Adaptive f-xy Hankel matrix rank reduction filter to attenuate coherent noise

Nirupama (Pam) Nagarajappa, CGGVeritas, Calgary, AB
Pam.nagarajappa@cggveritas.com

GeoConvention 2012:Vision

Summary

The reliability of seismic attributes depends on reliable signal. In land data, coherent noise is often stronger than signal and dominates a range of offsets which renders the signal underneath un-useable. In addition, the noise can be aliased and have variable properties in terms of velocity, strength etc. To remove such noise, a novel adaptive approach based on Block Hankel matrix rank reduction is demonstrated. A fast rank reduction approach based on randomized singular value decomposition (SVD) is used. The method works on 3D f-xy data that is re-ordered in a modified shot order. I demonstrate the adaptive rank reduction filter on 3D data with strong near-surface reverberations. The method is flexible to be used in various domains depending on the nature of coherent noise.

Introduction

In seismic processing, preserving the amplitude versus offset (AVO) behavior of signal is extremely important to obtain reliable seismic attributes. Land data is often overwhelmed by coherent noise, which if not removed will render the seismic amplitudes and thus the extracted attributes unreliable.

In land data, coherent noises of various kinds exist. The most common kind is ground roll (or Rayleigh wave). Other types of coherent noise that are less common in occurrence and yet equally important, include air blast, flexure waves and near surface reverberations. Each noise type has characteristics that are a result of the near surface. While ground roll have very low frequency and velocity compared to reflection data, some noise types such as air blast or near surface reverberations have broader bandwidth and can be higher velocity than ground roll. In typical land acquisition geometries, the noise is aliased spatially. A common factor among all noise types is the variability of noise in spatial and temporal directions and high noise-to-signal ratio.

Typically, the characteristics of noise that distinguish them from signal are used to separate the two. In particular, coherent noise attenuation methods use the dip or velocity and frequency information to separate the noise and signal. While some methods can deal with aliased noise, approaches that in addition have the ability to deal with variable noise conditions are necessary.

In methods such as FK fan filters where the assumption of regular spacing is made, smear artifacts are present. FX fan filters that are adaptive locally are effective in removing the coherent noise and can handle irregular geometry (Haffner 2006, Meur 2008). More recent methods of coherent noise attenuation are based on FX domain rank reduction (Chiu 2008, Oropeza 2010 and Chiu 2011). The rank reduction approaches have the advantages of a FX filter. In such methods, reduced rank space of the data contains the coherent noise model, where the assumption that coherent noise is much stronger than signal is made. Recent work has looked at using multiple frequencies considering that the signal/noise across frequencies is not independent.

In this paper, I revisit the assumption of frequency independence of signal/noise in rank reduction methods of Hankel matrix. For each frequency, Block Hankel matrix rank reduction filtering is performed adaptively to improve coherent noise estimation. I show that adaptive estimation is a necessary step to separate coherent noise from signal. To facilitate adaptive estimation, a novel data order is proposed. Further I implement the method in 3D (f-xy) windows and demonstrate the filter on near surface reverberation noise. The collective approach of using modified shot order, Block Hankel matrix rank reduction and adaptive estimation discussed is here-on referred to as adaptive rank reduction filter.

Theory and Method

Rank estimation of Hankel matrices provide an intuitive way to understand the dips being modeled. The rank of a Hankel matrix with m dips in the absence of random noise is m (Cadzow1988, Trickett 2008). In the presence of noise, the rank increases.

To analyze the separation of coherent noise in Hankel matrices when coherent noise, signal and random noise are present, consider the following model;

$$\mathbf{H} = (\mathbf{S} + \mathbf{N}_c + \mathbf{N}) = \mathbf{U}_H \mathbf{\Sigma}_H \mathbf{V}_H{}^H \qquad (1),$$

Where **H** is Hankel matrix for a given frequency and a group of traces in a spatial direction, **S**, $\mathbf{N}_c$ and **N** are the Hankel matrices of signal, coherent noise and random noise. $\mathbf{U}_H, \mathbf{\Sigma}_H$ and $\mathbf{V}_H$ are left singular, singular value and right singular matrices, respectively. The superscript ^{H} denotes hermitian conjugate.

