Microphone experiments and applications in exploration seismology
Alejandro D. Alcudia* and Robert R. Stewart. The CREWES Project, University of Calgary.

Summary

Coupling phenomena associated with energy conversion at the air-ground interface can be better understood if pressure levels and particle velocity, displacement or acceleration amplitudes are recorded in the field. In exploration seismology, the air pressure - ground motion relationship is essential to understand the coupling mechanism of air-associated noise into the geophones. The CREWES Project at the University of Calgary undertook two air-pressure recording experiments in western Canada to investigate using air-pressure data (from microphones) to attenuate air-coupled noise in geophones during two different seismic acquisition projects. A multichannel median filter was applied to the LMO-corrected microphone data to enhance the strong air blast arrival and allowed us to study our recorded data in terms of sound propagation and attenuation, power spectra and signal consistency. Adaptive filtering techniques produced reasonable estimates of the embedded geophone noise using a reference noise input (i.e. pressure data from several microphones). We had success in suppressing the 60 Hz interference by using the Least-Mean Squares (LMS) algorithm in a Finite-Impulse Response adaptive filter. The results are quite encouraging and more complex adaptive filter algorithms and other filtering techniques are under study.

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 extensively in research areas, for example, to study the impact of local atmospheric pressure changes on seismic station 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. For example, acoustics research has used the vertical seismic transfer function (m/s/Pa), also called the acoustic-to-seismic transfer function, to detect land mines or other buried objects (Xiang and Sabatier, 2000). Others have used such a transfer function to study the outdoor sound propagation and its interaction with the ground as it travels horizontally (Albert, 1993). 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 exploration seismology, the source-generated noise in shallow reflection or refraction surveys can be troublesome. Air blasts, ground-coupled air waves, and air-coupled ground roll are all potential problems in recording reflection signals, especially when the noise source is near the receivers. While there are many ways to filter this noise, it still can be a problem, due to aliasing, for example. In addition, strong winds can lead to the decision of shutting down seismic acquisition operations due to unacceptable high noise levels. Stewart (1998) proposed a noise-reducing multi-sensor for seismic land operations. It basically consists of a dual-sensor (two-element) instrument having a microphone within the geophone case or in the proximity to the geophone to give air-pressure measurements. It is worthy to note that previous mentioned applications in acoustics, earthquake and engineering seismology could be adapted to exploration seismology to better understand the air-noise coupling into the ground and consequently into the geophones. In this paper, we describe two experiments involving air-pressure measurements during two different 2D multicomponent surveys in western Canada. Two-hundred microphone prototypes were built by the CREWES Project at the University of Calgary in 2000 for the first experiment undertaken that year. Eight years later, we use 32 of the same prototypes to undertake a new experiment. Analysis of these unique datasets and potential filtering applications with some examples are presented.

Definitions

Sound is generated by any vibrating structure or mechanism. Sound pressure in Pascal units (Pa) and Sound Pressure Level (SPL) in decibels are the most common quantities to characterize any given sound. The SPL is an expression of a given sound pressure in Pa referenced to 20 μPa, which is considered to be the quietest sound some humans may hear. A positive pressure pulse corresponds to the compression phase of a sound wave and a negative pulse corresponds to a rarefaction. These two phases of a sound wave are deviations from the local atmospheric pressure (1 atm = 100 kPa), that is, the effective sound pressure is the RMS difference between the peak pressure deviation and the local atmospheric pressure. A sound pressure wave can be a composite of many frequencies, of course, but a distinction must be introduced when the dominant frequencies are within the humans' audible band or outside. A human being can hear pressure variations (or sounds) in the frequency range from 20 Hz up to 20 kHz. Any given sound with dominant frequencies below the threshold of human hearing is called infrasound. This type
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of sound is particularly important is earthquake seismology and volcano studies for air-vibrations monitoring. In exploration seismology, we are concerned about sound propagation within the seismic source and reflections bandwidth (i.e., it depends on the source type and the target depth), which means that both sounds and infrasounds are often generated.

Microphone Design

The microphones were designed, manufactured and tested by CREWES at the University of Calgary. The main component of these microphones is a Panasonic WM-54 BT (see Figure 1), still available in the market. It is an electret condenser microphone with flat frequency response in the range of 20 Hz to 16 kHz. This microphone model has a sensitivity of -44 dB ± 3 dB (6 mV/Pa, ±2 mV/Pa) with a reference level of 0 dB = 1V/Pa. In other words, if a sound pressure level of 94 dB (i.e., equivalent to 1 Pascal with 0 dB = 1V/Pa) were input to this microphone, the output would be 6 mV.

