Review Paper:

Earthquake Prediction using Convolutional Neural Network

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Abstract

Due to natural processes of the earth, some major adverse events can occur like earthquakes, tsunamis, storms, fire storms, dust storms, floods, tornadoes, volcanic eruptions hurricanes etc. which can result into financial, environmental or human losses. An earthquake in a populated area may result into not only extensive damage to property but also to huge casualties and injuries. Thus prediction of earthquake is very necessary to avoid these losses. Convolution Neural Network (CNN) applied to earthquake prediction has been reviewed here .

Keywords: Artificial Intelligence(AI), Artificial Neural Network (ANN), Convolution Neural Network (CNN), Earthquake Prediction, Seismology, Earth Science, Deep Learning, Deep Neural Network(DNN).

Introduction

Natural calamities include earthquakes[14]. They can happen anywhere in the world at any time and do significant damage depending on their magnitude. Buildings have been destroyed and people have died as a result of the damage. Predicting earthquakes is a difficult task. The internal dynamics of earthquakes is thought to be too complex to comprehend.

An earthquake can be defined in a variety of ways. It is defined as a natural tragedy as well as earthquake or ground shaking. The sudden shaking beneath the earth's surface causes damage to structures, the environment and human life. A natural occurrence that shapes the earth is an earthquake. This phenomena is caused by a large amount of energy being released at the plate boundaries in the crust which is created by floating continental masses and is the earth's top layer. Earthquakes occur in the lithosphere which extends from the surface of the earth to a depth of around 70–100 km. The lithosphere is the name given to the crust and a portion of the upper mantle where earthquakes and all geological processes are caused by rubbing of the earth's crust against each other.

The great majority of earthquakes on the planet happen within narrow strips near plate borders where plates exert strain on one another. Tectonic earthquakes are earthquakes that occur as a result of plate movement and are most commonly found along plate boundaries. This category includes the majority of the world's earthquakes. Tectonic earthquakes are the most common type of earthquake in the Eastern Mediterranean. Volcanic earthquakes are the second type of earthquake. Volcanic eruptions create these formations. Shallow earthquakes are those that occur less than 60 kilometers below the surface of the earth. They can only be sensed in a small area and can do significant harm inside that area. Shallow earthquakes typically strike mid-ocean ridges and transform faults, while intermediate and deep earthquakes strike subduction zones.

The earthquakes in the eastern Mediterranean are typically shallow-oriented with depths ranging from 0 to 30 kilometers. Intermediate earthquakes can occur up to 300 kilometers below the surface of the planet. They can be found in sinking forces like the Cyprus Arc. Deep earthquakes are felt over a large area, although they do little damage. Deep earthquakes occur in the earth's depths of 300–700 km. They are earthquakes that occur in the earth's upper mantle layer. They are felt throughout a large region, but the damage is minor. At a depth of around 700 km, the earthquakes abruptly diminish below the Moho Discontinuity and reach zero. When there is a sudden shift in plate motions beneath the earth's crust, the friction between two plates can increase, resulting in earthquakes that are dangerous to people, structures and the economy.

For a long time, scientific researches have made little progress, however, due to the advancement of neural networks, it is now possible to train to detect deep internal dynamics of complicated data from a variety of sources. Deep Learning[3] methodologies may educate us to attain our goals, especially if the data is non-stationary and existing linear models are limited to modeling such complicated data like the earthquake prediction challenge. Traditional earthquake detection methods are unable to detect occurrences buried behind even low levels of seismic noise.

Repeating earthquakes can be detected using waveform similarity if they come from the same place and have the same source mechanism. The most successful method for identifying these repeated earthquakes from seismograms is waveform autocorrelation. The method is computationally demanding, scales quadratically with the number of windows and hence is not practicable for lengthy time series, despite being especially durable and dependable. Selecting a small collection of typical waveforms as templates and correlating only these with the full-length continuous time series is one way to reduce processing.

Deep Learning is quickly mounting as a strong technique for solving complex problems as it has very high capability of

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finding complicated patterns especially in very huge datasets. The main advantages of Artificial Neural Networks (ANNs)[6] and Deep Neural Networks (DNNs)[22] are feature extraction as well as engineering done automatically. Deep Learning has emerged as highly trendy in Seismology[29]. Earlier this confrontation was thought-out impracticable.

