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A new method for microseismic event detection and automatic time picking

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Summary

Reliability of microseismic monitoring data interpretations is very much dependent on how accurate microseismic events are detected and picked. As microseismic monitoring data are mostly recorded for a long period of time (several days to years), and manual event detection and analysis is of subjective nature, existence of a time-efficient and accurate automatic event detection and picking algorithm is necessary. There are currently various algorithms available. The most commonly used one is Short-term Average and Long-term Average (STA/LTA) technique where ratios between energies within short and long moving windows are used as the criteria for detecting microseismic events. However, this algorithm may not work properly when the microseisms are not energetic enough with respect to the background noise. The method that we are proposing in this article does not suffer from this drawback. We use the idea that the average power spectral density (PSD) of the whole data (total PSD) is dominated by background noise not the events. Therefore, as long as the events' PSDs are different enough from the total PSD, we can use the crosscorrelation coefficient between the total PSD and the moving overlapping windows PSDs along the data as the criteria for picking the events. The PSDs are calculated using Short Time Fourier Transform (STFT). The maximum crosscorrelation values are normalized and then subtracted from 1 so that the highest values would correspond to times and windows containing events while the lowest values are related to windows containing background noise only. Since the correlation values do not depend on the energy levels, this method is expected to detect weak events more accurate than the STA/LTA technique. An example is presented to demonstrate the methodology. We show how this technique can detect and pick microseismic events or any event whose PSD is weakly correlated with the ambient noise PSD such as perforation shots or transients. We also describe how window size may affect picking accuracy.

Introduction

Microseismic monitoring involves the acquisition of continuous seismic data for the purpose of locating and characterizing seismic activity (microseismic events) induced by fracturing. The most common application of this technique is imaging hydraulic fracture stimulations where fractures are created due to injection of fluids under high pressures into unconventional reservoirs. Microseismic monitoring differs in many respects from seismic surveys that are traditionally used for oil and gas exploration and development, including the type of source, the receivers and methods of analysis. Microseismic data are typically broad-band (10-1000 Hz) and recorded at high sampling rates with 3-component surface and/or borehole receivers. A crucial step in the processing of microseismic monitoring data that significantly affects the interpretation of results is event detection. As microseismic data are mostly acquired continuously for a long period of time, an automatic event detection algorithm is required to make this process economic in terms of computation time and effort. There are a great number of event detection and time picking algorithms available. The most common method is the short-term and long-term average (STA/LTA) technique (Allen, 1978) in which the ratio between the average energy in a short-term average (STA) leading window and a long-term average (LTA) is used as a criterion for event detection and picking. The disadvantage of this method is that it cannot pick weak events whose energies are very close to that of background noise. In the current method we use the fact that the average power spectrum density of the data is dominated mostly by the ambient noise and is quite different from that of microseismic events. Therefore, depending on how different the power spectra of microseismic events and the average ambient noise are, the crosscorrelation value between power spectra of different data windows and the average power spectrum could act as the criterion for detection of events. Since the crosscorrelation values are controlled by the similarity between the power spectra not the energy levels, this method is preferred over the STA/LTA technique when weaker events are to be detected.

Theory and Method

Calculating the noise power spectral density (PSD) is a common method for quantifying seismic background noise. To compute the PSD's we used STFT analysis (McNamara and Buland, 2004). The preprocessing steps we applied to calculate the average PSD of the data include: windowing the data into small segments, removing the mean and trend from these segments, and multiplying them by Hanning windows of the same length. The windows are overlapped by 50% in order to lower variance in the PSD estimates. The window length should be selected carefully so that we have enough temporal and spectral resolution to pick the events. The time and frequency resolution are inversely related so that increasing one of them will cause the other one to reduce. Therefore, a compromise should be made. Elimination of trends prevents the distortions in spectral processing. By applying the Hanning tapers the Fast Fourier Transform (FFT) estimates are smoothed and the impact of discontinuities between the beginning and the end of time segments is decreased. The FFT's of these preprocessed segments are computed, squared and then normalized to get their estimated PSD's. These PSD's are then averaged to obtain the total PSD estimate of the data. The spectra are presented in units of decibels referred to 1 m2/sec2/Hz as a function of frequency.

