Earthquake Prediction System Based on The Earth's Electric Field Signal Prior to The Earthquake: Location Determination

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***Abstract*—The ability of the signal processing techniques to predict earthquakes may help to reduce the catastrophic effect of the earthquake. The earth's electric field signal is one of the features that can be used to predict the earthquakes (EQs) by analyzing the changes in its characteristic prior the earthquake. The signal is extracted using extended Linear Predictive Coding (LPC). This approach is based on the projection of the excitation signal on the right eigenvectors impulse response of the LPC filter. The resulting projected value is weighted by corresponding singular value, leading to an approximate sum of exponentially damped sinusoids (EDS). The extracted vector is used as input of the prediction system in order to determine the location of the incoming earthquake. Support vector machines (SVMs) method is applied as classification technique. The basic idea of SVMs is mapping non-linear training data into higher-dimensional feature space through the kernel function. This paper presents a detailed analysis of the earth's electric field signal due to earthquakes which occurred in Greece. The earthquake occurred during 2008 is used as model to train the system and some of the earthquakes that happened between 2003 and 2010 are used to evaluate the performance of the proposed system. The result shows good accuracy of 96.67% for training phase and 77.8% for the testing phase.**

***Keywords*—Earthquake prediction, Earth Electric field signal, Extended Linear Prediction Coding (LPC), Support Vector Machine (SVM).**

I. Introduction

One of the major earthquakes in the world after an Alaskan earthquake with a magnitude of 9.2Mw in 1964 is the Northern Sumatra earthquake with a magnitude of 9.1Mw on December 26, 2004. The Northern Sumatra earthquake killed over 230.000 people [1]. The most recent giant earthquake with a magnitude of 9Mw on March 11, 2011 occurred in Tohoku, Japan [2]. This earthquake was followed by a tsunami that killed 18,000 people [3]. Considering these catastrophic effectsof an earthquake, it is highly important to know 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 [4]. One of the methods that is applied for short-term earthquake prediction is the VAN method, which is named after the initials of the researchers initials, P. Varotsos, K. Alexopoulos, and K.Nomicos [5]. 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.

This work involved the analysis of the significant changes of the earth's electric field signal prior to the earthquake (EQ). The signal is used as input to the earthquake prediction system. There are two important steps of the earthquake prediction system, namely feature extraction and classification. LPC as feature extraction technique and SVM for classification. This paper is organized as follows; Section II describes the data collection of the earth's electric field. Section III discussed the proposed classification method. The experimental results are presented in Section IV. Finally, the conclusion is presented in Section V.

II. Earth's Electric Field

When a strong earthquake is going to happen, the activity of tectonic stress load change of the lithosphere specifically in the seismogenic area is increasing [6]. There are a great number of geophysical and geochemical phenomena that occur during this period. The implementation of the earth's electric field to predict the earthquake, has been widely used in Greece. There are three monitoring sites installed in a different area, they are Athens (ATH), Pyrgos (PYR) and Hios (HIO).

Earth's electric field used in this work was collected from the database that consist of three different monitoring sites in Greece is available at www.earthquakeprediction.gr [7]. These monitoring sites are located in certain 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.

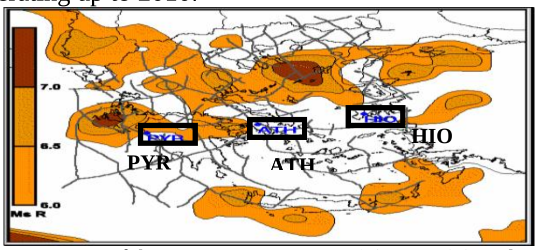

Figure 1. Location of the monitoring sites PYR (A), ATH (B), and HIO (C) [9].

III. Proposed Feature Extraction Technique

As mentioned, the objective of this work is to predict the location of the incoming earthquake based the earth's electric field signal that will be used as input to the earthquake prediction system. Figure 2 shows the flowchart of the proposed method.