Currently the studies on earthquake are focusing on where the earthquake will happen? When the earthquake will happen? What will be the magnitude of the earthquake? Still the answers of these questions are very difficult. However, post earthquake, disaster intensity and damage prediction can be done but predicting when an earthquake would happen is not possible currently due to dynamic nature of problem, happening many kilometers underground and occurring in slow geological time. In the current review, focus will be on earthquake prediction using Convolutional Neural Network (CNN)[12].

Literature Review on Earthquake Prediction

Adler et al[3] reviewed the solutions based on Deep Learning for earthquake prediction. Using ANN, Asim et al[6] evaluated the intensity of earthquake using fault parameters. For large earthquake magnitude prediction in Taiwan, Huang et al[22] extracted the implicit features out of the geographic images marked with seismic information using CNN. Their study demonstrated that good results can be achieved by considering the previous 120 day's earth shattering incidents to anticipate the maximum intensity of earthquake in Taiwan which can occur in the next 30 days. Jiao and Alavi[29] reviewed the capabilities of artificial intelligence in earthquakes.

Caragea et al[12] studied that by using CNN, informative tweets can be predicted which can be helpful at the time of disasters event. The earliest work on earthquake prediction using applications of ANN was provided by Panakkat and Adeli.[50] They compared 3 types of neural networks in their study: Radial Basis Function (RBF) Neural Network, Deep Neural Network (DNN) and Recurrent Neural Network (RNN). According to Krizhevsky et al,[35] CNNs are capable in computing powerful attributes layer by layer, by applying diverse sort of filters on local responsive attributes. Nguyen et al[13] studied that CNN outperformed Bag-of-Visual-Words (BoVW) in identifying harshness of damage through images found on social media after an event of calamity.

By using imbalanced classifier and ensemble learning techniques, Fernández-Gómez et al[17] tried to predict large magnitude earthquakes with horizon of five days. K. Ahmad et al[31] used CNN and Generative Adversarial Network (GAN) based satellite and social media data fusion for disaster detection. By using CNN, S. Ahmad et al[54] studied that when a late fusion technique is applied on visual details retrieved through social media after disaster and additional available information of meta-data, it works best with visual information only, works worst with met-data and performance is declined with combination of both.

Amit et al[55] studied about disaster detection from aerial imagery through satellite with CNN. By using CNN, Nguyen et al[65] concluded that using steaming API to extract the tweets data with keywords "quake," "tsunami," and "earthquake.", the earthquake event can be predicted. Asencio–Cortés et al[5] predicted magnitude of earthquake in the time frame of next 7 days in California using several regression[46] algorithms combining with ensemble learning on big data (1 GB catalog). Bao et al[8] used CNN in their study for categorization of scale of seismic activities.

Using CNN, Ji et al[26] tried to identify the distorted premises, post earthquake in Haiti in the year 2010 using very high resolution images through satellite. Maceda et al[38] applied Support Vector Machine (SVM) to earthquake problem in Phillippines. Their study demonstrated that SVM is perfect for solving classification problems of small-size training dataset. Using CNN, Perol et al[63] suggested a model "ConvNetQuake" which uses waveforms for earthquake prediction in Oklahoma, USA. Abraham et al[2] proposed a model "Particle Swarm Optimization Back Propagation" (PSOBP) to predict seismic activity in Japan. They demonstrated that quantity of vertexes in invisible layers can be improved through particle swarm optimization.

Arinta and Emanuel[4] conducted a review to understand the motive of machine learning and big data in the field of calamity management. Bellagamba et al[9] presented a neural network method to determine the quality of ground motions through small intensity of earth shocks. Bergen et al[10,11] reviewed on the role of Machine Learning and Deep Learning in earthquakes. According to them, machine learning techniques have capability to proficiently evaluate the abundant data sets concurrently to identify the links in the data known earlier. Using deep temporal convolution neural networks (CNN), Geng et al[18] addressed the dilemma of long-term historical dependency on seismic time series prediction.

Ignatiev et al[23] developed a formal problem statement that allows using the deep learning approach effectively to analyze the time-dependent series of remote sensing images. Jia et al[27] analyzed and compared the importance of features that affect seismic activity in China. Based on a deep convolutional neural network (CNN), Kang et al[32] considered and effectively addressed the many precise points connected to realistic Micro Electro Mechanical System(MEMS) sensors and developed a new earth shaking observing system for MEMS sensed data using a deep CNN.

