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Detection and location of small microseismic events using a Matched Filtering Algorithm (MFA)

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Summary

The Matched Filtering Algorithm (MFA) is a tool designed for detection and location of weak microseismicity, based on cross-correlation of continuous raw data with a set of master reference ("parent") events. In the presence of noise and polarity changes due to unknown source radiation pattern, accurate hypocentre locations of parent events are obtained by wavefield separation (P, S_{fast} and S_{slow}) followed by iterative refinement of time picks and trace polarization. Prior to cross-correlation, the application of an automatic gain control (AGC) normalization function is used to reduce spurious detections. MFA is tested on a synthetic dataset and subsequently on two real microseismic datasets recorded in western Canada. For each parent event, this technique yields a large number of "child" events. An efficient automatic procedure is used to compute locations and magnitudes of child events, *relative* to the parent events. Use of this approach yields a significantly higher density of microseismic events than conventional processing of downhole microseismic data, enabling improved determination of the stimulated reservoir volume (SRV) and more robust event catalogs, therefore leading to better magnitude statistics for *b*-value determination and/or mapping spatially varying magnitude statistics

Introduction

Template-based approaches for detection of lower-magnitude events are well documented in literature in studies conducted on earthquakes fault systems (e.g. Nadeau and Johnson, 1998; Igarashi et al., 2003) and large intraplate areas (e.g. Shaff and Richards, 2004). Van der Elst et al. (2013) developed a matched filtering technique to detect small earthquakes by cross-correlation of raw continuous waveform data using reference events. They applied this approach to demonstrate enhanced remote triggering of seismicity caused by fluid injection. Similar techniques have also been used in microseismic contexts. At the In Salah gas development project (Algeria) Goertz-Allman et al. (2014) detected more than 5000 microseismic events, allowing for correlations between clusters of microseismicity with injection rates and wellhead pressures. Oprsal and Eisner (2014), utilize the normalized cross-correlation (NCC), as one of the criteria to discriminate between natural and induced seismicity.

Here, we present results from application of this method to microseismic monitoring datasets from hydraulic fracture treatments conducted at two locations in western Canada (Duhault, 2012; Eaton et al., 2014). Our adaptation of the MFA approach for single-well downhole microseismic monitoring provides an efficient approach to increase the number of detections, including approximate magnitudes and locations of single-phase events.

Theory

The matched filtering process is based on cross-correlation of a long time series *u*(*t*) with a reference signal *f*(*t*), where *u*(*t*) represents a component (E, N, Z) of the continuous raw data, and *r*(*t*) is a windowed signal containing P and S wave arrivals. For an array of receivers, cross-correlation is performed for all three components on every receiver, to construct a multi-component cross-correlation record section.

For two events with similar waveforms, the separate P and S waveforms collapse into a single cross-correlation peak that is time shifted by the time interval between the events. An automatic gain control (AGC) function, is applied for preventing false detections. It is basically defined as the convolution product between the complex amplitude envelope of the raw data signal with a triangular smoother.

A stacked cross-correlation is produced by summing all components and receiver levels of the cross-correlation record section. Detections coincide with local maxima of the stacked cross-correlation functions that exceed a user specified multiple (denoted as ξ) of the standard deviation value of the cross-correlation signal. In the case of duplicate detections that correlate with multiple reference events, the reference event with the highest correlation value is used. A new technique is developed here based on the projection for both 'parents' and 'children' events in ray- centered coordinates (Cerveny, 2001) allowed for an estimation of magnitude and location of 'children' events. In essence, three-component signals for child events are projected onto the P, S_{fast} and S_{slow} co-ordinate directions for the parent event. Beam-formed P and Sfast signals for the parent and child events are obtained by aligning the signals based on the time picks for the parent events. An automated iterative refinement procedure is then used to update the time picks and P-wave azimuth direction for the child event. The relative location of the child event is obtained by cross-correlation of the beam-formed parent and child P and S_{fast} signals. The relative magnitude of the child is estimated based on the amplitude ratio of the beam-formed child and parent signal, accounting for geometrical spreading differences between the two.

Examples

We show two examples of this method applied on two datasets, synthethic and real, extracted from the recording of the HFME experiment (Eaton et al., 2014). Figure 1 shows a synthetic test containing three template events, from Hoadley dataset, as well as 10 scaled and time-shifted copies of the template events. A reference level of ξ =10 is indicated by a red line. Events not detected had signal levels < 5% of the reference waveforms and SNR << 1. Figure 2, upper panel, displays a Mw -1.86 reference event for treatment stage 1, from Hoadley. In lower panel, an additional smaller event detected with the MFA with that reference event, is shown, using ξ=6. Time difference between these two events is 111 s and P- wave time arrival can be estimated of the order of 0.01 s, supporting the hypothesis of a close location of these two events. Figures 3, 4 show a 'parent' event and a 'child' event from a Cardium microseismic dataset.

