

Modeling of time series structure of seismic waveforms based on hidden Markov models

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Modeling of time series structure of seismic waveforms allows to quantitatively evaluate time-series characteristics of waveforms or obtain clues about physical processes of earthquake generation. Modeled time series structure leads to phase detection, event classification, analysis of frequency structure, analysis of rupture process, and waveform synthesis. Hidden Markov model (HMM) is one of the typical methods for modeling time series structure statistically from observation data. In this study, we focus on phase detection and develop a new automatic detection method for first arrivals of P and S wave based on time series structure modeled by HMM. The new method is expected to demonstrate higher detection capability than conventional methods because information about time series of seismic events is incorporated directly in the new method.

Seismic events which occur in Ashio area (the western part of Tochigi Prefecture) at depths of 0 to 15 km are modeled in this study. Energy, polarity and higher order statistics are extracted as features from about 1,000 clear event waveforms observed from 2009 to 2011 at E.ASO, which is one of the observation points in Ashio. Three HMMs which represent noise, P wave and S wave are constructed from time series of the extracted features. A HMM which represents time series structure of event waveform is obtained by connecting the three HMMs. Detecting first arrivals of P and S wave of given seismic waveform is performed by inferring hidden states of the HMM from the waveform.

The automatic detection method based on HMM is compared with another method based on changes of amplitude and frequency (STA/LTA-AR method) using about 1,000 clear event waveforms observed in 2012 at E.ASO. For P wave, phase picking accuracy of the HMM-based method is equivalent to that of STA/LTA-AR method. For S wave, phase picking accuracy of the HMM-based method is higher than that of STA/LTA-AR method. It is thought that this high detection capability for S wave results from the process of detecting S wave arrival after recognizing subsequent waveforms of P and S wave.

Keywords: hidden Markov model, time series structure, automatic detection, seismicity