The Application of Machine Learning in Determining Earthquake Magnitude as an Early Warning

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Abstract. Since ancient times, earthquake disasters have always been one of the most harmful natural disasters, and it is necessary to reduce the damage caused by earthquakes effectively. The earthquake early warning is a new technology that has been gradually mature in recent years and can effectively reduce earthquake disasters. The ability to accurately and quickly predict the earthquake magnitude has become an important but difficult part of the earthquake early warning technology. Currently, many countries in the world have been engaged in the projects of establishing and improving the system of earthquake early warning, and completed two methods to predict the earthquake magnitude as a kind of earthquake early warning, namely, the method of characteristic frequency and the method of characteristic amplitude. In recent years, with the constant improvement of deep learning, the application of machine learning in determining the earthquake magnitude as an early warning has been showing great development prospects and application possibility.

1. Introduction
Earthquake early warning is a new technology that has gradually matured in recent years, which can effectively reduce earthquake disasters. However, it is important and difficult to estimate earthquake magnitude accurately and quickly in earthquake early warning technology. At present, many countries in the world have invested in the establishment and improvement of earthquake early warning system, and completed two kinds of earthquake early warning magnitude prediction methods: the characteristic frequency method and the characteristic amplitude method. In recent years, with the increasing improvement of deep learning, the application of machine learning in earthquake early warning magnitude determination shows great development prospect and application possibility. This paper mainly introduces the application of machine learning in earthquake early warning and the latest achievements.

2. What is Earthquake Early Warning?
After an earthquake happens, a warning will be given, known as the earthquake early warning. After the earthquake occurs, energy will be transmitted to all directions in the form of waves which mainly include the surface waves, the shear waves and the push-pull waves. In terms of the propagation speed, that of P waves (push-pull waves) is obviously higher than that of S waves (shear waves), and that of S waves (shear waves) is also higher than that of surface waves. In terms of the damage degree caused by the carried energy, that of surface waves is far less than that of S waves, and that of S waves is also less than that of P waves. In addition, the propagation speed of electronic signals is way higher than that of seismic waves. According to the speed difference of the seismic waves and the advantages of the propagation speed of the electronic signals, the system of earthquake early warning can release early warning information for people before “the destructive waves” of the earthquake arrive.

Figure 1. Schematic Diagram of the P Wave and the S Wave in the Earthquake

3. Traditional Ways of Determining Earthquake Magnitude as an Early Warning

3.1 The Class Method of Characteristic Frequency

An algorithm proposed by Nakamura (1988) to calculate the predominant period of the earthquake motion by using the real-time velocity was called as the τpmax method. On the basis of this method and in order to solve its limitations, Kanamori (2005) proposed an improved method to calculate the characteristic period, namely, the τc method. Its calculation formula is as follows:

$$\tau_c = \frac{2\pi}{\sqrt{r}}$$

$$r = \frac{\int u(t) v(t) dt}{\int u(t)^2 dt}$$

In the above τc formula, U is the surface displacement recorded by the vertical component of the seismic station, V is the velocity of the surface displacement recorded also by the vertical component of the seismic station, and the coefficient R, obtained after calculation, is an estimation of the quadratic of the characteristic frequency. The integral interval represents the selected duration of the adopted earthquake information which is calculated initially from the time when the station is triggered.

3.2 The Class Method of Characteristic Amplitude

The Pd method has the best effect in the characteristic amplitude algorithm. The Pd method is generally defined as: the displacement peak value, obtained after the filtration with the second-order Butterworth
high-pass filter (with a common low cut-off frequency of 0.075Hz), is adopted by the displacement records of the vertical component of the station in the time window of 3s after the P wave is triggered (Wu et al., 2007; Wu and Zhao, 2006). The Pd parameter can not only reflect the earthquake magnitude, but also reveal the certain peak ground velocity (PGV) and peak ground acceleration (PGA) of the earthquake. Due to the little impact of regional differences on the Pd parameter, it can also be used as an effective action parameter to determine the earthquake magnitude in the early warning of the earthquake. The relationship between Pd, Mw and PGV is shown in the following formula:

\[
\log(P_d) = A_1 + A_2 M_w + A_3 \log(R),
\]

\[
\log(P_d) = B_1 + B_2 \log(PGV).
\]

In the above formula, Mw is the moment magnitude, and Ai and Bi respectively represent the coefficient of the linear relationship between Pd and Mw and between Pd and Pd in local areas.