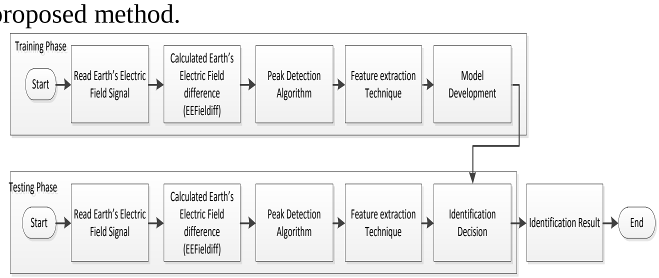

Figure 2. Flowchart of the proposed method of the earthquake prediction system.

There are two important steps included in the proposed method, namely training phase and testing phase. Training phase is a process of developing the model of the earthquake data, based on the location of the EQs occurance. The testing phase is a process of evaluating the performance of the proposed system. The training and testing phase consist of some similar steps, such as the raw data of the earth's electric field read properly. The differencing technique is then applied to the earth's electric field signal in order to observe the change of the signal. The peak detection technique is used to find the 1st significant change in the Earth's electric field signal. The extended LPC feature extractionis applied to extract the 1st significant change of the earth's electric field signal and the day before. This feature vector will be used as a model of the signal prior to the earthquake to determinelocation of incoming earthquakes. SVMs is used as the classification method to identify the location of the incoming earthquake.

A. *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 earth 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;

$$\left|\vec{E}\right| = \sqrt{E_{EW}^{\ 2} + E_{NS}^{\ 2}} \qquad (1)$$

An example 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 December 9, 2007 prior to the 6.6R EQ on January 6, 2008.

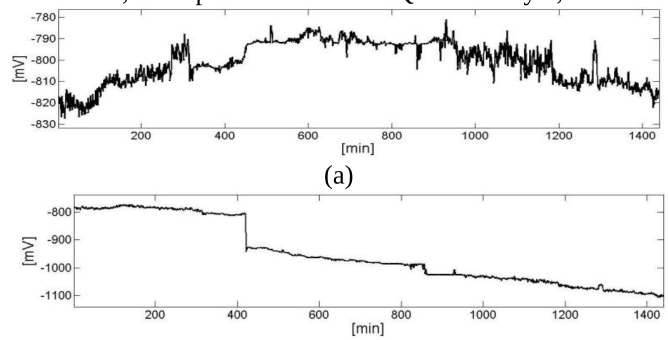

Figure 3. Raw Earth's electric field data: (a) E-W and (b) N-S polarity prior to 6.6R EQ on January 6, 2008.

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

The difference technique is implemented to observe the change of the earth's electric field over a certain period of time. When *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 difference of the earth's electric field, also called earth's electric field difference (EEfieldiff), is given by

$$\Delta E = E[n] - E[n-1] \qquad (2)$$

where ΔE is the resulting EEfieldiff. An example of the EEfieldiff is shown in Figure 4. As illustrated in Figure 4, the first significant change of the earth's electric field with the amplitude of 140 [mV/min] is found at the peak time of 420 minutes.

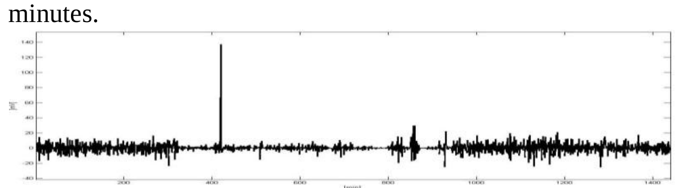
Figure 4. EEfieldiff prior to 6.6R EQ on January 6, 2008.

C. *Peak detection algorithm*

The idea behind peak detection algorithm is to find the 1st significant change of EEfieldiff signal prior to the earthquake. The algorithm for the peak detection of EEfieldiff signal shown in Figure 5. The maximum amplitude is determined by segmenting EEfieldiff signal per day. The slope is calculated from the maximum amplitude of the segmented signal on the day and the maximum segmented signal of the day after. The maximum slope is assigned as the 1st significant change of Eefieldiff signal as shown in Figure 6. These twodays signal will be processed at features extraction step. Once the 1st significant change of the earth electric field is detected at 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 first significant change from the previous monitoring sites is detected.