Then,

$$\mathbf{H}\mathbf{H}^H = (\mathbf{S} + \mathbf{N}_c + \mathbf{N})(\mathbf{S} + \mathbf{N}_c + \mathbf{N})^H = \mathbf{U}_H \mathbf{\Sigma}_H{}^2 \mathbf{U}_H{}^H \qquad (2),$$

$$\mathbf{H}\mathbf{H}^H = \mathbf{S}\mathbf{S}^H + \mathbf{S}\mathbf{N}_c^H + \mathbf{N}_c\mathbf{S}^H + \mathbf{N}_c\mathbf{N}_c^H + \sigma^2\mathbf{I} \qquad (3),$$

In equation (3), σ^2 denotes variance of random noise.

If $\mathbf{N}_c$>>**S**>>**N**, then

$$Tr\{\mathbf{N}_c\mathbf{N}_c^H\} \gg 2 * Tr\{\mathbf{S}\mathbf{N}_c^H\} \gg Tr\{\mathbf{S}\mathbf{S}^H\} \gg Tr(\sigma^2\mathbf{I}). \qquad (4).$$

Where *Tr*{ } indicates trace of matrix.

Relations (3) and (4) imply;

1. The trace of random noise is the smallest and the corresponding left singular vector is orthogonal to the remaining terms of the RHS of equation (3). Thus, a rank reduction of the matrix **H** can separate random noise.
2. The sum of eigen values of coherent noise is much larger than that of signal. This suggests that the higher rank images of **H** would correspond to coherent noise or rank reduction of matrix **H** would give coherent noise model. However, rank reduction of **H** will not result in complete separation of signal and coherent noise because of the presence of cross-terms $\mathbf{S}\mathbf{N}_c^H$. The cross-terms result in signal leakage into the coherent noise estimation. Thus, an adaptive approach following rank reduction is necessary to remove residual signal from rank reduced matrix **H**.

Variability of noise in spatial and temporal domains, irregular geometry and bandwidth of noise dictate the design of adaptive rank reduction noise filter. The characteristics of noise namely velocity, strength at a given trace depend on the distance from the shot. For example in a 3D data, noise in the receiver line close to a shot point is generally stronger compared to a receiver line farther. Thus, noise is varying spatially from receiver line to receiver line. To overcome this, the input data to the rank reduction filter is re-ordered in a novel scheme, where set of shot gathers with similar propagation paths are grouped (i.e., modified shot order). In this modified data ordering, the noise between neighboring shot gathers can be considered stationary. Further, to improve the coherent noise estimation, a 3D gather (f-xy) is formed by considering a range of neighboring shots from within the modified shot order set, for each frequency. A fast randomized SVD (Rokhlin 2009, Oropeza 2010) is used to perform rank reduction. The method is run over temporal and spatial windows allowing it to handle variability of noise in time and spatial domains including irregular sampling. In addition, the range of frequencies over which noise is estimated can be varied depending on bandwidth of noise. The criteria to model dominant dip/s also enable aliased noise to be estimated. Further, adaptive subtraction is done to optimize the noise estimation.

Examples

Adaptive and non-adaptive rank reduction filter were tested on synthetic data. A non-adaptive rank reduction filter means that rank reduction was performed to separate the dominant dip. The synthetic data consisted of a strong dip and two weaker dips with no noise (Figure 1a). Non-adaptive rank reduction filter (rank 1) separated the dominant dip, but the stronger of the two weak dips leaked into the estimate (Figure 1b). The difference between Figures 1a and 1b is shown in 1c. This is because the dips are not orthogonal. The result of adaptive rank reduction filtering applied to data in 1a is shown in Figure 1d. After adaptive rank reduction filtering, the leakage from other dips is no longer present. The difference between input and adaptive rank reduction filter is shown in Figure 1e.

