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Research paper

Single Layer Recurrent Neural Network for detection of swarm-like earthquakes in W-Bohemia/Vogtland—the method

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ABSTRACT

In this paper, we present a new method of local event detection of swarm-like earthquakes based on neural networks. The proposed algorithm uses unique neural network architecture. It combines features used in other neural network concepts such as the Real Time Recurrent Network and Nonlinear Autoregressive Neural Network to achieve good performance of detection. We use the recurrence combined with various delays applied to recurrent inputs so the network remembers history of many samples. This method has been tested on data from a local seismic network in West Bohemia with promising results. We found that phases not picked in training data diminish the detection capability of the neural network and proper preparation of training data is therefore fundamental. To train the network we define a parameter called the learning importance weight of events and show that it affects the number of acceptable solutions achieved by many trials of the Back Propagation Through Time algorithm. We also compare the individual training of stations with training all of them simultaneously, and we conclude that results of joint training are better for some stations than training only one station.

1. Introduction

Automatic seismic event detection is crucial in seismic data processing. Generally, seismic stations record huge volumes of continuous data which can be evaluated either automatically, or manually, or both. Effective manual processing inevitably requires excellent automatic event detection. We apply the method presented here to the earthquake swarm region in West Bohemia. During the swarms we have to process a large number of events which occur during short periods of time (i.e., hundreds of events per day). It is excessively time consuming to process events manually, and yet swarms are still processed this way. In past years short term averaging/long term averaging (STA/LTA) triggered recordings with coincidence on stations through the network were used. The number of the triggers was much higher than the number of local events (it also contained regional or teleseismic events and quarry blasts, storms or coincidental disturbances). On the other hand, during the swarms some weaker events were missing. That necessitated the use of a reliable automatic detector of local seismic events. In this paper we present the use of the Artificial Neural Network (ANN) to distinguish between disturbances (any signal except for local events) and local events.

After good detection the event could be then processed further manually or automatically. Firstly, the P-and S-phases are picked, the event is localized and the focal mechanism is computed. But with very weak events this task might even be impossible. Then detecting the event can indicate useful local seismic events which may be beneficial to complete the event statistics, i.e., lower the magnitude of completeness in a range which is unrealizable manually.

2. Brief overview of the detection approaches

Automatic processing of seismic events could be performed in different ways. The first approach accords with the steps of manual processing. Initially, an event must be detected, then the P- and S-phases are picked and the location of the event is computed using those picks (as in Sleeman and van Eck, 1999). In the second approach, a search is made for all possible phases to combine them to satisfy the events, which are subsequently located (Le Bras et al., 1994; Dietz, 2002; Fischer, 2003). During the third approach a search is made through all possible hypocenters ensure concurrence with real data, and an event is declared without picking

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(Withers et al., 1999; Kao and Shan, 2004). We apply the first processing scheme which begins with detecting an event.

There are several methods of detection, which can be sorted into the time domain methods, the frequency domain methods, particle motion processing, and pattern matching (Withers et al., 1998). All groups of detection can be achieved through the Artificial Neural Networks. The advantage of ANN detection methods is the ease of adjusting parameters of detection by training in the ANN. Consequently, a detailed description of what are common features for events, or on the other hand, what are the most significant differences between events and disturbances, are not required. Therefore, ANNs were widely used for seismic event detection or phase picking. ANNs were applied to detection in the time domain (Wang and Teng, 1995, 1997; Gentili and Michelini, 2006), the frequency domain (Wang and Teng, 1995; Tiira, 1999), as well as pattern matching (Madureira and Ruano, 2009; Tiira, 1999). Mostly all of these methods are based on feed-forward multi-layer-perceptron (MLP) networks with one hidden layer, where the ANN is fed by moving window vectors. Wang and Teng (1995) compared the detection performance of two ANN detectors with MLP architecture. The first was fed by consecutive samples of STA/LTA of the whole full frequency band signal, while the input of the second one was samples of moving window spectra. The authors concluded that a spectral content must be considered for successful detection. The work of Tiira (1999) uses MLP fed by STA/LTA of different lengths in seven frequency bands to detect teleseismic events. He also experimented with recurrent networks having one state neuron—Elman (1990) and Jordan (1986) networks but both performed worse than MLP. Madureira and Ruano (2009) designed an MLP network whose inputs are frequency samples in consecutive time windows.Another solution to incorporate the history of the signal is to use a network with recurrent neurons (Tiira, 1999; Wiszniowski et al., 2014). Detection of small local events by a Real Time Recurrent Network (Williams and Zipser, 1989) was undertaken by Wiszniowski et al. (2014). The network with 17 inputs of STA/LTA in narrow frequency bands and 12 recurrent neurons with one step delay compared to STA/LTA with filtration and proved to be better especially when signal to noise ratio was small. Nevertheless, the result shows the rapid forgetfulness of a recurrent network with single delay units, which limits discrimination in the time domain.

