Signal detection by amplitude distribution and Kullback-Leibler divergence

*Mitsutaka Oshima[1], Hiroshi Takenaka[2]

1. Shimizu corporation, 2. Okayama university

A variety of methods have been proposed to detect seismic signals from records of seismometers. We have developed a signal detection method that uses amplitude distribution (probability density function: PDF) of seismic records and Kullback-Leibler divergence (KLD) (Oshima and Takenaka, 2020). Records of seismometers that contains no seismic event are comprised of microtemor and electric noises. Namely, such records are assumed to be a summation of random noise. In contrast, according to Fermat’ s principle, the initial portion of seismic waveforms of epicentral distance up to about 100 km is constituted by direct wave that propagated through the shortest path from hypocenter to station. In telecommunications engineering, the sum of random phase waves is called as Rayleigh fading and Rayleigh distribution is known as a PDF of absolute amplitude for Rayleigh fading. According to scattering theory in seismology, the PDF of absolute amplitude for coda waves are shown to be a Rayleigh distribution. On the other hand, the central limit theorem says that the PDF of the sum of samples extracted from independent and identically distributed data becomes a Gaussian distribution. Taking this into account, the PDF of the amplitude of records of seismometers can be approximated by Gaussian or Rayleigh distributions, except the initial part of seismic waves. In information theory, Gaussian distribution is deduced as the statistical distribution with maximum entropy in all of the statistical distributions of the same average and standard deviation. This means that the seismometer records with PDF similar to Gaussian distribution contains no rare phenomenon (e.g., seismic signal emitted by an earthquake) that makes entropy small. Taking the aforementioned theoretical backgrounds into consideration, Oshima and Takenaka (2020) have developed a method to find signals of seismic events in seismometer recordings. The method by Oshima and Takenaka (2020) catches signals of seismic events by following 4 steps. 1. Estimate PDF of amplitudes of seismic records within a time window. 2. Calculate the Gaussian or Rayleigh distribution that have the same average and standard deviation as that obtained at step 1. 3. Quantify the dissimilarity of two PDFs obtained in step 1 and 2 by using KLD. 4. Repeat step 1 through 3 while shifting the time window from the start to the end of the seismometer records. The gained KLD time series takes a large value when the PDF of the seismic records deviates from Gaussian or Rayleigh distributions, namely around the arrival time of seismic waves. Hence we can detect signals of seismic events by searching the peaks of the KLD time series. In our presentation, we show examples of the application of the method.

Acknowledgement: We would like to express our gratitude to NIED for providing us with KiK-net data.

Keywords: signal detection, probability density function, Kullback-Leibler divergence