Kong et al[33] provided an overview of recent applications of machine learning (ML) in seismology. Kriegerowski et al[34] presented an alternative approach over traditional localization method using deep learning that once trained is capable to predict the hypocenter locations efficiently. Lomax et al[37] proposed a model ConvNetQuake_INGV using deep convolutional neural network (CNN) for local earthquake detection and epicentral classification using short single station waveforms to characterize earthquakes at any distances and magnitudes.

Mendoza et al[40] projected a method for early prediction of earthquake based on people's reaction in social networks about damages that provides early spatial Mercalli reports 30 minutes after an earthquake. Mignan and Broccardo[41,42] established that same outcome can be obtained through a one neuron than a deep neural network for aftershock pattern forecasting. Mousavi et al[44] constructed a network that was made of convolutional and recurrent layers for earthquake magnitude assessment. For parallel seismic activity detection and segment selection, Mousavi et al[45] presented a global deep learning model. The study showed that the model outperformed the past models. Rasel et al[52] used various supervised machine learning algorithms for prediction of earthquake.

Ross et al[53] developed a method using deep learning to get excellent performance on highly vigorous earthquakes chain in southern California. Zhou et al[70] prepared a combo algorithm by combining CNN and RNN to choose stages from the stored constant waveforms in two steps to identify earthquake actions through seismograms signals. Using historical earthquake data, Zhou et al[69] studied the additional attributes set up on the seismic activity catalog through a vigorous model. They studied that by using statistical machine learning models, such as Support Vector Machine (SVM), earthquake early warning can be predicted. Zhu et al[71] presented a deep neural network based method to pick arrival time "PhaseNet" to pick the arrival time of P waves and S waves. PhaseNet trained on the data set provided by Northern California Earthquake Data Center.

Audretsch et al[7] considered CNN for prediction of the scale for tiny actions obscured through background noise. Hong et al[21] summarized several studies and designed the thoughts of wings of neural networks and proposed that different architectures are adopted by different wings of the neural network. Jena et al[24] considered a CNN set-up for assessing the possibilities of seismic activities in the India. To predict the intensity of earth movements, Jozinovic et al[30] applied a CNN model.

Li et al[36] proposed a deep learning model "DLEP" for prediction of seismic activities. They fused the implicit and explicit features for accurate prediction of earthquake. As the explicit feature DLEP adopts eight precursory pattern based indicators and for extracting implicit features, CNN is used. Mignan and Broccardo[41,42] considered 77 articles on Neural Networks from year 1994-2019. The study was divided into 2 types- ANN based and DNN based. For solving forecasting problems, Oprea[49] presented a general benchmarking framework that can be applied to computational intelligence algorithms with set of guidelines to select the best or more relevant CI algorithm. Song et al[60] proposed an intelligent assessment method that was based on deep-learning, super-pixel segmentation and mathematical morphology for evaluating the degrees of damage of earthquake damaged buildings.

Tian et al[64] designed Multi Trace CNN (MTCNN) architecture which produced less prediction errors and high accuracy for micro seismic activities. Xie et al[67] conducted a comprehensive review for the progress and challenges to implement Machine Learning in the domain of earthquake engineering. Maya et al[39] combined neural networks and meta-learning to estimate the scale of the next several upcoming earthquakes in Italy. Nicolis et al[48] used Long Short Term Memory (LSTM) and CNN for prediction of seismic activities in Chile. Pu et al[51] built a modified model using CNN and RNN and trained this model on Acoustic Emission (AE) signals. Some recent review studies have been done in the direction of earthquake prediction[15,16,19,20,25,28,43,59,61,66,68].

Research Gap

Study of earthquake prediction is very necessary as it can minimize the loss of life, property and wealth of people. However still neither any research organizations nor any scientists have ever predicted a major earthquake, so there is immense need to do research in this area till success is achieved. There is abundance literature found about earthquake prediction using various methods but earthquake prediction using CNN is being recently used from last one decade.

