Vector Filters and Implications for New Seismic Acquisition and Processing Techniques

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Introduction

Advances in seismic hardware have produced very high quality three-component digital receivers. In most applications these receivers are intended to be deployed as single point receivers. This overcomes some of the known issues with three-component arrays (Hoff and Margrave, 2002), and arrays in general, but exposes the data recorded in this fashion to coherent noises which arrays were originally designed to attenuate. The digital vector filter was designed to take the place of physical arrays. Leveraging the multi-component nature of the data, the digital vector filter can utilize information from different components to isolate and attenuate various types of noise. There have been several publications on the vector filter process, sometimes referred to as an adaptive filter (Widrow and Stearns, 1985, Farhang-Boroujeny, 1998). In this article we do not intend to revisit this material in the same way but we wish to expose some of the successes and limitations of the method experienced in our efforts to utilize this new processing technology in production.

Theory

The theory behind the specific type of vector filter we have utilized is based on a concept similar to the adaptive filter methods used to eliminate noises in commercial products like head phones. The theory states that if you can isolate and characterize a noise with adequate fidelity, you can effectively subtract that noise from the observed data and preserve the signal you wish to observe. In our implementation we make the basic assumption that the horizontal channels from a three component receiver isolate surface wave noise with enough difference from the vertical component that we can simply measure the noise and subtract it. In theory, this seems a safe assumption because the particle motion of the surface waves is an elliptical motion with components on the horizontal and vertical axes while the p-wave signal that we wish to record on the vertical channel should be aligned in the vertical direction. The assumption has weaknesses. The noise is never completely isolated and the signal is never totally vertical. The degree that the assumptions are compromised impacts the effectiveness of the method and can place additional requirements on processing for successful attenuation of surface noises. One common result from the flaws in the assumptions is that desirable signal bleeds into the noise estimate. Yet even with these limitations, we have found the vector filter to be a very effective tool at attenuating unwanted surface wave noises and thus enhancing the final result of processing.

Application to field data

One of the principle advantages of the digital receiver is its undistorted low frequency response. A normal geophone has a resonance frequency which is usually around 10-12 Hz. This fact causes the geophone to attenuate frequencies below this point. The digital geophone has a resonance frequency well over 1000 Hz and can record the lower frequencies (significantly below 10 Hz) without distortion. Early in 2004, as we started recording production data with the new sensor, we realized that ground roll in some areas resided in these lower frequencies. A filter process capable of removing the ground roll without attenuating the low reflection signal frequencies is needed. The vector filter has the demonstrated capability of attenuating the low frequency ground roll noise without significantly impacting the desirable signal in this same band pass range. Simple enhancements to the method like time windowing and band pass filtering enhanced the results significantly.

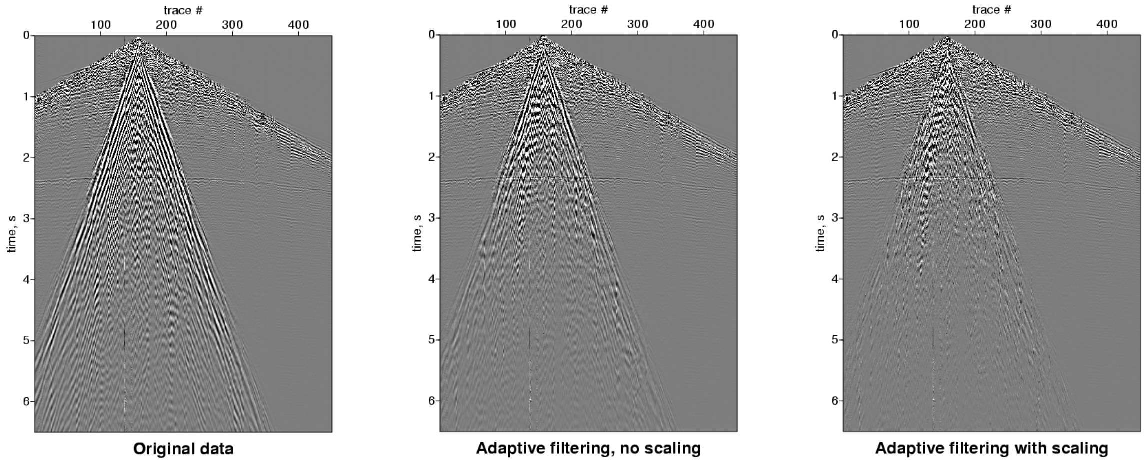

Figure 1 Application of adaptive filtering methodology to the surface noise contaminated data. All data are shown on the same scale.