As the data mostly consist of background noise, the total PSD estimate is dominated by background noise PSD's. The PSD estimates of the preprocessed windowed segments are crosscorrelated with the total PSD estimate. Since microseismic events usually represent quite different spectra than the ambient noise, the crosscorrelation values, when normalized and subtracted from 1, have their maxima at times that the moving windows contain microseisms or events (such as perf shots, transients etc.) with different PSD responses than the total PSD estimate. In contrary to the STA/LTA technique, the current method is expected to detect even weaker microseismic events, as long as theirs PSD is different enough from the total PSD estimate.

Examples

The microseismic data used for this study are the recordings of a borehole array consisting of six 3-component low-frequency (4.5 Hz) receivers from Spectraseis deployed in a slightly deviated monitoring well measured during the Rolla Microseismic Experiment (RME). RME is a major field program undertaken by the Microseismic Industry Consortium August 7-28, 2011 to record a multistage hydraulic fracture stimulation of a Montney gas reservoir in northeastern British Columbia. A plan view of the acquisition geometry and a cross section of the wellbore array are shown in Figure1a and 1b, respectively.

The procedure mentioned in the previous section is applied to the vertical component recording at the shallowest receiver which is located at 1668 m deep, as shown in Figure 1b. Figure 2a displays the average estimated PSD for the whole vertical component recording during 5 days of monitoring, calculated with the method described in the previous section. The calculated PSD's for all overlapping windows are plotted in Figure 2b in different colours. The sampling time interval is 0.5 msec. The window length used in this figure is 0.5 seconds which is close to the typical duration of microseismic events. This window length provides enough frequency resolution to represent the time series and enough time resolution to detect the events. Figure 3a shows an hour of data right after the fourth fracing stage. In this example, A is related to the perforation shot response, B and C are microseismic events corresponding to this injection stage at this data segment, and D1 and D2 are thought to be instrument glitches related to the digitizers. Figure 3b demonstrates a closer look at B where we actually see 4 microseimic events (B1, B2, B3 and B4) appearing at short time intervals.

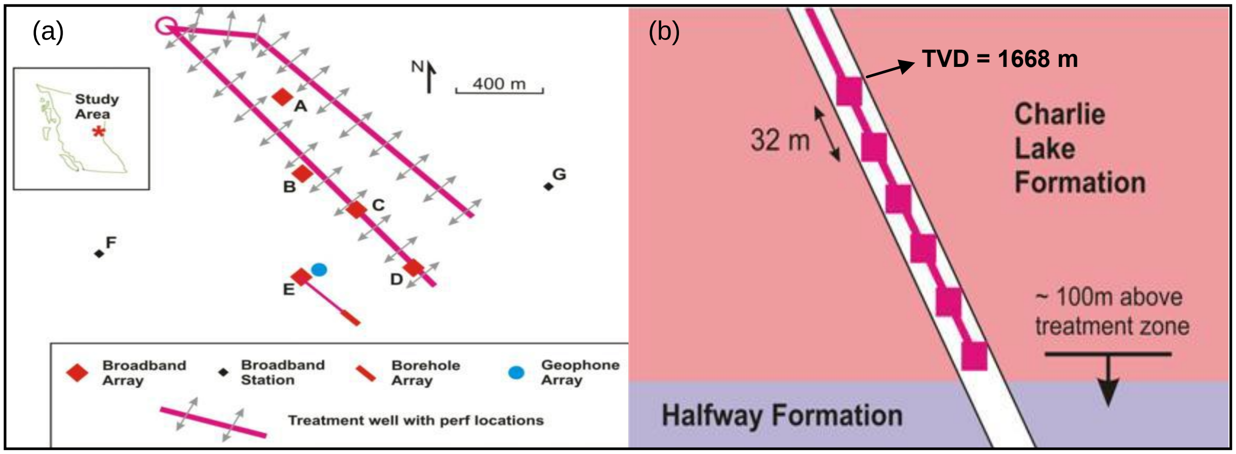


Figure 1: (a) The acquisition geometry of RME. (b) Cross section showing borehole tool string.

