Seismic event detection in time-frequency domain with CNN and phase picking with HED

*Liping Fan[1]

1. Institute of Geophysics, China Earthquake Administration

The P-wave and S-wave arrivals are critical data in seismic research. The quantity, accuracy and consistency of these greatly affect the final result of imaging of faults, earthquake early warning, and the inversion of Earth structure. Generally, earthquake phases are picked manually by analysts. On the one hand, poor data consistency maybe exists resulting from changes of analysts; on the other hand, the amount of seismic data increases exponentially, and it overwhelms analysts. It is urgent to develop an efficient and stable method of event detection and phase picking.

Traditional automatic event detection and phase picking methods are mainly divided into two categories: 1) Methods based on waveform characteristics such as amplitude, frequency and waveform envelope, which are the STA/LTA method, the regression method, the high-order statistics method, the main cycle method, the envelope function method, and the neural network method; 2) Various waveform correlation methods proposed according to waveform similarity, such as the waveform autocorrelation technique, the template matching technique, and the fingerprint and similarity threshold (FAST) method. Although these methods have achieved great success, they still have inherent disadvantages. For example, it's hard to set the threshold relative to varied noise level in the LTA/STA method; detected earthquakes in the template matching method are restricted to locations of the template earthquake position. Methods extracting waveform features automatically independent of the noise level and waveform similarity meet our requirements.

Deep Neural Network (DNN) is a breakthrough in feature learning methods in recent years. It has excellent automatic feature learning ability and the model is able to represent the essential characteristics of the data. Perol et al. trained a convolutional neural network for earthquake detection (ConvNetQuake), which gives a higher efficiency and precision than previous traditional methods. Ross et al. gave a convolutional neural network to detect seismic body-wave phases. Dokht et al. divided the automatic earthquake phases detection process into two steps: a pretrained model detecting earthquakes from continuous waveforms in the time-frequency domain and a supervised classification system discriminating between P and S waves. The first-part model enhanced the detection accuracy compared with ConvNetQuake. Inspired by the work of Dokht et al. and the latest progress in edge detection algorithms (the holistically-nested edge detection method), we propose a two-step phase picking framework. It is a former convolutional neural network for earthquake detection and a later network based on holistically-nested edge detection method (HED) for phase picking.

The data set used for training earthquake-detection model is 7,719 earthquake waveforms recorded by Xichang seismic array in Sichuan province of China during January 2013 to December 2016. The local magnitudes M_L range from -1.1 to 5.8. The number of noise records is 7,000. The time window length is 40 seconds. These earthquake waveforms are preprocessed by the following steps: removing instrument response, high-pass filtering above 1Hz, manually checking and removing low quality data, short-time Fourier transforming and normalization. The network contains 4 convolutional layers, 4 max pooling layers and 2 fully connected layers. The amount of P-wave arrival is 40,464 and that of S-wave arrive is 39,967. Ground truths of those 10-seconds-length windows are used for training network for phase picking. This network structure is built based on VGG16.

Providing continuous waveforms to seismic event detection model as input, it gives the start time of detected event windows. Feed these detected windows to the phase picking model and it export time of phase arrivals. Our models detect more seismic events and pick more accurate arrival time in comparison with previous models.

Keywords: event detection, phase picking, convolutional neural network, holistically-nested edge detection method