Abstract

Cases occur in which the signal, one is interested in, is superposed with periodic noise. This work is motivated by the perspective of supporting the Comprehensive Nuclear-Test-Ban Treaty Organization. During on-site inspections, seismic signals can be measured to detect aftershocks of an underground nuclear explosion in order to locate the hypocentre precisely and allow for instance the taking of samples. Aftershocks are weak and can be masked by signals produced on/above the surface, in particular, periodic ones from engines. Aftershock signals are profoundly non-periodic, whereas many anthropogenic signals are mostly periodic. Therefore, the removal of periodic disturbances will increase the signal-to-noise ratio. We are developing algorithms capable of reducing such disturbances.

The Fourier transform can distinguish between period and non-periodic signals. Periodic signals can be represented by sums of monofrequent sinusoids – their characterisation and removal has been proven to work earlier. This work describes and evaluates a procedure which includes linearly in time changing frequencies, processes a time interval of arbitrary length and provides the noise-reduced data.

At first, an analytic function is derived for the Hann-windowed discrete spectrum of a sine with linear frequency shift (LFS), defined by the four parameters amplitude, initial phase, initial frequency and frequency-change rate. This function is fitted to the complex values of the magnitude peaks in the spectrum. If successful, the peaks are removed successively by subtraction of the spectrum of an LFS sine with the corresponding parameters.

The curve progression of (LFS) sines in the spectral domain is illustrated and the influence of the parameters on the complex spectrum is investigated. The revealed dependencies can be reverted in the sense that characteristics of the curve progression are extracted and utilised to estimate the start parameters for the following fitting.

The success of the characterisation and removal is tested with synthetic (LFS) sines, sometimes superposed on pulse signals or Gaussian white noise. In order to quantitatively evaluate the fit results, three measures are introduced: the sum of squared deviations between spectral peak and (LFS) sine, the root-mean-square value of the difference between reconstructed and original signal in the time domain, and the absolute value of a four-component vector containing the deviations between input and fit parameters. However the latter two require the knowledge of the input values, which are not available if processing real data. Combinations of parameters and different levels of Gaussian white

noise are used to define the receiver operating characteristic in the form of thresholds for the first measure.

Then the algorithm is applied to real data. The principal procedure is demonstrated by adding pure synthetic LFS sines to a real seismic event of a coal mine, the resulting peaks in the spectrum are precisely fitted and subtracted resulting in minimal changes between original data and reconstructed ones even if the LFS amplitude is five orders of magnitude stronger than the event.

In a next step synthetic sounds played via a speaker and measured seismically and acoustically are investigated. Fits on narrow peaks are very successful both for acoustic and seismic measurements and the processed spectrum is reduced down to the background noise level. For the monofrequent case the peak magnitude is reduced by at least three orders of magnitude but the reduction factor might be principally unlimited, as indicated for synthetic superpositions. For sines with a strong LFS, the reduction is limited to 1.5 orders of spectral magnitude, probably caused by slight frequency dependencies in the transfer function between played signal and its measurement.

For real signals, all peaks which have been fitted successfully are reduced to the level of the background, but typically several smaller and sometimes even stronger peaks remain. On the basis of the acoustic signal of a propeller aircraft, the limitation of the described algorithm regarding peaks at the very margins of a spectrum is demonstrated. The acoustic data of a main battle tank are processed successfully in the sense of subtracting most of the strongest peaks. The non-periodic contributions remain in the signal – fitting to the goal of the work. The acoustic spectra of a helicopter signal recorded at close distance seem to contain peaks different from the ones of pure sinusoids, probably caused by second peaks at slightly differing frequencies. If a peak shape does not match the one of an (LFS) sine, the fit result is not very convincing; thus, strong (pseudo-)periodic components remain in the signal.

In sum, it is possible to reduce the periodic content of time-series data significantly. However, the signals of the vehicles analysed contain non-periodic components which remain in the signal. The achieved reduction of periodic content can increase the signal-to-noise ratio and therefore the chance to detect aftershock signals in data containing periodic disturbances.