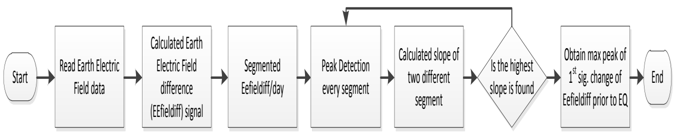

Figure 5. Algorithm of the determination of the first significant change of earth electric field prior to the earthquake.

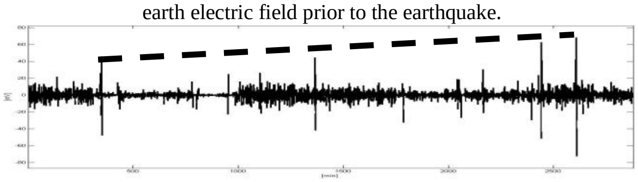

Figure6 . Slope between Febuary 14, 2008 and Febuary 15, 2008.

D. *Feature extraction technique*

Feature extraction is a process of extracting asignal into the feature vector that can be used as input to the classifier system. In this work we implement the extended LPC technique as shown in Figure 7.

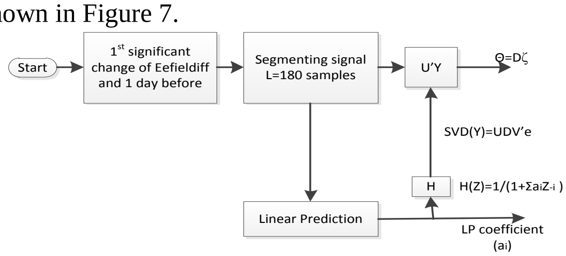

Figure 7. Schematic diagram of feature extraction technique using extended LPC.

LPC refers to the linear combination prediction of the output *y(n)*based on the previous output *y(n-1), y(n-2), …, y (n-p)*, where *p* is prediction order and *a (k)* is the linear prediction coefficients. The equation is given by:

$$\hat{y}(n) = -\sum_{k=1}^{p} a(k)\,y(n-k) \qquad (3)$$

where $\hat{y}(n)$ is predicted signal. The residual error*e(n)* between actual and predicted sample is given by:

$$e(n) = y(n) - \hat{y}(n)$$

$$= y(n) + \sum_{k=1}^{p} a(k)\,y(n-k) \qquad (4)$$

After computing the linear prediction coefficients, equation (4) is used to determine the excitation signal as shown in Figure 8.

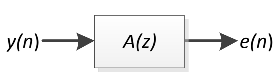

Figure 8. Analysis filter.

From the system point o view, the transfer function of the analysis filter is given by:

$$A(z) = 1 + \sum_{i=1}^{P} a_i z^{-i} \qquad (5)$$

The original signal is reconstructed from the residual error and the linear prediction coefficients using the synthesis filter as shown in Figure 9.

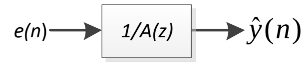

Figure 9. Synthesis filter.

$$H(z) = \frac{1}{\left(1 + \sum_{i=1}^{P} a_i z^{-i}\right)} \qquad (6)$$

where *H(z)* is the LPC impulse response.

Matrix representation of LPC filter

Since the original signal *s(n)*is constructed from the excitation of all previous sample of *μ(n)* and *y(n)*output contributed by excitation of all the new sample,therefore *s(n)* is given by

$s(n)=y(n)+ \mu(n)$ (8)

where *y(n)* is given by:

$$y(n) = \sum_{k=1}^{n} h(n-k)e(k)$$

where *h(n)* is the LPC impulse response.

Equation (8) can be written as;

$Y=He$ (9)

H is a lower triangular Toeplitz matrix and *Y* is the output. Then applied the singular value decomposition (SVD) to H, becomes;

$Y=UDV^{T}e$ (10)

To recall,

the SVD domain representation of *Y* and *e* are given by θ and ζ, respectively.

where$\theta=U^{T}Y$ and$\zeta=V^{T}e$ (11)

Equation 10 becomes;

$\theta= D\zeta$

To construct the original signal only the LPC coefficients and θ are used.