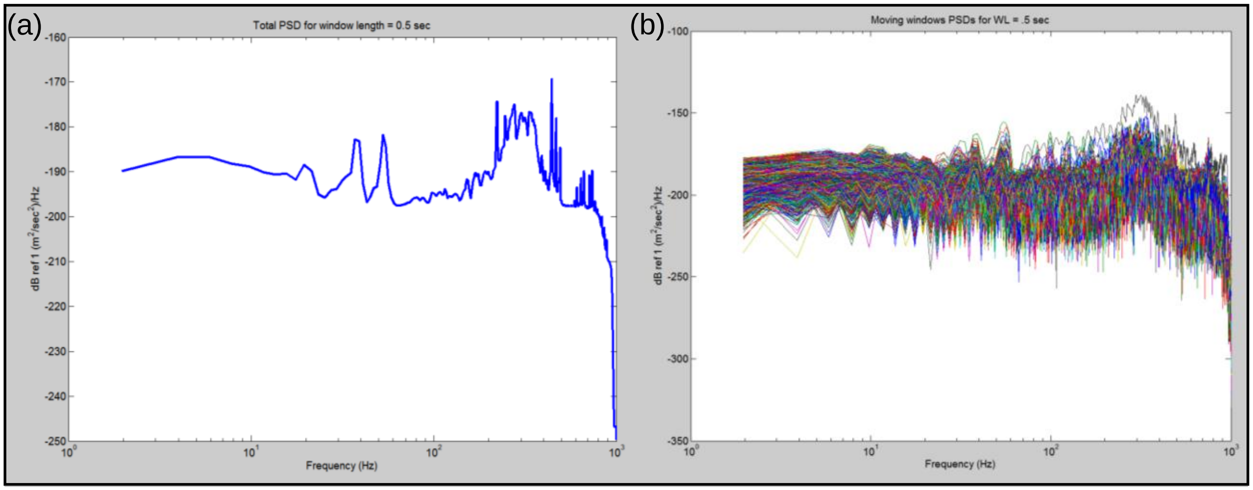


Figure 2: (a) The total PSD of the whole data. (b) PSD’s of all overlapping windowed time series.

We crosscorrelate the estimated PSD’s of each moving window along the trace (each of coloured plots in Figure 2b) with the total PSD (Figure 2a) and extract the maximum values. The crosscorrelation corresponding to the negative lag values are ignored. These values are normalized and then subtracted from 1. The result is shown in Figure 4a in which 1-crosscorrelation values are plotted versus times attributed to the center of the moving windows. Comparing Figure 4a with Figure 3a one can notice that all the features denoted in Figure 3a are accurately detected in Figure 4a where they are represent by anomalous correlation values. The anomalous value at the last point is related to the corner effect of windowing though. Figure 4b displays a zoomed view of the feature delimited by red dashe line in Figure 4a which is thought to be related to the feature B in Figure 3a.

