GeoConvention 2015
GEOSCIENCE
new horizons
Telus Convention Centre • 4-8 May 2015 • Calgary, AB Canada

Effect of data sampling on the location accuracy of high frequency microseismic events

Natalia Verkhovtseva
Pinnacle – a Halliburton Service, Calgary, AB

Summary

Data sampling and its effect on the microseismic events locations and in particular azimuth measurements is the objective of this study. The study focuses on how Principal Component Analysis efficiency [2] depends on the relationship between dominant frequency and sample rate using synthetic events with white noise. Moreover, the resistance of event location methodology to the sampling rate and to the number of geophones is studied for different dominant frequencies. The results show that higher sampling rate allows for the usage of higher frequency harmonics, leading to improved location accuracy for microseismic events.

Introduction

Microseismic Monitoring is a proven technology for determining geometries of stimulated fracture networks. There are many possible variations in the processing approach that can result in considerably different outcomes: different receivers systems, velocity models, picking algorithms, location approaches and incorrect phase identification can lead to inconsistent results. This study addresses the effects of data sampling on microseismic event location accuracy.

In downhole microseismic monitoring studies the most common frequencies of observed waveforms are between 200 and 2000Hz. Thus it is very important to maintain a higher sampling rate in order to preserve the signal, especially for frequencies 500Hz or higher. This is particularly true when utilising direct as well as refracted waves in a multiphase processing approach, as the former often have higher dominant frequencies.

The number and distribution of recording stations also have an influence on location errors. More geophones can significantly increase location accuracy especially if the signal is visible on all sensors, the sensors are properly oriented, and the velocity model is well calibrated. However, having more geophones means larger datasets and higher data rates, which in turn can cause difficulties for real time analysis when data transfer speed is critical for decision making. Data compression techniques may be used in order to increase the data transmission rate during real time monitoring, however, trade-offs between compression and data loss mean that it is often preferable to preserve the original recordings and if necessary reprocess the data with more sampling points later for better overall location estimation.

The temporal sampling interval is a compromise between the number of geophones and the data recording capacity. In some cases it may be preferable to use more geophones even if it leads to a sampling rate decrease. In such cases feasibility studies can estimate potential location errors introduced through using a smaller sampling rate with more spatial recording points versus a higher sampling rate with smaller number of geophones.

Method

Synthetic datasets were used to estimate the noise resistance of Principal Component Analysis (PCA) noise for different sampling rates. The Nyquist sampling theorem [3] provides a minimum sample rate in order to represent a given waveform. However, in practice, the presence of noise in the data may require greater redundancy and hence a higher sample rate. The purpose here is to demonstrate the effect of frequency content on PCA in the presence of white noise.

Considering the input signal as a sinusoidal wave masked with Gaussian function as presented in Figure 1a, we perform a number of PCA azimuth estimation experiments using waveforms sampled at 0.25ms and 0.5ms, for a number of dominant frequencies after the addition of white noise. Figure 1, c and Figure 1, d show examples of the waveform with added noise. In each case the signal to noise ratio (SNR) is 4.

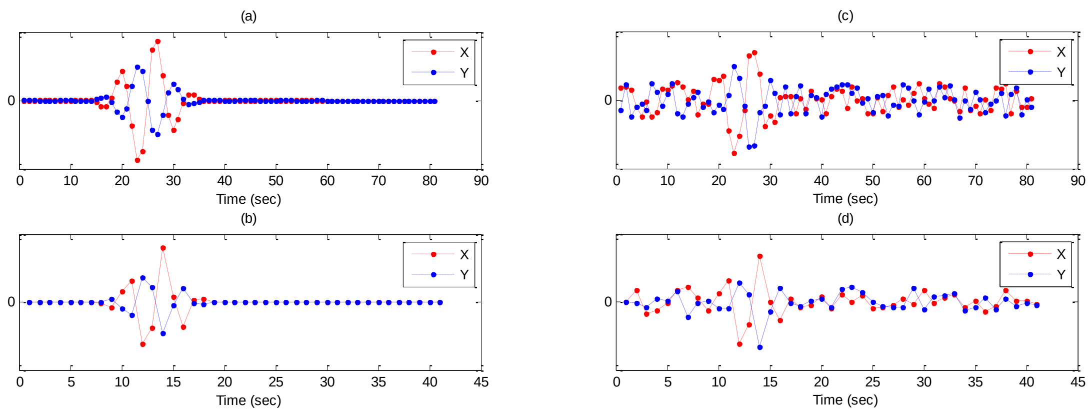

Figure 1. Synthetic signal 350Hz with projection on orthogonal axes: a – 0.25ms sampling rate without noise; b – 0.5ms sampling rate without noise; c – 0.25ms sampling rate with white noise (SNR=4); d – 0.5ms sampling rate with white noise (SNR=4).