Experiments

Experiment 1: Pikes Peak Oil Field, Saskatchewan, Canada

The CREWES project conducted a high-resolution multicomponent seismic survey at the Pikes Peak heavy-oil field located at Saskatchewan, Canada, in March 2000. It consisted of a 3.8 km 3C-2D survey of vibroseis sources (two HEMI 44, 25,000 kg each), conventional vertical geophone arrays, single microphones and single 3C geophones. These pressure-change sensors were co-located with the 3C geophones every 20 m in the same augered holes. The 3C geophone spacing was 10 m. A 90° shift of the pressure data with respect to the seismic data was found. The experiment was successful in measuring coherent air blast within 1330 m offset both sides of the vibroseis array with some amplitude variations due to topography and microphone response. For further analysis of this experiment and its other objectives refer to Hoffe et al. (2000) and Dey et al. (2000).

Experiment 2: Rothney Astrophysical Observatory, Priddis, Alberta, Canada

Eight years after the first microphone experiment was undertaken at Pikes Peak, the CREWES Project went back to the field in the winter of 2008. The new acquisition experiment was undertaken at the Rothney Astrophysical Observatory near Priddis, Alberta, Canada. The site is a rural area about 26 km southwest of downtown Calgary. The aim of the experiment was to acquire a unique dataset to test a 3C land streamer manufactured at CREWES and compare its shot records and processing results to those of a 200 m multicomponent seismic profile at 1 m spacing. We also deployed our microphones at 5 m spacing to span 155 m of the multicomponent line. In this paper, however, we only make use of the conventional 3C and microphone data. The shallow seismic profile consisted of 200 SM24 3C coil geophones (10 Hz) manufactured by I/O Sensor and planted at 1 m space. A small 15 cm deep by 6 cm wide hole was drilled for each geophone using a gas-powered handheld auger. Each of the microphones was powered by a 9V PP3 battery (square) and connected to a line cable with eight take outs. Four extra Remote Acquisition Units (RAM’s) were employed to support 32 microphones in total. The source was an environmental 17,000 Lb mini vibroseis (Envirovibe) manufactured by Industrial Vehicles International. Four sweeps were performed at each source location to increase the SNR. The radial component was oriented East-West (in-line with the source-receiver azimuth) and the transverse component North-South (cross-line with the source-receiver azimuth).

Data analysis

The signal analysis required the decimation of the vertical component data to match the spacing of microphone data. That was the case for both experiments since they were also designed for other purposes. Although microphone data interpolation was a viable option, we decided to keep it as simple as possible. The air blast is fundamentally a sweep-like signal whose frequency content depends on the sweep parameters (Figure 2). Time-frequency analysis is a powerful method for the analysis of amplitude variations with time and frequency. In this case, we used the Gabor transform to perform such time-frequency analysis of the uncorrelated data. The upper Gabor spectrum in Figure 2 corresponds to a 10-250 Hz linear sweep recorded from the Priddis experiment. The lower Gabor spectrum corresponds to a two-segment sweep (linear from 8 Hz to 25 Hz and nonlinear from 25-250 Hz) recorded from the Pikes Peak experiment. The highest amplitudes occurred at the highest frequencies and latest times in both cases (red color is highest in time-frequency spectra). Note the presence of second and third harmonics in the signal, which suggested the proximity of the seismic source to the seismic line in both experiments. Indeed, these two pressure signals were recorded within 40 m from the source in their respective experiments. Harmonics from vibroseis introduce strong correlation artifacts in correlated seismic records. An analysis of the uncorrelated microphone traces as a function of distance from the source was also performed in the Gabor domain. It revealed that the airwave amplitude decayed with distance in agreement with observations of others (Sallas and Brook, 1989; Brook et al., 1989). The time shift of the airwave “sweep” onset at one microphone station with respect to the next one, suggested that the airwave arrival time in the correlated microphone traces is
determined by the onset of the “sweep”. In other words, the maximum correlation value occurs at the onset of the airwave “sweep”. The amplitude decay was also analyzed in the correlated data. A multichannel 5x1 median filter was applied to the LMO-corrected pressure data to enhance the strong air blast arrival and allowed us to analyze our recorded data in terms of sound propagation and attenuation, power spectra and signal consistency (Figure 3). We used a linear moveout (LMO) velocity of 333 m/s which is the propagation speed of the sound in the air at 3°C. This velocity is highly variant and dependent on air temperature and air density. At -10°C its speed is about 325 m/s while at 10°C it travels at 337.5 m/s. It is important to note that the sound speed in air is determined by the air itself. It is not dependent upon the sound amplitude, frequency or wavelength. The dual-sensor experiment was successful in recording the air blast and some ambient noise (i.e., the 60 Hz interference) by means of several microphones. There is correlation between the air-associated noise recorded by the microphone and the geophone, especially high correlation of the air blast. Butler and Russel (1993) explained that the powerline noise may be recorded directly during time-domain measurements of electric and magnetic fields, or indirectly, by geophone cables during acquisition. We assume that the recorded 60 Hz is from a nearby power line, which induced a periodic noise train in the cables. However, power lines might also generate audible bursts, since it is well known that lights can be heard sometimes. We believe this is not the case in our experiments since the noise appeared in both sensor records, but we do not have the benefit of a specific powerline-noise experiment. However, as we show below, we could use the 60 Hz noise in the microphone to adaptively suppress this noise in the geophone.