The proposed adaptive rank reduction filter was applied to remove near surface reverberations found in real data. Figure 2a shows the shot record before adaptive rank reduction filter. Note that ground roll was removed prior to applying adaptive rank reduction filter. The near surface reverberations which are source generated have two different velocities and are stronger than signal thus masking the reflections underneath. Further, the noise and signal frequencies overlap considerably and noise is aliased. Unlike ground roll, the noise affects all offsets and frequencies. If the zone of interest lies within the noise cone, noise must be removed to obtain reliable signal amplitudes. Adaptive rank reduction filter was used to estimate near surface noise and remove it. Figure 2b shows the shot record after adaptive rank reduction filtering and Figure 2c shows the difference between figures 2a and 2b. After noise attenuation, coherent signal underneath the noise cone can be seen and the difference image shown no discernible signal.

Conclusions and Discussion

I have proposed a 3D adaptive f-xy Block Hankel matrix rank reduction approach to suppress coherent noise. The method assumes that coherent noise is stronger than the signal and separates the dominant dips from the weaker ones. The adaptive approach with the data ordering is adopted in this paper, further makes the filter robust in estimating noise model under varying noise conditions and removing signal leakage.

The method demonstrated in this paper was applied to modified shot ordered data where considered gathers have similar propagation paths. From the ordering, neighboring shot gathers can be considered stationary. The method can be run in other domains as long as the data being grouped remain relatively similar.

Adaptive rank reduction filter was successfully demonstrated on synthetic data and real data and shown that the noise dips can be separated from signal. The estimated noise in real data shows no signal leakage suggesting that the proposed method preserves the AVO response of signal and thus paves way for reliable seismic attributes.

Acknowledgements

I thank our client for permission to show the data, CGGVeritas for permission to publish this work, my colleagues in processing and R&D for useful discussions and feedback.

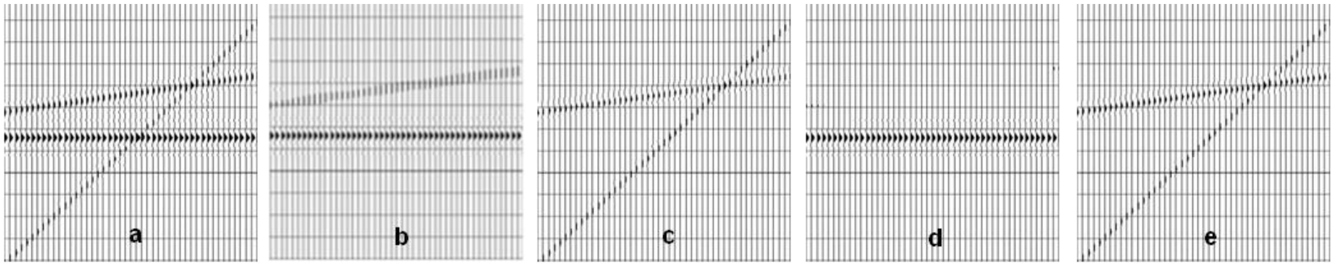

Figure 1 Dip estimation by rank reduction on synthetic data with 3 dips of varying strength. (a) input, (b)rank 1 estimation (non-adaptive), (c) difference of (a) and (b), (d) adaptive rank 1 estimation, (e) difference of (a) and (d)