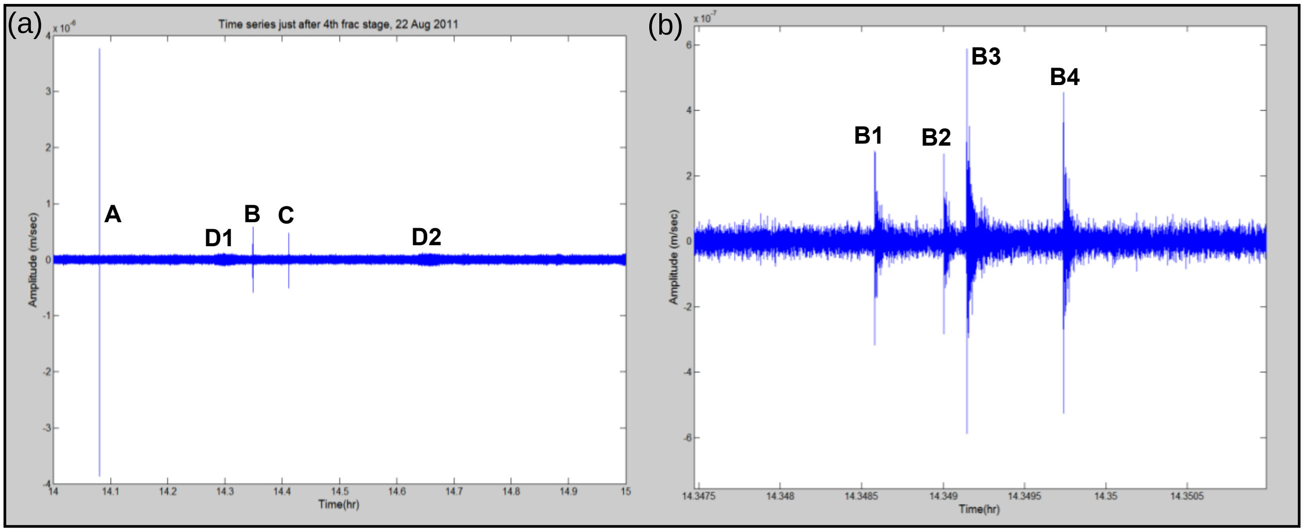
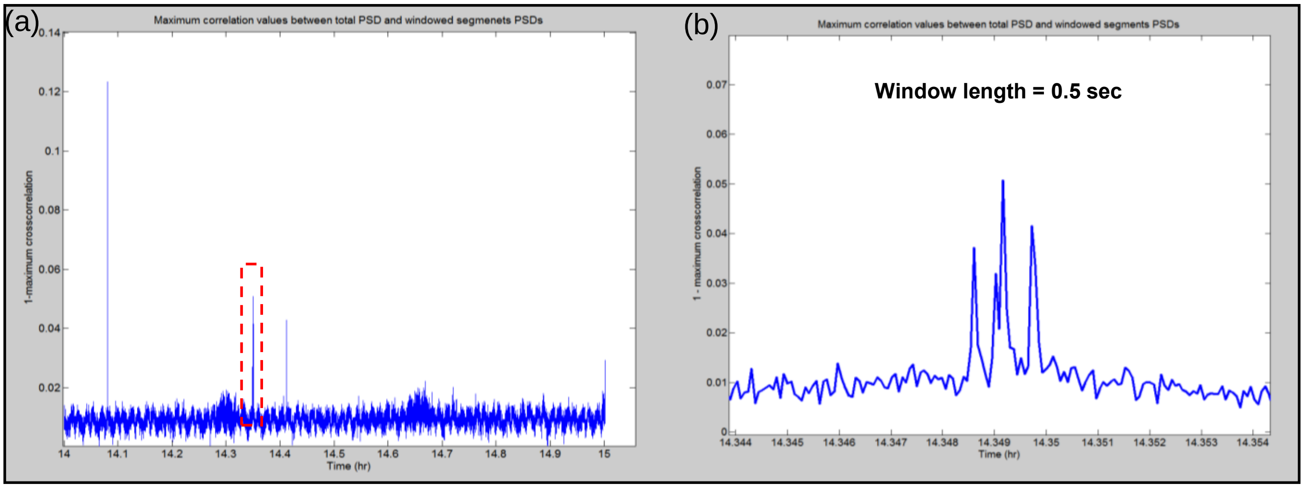


Figure 3: (a) An hour of vertical component recording in the shallowest receiver just after the 4th fracing stage showing different types of events. (b) A closer view of feature B consisting of 4 microseismic events.

