

A comparison of subspace techniques with matched filtering and STA/LTA for detection of microseismic events: a case study

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Summary

Microseismic events occur due to stress perturbations during hydrocarbon extraction, and are related to the generation or reactivation of pre-existing faults and/or intact rock failure. Detecting seismic events present in seismic data is vital for gaining an understanding of physical processes occurring in the subsurface and they are usually monitored by seismic arrays in wells or on the surface. However the low magnitude of most microseismic events and the presence of background noise degrades the accuracy of most event detection methods. Several algorithms are examined in order to evaluate performance. The STA/LTA trigger algorithm captures the most signals at the cost of a large number of false alarms. The matched filter has very low false alarm rates, but suffers from a number of missed events due to poor capture of waveform variation. The subspace detector provides a trade-off between both methods and is shown to improve detection capabilities with a reasonable amount of false alarms.

Introduction

Microseismic events can occur anywhere in the reservoir or surrounding rock and are sometimes indicative of the re-rupturing of the same fault. Microseismic monitoring has been a widely used tool in observing reservoir changes in order to optimize hydraulic fracturing stimulations (Van der Baan et al., 2013). Source locations can be obtained from the recorded data via the detected events, and these can reveal fractures and faults, which highlight directions of increased permeability and/or porosity. In most cases, the microseismic events tend to have very low magnitudes (about -2 to 3) (Van der Baan et al., 2013), and are usually immersed in high amplitude noise, making it more difficult to detect and differentiate between signal and noise. The low signal-to-noise ratio (SNR) of the events present challenges both in terms of accurate time picking of P and S-wave arrivals, and the number of events detectable (Song et al., 2014). The increase in sampling rates and data obtained make manual reviewing of seismograms extremely time-consuming and subjective (Trnkoczy, 1999). Therefore, it is more desirable to utilize automated detection routines with optimal parameter settings to provide robust detection capabilities of events, with low false alarm rates (Trnkoczy, 1999). In this paper we compare and examine three event detection schemes; The short time over long time average (STA/LTA) (Trnkoczy, 1999), the matched filter (Gibbons and Ringdal, 2005; Caffagni et al, 2015) and the subspace detector (Harris, 2006; Song et al., 2014). Each method is investigated and both synthetic and real data tests are presented in order to quantify robustness and effectiveness.

Theory

Sometimes repetitive sources produce similar but significantly variable seismic signals. The subspace detector projects a sliding window of data onto a vector subspace spanning a collection of events expected from a particular source(s) (Harris, 2006). The projected data is a least-squares estimate of the signal in the detection window, and gives a measure of the linear dependence between the windowed data and the signals comprising the signal subspace. The ratio of the energy of the projected data to the energy of the windowed data is obtained, and a detection is declared when the ratio exceeds a threshold value.

Construction of the signal subspace begins with detection of high signal-to-noise ratio events assumed to characterize the source(s) signals of interest. The waveforms are then clustered based on correlations between them and the cluster of interest selected. The waveforms are then aligned and a singular value decomposition is applied to the aligned set to obtain an orthonormal representation of the waveforms. A truncation of the orthonormal representation may be done such that signal energy is best represented while noise energy is minimized. The matched filter compares recorded waveforms with one or more event templates and signals a detection if the correlation coefficient exceeds a given threshold (Gibbons and Ringdal, 2005; Caffagni et al, 2015). The STA/LTA trigger simply computes the short-term over long term energy ratio in a detection window, and triggers a detection if this ratio exceeds a predefined threshold (Trnkoczy, 1999).

Examples

We apply the methods to a real data set, obtained from a hydraulic fracture treatment of 2 wells near Rimbey, in Alberta. Figure 1 shows the template signals from a cluster with good signal-to-noise ratio, utilized in the construction of the signal subspace and for the matched filter before and after alignment. Alignment was done using an adaptive stacking procedure. An initial stack of all the template events is used as a pilot trace for correlation based alignment. A new stack is obtained and correlations repeated til the lag corrections converge to zero (Meersman et al. (2009); Song et al. (2014)). After alignment, a signal length of 0.5s is used, with 0.05s before the P-wave arrival and 0.075 seconds after the end of the S-wave arrival. Figure 2 shows the application of all three detectors to the real data set. Close examination of the signals reveal a dominant period of ~0.03 seconds, so we pick STA and LTA windows of 2 and 5 times the dominant period respectively. We also used all 16 events as individual templates for the matched filter, and a dimension of 2 was used in the subspace detector. The results are summarized in table 1.

