

Denoising of earthquake signals with CATS

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Summary

Denoising of earthquake signals is important for the improvement of signal-to-noise ratio (SNR) and waveform quality, which in turn can improve the quality of arrival time picking and, consequently, quality of the spatial localization, source mechanism inversion, and magnitude estimation of the detected earthquakes. We propose a denoising method based on Cluster Analysis of Trimmed Spectrograms (CATS), which provides a sparse time-frequency representation and can facilitate denoising. We test this technique on real earthquake signals from the Tower Lake area in Northeast British Columbia with different levels of additive random noise. Our results indicate that the CATS denoiser can robustly reconstruct earthquake signals in the presence of even strong random noise. However, the amplitudes of very weak parts of the signal may be distorted considerably.

Theory and Method

Denoising of earthquake signals aims at suppressing the background noise to improve signal-to-noise ratio (SNR) and waveform quality. The denoising can enhance arrival times picking (of P and S waves) with even standard methods (Akram & Eaton, 2016) and facilitate waveform analysis. This is essential for quality localization, source mechanism inversion and magnitude estimation of the detected earthquakes.

In this work, we propose a denoising method based on Cluster Analysis of Trimmed Spectrograms (CATS) introduced by Grubas et al. (2023). The CATS is a signal-processing technique which finds a sparse representation of continuous data by searching high-energy clusters in time-frequency domain. This can be used both for detection, as shown in (Grubas et al., 2023), and for denoising of earthquake signals, which we propose in this work. This approach of analyzing the time-frequency domain is similar to such methods as block thresholding (Mousavi & Langston, 2016) and sparse Gabor inversion (Bui et al., 2023). The CATS method is fast and accurate, providing a framework for quality control. It has only 8 input parameters: the length and overlap of STFT window, minimum SNR, noise stationarity window, minimum time duration and frequency width of a seismic event, minimum separation in time and in frequency of different events.

The workflow for denoising with CATS consists of four steps (see Fig. 1):

- (1) Short Time Fourier Transform (STFT) of the input seismic data to get spectrogram (Fig. 1.1).
- (2) Automatic noise estimation using B-E-DATE (Mai et al., 2015) and trimming the spectrogram by the estimated noise level (Fig. 1.2).
- (3) Clustering the trimmed spectrogram to get sparse representation (Fig. 1.3).
- (4) Inverse STFT of the sparse spectrogram (Fig. 1.4).

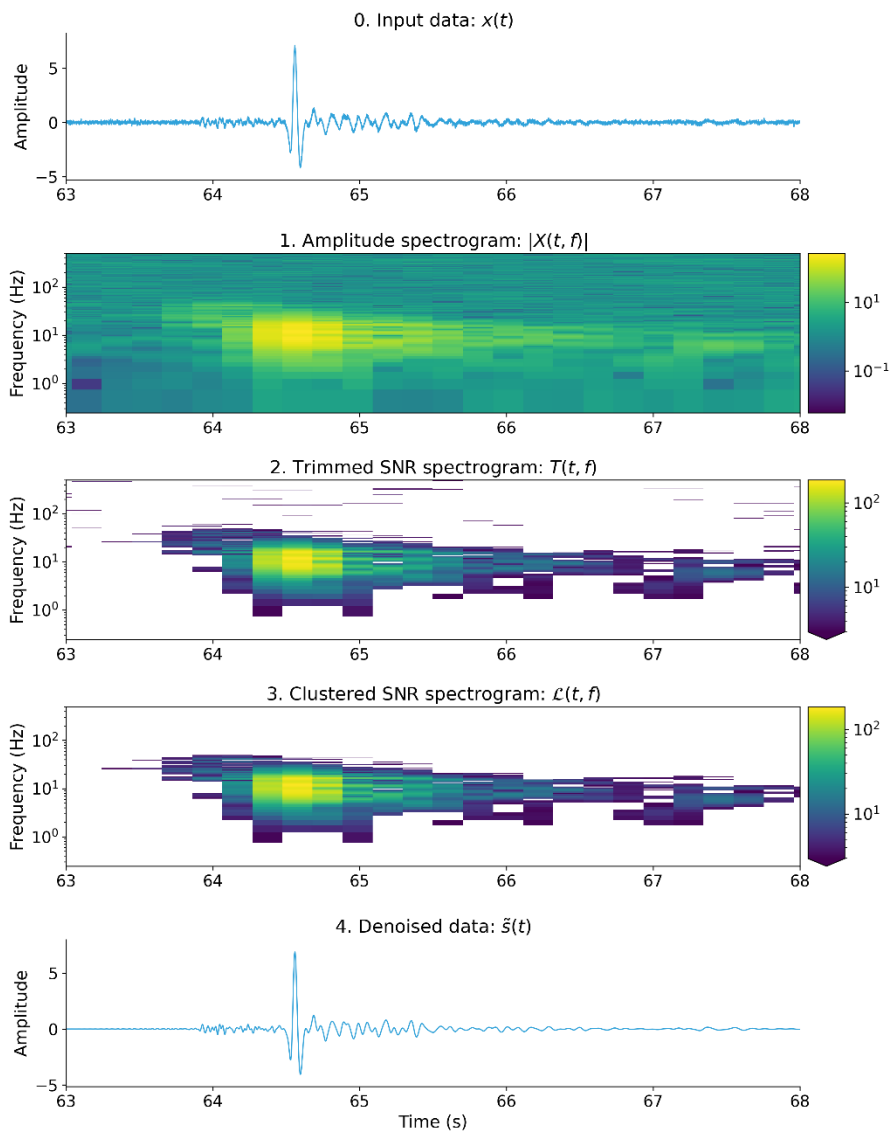


Figure 1. The demonstration of the denoising workflow with CATS applied to a sample earthquake signal from Tower Lake area in Northeast British Columbia (Kao and Venables, 2021) with 10% AWGN. The time shown is relative to the timestamp 16 hours 56 minutes 40 seconds (Apr 9, 2021), Easting component of station 001.