For each dominant frequency/ sample rate combination 5000 experiments of PCA azimuth computation were performed. Then the average of the azimuth estimation was computed as well as its standard deviation. It was found that the average value of the azimuth estimation error is quite close to 0 in both sampling rate cases while the standard deviation varies depending on sampling rate and the dominant frequency of the signal. It allows one to assume that the expectation of the PCA results, quality and reliability depend on these factors. As it can be observed in Figure 2, with SNR=4 and sampling 0.5ms, standard deviation of the azimuth error grows dramatically with 500Hz and higher for a set of 5000 experiments with random white noise, while 0.25ms sampling provides a much better accuracy in azimuth.

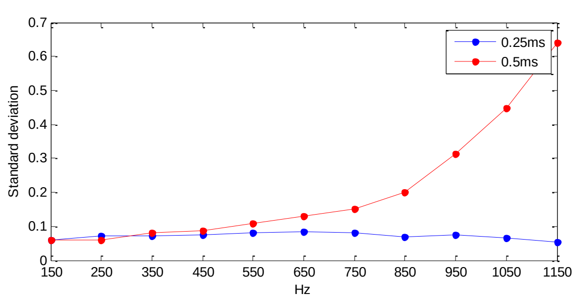

Figure 2. Azimuth estimation standard deviation (radians) against dominant frequency for sampling rate cases 0.25ms and 0.5ms.

One can conclude that frequencies 500Hz and higher definitely require at least 0.25ms sampling. At the same time a signal below 500Hz may be effectively processed with 0.5ms sampling. In practice, in many cases P-wave detectable with 0.25ms appears to have strong harmonics of 500Hz+ which makes high-rate sampling preferable.

Location Experiments

A synthetic dataset was created in order to test the effects of downsampling on azimuth accuracy of microseismic event locations. Synthetic events were created for a set of 36 geophones placed on a straight line starting from 50m distance up to 800m from the toolstring with 50m increments. A number of different SNRs and dominant frequencies were used for the simulated events. In each case the dependence of azimuth error was estimated from distance to the event. Original data holds 0.25ms sampling rate. The dataset was then resampled to 0.5ms sampling rate and events were repicked and relocated accordingly. For details for the resampling strategy see [1]. The results are shown in Figure 3. Left plot in the figure shows azimuth error for three different dominant frequencies (200, 400 and 800Hz) synthetically created with 0.25ms sampling rate. As can be seen in Figure 3, the 800Hz signal shows the highest azimuth estimation error: up to 18m at 750m distance from the toolstring. At the same time, the 200Hz signal shows the smallest error: up to 8m for the same 750m. Right plot in the figure shows the same experiment results with dataset resampled to 0.5ms signal using standard multigrid restriction-prolongation technique [1]. Signals with dominant frequencies of 200Hz and 400Hz have similar azimuthal errors: up to 10m of error for events located 750m away from the toolstring. At the same time 800Hz events show up to 50m azimuth error for the same 750m distance. However, events 200Hz or lower show approximately the same error distribution for both sampling rates. It can be concluded that azimuth residual is very sensitive to the sampling rate especially for high frequency events.

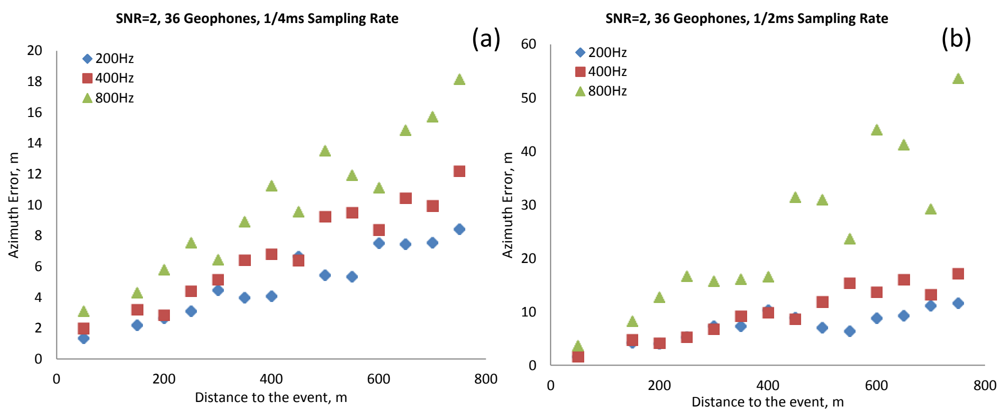

Figure 3. Azimuth estimation errors dependence on distance to event for synthetic datasets, 36 geophones with 0.25ms sampling rate (a) and 0.5ms sampling rate (b)

Next, the number of spatial receivers was decreased to demonstrate how doing so will affect azimuth accuracy. The number of geophone points was varied in the string from 36 down to 12 in order to correlate it with the azimuth location error. Results are presented in Figure 4. Signals with lower dominant frequencies give smaller errors than those with higher dominant frequency. Errors may change as much as from 12 to 30m depending on number of recording points in 0.25ms signal sampling case (Figure 2, a) and from 20 up to 90m in 0.5ms sampling case. One can conclude that decreasing the number of receivers results in higher azimuthal errors especially for high frequency events along with low rate sampling case.