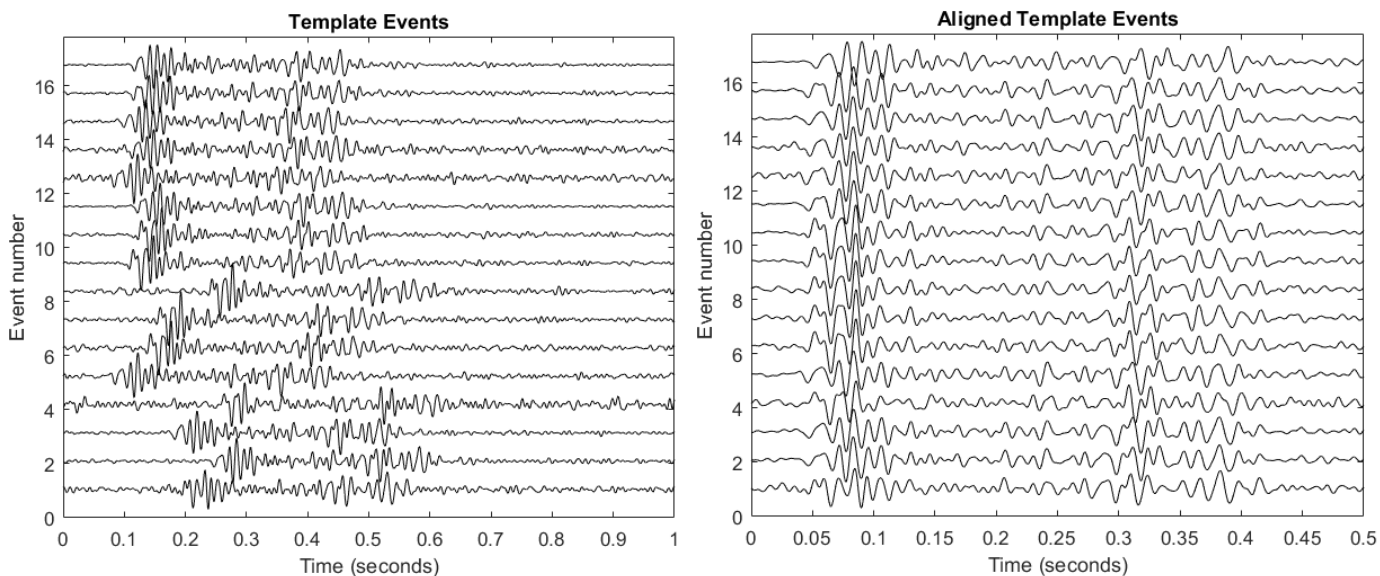


Figure 1: 16 event cluster used for subspace detector and matched filter. Waveform alignment done using an adaptive stack procedure. Clearly aligned P and S-wave peaks are visible after alignment.

Detections, false alarms and missed events over a 10 min period of real data for selected cluster						
Detector	Detections	False Alarms	Missed Events	% True Detections	% False Alarms	% Missed Events
STA/LTA detector	67	25	9	82.4	37.3	17.6
Subspace detector	30	1	22	56.8	0.03	43.1
Matched filter template with the most detections (Template 3)	22	0	29	43.1	0.0	56.9
Matched filter template with the least detections (Template 4)	14	0	37	27.5	0.0	72.5
Total matched filter detections	30	1	22	56.8	0.03	43.1

Table 1: Detection results over 10 mins of data. A total of 51 events were located in that interval.