Conclusions

The Matched Filtering Algorithm (MFA), is a reliable tool for the automatic detection and location of weak microseismicity, including single-phase events. The procedures relies on cross-correlation between reference events ('parents') and continuous raw data, generating 'children' events. A new technique based on the projection for both 'parents' and 'children' events in ray-centered coordinates allows for estimation of relative magnitude and location of 'children' events. Two microseismic real datasets from western Canada have been analyzed with the MFA approach, demonstrating the effectiveness of this technique.

In the future, we plan to apply MFA as a cascading process, to automatically yield 'grandchildren' events in order to enlarge catalogs that contain more numerous events (especially weak events with low SNR) than would otherwise be possible. Such a cascaded procedure is expected to generate more events, since it is unlikely that the originally selected set of parent events spans the entire space of microseismicity that occurs during a hydraulic fracture treatment.

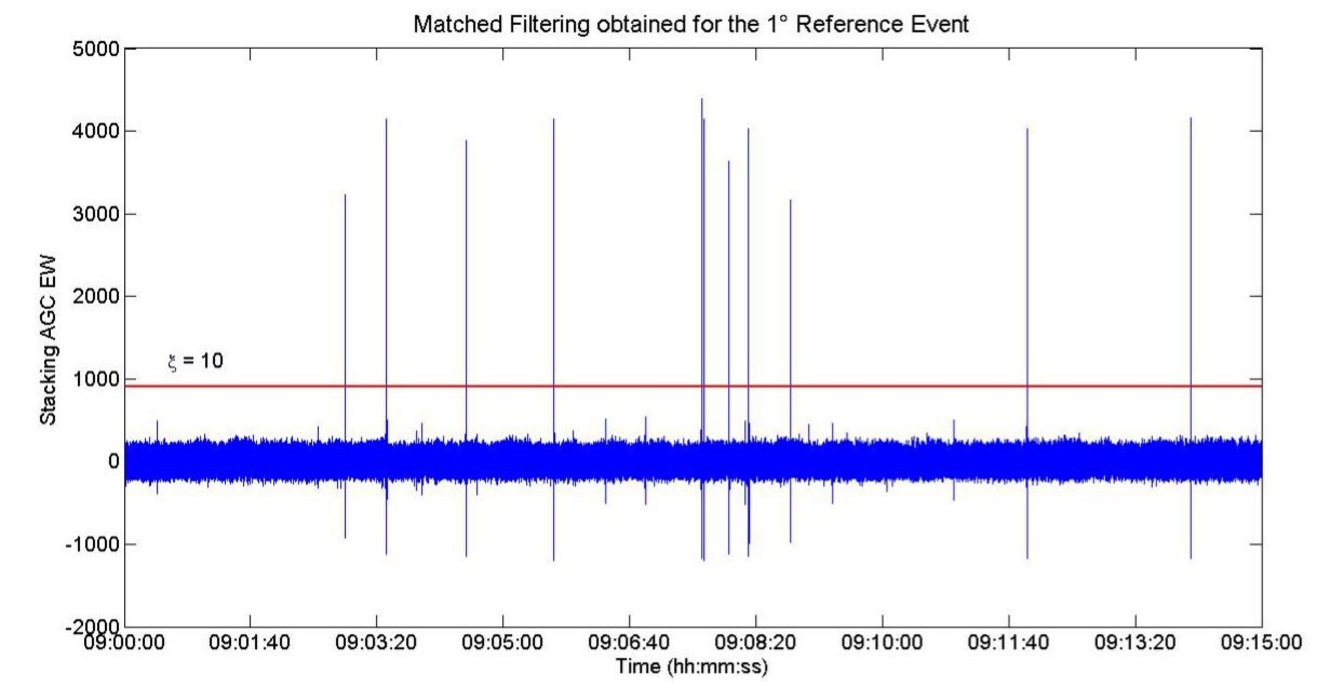

Figure 1. Synthetic example showing cross-correlation function generated using 10 copies of a scaled and time-shifted reference event, detected with the MFA. The continuous red line indicates the standard deviation of the reference level used for event detection.

