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SVD-based Hydrophone Driven Shear Noise Attenuation for Shallow Water OBS

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SUMMARY

In ocean-bottom seismic (OBS) data processing, the vertical geophone component Z data is often corrupted by a high level of "shear" noise which is not recorded by the hydrophone P. This noise highly influences the quality of the wavefield separation and, consequently, the final up-and down-going wavefield imaging products. With the growing importance of large, dense OBS acquisitions, we need methods that are both capable of accurately attenuating the "shear" noise and applicable to large amounts of seismic data. In this paper, we propose a singular value decomposition (SVD)-based noise attenuation method that relies on the hydrophone to drive the algorithm, allowing a good signal preservation on the vertical geophone. The proposed method uses a cross-correlation matching pursuit to compare the hydrophone and geophone data, and is equipped with an optimized SVD kernel. We demonstrate the performance of the method on a dense wide-azimuth 3D OBS shallow water acquisition involving 56,000 4-component nodes. Results demonstrate the efficiency of the proposed method in removing "shear" noise on the vertical geophone component with no damage to the signal.

Introduction

Ocean-bottom seismic (OBS) technology has been shown to be an effective alternative to conventional towed streamer acquisitions in open seas or obstructed areas. This technology is appropriate for both shallow and deep water environments.

In OBS acquisition, each individual receiver (autonomous or embedded in a cable) consists of four sensors: one hydrophone (P) and three orthogonal geophones that respectively measure pressure and vertical (Z) and horizontal particle velocities (or accelerations). This allows us to record the full elastic wavefield as well as its separation into up- and down-going parts.

The vertical geophone component data is often corrupted by a high level of noise compared to the data recorded by the hydrophone. This noise, often referred to (sometimes incorrectly) as “shear noise,” or “Z-noise”, is characteristically weak or absent on the hydrophone, sometimes exhibits converted-wave moveout, can be dominant at low frequencies, and it is coherent in the receiver domain but not in the shot domain. Paffenholz et al. (2006) designate local scatterers on the seabed as the main cause of this noise wavefield.

The presence of strong “shear” noise affects the quality of wavefield separation, since the calibration filters that match Z to P can focus on the differing noise characteristics on these components instead of the different signals. Poor wavefield separation can degrade subsequent processing and imaging steps, motivating techniques for removal of the “shear” noise. An early approach to this described by Shatilo et al. (2004) is based on a dip filtering technique in the F-k domain. By taking advantage of the absence of this noise on the hydrophone, a few methods were then developed using P for driving algorithms that preserve the signal on Z through a guided-denoise approach. In fact, P and Z are first decomposed in a specific domain. Any event on Z that is inconsistent with P events during a joint process is not desirable and is rejected as noise. Craft (2008) proposes a four-dimensional (Tau, Px, Py, Frequency band) domain approach, and Poole et al. (2012) a sparse (Tau, Px, Py) domain approach, to compare the two components for hydrophone-guided denoise. Recently, Peng et al. (2013) proposed a decomposition approach in the complex wavelet domain.

In this paper, we propose a guided-denoise technique based on singular value decomposition (SVD) that relies on P to drive the algorithm allowing a good signal preservation on Z, in the spirit of the methods developed by Deschizeaux et al. (2013) and Sanchis and Elboth (2014). The first authors describe a case study for de-noising OBS vertical geophone data in the presence of an extremely poor signal-to-noise ratio, and the second authors adapt this SVD-based technology for removing interference noise on the geophone of multicomponent streamer data. As an alternative, we propose the use of a SVD-based cross-correlation matching pursuit algorithm to better preserve the signal on the geophone. This method efficiently handles the decomposition, so that it is applicable to large and dense datasets.

We demonstrate the effectiveness of our approach on a large shallow-water 3D OBS dataset acquired offshore Gabon, involving 56,000 4-component nodes, where strong noise is present on the Z component.

