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Application of Artificial Neural Networks in Civil Engineering

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Abstract: The use of artificial neural networks (ANNs) has increased in many areas of engineering for over the last few years. The ANNs have been applied to many geotechnical engineering problems and have demonstrated some degree of success also. A review of the literature reveals that ANNs have been used successfully in pile capacity prediction, modeling soil behaviour, site characterization, earth retaining structures, settlement of structures, slope stability, design of tunnels and underground openings, liquefaction, soil permeability and hydraulic conductivity, soil compaction, soil swelling and classification of soils. In this paper the various architectures of NN and learning process have been examined. The needs for neural networks, training of neural networks, and important algorithms used in realizing neural networks along with identifying limitations, recent advances and promising future research have also been briefly discussed. Its applications in electrical, civil and agricultural engineering were also examined.
Keywords: Artificial Neural Network, data mining, earthquake forecasting.

I. INTRODUCTION

Artificial neural networks are computers whose architecture is modeled after the brain. In other words it is a computational system inspired by the structure, processing method and learning ability of a biological brain. They typically consist of many hundreds of simple processing units which are wired together in a complex communication network. Each unit or node is a simplified model of a real neuron which fires (sends off a new signal) if it receives a sufficiently strong input signal from the other nodes to which it is connected. An artificial neural network (ANN) is applied to several civil engineering problems, which have difficulty to solve or interrupt through conventional approaches of engineering mechanics. These include tide forecasting, earthquake-induced liquefaction and wave-induced seabed instability. ANN model can provide reasonable accuracy for civil engineering problems, and a more effective tool for engineering applications. A natural disaster is the effect of a natural hazard (e.g., flood, tornado, hurricane, volcanic eruption, earthquake, heat wave, or landslide). Earthquakes, landslides, tsunamis and volcanoes are complex physical phenomenon that leads to financial, environmental or human losses. Also, prediction of these disasters is a complex process that depends on many physical and environmental parameters. Many approaches exist in the literature based on scientific and statistical analysis. Data mining techniques can also be used for prediction of these natural hazards. Unfortunately, successful earthquake predictions are extremely rare. There are two basic categories of earthquake predictions: forecasts (months to years in advance) and short term predictions (hours or days in advance). Forecasts are based a variety of research, including the history of earthquakes in a specific region, the identification of fault characteristics (including length, depth, and segmentation), and the identification of strain accumulation. Data from these studies are used to provide rough estimates of earthquake sizes and recurrence intervals. An example of an earthquake forecast is the identification of seismic gaps, portions of the plate boundaries that have not ruptured in a major earthquake for a long time. These regions are most likely to experience great earthquakes in the future. Short-term earthquake prediction is still a challenge and no method is known to be reliable. Due to the complex and chaotic nature of the earthquake process it is being considered that short-term prediction may be inherently impossible. Various data mining techniques that can be applied to the areas such as seismic activity, volcanic eruption, liquefaction and many others factors relevant to earthquake. Data mining applications in geology and geophysics have achieved significant success in the areas as weather prediction, mineral prospecting, ecology, modeling etc and finally predicting the earthquakes from satellite maps.

II. HISTORICAL BACKGROUND

The history of neural networks can be divided into several periods: from when developed models of neural networks based on their understanding of neurology, to when neuroscience became influential in the development of neural networks. Psychologists and engineers also contributed to the progress of neural network simulations. Neurally based chips are emerging and applications to

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complex problems developing. Clearly, today is a period of transition for neural network technology.

Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques. A trained neural network can be thought of as an "expert" in the category of information it has been given to analyze. This expert can then be used to provide projections given new situations of interest and answer "what if" questions. Other advantages include: Adaptive learning, Self-Organization, Real Time Operation and Fault Tolerance via Redundant Information Coding Neural networks process information in a similar way the human brain does. The network is composed of a large number of highly interconnected processing elements (neurons) working in parallel to solve a specific problem. Neural networks learn by example. The disadvantage is that because the network finds out how to solve the problem by itself, its operation can be unpredictable.

III. ARCHITECTURE OF NEURAL NETWORKS

Neural networks are not only different in their learning processes but also different in their structures or topology. Bose (1996) has broadly classified neural networks into recurrent (involving feedback) and non recurrent (without feedback) ones. The network architectures are divided into Feed-forward Networks includes single-layer perceptrons and Multilayer perceptrons are classes of feed forward networks and Feedback networks.