Results and Conclusions

We tested the denoising capabilities of the CATS technique on the same signal from Fig. 1 with different levels of additive white gaussian noise (AWGN). The noise level is measured as the ratio of standard deviations of the earthquake signal and noise in time domain. The denoising error is represented by the relative L_2 -norm of the error and the ground truth signal. The error is the difference of the denoised signal and the ground truth.

Our results are shown in Fig. 2 which showcases the denoising results for noise levels 10%, 30%, and 75%. The resulting denoising errors are 4%, 13%, 20% respectively. By comparing the denoised waveforms with the ground truth (the left panel of Fig. 2), one can see that the S wave was reconstructed with very good precision at all noise levels. The amplitudes of P-wave were more challenging due to much lower magnitude relatively to the noise, the denoising accuracy is in good agreement for 10% noise, but for 30% noise the accuracy deteriorates, and the amplitudes are distorted.

Thus, we can conclude that the CATS denoiser can robustly reconstruct earthquake signals in the presence of strong random noise. However, the amplitudes of very weak parts of the earthquake (likely P-wave but can be S-wave too) after denoising may be distorted considerably because the strong noise may significantly corrupt weak parts.

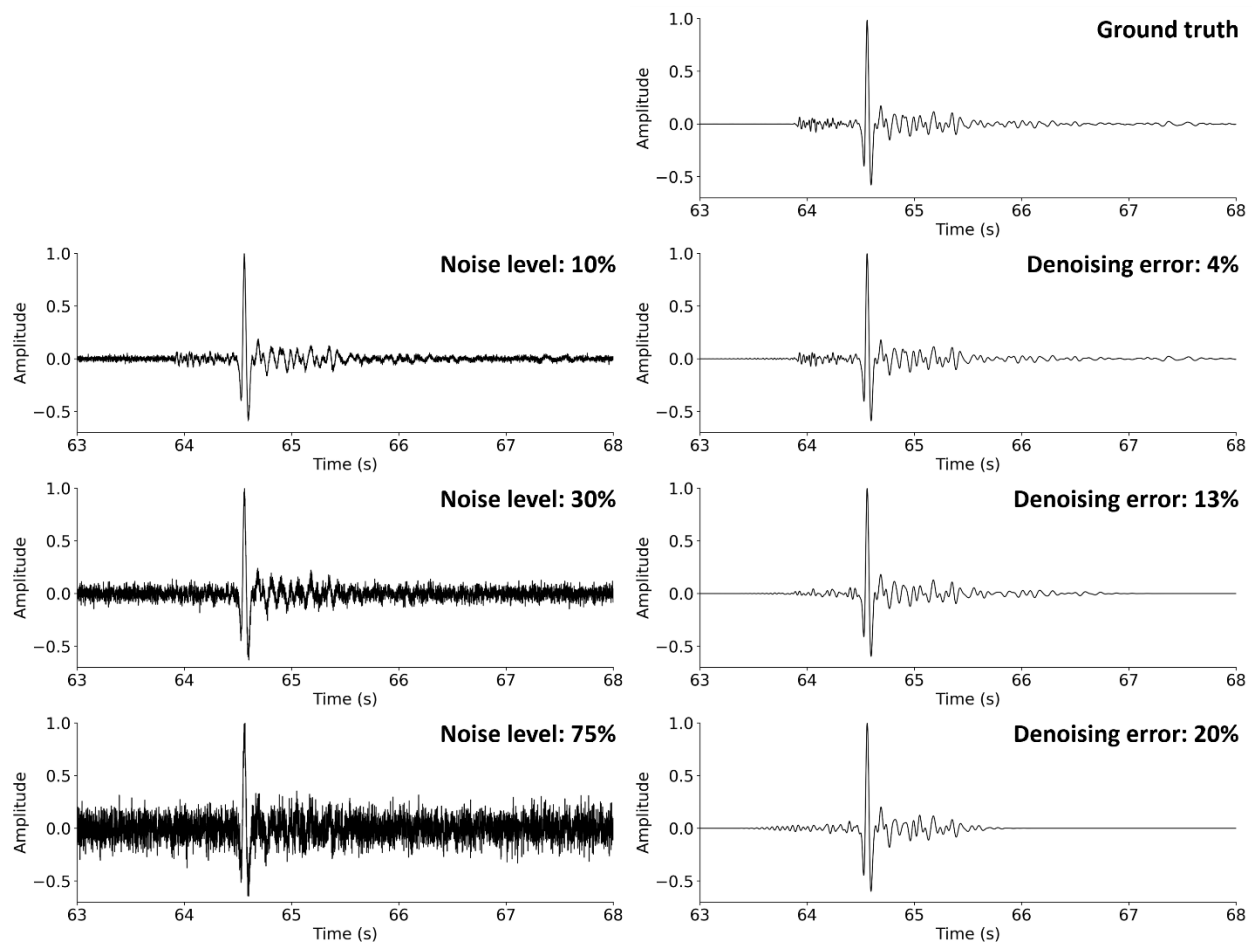


Figure 2. The results of the denoising test with additive white gaussian noise applied to the same signal from Fig. 1. The right panel displays the denoised signals, where the top right is the ground truth signal; the left panel is for the input noisy signals. P wave is visible at time ~64 sec, S wave is at ~64.5 sec.

Novel/Additive Information

We presented a novel approach for denoising earthquake signals based on cluster analysis of trimmed spectrograms. The proposed approach is fast, accurate, and provides framework for a straightforward quality control.

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