Methodology – SVD-based hydrophone driven “shear” noise attenuation

SVD has been extensively used for attenuating random noise (Trickett (2003, 2008), Sacchi (2009)), as the large singular values represent the laterally coherent signal whereas the low ones are associated with random noise. However, as explained above, the noise is coherent in the common-receiver domain. This is addressed in SVD-based guided-denoise using a Cadzow style rank reduction. For a given spatial window in a frequency slice, we map the hydrophone and geophone data respectively into Hankel matrices $\boldsymbol{H_p}$ and $\boldsymbol{H_z}$ (Trickett 2008, Sacchi 2009). A set of n and m singular values and singular vectors are then extracted by computing the SVD of the matrices $\boldsymbol{H_p}$ and $\boldsymbol{H_z}$, respectively. We typically choose $m > n$ as our goal is to eliminate the elements in the decomposition of $\boldsymbol{H_z}$ corresponding to the “shear” noise, based on a measure of dissimilarity with the elements in the decomposition of $\boldsymbol{H_p}$. Since we do not need all singular values of $\boldsymbol{H_p}$ and $\boldsymbol{H_z}$, we can use a fast SVD kernel based on fast Hankel matrix-vector products (Gao et al., 2012) achieving an O(n log (n)) complexity in floating point operations, where n is the number of traces per frequency slice. This allows us to efficiently process dense acquisitions with a large number of nodes.

With respect to the singular vectors extracted from the Hankel matrices $\boldsymbol{H_p}$ and $\boldsymbol{H_z}$, denoted by $(U_p^i, V_p^i), i = 1, \dots, n$ and $(U_z^j, V_z^j), j = 1, \dots, m$, we look for a subset of singular vectors (U_z, V_z) close to those of the hydrophone. For each of the n singular vector pairs (U_p, V_p), we perform a k-term matching pursuit with the m singular vector pairs (U_z, V_z), in which the k most similar singular vectors are conserved. Usually k varies between 1 and 3, depending on the desired noise attenuation power. The chosen similarity measure corresponds to the cross-correlation between the elementary signals reconstructed from single singular vector pairs (U_p^i, V_p^i) and (U_z^j, V_z^j), so that the algorithm is sensitive neither to amplitude nor to phase differences between the P and Z components. In other words, only the kinematics of elementary events are used in this SVD-based cross-correlation method to distinguish noise in the geophone data. This avoids the need for amplitude matching prior to denoising. Finally, the conserved Z singular vectors are used to reconstruct the denoised geophone gathers while the other directions are considered as coherent noise and discarded. Figure 1 illustrates the schema of the proposed method. The cross-correlative matching pursuit algorithm (step 4 of Figure 1) is described as follows:

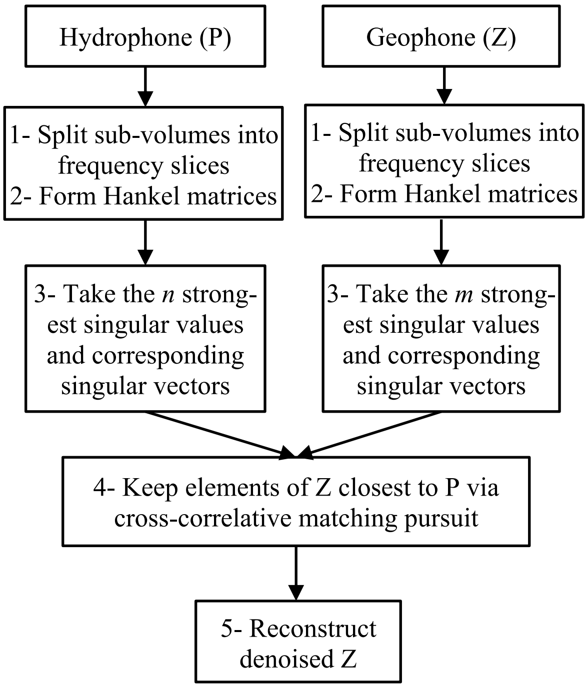

Figure 1 *Proposed SVD-based hydrophone driven "shear" noise attenuation flow*

- For each pair $(U_p^i, V_p^i), i = 1, \dots, n$,
- Find the k closest $(U_z^j, V_z^j), j = 1, \dots, m$, based on maximum peak of cross-correlation of the reconstructed kinematics.

Real data example

We demonstrate the effectiveness of the proposed noise attenuation method on a dense wide-azimuth 3D 4-component "node-on-a-rope" OBS survey acquired offshore Gabon. (Individual nodes are simply attached on a rope with no connection through cables). The water depth varies from 23 m to 60 m. The study area is approximately 284 km^2 covered by a 200 m x 25 m receiver grid, complemented by a carpet-shooting geometry on a 50 m x 50 m grid. A total of 56,000 nodes were recorded during the survey. The acquisition geometry was designed to obtain very high fold and rich azimuth and offset sampling. An optimal imaging quality in terms of amplitude preservation was a strict requirement for the processing.

