

## Microphone Applications in Seismic Exploration

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### Summary

Coupling phenomena associated to energy conversion at the air-ground interface can be better understood if pressure levels and particle velocity, displacement or acceleration amplitudes are recorded at the field. For engineering seismology applications, this is very valuable since ground motion is closely related to air pressure. In exploration seismology, the air pressure - ground motion relationship is essential to understand the coupling mechanism of air-associated noise into the geophones. The reliability of using pressure data (i.e. recorded using microphones) to attenuate some of the air noise coupled into the geophone records remains the main goal of the undergoing research. Adaptive filtering techniques using the Least-Mean Squares (LMS) algorithm proved to be successful in removing the 60 Hz interference noise from the raw geophone signal. This filtering approach produces a reasonable noise estimate of the embedded geophone noise using a reference input (i.e. a microphone).

### Introduction

Past experiments in earthquake seismology have shown the feasibility of using co-located microphones and multicomponent geophones for sensing related air pressure and particle velocity at the surface. This type of instrumentation has been used extensively in research areas, for example, to study the impact of local atmospheric pressure changes on seismic stations records. Engineering seismologists have used microphones and geophones for the purpose of understanding how a significant transfer of energy can take place from the air to solid rock even though a great contrast in impedance exists. Another major application is found in blasting monitoring, where the air and ground vibration levels are directly measured using a high-precision microphone and a triaxial geophone connected to a portable recorder. This is linked to exploration seismology in some sense, because blasting monitoring of seismic sources will become a common practice as the seismic operations move toward more densely populated areas.

In seismic exploration, the airblast (airwave) can be very problematic, especially for shallow surveys because it occupies a comparatively large window on the scale of the shot records. It can obscure primary reflections at the near-offsets, especially in areas of poor geophone coupling, and conventional f-k or frequency filtering techniques often fail due to spatial aliasing.

Stewart (1998) suggested that air-associated noise (e.g., wind, airblast, and other ambient noise), recorded on a geophone, might be reduced by using the output from a nearby microphone. In principle, it would be possible to estimate the air noise by applying an appropriate filter to the output of the microphone and minimize the coherence between the observed seismic data and the air-pressure data. This would lead to the suppression of correlated air noise in the geophone.

In this paper, we present two cases of microphone applications in seismic exploration. The first case summarizes some preliminary results from a dual-sensor experiment (microphone - 3C geophone) aimed to attenuate some of the ambient noise from the geophone records. The second case introduces some results from the vibration monitoring of seismic sources at Nanton, Alberta. The latter case was also used here to analyze the air pressure – ground motion signal relationship after a dynamite shot.

## **Case 1**

The CREWES project at the University of Calgary conducted a high-resolution multicomponent seismic survey at the Pikes Peak heavy oil field located at Saskatchewan in March 2000. It consisted of a 3.8 km 3C-2D survey of vibroseis sources and conventional vertical geophone arrays, single microphones and single 3C geophones. The microphones were designed, manufactured and tested by CREWES at the University of Calgary. These pressure-change sensors were co-located with the 3C geophones every 20 m in the same augured holes (see Figure 1). The 3C geophone spacing was 10 m. For further analysis of this experiment and its other objectives refer to Hoffe et al. (2000) and Dey et al. (2000). Figure 2 shows two different shot records. The airwave coupled into the geophone shot record with an apparent velocity of about 340 m/s.

## **Adaptive Filtering**

The characteristics of the airwave source (i.e., vibroseis or dynamite fired on the earth's surface) and the environment are time varying, that is, the frequency content, amplitude, phase, and sound velocity of this undesired noise are nonstationary. Therefore, any filtering must be adaptive to account for such variations. Adaptive filters adjust their coefficients to minimize an error signal. They make use of an auxiliary or reference input derived from one or more sensors to estimate the noise embedded in the original signal, which is then used to filter and subtract the noise from the original input containing both signal and noise. As a result the primary noise is attenuated or eliminated by cancellation (see Figure 3 for a schematic).