A. Structure and features of MLP

Multi-layer perceptron (MLP) networks are feed forward nets with one of more layers of nodes between the input and output nodes. The structure of an unadorned multilayer perception network is shown in Figure 1:

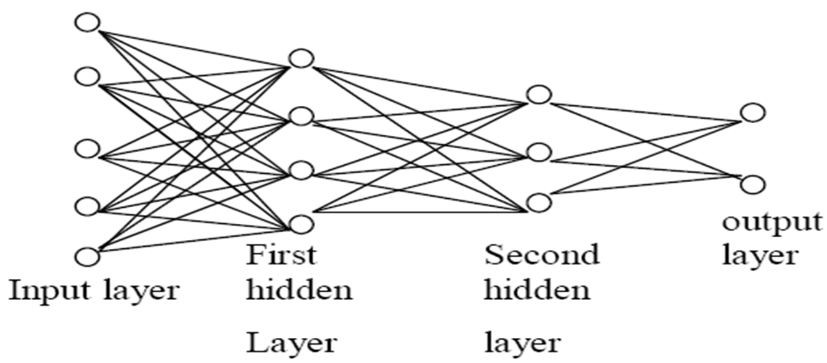

Figure 1, Feed forward multi-layer perceptron architecture

B. Feedback networks

Feedback networks (Figure 1) can have signals traveling in both directions by introducing loops in the network. Feedback architectures are also referred to as interactive or recurrent, although the latter term is often used to denote feedback connections in single-layer organizations. In the neural network literature, neural networks with one or more feedback loops are referred to as recurrent networks. A recurrent network distinguishes itself from a feed forward neural network in that it has at least one feedback loop.

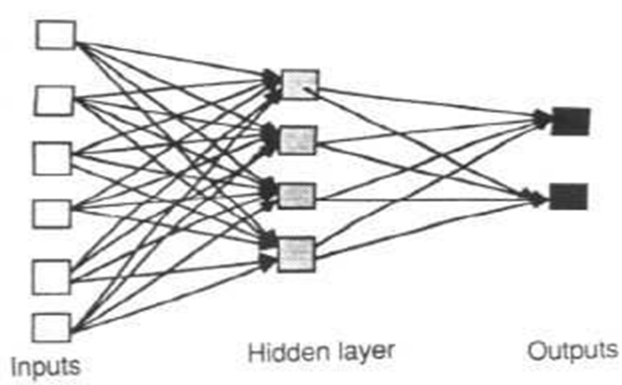

Figure 2, An example of a simple feed forward network

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C. Network Layers

The commonest type of artificial neural network consists of three groups, or layers, of units: a layer of "input" units is connected to a layer of "hidden" units, which is connected to a layer of "output" units. The activity of the input units represents the raw information that is fed into the network. The activity of each hidden unit is determined by the activities of the input units and the weights on the connections between the input and the hidden units. The behavior of the output units depends on the activity of the hidden units and the weights between the hidden and output units.

D. Training a Neural Network

A network is trained by changing the weights of the connections between nodes. These weights can be randomly chosen or individually chosen. Usually, a computer program randomly generates values for connection weights. Then, the network is given an input, and it is allowed to process the information through its nodes to produce an output.

The memorization of patterns and the subsequent response of the network can be categorized into two general paradigms: Associative mapping in which the network learns to produce a particular pattern on the set of input units whenever another particular pattern is applied on the set of input units and in auto-association: an input pattern is associated with itself and the states of input and output units coincide. All learning methods used for adaptive neural networks can be classified into two major categories: Supervised learning which incorporates an external teacher, so that each output unit is told what its desired response to input signals ought to be. Unsupervised learning uses no external teacher and is based upon only local information.

E. The back-propagation algorithm

In order to train a neural network to perform some task, we must adjust the weights of each unit in such a way that the error between the desired output and the actual output is reduced. This process requires that the neural network compute the error derivative of the weights (EW). The back propagation algorithm is the most widely used method for determining the EW.

IV. APPLICATIONS OF NEURAL NETWORKS

A. A Simple Neuron

An artificial neuron is a device with many inputs and one output (Figure 3). The neuron has two modes of operation; the training mode and the using mode. In the training mode, the neuron can be trained to fire (or not), for particular input patterns. In the using mode, when a taught input pattern is detected at the input, its associated output becomes the current output. If the input pattern does not belong in the taught list of input patterns, the firing rule is used to determine whether to fire or not.

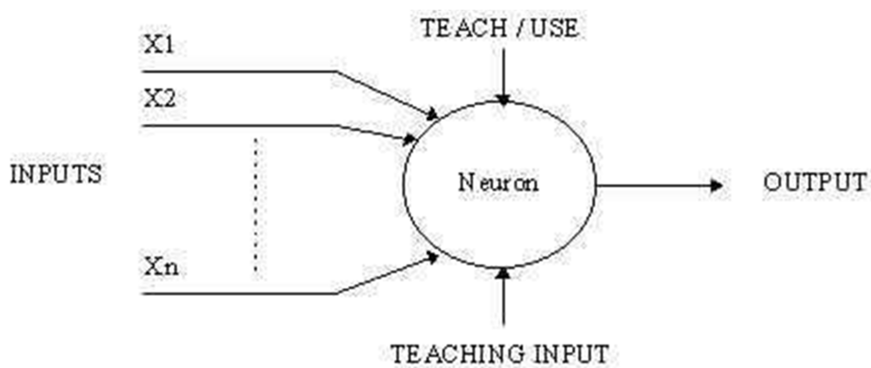

Figure 3. A simple neuron

B. Firing Rules

The firing rule is an important concept in neural networks and accounts for their high flexibility. A firing rule determines how one calculates whether a neuron should fire for any input pattern. It relates to all the input patterns, not only the ones on which the node was trained. The firing rule gives the neuron a sense of similarity and enables it to respond 'sensibly' to patterns not seen during training.

