Wavelet analysis of seismograms recorded by home seismometers

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Using real-time seismic data from the Hi-net array, Horiuchi et al. (2005, 2006) were able to developed a highly effective earthquake early warning system. This research will be further advanced (Horiuchi et al. 2007, this meeting) by the promotion of an ultra-dense (nationwide) nongovernmental seismic network. This network will be comprised of IT-adapted, household-installed low-price seismometers, data centers operated by private enterprises, and technical support from groups at NIED and IT companies. The environment of a home seismometer will contain common household noise, traffic noise and industrial noise; noise levels of this new type of seismometer will be 2-3 orders larger than that of Hi-net. Conventional methods of noise suppression may not be applicable here and therefore new techniques are required to analyze seismograms recorded by home seismometers.

Real-time Monitoring. In the case of a real-time monitoring system, the short time Fourier transform (STFT) has been used to detect the source from the ambient noise since the spectrum of the seismic signal is temporally localized whereas certain kinds of background noise are usually contained within specific frequency bands (e.g. earthquakes from volcanic activity). In contrast to STFT, which uses a single window for analysis, the wavelet transform is a more general method to simultaneously analyze the local spectral and temporal information within a signal, since short windows at used for high frequencies and long windows for low frequencies. For example, using the wavelet transform, we could easily detect the seismic signature of the deadly Saroma, Hokkaido tornado (Nov. 3, 2006) from the seismograms recorded at the closest Hi-net station; the signal was less clear when STFT analysis was used. Moreover, the wavelet transform can use various shaping functions that are already available, thus allowing the choice of the most appropriate function for the signal under investigation, in contrast to Fourier analysis that relies on sinusoids of varying frequency.

De-noising. Using a method of sub-band coding, the discrete wavelet transform (DWT) can decompose a discrete digital signal into subsets of translated and dilated parent wavelets, octave by octave. Because of the linearity of the DWT, small details in a signal are transformed into small magnitude coefficients in the wavelet domain; insignificant details can therefore be reduced by truncating the coefficients below a certain magnitude threshold. If the small signal details are mostly noise, then the inverse wavelet transform returns a de-noised signal. Previous studies have shed light on discriminating seismic signals from background noise and these studies have helped us develop a method to de-noise home seismometer records. Instead of assuming a certain noise model, here we introduce the reference noise levels by applying the DWT to background noise (i.e. records without seismic signals) and take the maximum value of the coefficients at each level as a reference. We take these reference values as thresholds and simply set to zero the coefficients of the seismic signal decomposition that are smaller than the reference values at each level (or certain levels). We applied this method to the records from home seismometers with earthquake occurrence and successfully obtained clear waveforms (bottom in Fig.1) from large background noise (top in Fig.1). The method can be much improved by constructing a proper noise model from the reference values for each station after we have collected a sufficient number of records.

Wave decomposition. The de-noised seismograms can be further analyzed by Fourier analysis or wavelet analysis, which can decompose the seismograms into the dominant waveforms at the expected seismic frequencies. These calculation are straightforward and applicable to the analysis of seismic waveform data obtained from real-time warning systems.