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Seismic Alert System based on Artificial Neural Networks

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***Abstract*—**We board the problem of creating a seismic alert system, based upon artificial neural networks, trained by using the well-known back-propagation and genetic algorithms, in order to emit the alarm for the population located into a specific city, about an eminent earthquake greater than 4.5 Richter degrees, and avoiding disasters and human loses. In lieu of using the propagation wave, we employed the magnitude of the earthquake, to establish a correlation between the recorded magnitudes from a controlled area and the city, where we want to emit the alarm. To measure the accuracy of the posed method, we use a database provided by CIRES, which contains the records of 2500 quakes incoming from the State of Guerrero and Mexico City. Particularly, we performed the proposed method to generate an issue warning in Mexico City, employing the magnitudes recorded in the State of Guerrero.

***Keywords*—** Seismic Alert System, Artificial Neural Networks, Genetic Algorithms.

I. Introduction

EARTHQUAKE represents a movement on the earthbound crust, that affect the buildings and other structures that the mankind has constructed. Due to the rapid increasing population and a high distribution of humans settlements, people have inhabited in seismic zones; for this reason, the development of a seismic alert system that warn the population about an imminent quake is necessary ([15]).

Actually, seismic alert systems are based on the propagation wave of an earthquake ([11]). The correct detection and the analysis of the wave, depended of the information that passes through the sensors located alongshore the region that want to be controlled. To corroborate the existence of an earthquake, the information has to be sent to a central sensor that determine if it is necessary emit an issue warning for the population ([11], [5], [3]).

Designing a seismic alert system based on the prediction of an earthquake is too difficult to study, because of its chaotic conditions. For this reason, mathematical computing methods, based on detecting some patterns of an earthquake have been developed ([8]).

An assortment of works using artificial neural network has been proposed in this field ([10], [1], [7], [9]). For example, in ([6]) the authors search for a prediction model using multiple indicators on an earthquake to estimate the pressure generate on a bridge. It exists some works that use a control model for setting on the structures of buildings when an earthquake occurred and determine if it affects ([3]). A quite variety of dynamic analysis system is developed for estimate the deformation produced by an earthquake ([2]). Some other works measure the percentage of radon in the soil to predict an earthquake ([8]).

The main goal of this research is to generate a seismic alert warning for a determinate region, that posses a high population, such like a city, to prevent human loses and disasters. Examples of these systems could be found in ([5], [12],[14], [13]).

In this paper, we proposed a seismic alert system based on feed-forward artificial neural network (ANN). To train the ANN, we used two different method during the learning phase the well-known back-propagation and the genetic algorithm. To train the ANN we used the historical records of seismic zones in term of the Richter scale, instead of using the propagation wave of the earthquake. Using this information, the ANN learns a correlation in term of the Richter scale, between two regions: The monitored region that it alert, and the regions where the earthquake is detected. To test the accuracy of the proposed method, we use a database which contains the records of 2500 quakes incoming from the State of Guerrero and Mexico City.

II. Artificial Neural Network

Usually called neural network, is a computational model inspired in the structure and functional aspects of biological neural networks, it consists of an interconnection group of artificial neurons. Akin to the biological neural networks, it has the same structure, where we could find axons that represent the weights of the network, dendrites that represent the inputs of the network, the body neuron that represents the activation function, and the synapses that represent the connections between neurons.

Most of cases based on Artificial Neural Network (ANN) are an adaptive system that change, their structure based on external or internal information that flows through the network during the learning phase. This ANN, proposed some methods that came from the examination of the central nervous networks and their neurons, which constitute their elements. In this method, the inputs represent the data we wanted to train or the approximation mechanism that learns from the observed data.

The ANN mimetic the functionality and structure of the biological neural network, such as the human brain do, where we could appreciate the million neurons interconnected each one.