Seismology and AI: The geosciences community must keep up with the rapid growth of observational datasets and develop usable AI models fast and accurately at an affordable cost. Earth AI research and development are still in their early stages, but all of the grand issues, from data to model to operation, can lead to countless opportunities in a variety of sectors from academia to Government and industry. Earth AI's future is bright and is significantly helpful to the entire human society and earth system and it has the potential to propel our civilization into its next epic phase and change the earth into a more sustainable, healthy planet[62].

Artificial Intelligence in Disaster Management: A disaster is an occurrence that causes harm to a community through the loss of human life, environmental damage, or economic loss.

The community's ability to respond is limited. Between 1998 and 2017, disaster-affected countries lost \$2.9 trillion in economic value, according to the Center for Research on the Epidemiology of Disasters. The United States tops the group with nearly \$1 trillion in losses followed by China, Japan and India. The rate of natural disasters has roughly doubled in the previous 20 years, according to the UN Refugee Agency. The Asia–Pacific area has been the most susceptible since 1995. Catastrophe management is a multi-faceted strategy for disaster mitigation, readiness, response and recovery designed to protect vulnerable communities and essential intrastate infrastructure. Working in the field of disaster risk reduction, researchers, decision-makers and Government officials share a same vision of disaster and take preemptive measures before a disaster occurs. All calamities, on the other hand, are tied to humans coping with their repercussions.

As a result, the success or failure of effective disaster management practices is determined by the design and implementation of effective disaster management practices. Furthermore, a primary hazard might produce a secondary hazard with far-reaching consequences such as a tsunami that causes coastal flooding. AI is a tremendous force multiplier in the ability to safeguard people and property in the event of disaster in disaster management and it is unquestionably the future of disaster management. Artificial intelligence and geospatial technology are highly developed now and they have the potential to be extremely useful in crisis situations. The topography of the location, weather conditions, ecology and other considerations, as well as the machinery's available resources, all have an impact on disaster response strategy. It is suggested that operations research and management science criteria can be used to improve resilience in emergency relief while taking into account the population's impact on relief resource allocation.

Several studies in the literature, on the other hand, assess the utility of artificial intelligence in disaster management. Other countries' crisis response situations are drastically different from India's. As a result, data essential for compelling emergencies in natural catastrophes must be identified and prioritized. In disaster management, the right strategies to minimize the impact of a disaster include prevention and minimization, vulnerability, readiness and resilience. Many scientists employ artificial intelligence and geographic information systems to plot the spatial dispersal of flood hazards and susceptibility to flooding. For prompt and effective hazard preparedness and flood crisis management, a geographic information system (GIS) serves as a facilitator[1].

Seismology and Machine Learning: Machine Learning is a part of Artificial Intelligence and study of computer algorithms which are automatically improved by experience and by use of data. Detecting outliers and removing outliers can improve Machine Learning Algorithms[47,56-58]. Extractions of features are done manually in Machine Learning whereas it is done automatically in Deep Learning. Machine Learning becomes difficult when it is tried to implement an existing algorithm and model to work with new application. The prediction of earthquake is a very challenging job. Many research articles have been found in the literature to predict the earthquake using machine learning models from last decades with no satisfactory results.

ML is a branch of AI that comprises systems that can learn from data, spot patterns and make decisions on their own. The most appealing feature of machine learning is that it allows computers to learn without having to be explicitly taught. The majority of machine learning algorithms is based on biological learning. In seismology, machine learning (ML) employs a set of algorithms to uncover the underlying rules and relationships between data, which are subsequently classified or regressed. In addition, unlike seismologists who evaluate data using intuition and logics, ML is frequently used to categorize and analyze previously unknown patterns or features in detected data since it discovers previously unconsidered features beyond human competence.

The main components of machine learning can be classified as supervised or unsupervised. Regression and classification methods are common in the former, whereas reduction and clustering techniques are used in the later. There is also a subcategory of learning algorithms known as semi-supervised learning algorithms which can both organize and predict data.

However, ML in seismology is developed in five steps including collecting and partitioning seismic data for training and testing, preprocessing to clean, format and remove/recover seismic data, raining model uses numerical optimization algorithms to tune the seismic variables, evaluating model with respect to prediction accuracy using the test data and generating new data.

In general, ML has three applications in seismology: a code accelerator tool to minimize the computational cost of deterministic models, constructing an empirical model if a deterministic model is not practicable and tackling classification challenges. Because they are unable to produce realistic prediction equations, ANNs and many other ML approaches are classified as black-box model generators. Other machine learning methods such as Genetic Programming (GP) and Decision Trees, have addressed this problem (DT).