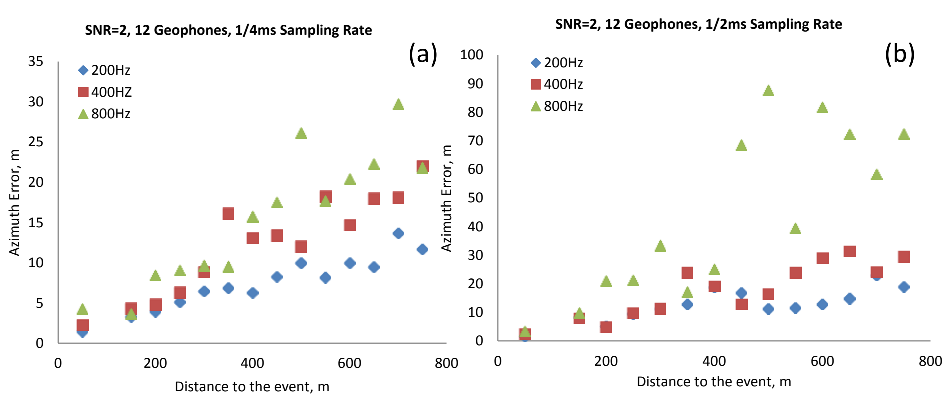

Figure 4. Azimuth estimation errors dependence on distance to event for synthetic datasets, 12 geophones with 0.25ms sampling rate (a) and 0.5ms sampling rate (b)

Real Dataset Examples

It is generally accepted within the microseismic community that perforation shots are the preferable source in terms of velocity model calibration and sensor orientations. Therefore clear P-wave recordings and accurate perforation shot analyses are crucial for the microseismic event location accuracy.

In this study a set of perforation shots recorded on a 24 geophone array was used with 0.25ms sampling interval. The P wave signal for this particular dataset has a dominant frequency of ~550Hz (Figure 5.)

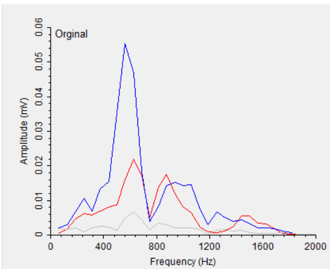

Figure 5. Amplitude spectrum of the perforation shot signal (P wave) recorded on a triaxial geophone (blue and red are horizontal components, grey is the vertical component)

The original data was recorded with 0.25ms sampling interval. After arrival times were identified, sensor orientation angles and a velocity model were applied. Then the same multigrid finite elements restriction approach was used to resample the data into 0.5ms signals. Arrival times were identified in the newly obtained data and then the same sensor angles and velocity model were applied. Location errors were calculated and are presented in Table 1.

Table 1. Perforation location errors comparison for 0.25ms and 0.5ms sampling intervals

Data Type	Distance from Array	Average Azimuth Error, m	Average Distance Error, m	Average Depth Error, m
24 levels 0.25ms	145 to 295m	7.23	5.63	3.15
24 levels 0.5ms	145 to 295m	8.68	9.86	6.25

As can be seen from Table 1, azimuth error increased slightly when a lower sample rate was used however distance and depth errors are almost doubled.

Conclusions

Sampling rate and its relationship with other factors such as dominant frequency and data quality has a critical effect on microseismic event locations. The results of this study are summarized as follows:

- high frequency signal 500Hz+ requires sampling rate at least 0.25ms for predictable azimuth estimation with PCA and expectable deviation of the results;
- azimuth accuracy can be improved by using more receivers due to azimuth averaging;
- perforation dataset processing will definitely benefit 0.25ms sampling as far as the dominant frequency of the perforation shots is quite high

Acknowledgements

We would like to thank our colleagues from Pinnacle – a Halliburton Service for the support of this study, their expertise and opinion on the data processing methodology and the results, especially Norm Warpinski.

References

1. Olshanskii M.A. Lecture notes on multigrid methods. Moscow: Institute of Numerical Mathematics, RAS 2012. -180p

2. Jolliffe, I. 1986. Principal Component Analysis. Springer-Verlag. p. 487.

3. Nyquist, H. 1928. Certain topics in telegraph transmission theory, Trans. AIEE, vol. 47, pp. 617–644