V. NEURAL NETWORKS IN PRACTICE

Neural networks have already been successfully applied in many industries for prediction or forecasting needs including: sales forecasting, industrial process control, customer research. Even it is applied in engineering for data validation and risk management.

Volume 4 Issue IX, September 2016
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ANN are also used in recognition of speakers in communications; diagnosis of hepatitis; undersea mine detection; texture analysis; three-dimensional object recognition; hand-written word recognition; and facial recognition. Typical applications of hardware NNWs are: OCR (Optical Character Recognition), Data Mining and Voice Recognition.

A. Application of Neural Networks in Engineering

Control engineering also involves robotics, where Intelligent Control is the discipline that implements Intelligent Machines (IMs) to perform anthropomorphic tasks with minimum supervision and interaction with a human operator (Jegede, Awodele, Ajayi, & Ndong, 2007). Control and management of agricultural machinery offers many opportunities for application of general purpose empirical models. Artificial Neural Networks (ANNs) have these characteristics and are attractive for use in control and modeling in agricultural machinery like sprayer sensor and nozzle element (Zhang, Yang, & El-Faki, 1994), weed detection in sprayers and weed identification. Artificial Neural Network (ANN) is currently a 'hot' research area in electrical engineering. The model used to simulate artificial neural networks is based on the biological nerve cell or neuron. Electrical signals arising from impulses from our receptor organs (e.g. eyes, ears) are carried into neurons on dendrites. Neural networks and its application in engineering are applied as hand written documents to be automatically transformed into formatted word processing documents. The trends found in the human genome to aid in the understanding of the data compiled by the Human Genome Project would be applied through neural network and self-diagnosis of medical problems using neural networks and much more would be easier.

B. Neural Networks and Its Application in Civil Engineering

Neural networks have gained a broad interest in civil engineering problems. They are used as an alternative to statistical and optimization methods as well as in combination with numerical simulation systems. Application areas in Civil Engineering are e.g. forecasting, water management, controls and decision support systems. The application of ANN is used in tidal level forecasting to accurately estimate the tidal level for the complex bottom topography in the near-shore area. It is also used to estimate the earthquake-induced liquefaction potential which is essential for the civil engineers in the design procedure. ANN model is further applied in evaluation of the wave-induced seabed instability particularly important for coastal geotechnical engineers involved in the design of marine structures (such as offshore platform, pipeline and caisson etc.). –Data mining is used to find patterns and relationships in data patterns. Two types of models are used to analyze the relationships in data patterns i.e. descriptive models and predictive models. The various data mining techniques like statistics, clustering, visualization, association, classification & prediction, outlier analysis; and trend and evolution analysis are used. Prediction studies can be broadly grouped based on two different approaches: (1) Neural Network based approach; and (2) Data Mining approach.

1) *Neural Network Based Approach:* Adel M. Hanna (2007) [20] in his paper proposed a general regression neural network model to assess nonlinear liquefaction potential of soil. A total of 620 sets of data including 12 soil and seismic parameters are introduced into the model. The data includes the results of field tests from two major earthquakes that took place in Turkey and Taiwan in 1999. The proposed GRNN model was developed in four phases, mainly: identification phase, collection phase, implementation phase, and verification phase. An iterative procedure was followed to maximize the accuracy of the proposed model. The case records were divided randomly into testing, training, and validation datasets. Generating a model that takes into account of 12 soil and seismic parameters is not feasible by using simplified techniques; however, the proposed GRNN model effectively explored the complex relationship between the introduced soil and seismic input parameters and validated the liquefaction decision obtained by simplified methods. The proposed GRNN model predicted well the occurrence/nonoccurrence of soil liquefaction in these sites. The model provides a viable tool to geotechnical engineers in assessing seismic condition in sites susceptible to liquefaction.