The well known AGC (Automatic Gain Control) procedure in seismic processing is an adaptive filter too: the AGC operator adjusts itself inversely to the amplitude characteristics of the data within the analysis window. Adaptive filters can self-optimize under the changing environment (Widrow, 1985). Figure 1 shows an application of the most widely used LMS-based (Least-Mean-Square) adaptive filter to actual field data. Straight application of the algorithm usually yields about 10 dB noise attenuation. By further optimizing an LMS algorithm with noise scaling methodology one can add another 5 dB of noise suppression. Figure 2 illustrates the previous statement by plotting the amplitude spectra of the original data (solid black), straight adaptive filter application (dotted red) and a result achieved by the combination of adaptive filter noise estimation and scaling methodology (dashed blue).

Whereas other surface noise filtering techniques can be effective also (filtering in F-K domain, wavelet transform based filtering and others), all of these methods use various schemes of data mixing, or multi-trace spatial processing. Mapping of the data into other domains (F-K, for example) and further processing assumes unaliased sampling of the noise, which is, for the most part, not always achieved due to the acquisition constraints. The vector filter method makes no assumption related aliasing of the noise. It is strictly a trace by trace approach and does not depend on spatial relationship between adjacent traces so it works effectively on aliased data as well as unaliased data. This makes it possible to relax constraints in the survey design phase related to sampling of noise.

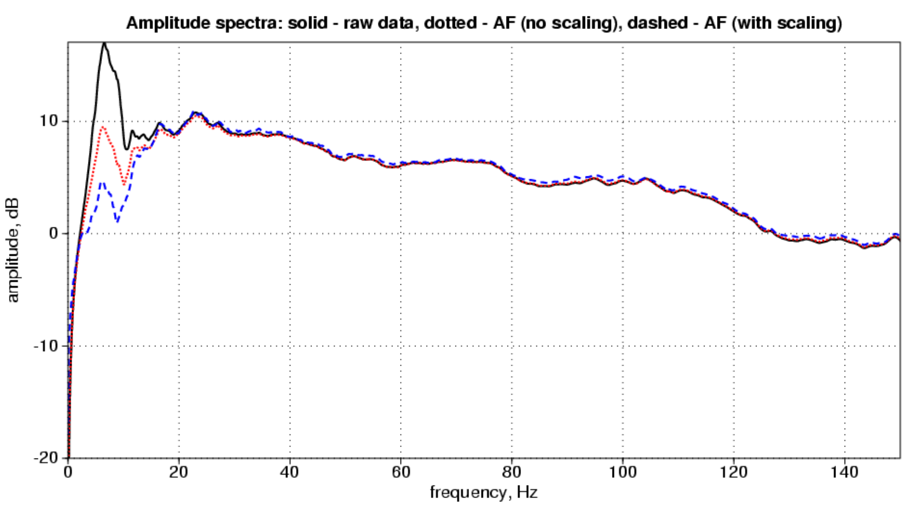

Figure 2 Amplitude spectra of the original and filtered data shown in Figure 1.

With the recent acquisition paradigm shift toward wide-azimuth, long offset patterns, preservation of the subtle trace-to-trace time shifts is essential to be able to invert these time shifts for velocity variation and seismic anisotropy estimation from the seismic data. Obviously, trace mixing filters will blur the difference between the traces and make anisotropy parameter estimation more uncertain.

Historically, a very effective tool to eliminate ground roll from the data, especially in the case of low frequency noise, was a bandpass (low cut) filter. With the new digital sensors capable of recording undistorted signal with frequencies as low as 1-2 Hz, application of the low-cut filters to eliminate the ground roll seems to be a poor choice, since it eliminates the useful low frequency signal component as well. Preservation of the low frequency component in the data increases the stability of the seismic inversion solution, an integral part of the seismic data analysis.