## **Discussion**

The dual-sensor experiment was successful in recording the airblast and some ambient noise (e.g., the 60 Hz interference) by means of several microphones. There is correlation between the air-associated noise recorded by the microphone and the geophone noise. An example of adaptive filtering using the Least-Mean Squares (LMS) optimization algorithm for 60 Hz attenuation is showed in Figure 4. The raw geophone signal has a strong 60 Hz interference from a power line, which is often suppressed from seismic data by using notch filters. The reference input to the filter is the raw microphone signal, which also picked the interference. The filter structure is a transversal Finite-Impulse Response (FIR) with 32 taps (also called coefficients or weights). The adaptive algorithm takes the error signal from the filtering operation for every sample in the time series and compares it with the raw geophone signal until the adaptation algorithm converges to an optimal solution, that is, an optimal coefficient series. The amplitude spectrum is also shown in Figure 5. Note the improvement in SNR due to interference attenuation. The strong peak at 60 Hz was collapse while keeping the other frequencies almost unaffected

## Gabor Filtering

The analysis of non-stationary signals requires mapping the signal in such a way that frequency and amplitude variations with time can be observed. A powerful tool to achieve this goal is the representation of the signal in the time-frequency domain. The Gabor transform is a particular case of the windowed, short-time Fourier transform. A signal is localized by windowing it with a shifted Gaussian centered at time  $t_k$  given by  $g_k = \exp(-t(t-t_k)^2 / \sigma^2)$  and then a Fourier transform is applied to each windowed part of the signal (Margrave and Lamoureaux, 2006).

The Gabor transform proved to be an acceptable technique for mapping both signals into the frequency-time space with good localization in both time and frequency (see Figure 6). This is an encouraging result and we are now working in the development of a filtering technique in the Gabor domain.

## Case 2

WorleyParsons Komex was contracted by Compton Petroleum Corporation to conduct the vibration monitoring of a seismic exploration program in the area around Nanton, Alberta. The survey area was in the proximity close to water springs which are economically important for the Nanton community. There was a concern about the potential damage to the water springs caused by seismic activities. Therefore, the aim of the project was to monitor vibrations generated by vibroseis and dynamite sources. The recordings and their analysis are further discussed in a document prepared by WorleyParsons Komex (2007).

Dynamite shots consisted of 2 kg of buried explosives in holes 15 m deep. The vibration monitor system was a Blasmate II developed by InstanTEL. It recorded four channels with a sampling rate of 1024 samples per second (1.024 kHz). The triaxial geophone and microphone both had bandpass responses from 2Hz to 250Hz.

An example of typical waveform is shown in Figure 7. It corresponds to a dynamite shot monitored at 25 m offset. The recorded peak particle velocity was 90.4 mm/s in the vertical component with dominant frequency of 19.2 Hz. The peak air pressure was 30.5 Pa (123 dB) with dominant frequency of about 2.44 Hz. The cross-correlation of the signals suggests that there is strong negative correlation and that the air-pressure signal is shifted with respect to the particle velocity signal. From the upper plot of Figure 7, there exists a difference in polarity. An over-pressure is taken as a positive pulse whereas a direct seismic arrival is taken as negative (as it is often the case). Further analysis of these signals would lead us to a deeper understanding of the air pressure - ground motion relationship.

## Acknowledgements

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Figure 1: Co-located microphone and 3C geophone (left) in a 30 cm deep hole (right)

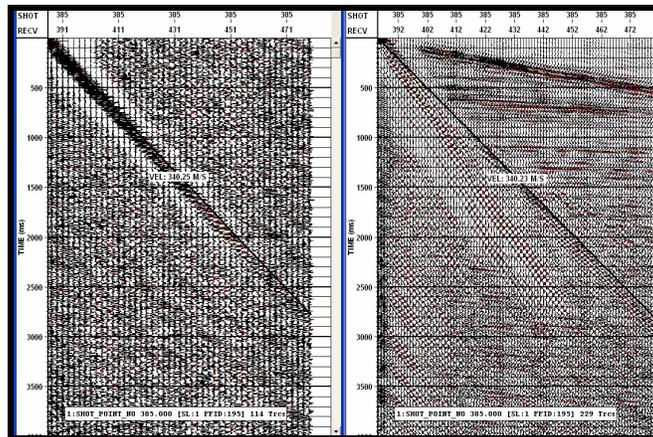


Figure 2: Microphone (left) and geophone shot records (right) with AGC of 500 ms. Note that the airblast (airwave) was recorded by both sensors with an apparent velocity of about 340 m/s.