   Hung-Ming Lin (March 2009) [21] created an empirical model for assessing failure potential of highway slopes, with a special attention to the failure characteristics of the highway slopes in the Alishan, Taiwan area prior to, and post, the 1999 Chi-Chi, Taiwan earthquake. The basis of the study was a large database of 955 slope records from four highways in the Alishan area. Artificial neural network (ANN) was utilized to "learn" from this database. The developed ANN model was then used to study the effect of the Chi-Chi earthquake on the slope failure characteristics in the Alishan area. Significant changes in the degrees of influence of several factors (variables) are found and possible reasons for such changes were discussed. The developed ANN models were used as a tool to investigate the slope failure characteristics before and after the Chi-Chi earthquake. L. Dehbozorgi during his research investigated an application of Neuro-Fuzzy classifier [22] for short-term earthquake prediction using saved seismogram data. This method is able to predict earthquakes five minute before, with an acceptable accuracy

(82.8571%). The features were obtained from statistical and entropy parameters, Discrete Wavelet Transform (DWT), Fast Fourier Transform (FFT), Chaotic Features (Maximum Lyapunov Exponent), estimated power spectral density (PSD), and the classifier used this extracted features to indicate whether the earthquake were takes place in the next following five minutes or not. Finally, after training of Neuro-Fuzzy classifier effective features were selected with UTA algorithm.

2) *Data Mining Approach:* Witold Dzwinel [23] developed a novel technique based on cluster analysis of the multi-resolutional structure of earthquake patterns and applied to observe and synthetic seismic catalogs. The observed data represent seismic activities situated around the Japanese islands in the 1997- 2003 time interval. The synthetic data were generated by numerical simulations for various cases of a heterogeneous fault governed by 3-D elastic dislocation and power-law creep. At the highest resolution, the local cluster structure was analyzed in the data space of seismic events for the two types of catalogs by using an agglomerative clustering algorithm. It was found that small magnitude events produce local spatio-temporal patches corresponding to neighboring large events. Seismic events, quantized in space and time, generate the multi-dimensional feature space of the earthquake parameters. Using a non-hierarchical clustering algorithm and multidimensional scaling, the multitudinous earthquakes were explored by real-time 3-D visualization and inspection of multivariate clusters. At the resolutions characteristic of the earthquake parameters, all of the ongoing seismicity before and after largest events accumulate to a global structure consisting of a few separate clusters in the feature space. By combining the clustering results from low and high resolution spaces, precursory events were recognized more precisely. Dave A.Yuen1 [24] presented a web client-server service WEB-IS for remote analysis and visualization of seismic data consisting for both small and large earthquakes. A problem solving environment (PSE) designed for predicting of large magnitude earthquakes can be based on this WEB-IS idea.

Aydin [25] proposed a prediction algorithm using time series data mining based on fuzzy logic is proposed. Earthquake prediction has been done from a synthetic earthquake time series by using investigating method at first step ago. Time series has been transformed to phase space by using nonlinear time series analysis and then fuzzy logic has been used to prediction optimal values of important parameters characterizing the time series events. Truth of prediction algorithm based fuzzy logic has been proved by application results. Seismic data is generated in nature by the changes or movement of the earth crust. This data has evolutionary patterns. Since this data is based on time, a model can be formed to predict the future pattern.

Tao Pei [26] employed the support domain of feature (SDF), the region over which any feature event has the equivalent likelihood to occur, to approximate the ‘‘territory’’ of feature events. A method is developed to delineate the SDF from a region containing spatial point processes. The method consists of three major steps. The first is to construct a discrimination function for separating feature points from noise points. The second is to divide the entire area into a regular mesh of points and then compute a fuzzy membership value for each grid point belonging to the SDF. The final step is to trace the boundary of the SDF.

VI. LIMITATIONS OF NEURAL NETWORKS

Neural network programs some-times become unstable when applied to larger problems. The mathematical theories used to guarantee the performance of an applied neural network are still under development. The solution for the time being may be to train and test these intelligent systems much as we do for humans. Also there are some more practical problems like: the operational problem encountered when attempting to simulate the parallelism of neural networks instability to explain any results that they obtain. Networks function as "black boxes" whose rules of operation are completely unknown.

VII. CONCLUSION

Neural Networks will fascinate user-specific systems for education, information processing, entertainment, genetic engineering, earthquake prediction, neurology and psychology. Perhaps the most exciting aspect of neural networks is the possibility that some day 'conscious' networks might be produced. NNs might, in the future, allow: robots that can see, feel, and predict the world around them, improved stock prediction, common usage of self-driving cars, composition of music. Even though neural networks have a huge potential but if they are integrated with computing, AI, fuzzy logic and related subjects will get the best of them. ANN will be useful in prediction of disasters like earthquakes, landslides, tsunamis and volcanoes. Data mining applications will significantly be useful for weather prediction, mineral prospecting, ecology, modeling etc and finally predicting the earthquakes from satellite maps.

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and G. V. Otari, R. V. Kulkarni, "A Review of Application of Data Mining in Earthquake Prediction as at reference [21, 27, 28], is gratefully acknowledged.

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