A neural network, in general, is made up of various processing components organized into layers such as an input layer, multiple hidden layers and an output layer. An ANN model in seismology begins with information propagation at the input layer. The network examines and modifies the weights based on the training dataset's presentation and produces a set of weights using learning techniques to provide the most accurate correlations between input and output data. The performance of the ANN model can be validated using separate datasets during the training process.

Unsupervised Learning: Without the use of annotations or intervention, unsupervised learning looks for hidden patterns in a dataset. Unsupervised learning, unlike supervised learning, which is primarily reliant on manual labels, investigates the generic probability densities solely based on the inputs. Clustering analysis is used in earth scientific analysis. Geochemical sample grouping is a common

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example. Distance metrics like Euclidean distance in a feature space and algorithms like K Means, Hidden Markov and others are used to automatically sort the clusters[62].

Supervised Learning: The majority of today's AI applications use supervised learning which creates a transformer that connects outputs and inputs. It is further divided into two categories: regression and classification. Any continuous number in a range could be produced through regression (such as atmospheric pressure, surface temperature, precipitation). The output of a classification model is limited to a set of pre-determined numbers. K Nearest Neighbour (KNN), Decision Tree (DT), Support Vector Machine (SVM), Random Forest (RF), Artificial Neural Network (ANN) and other supervised learning methods are among them[58]. Bagging and boosting are examples of meta algorithms that can be used to improve accuracy and stability.

Seismology and Deep Learning: Deep Learning[3,14] is a subset of Machine Learning. It is a Machine Learning technique used to teach a computer to filter inputs through layers for learning to do prediction and classification of information. Deep Learning is used to solve complex problems as it can discover the hidden patterns in the data and it has deep understanding to intricate relationship among a large number of interdependent variables. Deep Learning has extensive capability to train models on large datasets with high computational power, so Deep Learning is suitable in real time seismology and earthquake prediction. Deep learning technology has recently been used to great success in image identification, natural language processing, object detection, motion modeling and other areas[7]. A deep learning algorithm's main concept is to extract features from low- to high-level data with different structures.

In the realm of machine learning, how data is represented, has a big impact on how well a model performs. As a result, developing appropriate data representations is a key part of building a high-performing model. Deep learning can learn these underlying representations or characteristics automatically from the data. The third wave of artificial intelligence research is being led by deep learning technologies.

Convolutional Neural Network (CNN): CNN[31,32] is a class of DNN which is commonly used in analyzing visual images. CNN has applications in image and video recognition, image classification, facial recognition, object identification, recommender engines, medical image analysis etc.

CNN is made up with layers and each layer uses a differentiable function to translate one volume of activations to another. CNN is made up of three main hidden layers: a convolution layer, a pooling layer and a fully connected layer, each with its own neuron arranged in three dimensions (width, height, depth). CNN is gaining popularity as a result of its remarkable effectiveness in resolving numerous issues. Facebook is an example of a firm that is using CNN for tagged face detection. It is also used by Google for photo searches and speech recognition. In addition, CNN's use in Spotify and the LINE Company is highly recommended in the majority of projects.

CNN was initially investigated for a scribbled postal code character. Because the results are promising and more efficient than previous research, CNN is now widely utilized in image recognition tasks such as object detection using a trained CNN classifier that is resistant to feature extraction from raw pixel values.

The CNN is then trained to estimate human stance. It has been used in emotion analysis, text categorization, translation and semantic segmentation tasks in natural language processing.

Conclusion

Among all natural calamities, earthquake is enormously dangerous and destructive due to its unexpected occurrence. An earthquake can demolish a major quantity of buildings, bridges etc. and results into loss of many lives. Most of the presented models used to predict earthquake give wrong warnings, consequently, poor prediction method cannot escape us from disastrous outcome of earthquake. The methods based on CNN twisted a novel span for betterment in forecast procedure because of its outstanding correctness in comparison to other techniques. These techniques can considerably decrease destructions.

To smoothen the progress of the prediction procedure, this study reviewed the methods for earthquake prediction, specially based on CNN. The aim of this review study was to show up the bang of CNN methods in seismic activities forecast that is definitely going to assist the experimenters to build up further precise techniques.

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