The ability to distinguish microseimic events appearing at short time intervals depends mostly on the window length selection that in turn determines the time and frequency resolution. Figure 4c and 4d show similar examples as Figure 4b but for window lengths of 1 sec and 0.25 sec, respectively. Comparing these three case, one can suggest that the smaller the window length is, the better distinguished the events are. However, the window length should not be taken so small that we lose enough frequency resolution. The smaller window sizes will not result in representative PSDs, especially for lower frequencies.

According to this example, windows containing microseismic events or the perf shot represent the lowest correlation values while the windows containing only noise are highly correlated with the total PSD. This is due to the fact that microseisms and perf shots' PSDs are quite different than the total PSD which is mostly dominated by the background noise.



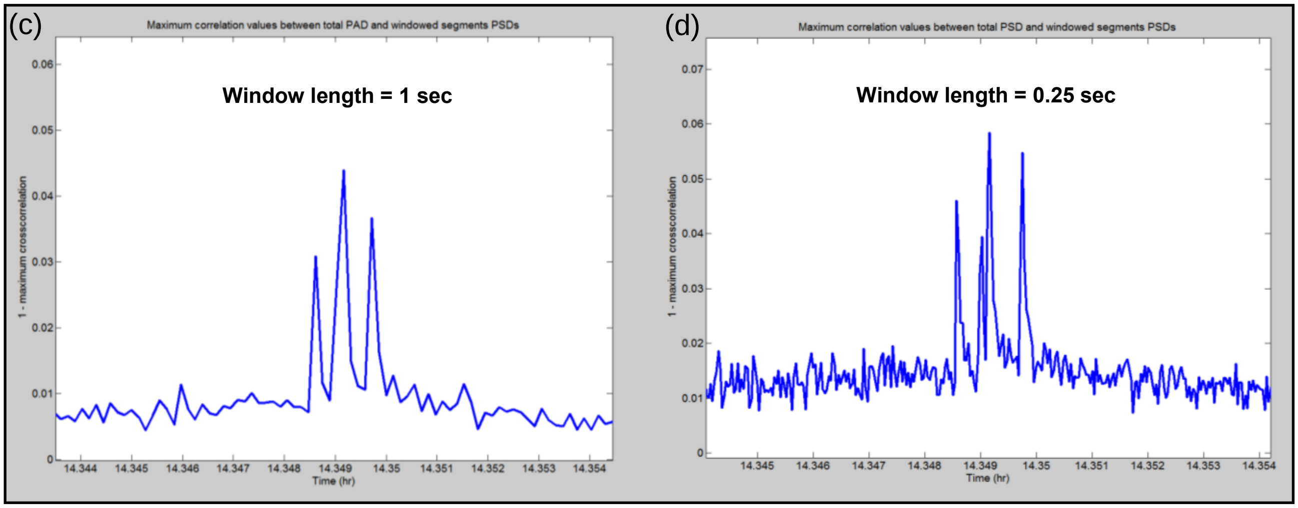


Figure 4: (a) The maximum crosscorrelation values between the segments' PSD's and the total PSD are computed, normalized and subtracted from 1. The features of anomalous correlation values are related to events shown in Figure 3a. The anomalous value at the last sample is related to windowing corner effect not an event. (b), (c) and (d) Zoomed view of the anomalous feature delimited by red dashed line (related to feature B in Figure 3a) for three different window sizes as denoted.

Conclusions

This study proposes a new method for event detection and automatic time picking for microseismic monitoring data. Based on this technique, the average power spectral density of the whole data is crosscorrelated with the estimated PSD's of windowed segment moving along the data. The windows containing the events are less correlated compared to the windows which consist of only background noise. The crosscorrelation values are dependent on the similarity of the PSD's not the energy levels. Therefore, this technique is preferred over STA/LTA method for detecting weak events.

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