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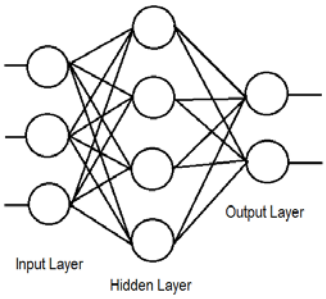
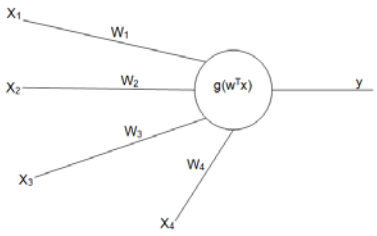


(a) Artificial Neural Network



(b) ANN Simple Neuron

Fig. 1 Artificial neural network and ANN simple neuron

As the reader could appreciate, the ANN will have as many inputs and outputs as it needed. This inputs and outputs are connected with a hidden layer, that is a set of neurons, that are used to generate the desired output. This hidden layer, it has to be set by the problem, but it could used some methods that we would not explain on this work. The artificial neural networks, used in equations represents, how the information flows over the network, this function is usually called network function.

$$f(x) = K\left(\sum_i w_i g_i(x)\right), \tag{1}$$

where w_i represents the weights, K referred to as the activation function and $g_i(x)$ represents the collection of functions g_i as a vector such like $g_i = (g_1, g_2, g_3, \ldots)$ that represents the function of neurons in the network.

The activation function would be represented by any function we wish, on this work we will use the sigmoidal function represented by:

$$g(n) = \frac{1}{1+e^{-n}} \tag{2}$$

When we use an artificial neural network (ANN) is important to talk about the learning paradigm, this learning paradigm represents how does the neural network learns, and affects the behaviour of the ANN. There are different kinds of learning paradigms, such as the supervised learning, that consists in reach the solution, with the supervision of an expert, other paradigm is referred to reinforcement learning, that consist in punish or reward the action of the network, if it give us a correct or incorrect solution, depending the knowledge of an expert, another paradigm referred to the unsupervised learning, that consists in reach the solution, without the supervision of an expert.

A. Back-propagation

This method is based on the fact that we could teach an artificial neural network (ANN) to perform a determinate task, is part of the supervised learning method, and its require an expert that knows the desire outputs for any training data set. Akin to the ANN, its kept similarities between the feed forward ANN and the back-propagation method, such as the network function, the inputs and outputs, but in this case the output it will loop to the inputs to generate a better solution, the weights, and the transfer function.

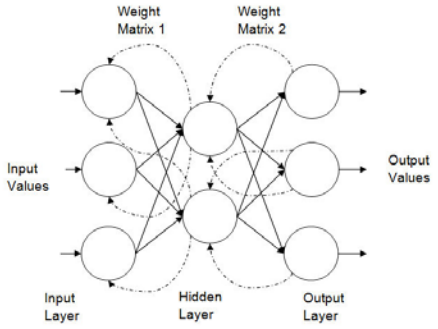


Fig. 2 Back-propagation Network

Algorithm 1 Back-propagation algorithm

Initialize-the-weights-in-the-network
Do
  Forward-Pass *(is like the ANN doing before)*
  give-the-desire-output
  Calculate-error (desire − output)
  Compute-the-weights-from-hidden-layer
  Compute-the-weight-from-input-layer
  Update-the-weights-in-the-network
While not-fulfil-the-stop-criteria **Or** fulfil-classification-rates

III. Genetic Algorithm

This class of algorithms mimics the process of natural evolution, where the information pass through any amount of epochs to give a possible solution. Its used to optimize the solutions of an specific problems. The genetic algorithms (GA), akin to the natural process of evolution has some similarities, such as inheritance, mutation, selection and crossover, all of this characteristics of a group of individuals.

In the natural process of evolution, we have a population, those population have a group of individuals, each individual has a specific characteristics, that are called genotype, which is encode in binary and represents a set of alels. The alel is one of the characteristics of the genotype, the numerical representation of genotype is usually called phenotype.