The hydrophone and vertical component data were selected for processing very early in the project, after vector fidelity quality control including clock drift, node positioning, and node orientation. The data were first processed through a noise attenuation sequence to remove spikes, mud-roll, and interference noise. One of the main processing challenges of this dataset was severe noise contaminating the vertical geophone data. We next consider the results of the proposed SVD-based hydrophone driven denoising on the vertical geophone data.

To illustrate the characteristics of the "shear" noise in the receiver domain, Figure 2 shows frequency panels for a hydrophone (a) and a vertical geophone (b). We observe that this noise is dominating the geophone data in the low frequencies, particularly below 10 Hz (see arrows).

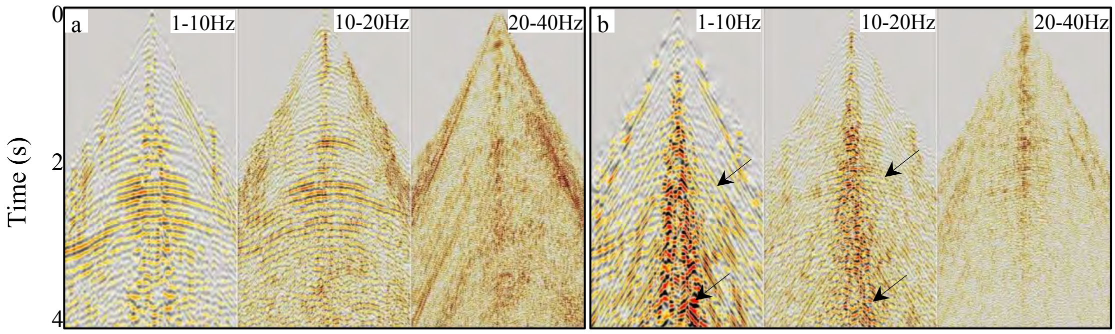

Figure 2 *Receiver gather frequency panels: a) hydrophone, b) vertical geophone.*

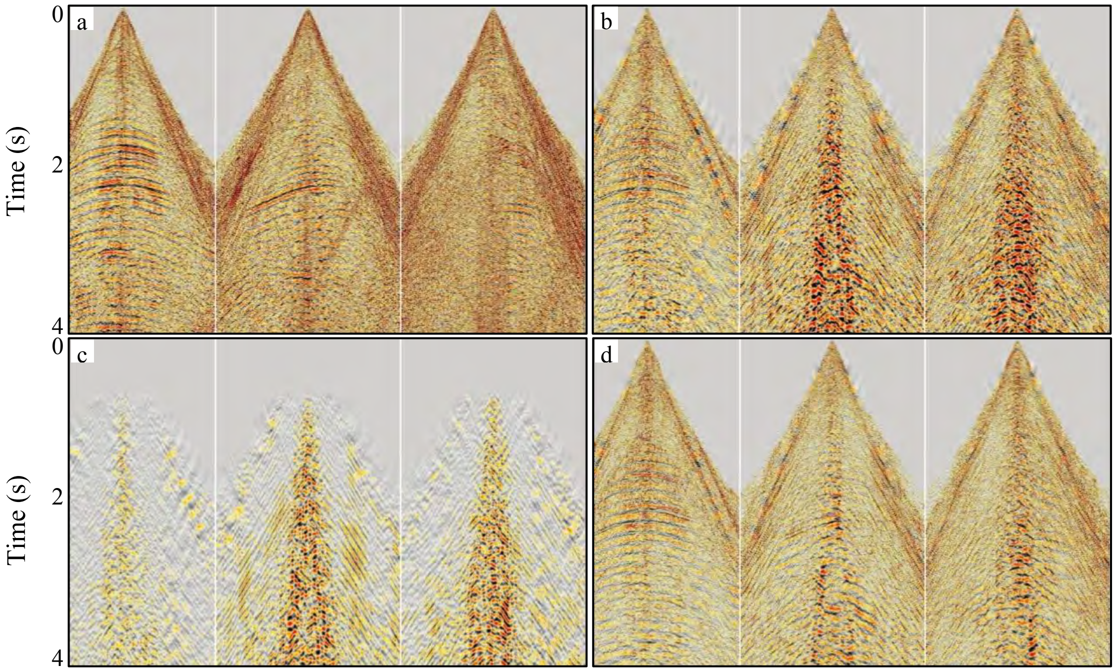

Figure 3 *Three receiver gathers: a) input hydrophone, b) input vertical geophone, c) noise removed, d) output denoised vertical geophone.*