Example Data
We will show some example data from the tar sands area of Alberta. In this example, the vector filter reduced the ground roll recorded by single point receivers by 10-15 DB which improved the signal processing result and the high frequency response of the data. Figure 3

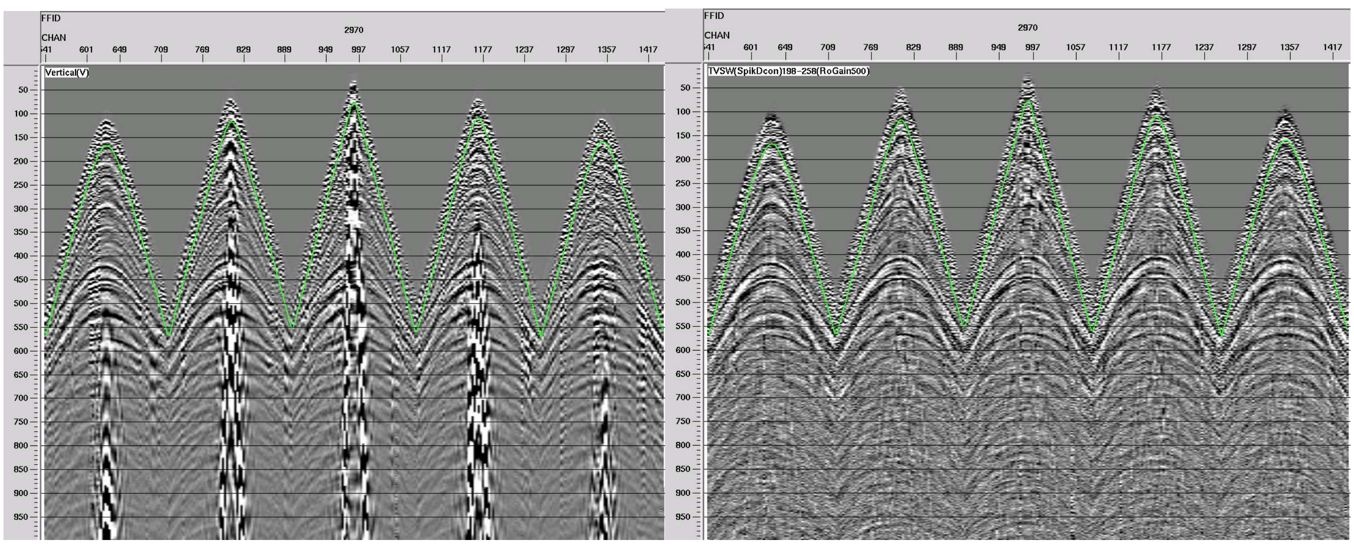

Figure 3 Before and after signal processing which included vector filter application.

Conclusions
Adaptive filtering methodology is an effective way to attenuate ground roll without changing the trace-to-trace dynamics in the field record, and preserving the useful low-frequency component of the reflected waves. Application of the adaptive filters in the seismic data processing is driven by the introduction of the new multi-component seismic sensors and acquisition patterns. The new sensors allow simultaneous recording of three components of the seismic data while preserving undistorted low frequencies in the recorded data. Sampling the same ground roll on the vertical and horizontal components allows the effective removal of source-generated noise without hurting the low frequency component of the reflected energy. Current acquisition methodology assumes wide azimuth coverage with long offsets, which puts constraints on the use of multi-trace processing tools for trace-to-trace dynamics preservation. The following key properties uniquely identify adaptive filter advantages over the conventional methodologies:

- single trace analysis (no-trace mixing);
- preservation of the low frequency component in the data related to the reflected wave energy;
- does not put any constraints on the noise sampling (insensitive to spatial aliasing).

The use of the new multi-component digital sensors in acquisition (even for the purpose of P-wave data alone), coupled with the processing flow preserving low frequencies and trace-to-trace dynamics, yields a reservoir model with higher confidence.

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