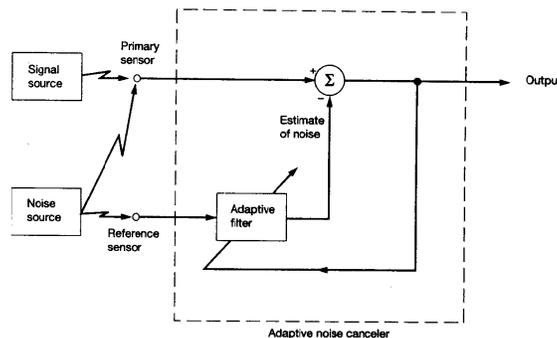


Figure 3: Adaptive filter configured as an adaptive noise canceller (From Haykin, 1996).

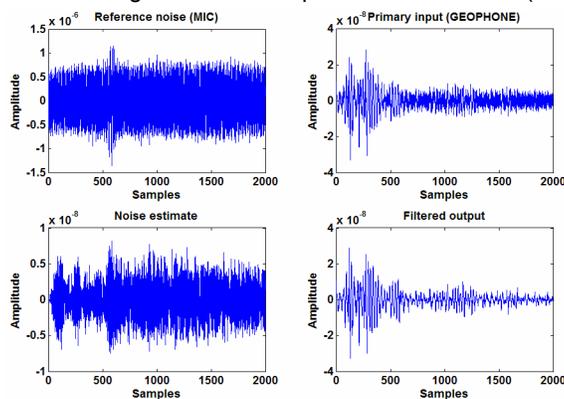


Figure 4: Example of adaptive filtering using an LMS algorithm for filter coefficient update. Note the improvement of SNR due to cancellation of the 60 Hz interference in the geophone output.

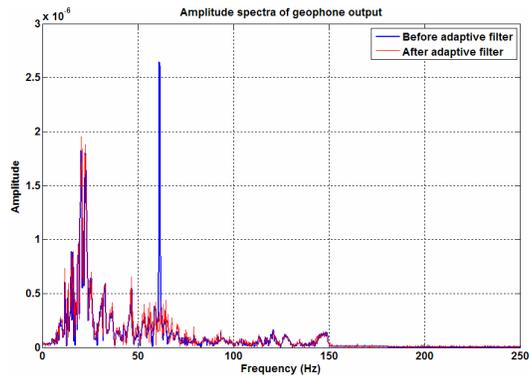


Figure 5: Amplitude spectrum of the seismic trace before and after adaptive filtering.

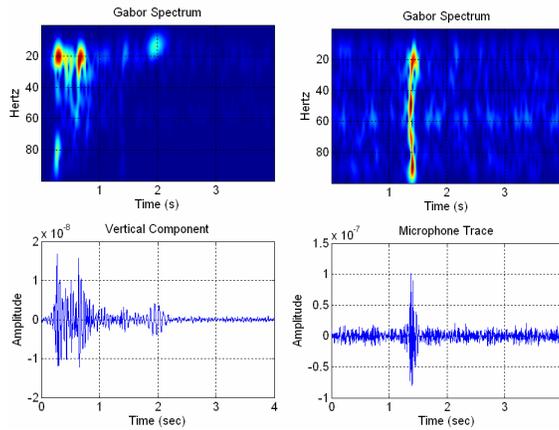


Figure 6: Gabor transform in the time-frequency space (upper), and time domain representation (bottom) of the vertical component (left) and microphone trace (right). Both signals were band-pass filtered (10-15-90-100 Hz).

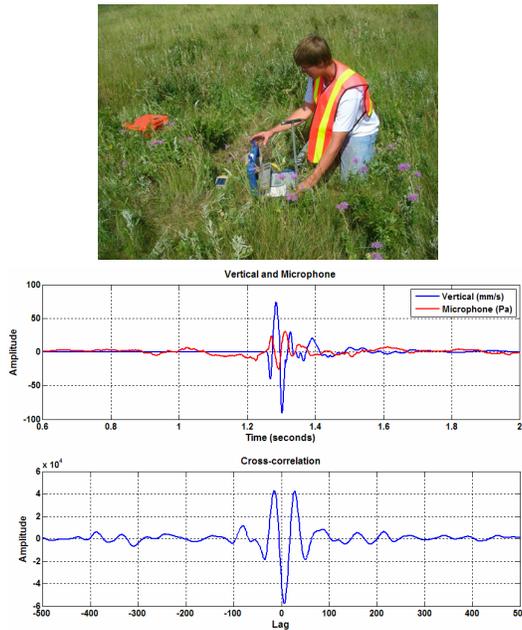


Figure 7: Blastmate II set up (top). Cross-correlation of microphone and vertical component of the triaxial geophone (bottom).