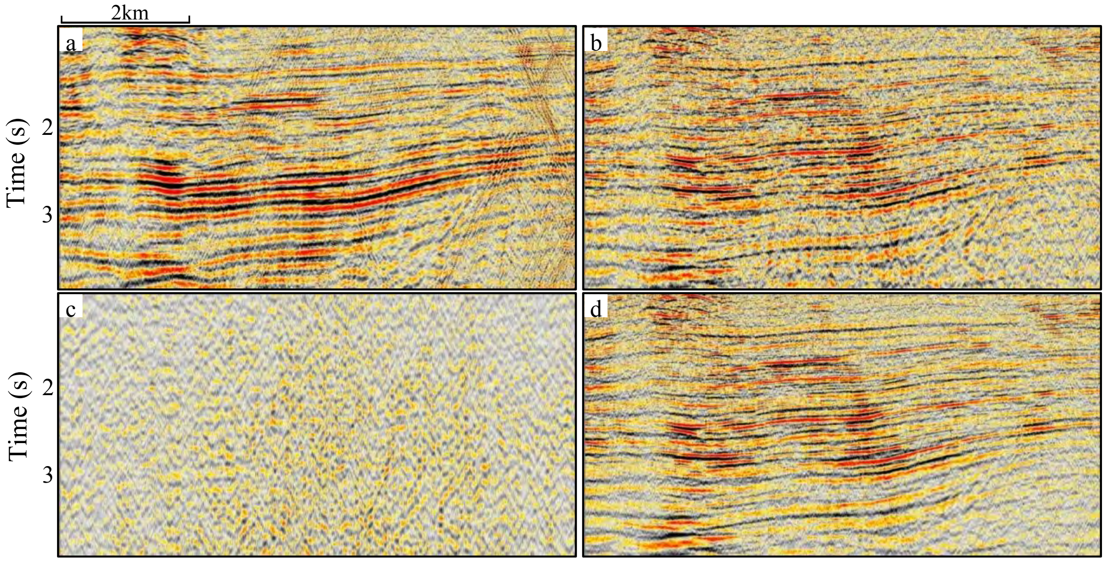

Figure 4 *3D bin stacks: a) input hydrophone, b) input vertical geophone, c) noise removed, d) output denoised vertical geophone.*

Figure 3 shows the results, on the full frequency bandwidth, on the closest shot line of three receiver gathers with different levels of contamination. The top panels illustrate the comparison between the relatively noise-free hydrophone (a) and the noise-contaminated geophone (b). The “shear” noise is strong (with varying amplitude) and masks the geophone signal, particularly for the two receivers on the right. The bottom panels illustrate the noise removed by the proposed method (c) and the geophone signal after denoising (d).

Figure 4 shows the results on the 3D bin stacks. The top panels illustrate the hydrophone (a) and geophone (b) before denoising. The “shear” noise looks like linear noise on the bin stack that breaks the event continuity. The bottom panels illustrate the noise removed by the proposed method (c) and the noise-attenuated geophone (d).

We observe that the “shear” noise on the geophones has been significantly attenuated while preserving the signal. There is minimal signal leakage in the removed noise for both receiver gathers and stacks. This results in higher signal to noise ratio of geophone gathers and more continuous events on the geophone bin stack.

Conclusion

In OBS projects, the vertical geophone data is often contaminated by “shear” noise, and its attenuation is a challenging task. In this paper, we presented a SVD-based hydrophone driven noise attenuation technique that relies on P to drive the algorithm. The proposed method uses a cross-correlation matching pursuit technique, allowing a good signal preservation on Z. Moreover, the implementation of an optimized SVD kernel makes the method suitable for large datasets. We demonstrate its performance at production scale on a shallow-water dense and wide-azimuth 3D OBS data. The results prove the effectiveness of the proposed method in attenuating “shear” noise.

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