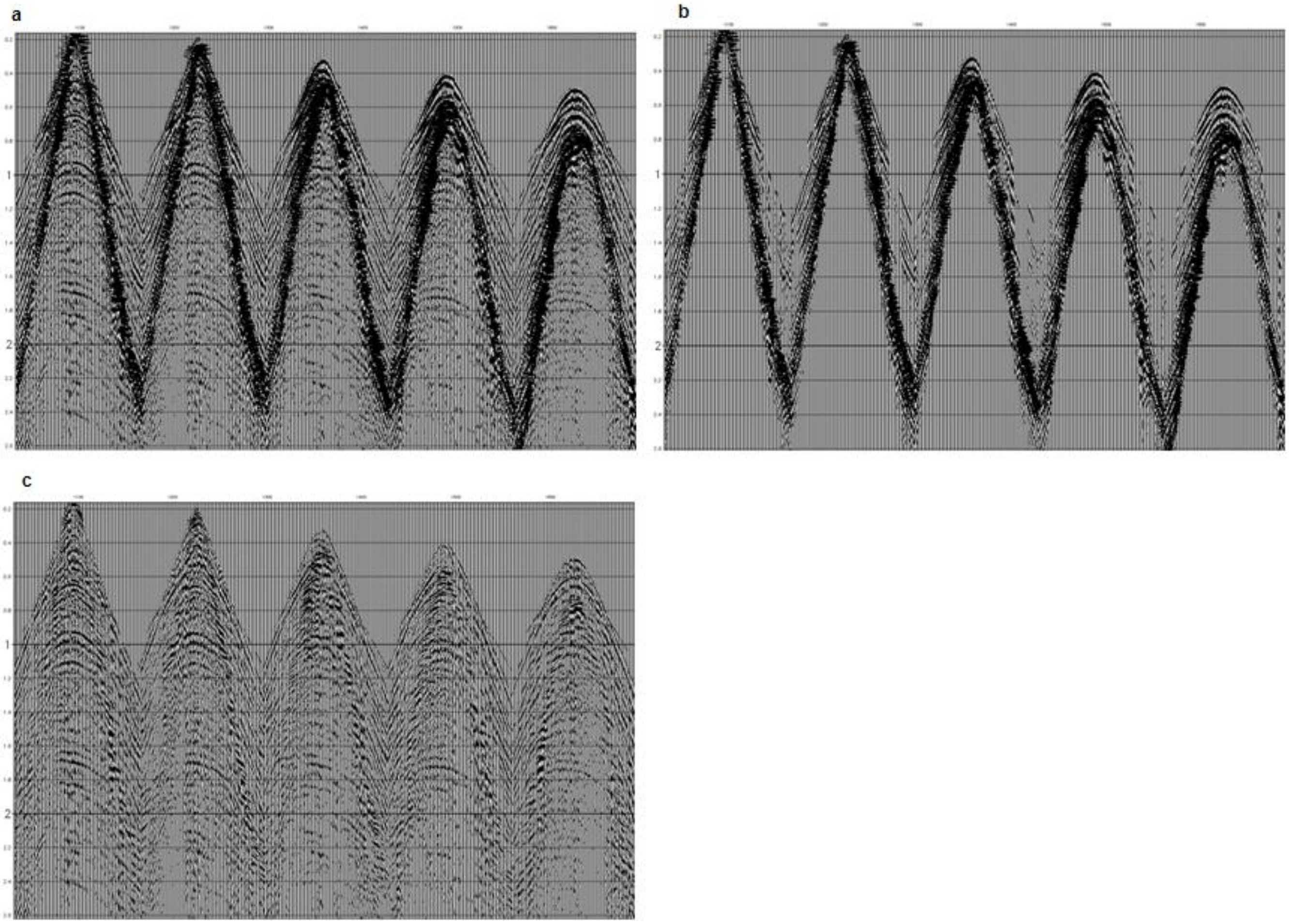

Figure 2 Proposed adaptive rank reduction of near surface noise on shot gathers. (a) input shot gathers, (b) estimated noise and (c) gathers after noise attenuation

References

Cadzow, J., 1988, Signal enhancement – a composite property mapping algorithm: IEEE Transactions on acoustics, speech and signal processing, 36, 49-62

Chiu, S. K., Howell, J. E., 2008, Attenuation of coherent noise using localized-adaptive eigenimage filter: SEG Expanded Abstracts, 27, 2541-2545

Chiu, S. K., 2011, F-xy noise attenuation via multichannel singular spectrum analysis in randomized domain: SEG Expanded Abstracts, 30, 3612-3616

Haffner, S., Trad, D., 2006, Coherent noise attenuation (CNA)/ coherent signal estimation (CSE): Internal Report

Meur, D. L., Traonmilin, Y., 2008, Adaptive noise attenuation: SEG Expanded Abstracts, 27, 3667-3670

Oropeza, V. E., Sacchi, M. D., 2010, Multifrequency singular spectrum analysis: SEG Expanded Abstracts, 28, 3193-3197

Oropeza, V. E., Sacchi, M. D., 2010, Application of singular spectrum analysis to ground roll attenuation: CSEG Abstract

Rokhlin, V., Szlam, A., Tygert, M., 2009, a randomized algorithm for principle component analysis: SIAM journal on matrix analysis and applications, 31 (3), 1100-1124

Trickett, S., 2008, F-xy Cadzow noise suppression: SEG Expanded Abstracts, 27, 2586-2590