Removing Periodic Noise to Detect Weak Impulse Events

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Exact Localisation of Underground Explosion

Teleseismic detections of an underground explosion result in localisation uncertainties on the order of 10 km. In order to find radioisotopes in the soil as indicators of a nuclear explosion, an CTBTO on-site inspection needs to localise the epicentre much better, maybe to around 0.1 km. For this purpose a local seismic network can be set up shortly after the event in the area of interest determined from teleseismic signals. The purpose is to detect weak aftershocks which will occur for several weeks – from cracking and falling rocks around and in the cavity. Extreme sensitivity is required to detect the weak aftershock signals.

Impulse Signals and their Spectra

Aftershock events are single impulses which change form during propagation due to different seismic wave types with different velocities and to reflection at layer boundaries. Nevertheless, seismic signals received retain the impulsive character. Their spectrum is broad-band (see impulse figures right of centre).

Masking by Periodic Noise

Seismic signals measured at the surface can be masked by periodic noise from machinery, road traffic, propeller aircraft or helicopters. In experiments, we have measured acoustic and seismic signals of tanks, trucks, propeller aircraft and helicopters. Spectra of periodic signals consist of discrete lines at the fundamental frequency and its harmonics.

Theoretical Expression for the Spectrum of a Sinusoid

Sinusoid in time domain: \( s(t) = A \sin(2\pi f_0 t + \phi) \)

Apply shah function

\[ b(t) = \begin{cases} 1 & \text{if } |t| \leq \frac{1}{2} \frac{T}{2} \\ \frac{1}{T} & \text{if } \frac{1}{2} \frac{T}{2} < |t| \leq \frac{1}{2} \end{cases} \]

Fourier transform: \( G(v) = \int_{-\infty}^{\infty} b(t) s(t) e^{-j2\pi vt} dt \)

Expression for complex spectrum (= discrete Fourier transform)

\[ G(v) = \frac{A}{\sqrt{\pi}} \int_{-\infty}^{\infty} \frac{e^{j\pi v t}}{\sqrt{2\pi}} \sin(\pi v t) e^{-j2\pi vt} dt \]

Subtracting a Theoretical Line

Various sets of lines were tested: harmonic series of 8 lines (“Line Series”), 8 lines at varying distances (“Line Series NF”), 10 lines with 3 close pairs (3 and 5 Hz mutual distance) (“Double Lines”), 25 Hz neighbour distance (“Double Lines NF”). Also, Gaussian white noise of rms value 0.5 and 2.0 Pa was added (“GWN”).

Testing the Performance

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Testing the Performance

An acoustic impulse is used as the test signal.

Fitting Line Parameters to a Given Spectrum

The three highest points have most of the power and are least influenced by lines at other frequencies. The line parameters frequency, phase and amplitude are fitted to these points by the non-linear Loeblen-Marquardt method. Start values for frequency and amplitude are gained from the three points. Various thresholds define when iterations are to stop and if a fit is acceptable.

To be accepted as a valid line for subtraction, a peak must fulfil the following criteria:
- It must have a minimum height above the background.
- Its width must be below a threshold.
- The theoretical line must approximate the peak well enough (normalised sum of squared deviations at the three highest points below a threshold).

Finding Lines in a Spectrum

Conclusions

- The present algorithm allows to reduce the contribution of periodic noise in synthetic signals by several orders of magnitude, promising detection of much weaker impulse-type events.
- Lines in spectra of real signals are not always found and fitted satisfactorily (not shown).
- There are possibilities for improvement: better inclusion of absolute phase, full inclusion of contributions centred at negative frequencies, better treatment of two neighbouring lines, adjustment of thresholds.
- The procedure is generic and can be applied to any kind of signal. Further research is needed to assess the performance limits in detecting seismic events in the presence of periodic noise.

Selected References