4. Determining Earthquake Magnitude as an Early Warning with Machine Learning

4.1 What Is Machine Learning?

The classic artificial neural network architecture is a kind of shallow network structure, while with the computer power continuously developing and the technology of large data analysis constantly turning mature, the concept of DNN (Deep Neural Network) also entered into people’s horizons. Hinton and Salakhutdinov (2006) put forward the idea of adopting the DNN which integrated a large number of hidden layers to extract the abstract attributes and could also recognize its characteristics, so as to lay a good foundation for people to complete the tasks such as classification, regression, visualization and high-latitude modeling. DNN symbolizes a great step in human history and a major breakthrough in machine learning which opens the door to deep learning.

In a broad sense, machine learning is a method that can give a machine the learning ability to complete the functions that cannot be completed by direct programming. However, in the practical sense, machine learning is a method that trains the model by using data and then uses the model to predict. “Training” and “prediction” are two processes of the machine learning, and “the model” is the intermediate output of the process. “Training” produces “the model” which guides “prediction.”

Machine learning is a method in which the computer uses the existing data (the experience) to obtain a certain model (the belated law) and then uses this model to predict the future (whether belated or not).

4.2 The Classification Application of Machine Learning

4.2.1 From the perspective of the task type, the models of machine learning can be divided into the regression models, the classification models and the structured learning models. The regression models are also called as the prediction models, the output result of which is a numerical value that cannot be enumerated. The classification models are also known as the binary classification models and the multi-classification models. The common binary classification models have the problem of filtering spam mails, while the common multi-classification problems have the problem of automatically classifying the documents. The output result of the structured learning models is no longer a value of a fixed length, such as the semantic analysis of an image, but a verbal description of the image.

4.2.2 From the perspective of the method, there are two kinds of models: the linear models and the nonlinear models. Although the linear models are relatively simple, their role cannot be ignored. The nonlinear models are based on the linear models, and most nonlinear models are obtained through transformation after being built on the basis of the linear models. The nonlinear models can be divided into the traditional machine learning models, such as the SVM, the KNN and the decision trees, and the deep learning models.
4.2.3 From the perspective of tracing learning theory, the machine learning models can be regarded as the supervised learning, the semi-supervised learning, the unsupervised learning, the transferred learning and the reinforcement learning. The supervised learning occurs when the training sample sets are labeled; the semi-supervised learning occurs when part of the training sample set has labels, and part without labels; the unsupervised learning occurs when the training sample sets are all unlabeled. The transferred learning is used to transfer the trained model parameters to the new model to help the training of the new model. The reinforcement learning is the optimal policy for learning which enables the agent to take actions according to the current state in a specific environment, so as to obtain the maximum rewards. The biggest difference between the reinforcement learning and the supervised learning is that there is no right or wrong decision each time, and it just means to get the most accumulated rewards.

Figure 2. Schematic Diagram of the NN Neural Network

Figure 3. Route Chart of the Machine Learning (Different colors represent different learning theories: orange represents the task, green the method and blue the prediction.)

5. Summary and Conclusion
Although there is still a long and difficult way for the development of earthquake early warning, human never stop in their exploration of true knowledge, and the emergence of machine learning at the historic moment has also brought new direction and hope for the earthquake early warning. Even though the
application of machine learning is not yet mature in earthquake early warning, and in the selection of algorithms and the selection principles of data, even in the explanation of the following physical principles, there are still many problems to be solved urgently, great success has been made in feature extraction, automatic processing and trend prediction. Hu and Zhang et al. have already proposed the new train of thought to use the class algorithm of machine learning to solve and optimize the predicted earthquake magnitude in the early warning system of the earthquake emergency, designed two kinds of neural network models, and realized one of them. Compared with the existing single-station prediction algorithm of earthquake magnitude, the neural network model with NN network as its basis has a better effect. In the approaching big data era, with the constant improvement of the deep learning framework, the application of machine learning in earthquake early warning has a very broad development prospect.

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**References**

[1] Allen R M, Kanamori H. 2003. The potential for earthquake early warning in Southern California. Science, 300(5620): 786-789.

[2] Hao Meixian, Zhou Yinxing, Zhang Jianzhong, Zhang Ke, Yin Zhanjun, etc. Earthquake in China Application of τC method in early warning magnitude calculation in Inner Mongolia region 2020, 36(01), 136-145.

[3] Jinxian, Zhang Hongcai, Li Jun, et al. 2012b. Study on the determination method of earthquake magnitude for earthquake early warning, 34(5): 593-610.

[4] Olson E L, Allen R M, 2005. The deterministic nature of earthquake rupture. Nature, 438(7065): 212-215.