E. *Support vector machines (SVMs)*

SVMs performs a non-linear mapping of the input vector *x* from the input space into a higher dimensional feature space, where the mapping data are determined by kernel function, as shown in Figure 10.

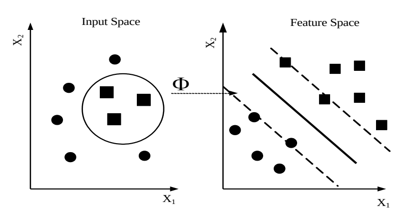

Figure 10. The non-linear separable data space is transformed into linearly separable data space, using kernel function [9].

Three typical kernel functions are used in SVM, namely linear, polynomial kernel and Gaussian Radial Basis Function (Gaussian RBF) kernel. The choice of the kernel function depends on the characteristic of the data. Difference kernel function can be selected to obtain the optimal classification results. The choice of the degree in polynomial kernel and choice of weight in the Gaussian RBF kernelalso depends on the characteristic of data.

SVMs can be extended to multi-class classification [9]. The use of Multi-class classification SVMS, not only improve the error rate in the learning and testing set process but also the result in faster adaptation and classification times. There have been many methods proposed to solve multi-classification problem, one of the methods that used in this work is one-against-one. This method is based on the binary classification problem. Multi-class classification one-against-one constructs $k{\cdot}(k\text{-}2)/2$ classifiers where each one is trained on the data from a combination of two classifications [9].

IV. Experimental Result and Discussion

Several earthquake data registered in Greece between between January 1, 2008 and July 30, 2008. In that period of time, 10 earthquakesare used to model the system. 5 of them were recorded with magnitudes greater than Ms=5R, and another 5 of them were recorded with magnitudes greater than Ms=6R. The earthquake is classified based on the area where the earthquake has occurred as shown in figure 9. Some of the earthquakesoccurred between 2003 and 2010, are used to observe the performance of the system.

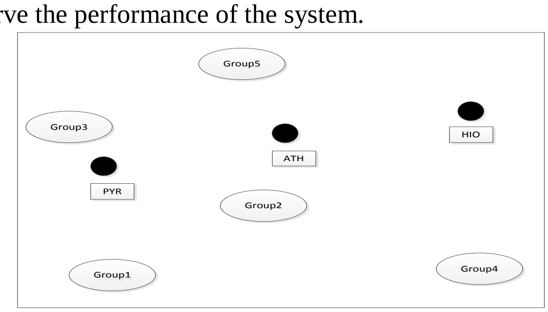

Figure 9 . Grouping based on the area of earthquakes in the period of January 1, to June 30, 2008.

The data chosen have three subsets data from three monitoring sites. The 1stsignificant change EEfieldiff prior to the earthquake registered at three monitoring sites are investigated. For the analysis, the EEfieldiff data are extracted using the extended LPC method. The experiment result shows that the 11th order is the best order for the earth's electric field signal in obtaining the coefficient. The feature vector is used as the input for the SVMs classification.

The SVMs-based multi-class classification is applied to perform classification process using one-against-one method. Here, the RBF kernel function is used. In the training phase, SVM-based identification system gives results with a 96.67% classification accuracy. The SVM-based classification system have good accuratefor location determination of incoming earthquakes. In the testing phase, the effectiveness of the proposed system is evaluated. Further experimentsare carried out using another earthquake data. The proposed system gives a classification accuracy of 77.8%. This result indicates that the testing data have different characteristic with the training signal.

V. 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 1st first significant EEfieldiff has been detected. The extended LPC is used as feature extraction technique to extract the signal that will be used as input to thesystem. SVMs based system is used to classify the incoming earthquake based on the location. The result shows that the training system has good accuracy of 96.67% in location determination of the incoming earthquake. The evaluation of the proposed system has good accuracy of 77.8%. Hence, it can be concluded that the proposed system is effective for earthquake location determination.

Acknowledgment

We thank H. Baalifor his valuable advice, information, encouragement and discussion in support of this work.

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