In GA the individual would represented a possible solution, the fitness function it would represented how good is the individual to give solution to the main problem, and there are reproductive operators, that are represented by the selection, crossover, mutation and rearrangement.

The selection phase, has some methods, such as the elitism, that consists it kept the individual with the better phenotype, roulette that consists in select a random individual of the population, and tournament, where the individuals fight randomly, and the better individual pass the main process. So in this phase we guarantee has the best individual of the population.

The crossover phase consists, having the selected population we have to crossover each individuals to generate a new individual, and the mutation phase where we vouch that the better characteristics of two individuals pass to the next generation.

The GA process begins with the main population and finish when the population reach the best solution through the pass of any amount of epochs or generations.

For this algorithm we employed, it needed a fitness function, that is the minimization or the maximization of the solution. The solution its depend on the problem we studied.

Algorithm 2 Genetic Algorithm

```
Generate-Population
Calculate-Fitness-Function
Do
    While population-size / 2 Do
        Select-2-individuals (Random Selection)
        Crossover-using-a-mutation-operator
        get-the-phenotype-of-new-individual
        insert-individual-in-the-new-population
    if population-converge or generation-reach-limits
        finish = true
While not-finish
```

A. Training Artificial Neural Network

This method it could use with the genetic algorithm (GA) to find the best solution for the neural network, to apply this method we have first to select the data we would use in the genetic algorithm, in this case the information we used it has to be the weights of the artificial neural network (ANN).

This weights, represents the individual of the GA, and it evolve to reach the best solution, for this procedure we used some operators such as mutation, crossover and selection, in this case all this weights that are represented in the artificial neural networks and the genetic algorithm is used to find a better solution for this weights and then pass it to the ANN.

Employing the GA, where we used the population that its form by the earthquakes grouping by date, we set the initialization phase employing this population, we passed the information of the chromosome just to obtain the better configuration, resulting by the selection phase, reproduction mutation and the output of this GA it represents the the weights we will used for the ANN.

In the ANN, we will used the weights obtained by the GA to set, first the data set of weights for the ANN, then we employed the 70% of the data set of earthquakes to train the network, and then we proved the ANN using the last 30% of the data set we used to test.

Finally the results we obtain, will represented the information of an issue warning, if the information we proposed to used is a random method of selection for the earthquakes occurred in a specific date. This test will give us the alert for the population to prevent a distaster.

IV. Methodology

Developing a seismic alert system, needs different regions that give us the information about the monitoring zone and the city we wanted to alert. This information it collected by a set of sensor distributed alongshore the zone we monitor for detecting an earthquake, and the city we wanted to prevent for an imminent disaster. Due to this, the current information we posses has the relationship between the earthquakes based on the magnitude of the earthquake.

The relationship we used for this system was stored in a database, that contains the information of any country in the world. First at all, we need to determine the most seismic zone in the country, for this reason we used a clustering algorithm to set the most seismic zone, where we could have the sensors to detect earthquakes.

For this reason we apply several times the clustering method, first to determine the most seismic zone, and then to check the monitor city, that it needs to be alert. This correlation between the seismic zone and the monitored city give us the data set that we will used to develop our seismic alert system.

The data set we will used, it contains the information about the earthquake, such like the date, the magnitude, the number of sensors it detect, the geographical coordinates of the epicentre divided into latitude and longitude. This information that represents the earthquake, it has to be store in a data set, because give us a full panorama of the impact of the earthquake and how does it propagate in the region to reach the city.

This dataset it has to be order by date, and the sensors give us the complete region does the earthquake pass-through before it reach the city if its the case, some earthquakes does not reach the city, so we have the information about the earthquake, where it present the epicentre and if it reach or not the city order by date.

All the earthquakes it represented in the data set, posses the information about the earthquake, for example when an earthquake is detected in any sensor, this sensor pass the information to another sensor till it reach the city, and the city sensors represents if the earthquake reach or not this city. The period of the database, is nearly of the 60 seconds, due to this all the information about the city represents the epicentre and if in the main period reach the monitored city. In rare cases we posses information about an earthquake that it detected in the city but not in the other antennas or sensors, for this cases we have to study the seismic event.