Applications and examples

The characteristics of the airwave source (i.e., vibroseis) seem to be nonstationary in general, since the air blast amplitude decays with distance, even though the frequency content and waveform shape seem to be consistent. In our experiments, the consistency is highly attributed to the gentle topography. However, in rough terrains these might not be the case. On the receiver side, the air blast seems to be more complicated, at least for the geophone records. Because the ground interacts with the air blast as it propagates, the air blast can induce motion in the geophone in two different ways: 1) by direct pressure on the geophone case as it passes over the geophone, or 2) by inducing ground motion in the proximity to the geophone case. When a given signal is nonstationary (as is often the case), any filtering must be time-variant to account for any variation in the statistics on the signal. Adaptive filters are examples of nonstationary filters, since they are designed to adjust their coefficients on a sample by sample basis to minimize an error signal. Adaptive filters make use of an auxiliary or reference input derived from one or more sensors to estimate the noise embedded in the original signal (Figure 4), 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. Figure 5 show some results from the adaptive filter applied to the raw geophone after vibroseis correlation. The upper plot is from the Pikes Peak experiment and shows strong 60 Hz interference and its filtered version. The plot in the middle is from Priddis and shows strong air blast in the vertical component. The noise reduction is apparent in both time and frequency domain signal representation. The 60 Hz peak was collapsed while keeping the other frequencies almost unaffected. The air blast was partially attenuated at high frequencies (around 150-250 Hz). Figure 6 shows an example of adaptive filtering in a seismic shot gather (5m spacing). The minimum offset is 100 m, thus the airwave arrival time in the first trace is about 300 ms. The airwave coupled into the geophones with an apparent velocity of 333 m/s. The amplitudes of each seismic and pressure trace are normalized to the maximum value in each trace. Notice that the air blast has been partially attenuated after adaptive filtering using microphone data as the reference noise. Although other methods exist to handle the airwave effectively, our purpose with these examples was to demonstrate the potential use of air-pressure data from microphones to attenuate air-coupled noise in geophones.

Conclusions

Microphone output signals can be measured and used for air-noise attenuation in seismic records. Our measurements showed fairly consistent waveforms from trace to trace with amplitude decay due to geometrical spreading. We have used the pressure data as an attempt to suppress the air blast from the geophone records. A simple form of adaptive filter algorithm (Least-Mean Squares) was used. Our results showed success in suppressing the 60 Hz interference but we were unsuccessful in removing the air blast completely. However, our results are quite encouraging. We are currently exploring more complex adaptive filtering algorithms and other filtering techniques. Furthermore, the acoustic-to-seismic transfer function is also under study.

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Figure 1: Microphone designed by CREWES at the University of Calgary for air-pressure recordings. The main element is a Panasonic WM-54 BT electret condenser microphone.

Figure 2: Time-frequency analysis of vibroseis-uncorrelated microphone output. The air blast is fundamentally a sweep-like signal whose frequency content depends on the sweep parameters. The upper Gabor spectrum corresponds to a 10-250 Hz linear sweep recorded from the Priddis experiment. The lower Gabor spectrum corresponds to a 25-250 Hz nonlinear sweep recorded from the Pikes Peak experiment.

Figure 3: Microphone signal enhancement by correcting for LMO and median filtering applied in the horizontal direction. This example is from the Priddis experiment with the source at 100 m offset.

Figure 4: Noise estimate produced by an adaptive filter using the microphone signal as a reference.

Figure 5: Examples of adaptive filtering using microphone signals as noise reference.

Figure 6: A real shot gather before (left) and after (right) applying an adaptive filter with microphone data as noise reference.