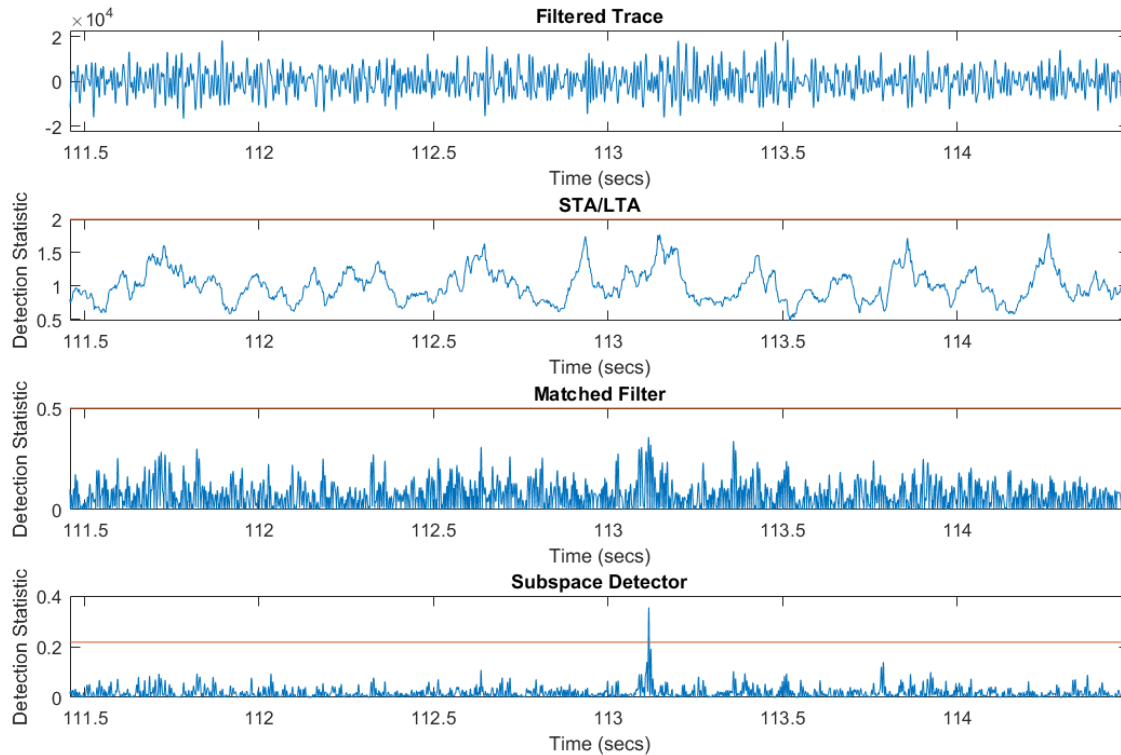


Figure 2: Application of the three detection methods to a segment of real data. The subspace detector registers a detection at about 113s that is missed by both the STA/LTA detector and a single matched filter template.

Overall the STA/LTA detector had the most detections, detecting 42 of the 51 events present over the interval. It also picked up 25 false alarms, which made up 37.3% of the total detections, the highest of the three methods. It had the lowest number of missed events, missing 17.6% of the total events. The results of the individual matched filter templates showed total detections ranging from 14-22 detections per template, with a maximum of 1 false alarm over all templates. On average the templates registered a large

number of missed events ranging from 56.9% - 72.5% of the total number of events in that interval. The subspace detector with 2 dimensions detected the same number of events from all 16 matched filter templates combined, at the same false alarm and missed event rate. It is evident that the subspace detector with a few dimensions is able to capture waveform variation more adeptly than the use of single matched filter templates. It is also more sensitive to events from the particular cluster compared to single matched filter templates not exactly matching the waveform. Figure 2 shows the subspace detector highlights an event at 113s more from the noise population than the matched filter template used in this example. The noise levels make it difficult for the STA/LTA trigger to differentiate signal from noise, hence resulting in the event being missed.

Conclusions

We performed a study of the three detection methods to gain a better understanding of how they work, and to quantify performance in terms of number of detections and false alarms on a real data set. Matched filters are template-based detectors, with very low false alarm rates. However, they cannot capture waveform variations and performance is directly proportional to the completeness of the template dictionary, increasing the likelihood of undetected events. The STA/LTA trigger captures more waveform variation than both the subspace and correlation detectors resulting in more detections, but also suffered from an increased number of false alarms. The subspace detector constitutes a useful trade-off between both other techniques and it is broadly applicable.

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