In the data set we used, the information it appear was the date, its important because all the relationship of the earthquakes are based on the period we mention before. Another field we have was the sensors that is represented by the geographical coordinates divided into latitude and longitude, and the magnitude does the sensor detect this earthquake, and

for the last field we posses the information about the monitor city, that represents the impact of the earthquake, if it reach we present an issue warning and if not reach we do not emit this alarm.

V. Results

For the results we made some experiments using the methods describe it before, for those experiments we used a database of earthquake, those the CIRES (Centro de Instrumentacion y Registro Sismologico) has, this database posses the information of 2500 earthquakes in Mexico City.

This information is from all the territory, we do not need all information does the database has, so we clustering all the information to obtain two different zones, the first the city does it be affected by the earthquakes and the second zone, the most seismic zone. This give us the relationship between those two areas, that present the information of the earthquakes, then we clustering the information but using the information of one cluster where it present the earthquakes that affect the city, this clustering give us the zones where the sensors have to be establish.

We have been done 10 experiments for both methods, those methods used the information to train a network and a genetic algorithm to train a network, we used the information to maximize the pattern recognition of an earthquake and minimized the possible error.

To determinate when a wave could be considered as an earthquake, we need to measure the wave in terms of the magnitude in Richter scale, to considered a wave as an earthquake we have to detect the wave and the measure of it, has to reach a magnitude of 4.5 degrees in Richter scale for the first experiment, and 6.5 degrees in Richter scale for the second experiment.

Both methods used an artificial neural network, one of them use a back-propagation algorithm and the other one, use a genetic algorithm. For both cases we used the next information to train a neural network:

TABLE 1
Configuration for the experiments.

Neural Network Architecture	12,7,21,1
Beta	0.45
Activation Function	$g(x) = \frac{1}{1+e^{-x}}$
Network Function	$f(x) = K\left(\sum_i w_i g_i(x)\right)$
Fitness Function	$r(x) = \min f(x)$
Generations or Epochs	$50,000$

Both methods tries to compute the solution of the problem, that it is recognized the wave as an earthquake, for both methods, we need a part of all the database to train, so we decided to train the neural network using the 70% of the data, so we use the first 1750 earthquakes to train the network and for the testing phase we used the other 30% of the information, so we used 750 earthquakes to test the artificial neural network and compare the information to verify the data we compute.

For each method we made 10 experiments using the information about the data base and the main characteristics of the artificial neural network and genetic algorithm.

A. Genetic Algorithm

This method needs the information of the earthquakes, the individuals represents the solution of the problem, so in our case this individual would be the earthquake in the city that we wanted to monitored.

For the Experiments we used a selection process based on the *elitism* where we used the information of the better individuals of the set, this selection process used the phenotype of the individual to determine the best individuals.

Then we crossover the best individuals using a reproduction parameter that it was set in 70% to cross the individuals, and we select a mutation operator of 20% that give us the differences in the individuals, because we do not wanted that the changes in the new individual are to high.

In this experiments we have been done, we use the information of the TABLE 1, becuase both methods use the information to train a network as we mention before.

Using the information about the experiments we construct a table to set the results of the experiments: In the TABLE 2 we

TABLE 2
Genetic Algorithm with 4.5 degrees or more.

Exp. #	Training Error	Testing Error
1	5%	5%
2	25%	15%
3	5%	25%
4	15%	20%
5	1%	4%
6	5%	12%
7	2%	10%
8	12%	18%
9	0.5%	2%
10	5%	5%
	7.55%	11.6%

presented the results of the 10 experiments using the scale of 4.5 degrees in Richter scale to detect an earthquake, using the genetic algorithm. In this table we presented the information about the experiment in the first column, in the second column we referred the information about the training error in the last row we have an average of error in the training phase, in the third column we set the information about the error in the testing phase, and in the last row we presented an average in the testing phase.