The method introduced is applied to data from the West Bohemia earthquake-swarm region, which is now automatically processed by two algorithms. The first (Fischer, 2003) is based on looking for all possible phases first, searching for such groups of picks that will comprise a local event. All events with small number of picks or with large residual of locations are then removed. The other method uses automatic locations from Antelope software. Antelope locations are usually more scattered and many smaller events are omitted.

3. Data

A local seismic network WEBNET (operated by the Institute of Geophysics, 1991 and Institute of Rock Structure and Mechanics of the Czech Academy of Sciences (CAS)) has been monitoring the seismicity in the West Bohemia earthquake-swarm region since the 1980s. At present there are a total of 22 seismic stations. They operate in two different data-transfer regimes. The first one is an on-line data transmission mode used at 13 stations, and the second one is an off-line data collection mode used on the 9 remaining stations. Available immediately are data from on-line stations (Fig. 1), while off-line stations data are collected while visiting the sites. Until upgraded in 2015, the stations were equipped with short period seismometers, mostly SM3, LE-3D and one broadband CMG-40 T seismometer. Since we want to apply our method to a quick estimation of current activity, we use on-line stations only.

All data used are continuous three component ground-velocity records sampled at 250 Hz. Until 2013 some of the stations were operated in triggered mode only and we do not use them (KOC, LAC, TRC, NKC). During more than 30 years of observation several earthquake swarms were recorded well (Horálek et al., 2000; Čermáková and Horálek, 2015). The most recent installed station (in 2006) is ZHC (see Fig. 1), therefore we focus on activity since 2006. We chose the swarms in 2008 and 2010 without swarm-like seismicity as training data and the swarm of 2011 to test the results.

In addition, we use manual P- and S-wave picks that serve to

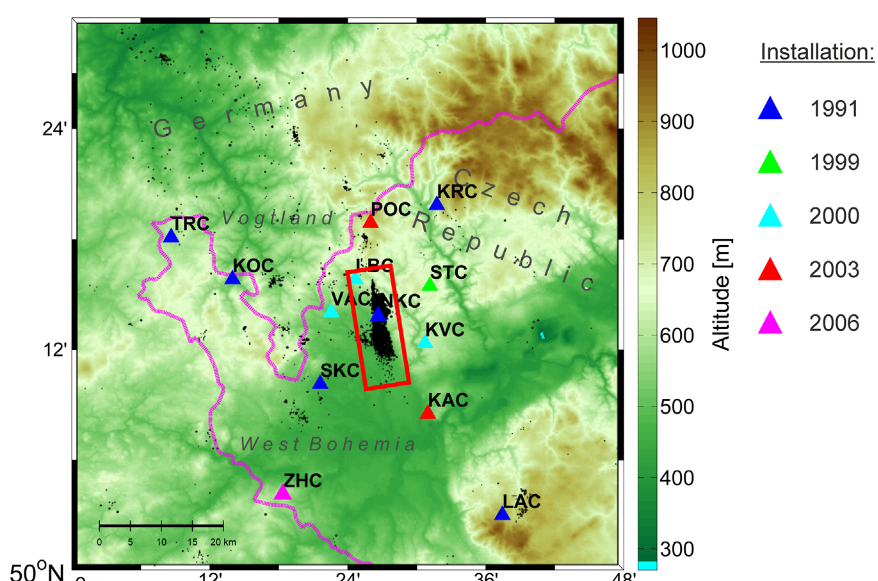

Fig. 1. On-line stations of WEBNET (triangles) and epicenters (black dots) of the swarm-like events in West Bohemia and adjacent territory of Germany. The red rectangle marks the main epicentral area where more than 90 percent of events have occurred in the last 30 years. The years of getting the individual stations into operation are indicated by colors. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)