown in equation below:

$$SSI_k = \sum_{i=1}^{N} \left(\left| x_i^2 \right| \right) \tag{4}$$

where $\boldsymbol{x}$ is the amplitude of the signal. $\boldsymbol{N}$ is number of sampled signals.

Root Mean Square (RMS). This technique is modeled as amplitude modulated Gaussian Random process which RMS is related to the constant force and non-fatiguing contractual, as shown in equation (5):

$$RMS_k = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \tag{5}$$

3.5 Classification of earthquake prone area.
Thirteen earthquake data registered in Greece between from January 1, 2008 to June 30, 2008 are used in this work. Six of them were recorded with magnitudes greater than Ms=5R (5R), while 7 of them were recorded with magnitudes greater than Ms=6R (6R). The earthquakes are classified based on the location where the earthquake has happened. Figure 7 shows that 13 earthquake can be grouped with five different locations. Two different time domain feature extraction techniques are applied to extract 1^{st} significant difference of EEfieldiff.

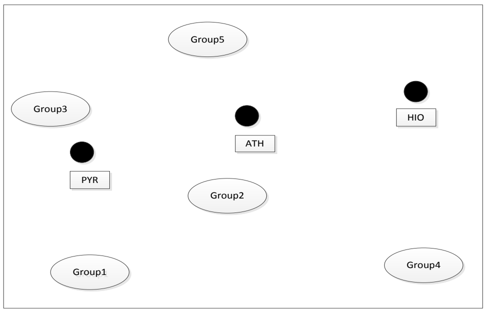


Figure 7. Grouping based on the area of 13 earthquakes in the period of January 1, to June 30, 2008.

4. Experimental Result and Discussion

The detailed analysis is performed on EQ data between January 1, 2008 and June 30, 2008, as shown in Table 1. The 1^{st} significant change signal prior to the earthquake registered at three monitoring sites are investigated, part of the results are shown in Table 2. For the analysis, the EEfieldiff data are extracted using SSI and RMS methods, as shown in Table 3. The result shows the average energy and RMS among three monitoring sites. It shows that

- The smaller the magnitude of the earthquake, the short time duration of the 1^{st} significant change signal EEfieldiff detected prior to EQ, with greater energy and smaller RMS for the same epicenter area.
- The greater the magnitude of the earthquake, the longer time duration of the 1^{st} significant change signal EEfieldiff detected prior to the EQ, with smaller energy and greater RMS for the same epicenter area.

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Table 1. List of EQs registered in Greece between January 1, 2008 and June 30, 2008

No.	Group	Mag. (R)	Date
1	1	5.6	2/19/08
2	1	5.7	2/26/08
3	1	5.5	3/19/08
4	1	5.0	1/14/08
6	1	6.7	2/14/08
7	1	6	6/21/08
8	1	6.5	2/20/08
9	2	5.1	1/29/08
10	2	6.6	1/6/08
11	3	5.5	2/1/08
12	3	7	6/8/08
13	4	5.6	3/28/08

Table 2. List of 1st significant EEfieldiff prior to the earthquake registered at three monitoring sites (part of the result).

Class	Mag.	Date of EQ	1st sig SESD	Days prior EQ (days)
1	5.6	2/19/08	2/14/08 2/15/08	4
			(PYR)	
			2/16/08 2/17/08	2
			(ATH)	
			2/16/08 2/17/08	2
			(HIO)	

Table 3. The energy and RMS result of the 1stsig. diff EEfieldiff prior to EQ.

Cls	Mag.(R)	Date of EQ	Days Prior to EQ	Energy (E)	RMS
1	5.6	2/19/08	2	6.55×10^5	12.65
1	5.7	2/26/08	4	5.57×10^5	11.94
1	5.5	3/19/08	1	11.19×10^5	14.6
1	6.7	2/14/08	17	33.17×10^5	23.56
1	6	6/21/08	9	1.85×10^3	4.62
1	6.5	2/20/08	3	6.24×10^5	11.85
2	5.1	1/29/08	4	7.85×10^5	13.85
2	6.6	1/6/08	20	13.07×10^5	16.97
3	5.5	2/1/08	1	7.46×10^5	13.25
3	7	6/8/08	41	43.55×10^5	25.92
4	5.6	3/28/08	5	2.896×10^5	9.15
4	6.7	7/15/08	17	0.81×10^5	5.208
5	6.1	10/14/08	21	0.51×10^5	4.16

Table 3 shows that the 1stsig. Diff of EEFieldiff has certain characteristics in its energy and RMS feature. Therefore, it is highly probable that the 1st significant difference of EEfilediff could be used in predicting and determining the location and magnitude of EQs. This characteristic can be applied to the identification system to predict any incoming earthquakes.

5. Conclusion

In this work, the extraction of the earth's electric signal prior to the earthquake has been investigated. We first generate the data of EEFieldiff (earth's electric field difference) which represents the change of the earth's electric field over a certain period of time. In this case, the 1stsignificant EEfieldiff has been detected.

The SSI and RMS techniques are applied to the 1st significant EEfieldiff signal. The result shows that the duration of the 1st significant EEfieldiff is detected prior to EQ and its resulting energy will determine the magnitude of the incoming earthquake. The RMS feature extraction technique has the same characteristic as SSI feature extraction. It is very likely that these characteristics can be used as input parameters to the prediction system of the incoming earthquake.

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