Using the same information we explain before, we realized some extra experiments using the scale of 6.5 degrees in Richter scale to detect an earthquake, using the genetic algorithm too. in the TABLE 3, we present the result of this experiments, we presented the information similar as we do in the TABLE 2, so in the fist column we showed the information of the experiments, in the second column we referred the information of the error in the training phase and in the last row the average of the training phase, in the third column we shows the information of the error in the testing phase, and in the last row the average of the testing phase.

TABLE 3
Genetic Algorithm with 6.5 degrees or more.

Exp. #	Training Error	Testing Error
1	10%	30%
2	20%	35%
3	25%	25%
4	35%	25%
5	15%	20%
6	35%	60%
7	50%	40%
8	12%	38%
9	10%	25%
10	15%	15%
	22.7%	31.3%

TABLE 5
BackProgation Results with 4.5 degrees.

Experiment #	Training Error	Testing Error
1	22%	35%
2	28%	90%
3	17%	50%
4	30%	50%
5	71%	70%
6	32%	90%
7	24%	25%
8	25%	50%
9	10%	50%
10	26%	70%
	28.5%	58%

The reader could appreciate that the best result are obtained using a scale of 4.5 degrees in Richter scale, with this method, and using this method a seismic alarm system based could be developed using a genetic algorithm with an artificial neural network.

B. Back-propagation

For the experimentation, we used a sigmoid function as the activation function, we have a network function that we used on (1), the architecture we used posses an input of 12 sensors, 7 neurons and then 21 neurons for the hidden layer, and a unique output that represents the issue warning.

This is the algorithm to pass through the layers as we could check on the algorithm (1). As we mention before we made 10 experiments using the information in the TABLE 1, this information give us the initial conditions to compute the solutions. In the TABLE 5 we posses the information

TABLE 4
Back-propagation Results with 6.5 degrees.

Exp. #	Training Error	Testing Error
1	1%	5%
2	10%	20%
3	1%	5%
4	20%	15%
5	20%	15%
6	5%	15%
7	2%	10%
8	2%	5%
9	1%	15%
10	1%	5%
	6.3%	11%

in the three columns, the information of the experiments are presented in the first column, using the second column to refer to the error in the training phase, presenting in the last row an average of the error in this phase, in the third column we present the information of the error in testing phase, and in the last row of this column we presented the average of this phase.

As in the genetic algorithm we presented in this section 2 experiments the first one using 6.5 degrees in Richter scale that is the last experiments we show. And a second experiments using 4.5 degrees in Richter sclale that is the experiments we present below. In the TABLE 5 we presented the information of the experiment, presenting in the first column the experiment done, in the second column we referred the information about the error in the training phase and in the last row the average of this errors, in the third column we present the information about the error in the testing phase and in the last row the average in the testing phase. As the reader could appreciate this method present the best result in the 6.5 degrees in Richter scale, for this method.

VI. Conclusion

Using the information generated with the back-propagation algorithm and the genetic algorithm (GA) we could appreciate that is possible to generate pattern recognition using the magnitude scale of an earthquake.

Using the same information we could determine that depending on the case we tried to analyse, the artificial neural network (ANN), and the genetic algorithm (GA) have different behaviours, but both methods could reach a solution. Setting a seismic alert system for Mexico City is too difficult but not impossible, the information we gather using the database give us the relationship we need, but this information are known only by the experts on the area.

The information we used, is an intent to recognize the pattern on earthquakes, without use the information of the wave, so we could said that our system could recognize this pattern, and maybe if we could know more about the earthquakes such like the propagation wave, the characteristics of the terrain and soil, etc., we could predict the earthquake, but at this moment its impossible due to the chaotic conditions.

There are numerous investigations on the area, but we want to conclude that it is possible to set a seismic alert system with artificial neural networks, and we could set a better results employing the information on the wave.

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