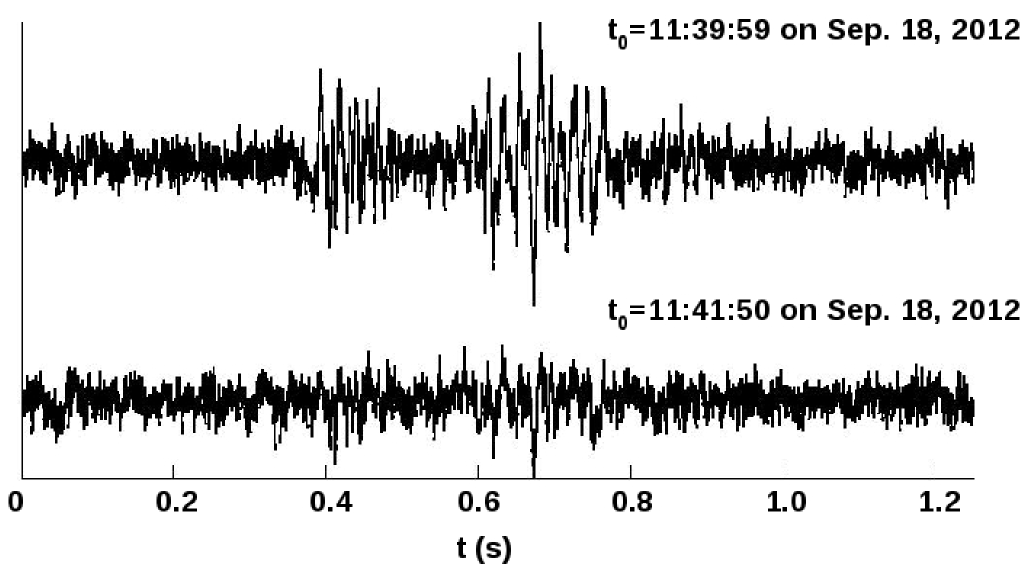

Figure 2. Noisy real data example of a 'child' event (lower panel) detected with based on the 'parent' event shown in the upper panel. This example is from the HFME experiment (Eaton et al., 2014).

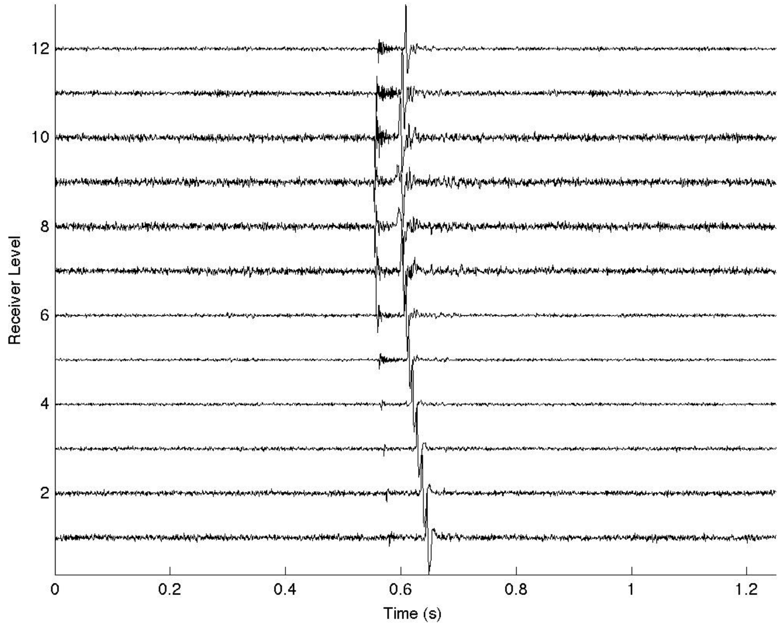

Figure 3. Real-data example of a 'parent' detected for the Cardium dataset.

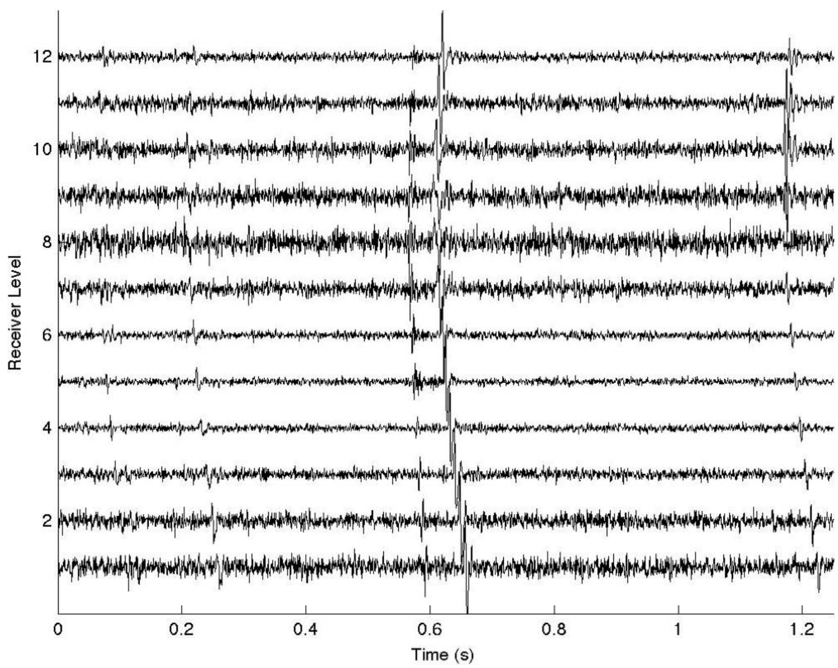

Figure 4. Example child event detected for the parent event in Figure 3.

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