2D Stationary Wavelet Transform based Acquisition Footprint Suppression
Milos Cvetkovic, Scott Falconer, Kurt J. Marfurt, University of Houston; Sergio Chávez-Pérez, Instituto Mexicano del Petróleo

Abstract

Acquisition of seismic data over a large 3D survey acquired in Mexico is constrained by both cultural and ecological limitations, resulting in strong acquisition footprint that contaminates the target turbidite reservoir of interest. Due to the acquisition obstacles, the source and receiver grid is quite irregular, such that we cannot suppress acquisition footprint through simple \(k_x-k_y\) filtering of time slices. In this survey, the most vexing components of acquisition footprint are due to leakage of backscattered ground roll into the migration-stack and migration artifacts. 2D Wavelet Transforms provide a spatially varying filter that better adapts to the irregular acquisition geometry. We find that 2D Stationary Wavelet Transform (2D SWT) based filters applied to seismic time slices allow us to suppress both acquisition footprint and random noise, while preserving geologic discontinuities of interest. We decompose each seismic time slice into five levels of wavelet components that represent progressively coarser details. In the shallow section, acquisition footprint is strong and geologic structure is weak. We therefore examine successive levels (or panels) to determine where the acquisition footprint lies. Once identified, we suppress these components in the data reconstruction. We find that 2D SWT filtering on time slices allows us to suppress backscattered ground roll, as well as migration artifacts that leak through the seismic processing. We evaluate the efficacy of this processing through the use of geometric attribute imaging of the turbidite system.

Introduction

Interpretation of 3D land seismic data and attribute analysis can be quite challenging in the presence of severe acquisition footprint. This is defined as coherent noise correlated to the surface acquisition geometry. The causes of acquisition footprint are: 1) inaccurate velocity models, 2) inaccurate statics, 3) leakage of aliased coherent noise (such as surface waves), 4) regular patterns of varying fold and azimuthal distribution in CMP gathers, 5) missing data due to surface obstacles, and 6) migration operator aliasing. Our data volume suffers from all of these problems.

There are several filtering techniques that have been suggested to remove acquisition footprints during the processing stage including \(f-k\) (Chopra and Larsen, 2000), \(k_x-k_y\) (Soubaras, 2002; Gulunay, 1999) and principal component (Al-Bannagi et al., 2004) filtering.

Jervis (2006) describes an edge preserving technique for acquisition footprints removal based on successive 1D Complex Continuous Wavelet Transforms applied to time slices. He finds improved separation of signal and noise after filtering compared with the corresponding 1D Discrete Wavelet Transform filtering and principle component filtering methods.

Although we are not able to duplicate Jervis’ (2006) method, we find that a time-invariant 2D stationary wavelet transform provides good acquisition footprint suppression.

The 2D Stationary Wavelet Transform

Yu et al. (2004) demonstrate the use of Wavelet Transform filtering in ground roll suppression, seismic resolution enhancement and seismic data interpolation. Several papers describe 1D and 2D Discrete Wavelet Transforms: Deighan and Watts (1997) apply discrete Wavelet Transform to raw shot gathers to suppress ground roll. Yu et al. (2004) apply similar techniques to marine data interpolation, and provide an excellent review of wavelet theory and 1D Stationary Wavelet Transforms. To our knowledge, there are no published reports on the application of 2D SWT to the suppression of acquisition footprint.

2D Wavelet Transforms decompose a seismic slice into one or more levels of horizontal, vertical and diagonal components (Figure 1). A well-known limitation of conventional discrete wavelet transforms is the generation of time-shift artifacts if we filter out any of the components prior to reconstruction. In contrast, the Stationary Wavelet (also called the \(\varepsilon\)-decimated Discrete Wavelet) Transform, avoids such artifacts, and provides equivalent results as the continuous wavelet transform but with less computational effort (Misity et al., 1996). SWT decomposes signals or images of lengths divisible by \(2N\), where \(N\) is the highest number of decomposition level, requiring simple zero-padding of the input time slices.

Our experience is that the choice of wavelet basis does not produce a significant difference in the results; however, a wavelet basis with a low number of vanishing moments provides improved computational efficiency. In this work we use Coiflet wavelets with four vanishing moments and five levels of decomposition.
2D Stationary Wavelet Transform based Acquisition Footprint Suppression

Methodology

We selected 20 time slices spaced at 200 ms increments for our initial analysis. For each time slice the optimum filtering parameters were chosen based on the criteria that 1) the denoised slice has less acquisition footprint, and 2) the residual slice does not show any rejected geological features of interest. By applying weights to the components prior to reconstructing the data, we can obtain any level of noise rejection. In Figure 2, we reject the 2 finest levels at \( t = 400 \) ms, while we reject only the finest level at \( t = 1400 \) ms. At \( t = 1000 \) ms we reject the finest level and one half of the 2\(^{nd}\) finest level, which we denote by 1.5.

Selection of the optimum level of filtering is interpreter-driven, simple, and computationally fast. Once filter levels at each of our 20 coarsely-spaced time slices have been selected, we simply interpolate filter levels for every time slice in the volume. We apply these filters to the transformed data and reconstruct the filtered seismic data volume. Finally, we compute seismic attributes to verify that we have not inadvertently rejected discontinuities of geologic interest.

Example

We apply the above workflow to a 3D PEMEX’s data volume acquired over the Agua Fría-Coapechaca-Tajín fields, in Chicontepec basin, Mexico (Chavez-Perez et al., 2006). This survey suffers from severe acquisition footprint problem. Non-geological patterns produced primarily in the acquisition stage vary with depth. Previous work attempted to address the root cause of acquisition footprint through the application of migration deconvolution. In this paper, we evaluate an alternative, interpreter-driven approach described above.

We show the results of 2D SWT filtering on seismic time slices from the 3D data volume in Figure 3. Almost all the acquisition footprint is removed without serious alteration of useful data or major geological features. In this geological environment there is no removal of fault detail by 2D SWT filtering. Figure 4 shows seismic sections before and after 2D SWT filtering. The removed part of the data contains random “vertical” noise, migration artifacts, acquisition footprint and almost no geological features.

Future work includes the application of the algorithm scheme to small faults, listric faults and orthogonal faulting systems and their appearance on coherency and other seismic attributes.

Conclusions

The main advantage of the 2D SWT filtering scheme is the flexibility in assigning the parameters in which to adapt the data. For land data sets with non-orthogonal acquisition footprint, a similar approach with 2D SWT filtering of seismic sections would yield satisfactory results. Here we presented a new tool for acquisition footprint suppression that is easy to understand and relatively fast.
2D Stationary Wavelet Transform based Acquisition Footprint Suppression

The proposed filtering technique has promising results for marine data sets, where wide streamer acquisition and feathering produce strong cross line footprints.

Future studies should test impact of the proposed filtering method on attributes and interpretation. We expect curvature, coherency and principal component to be highly sensitive to noise and artifacts in data (Marfurt et al., 1999). Contourlet and curvelet transforms promise to have similar or better separation between signal and noise for this type of filtering.

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Figure 3. Seismic time slices from PEMEX's Agua Fría-Coapechaca-Tajín 3D data set 400 ms above the target turbidite reservoir before (top) and after (middle) removing 1.75 levels of 2D SWT components and the difference (bottom) between the two. All images are plotted at the same amplitude scale. Note the highly organized, short wavelength acquisition footprint that runs primarily NE. Yellow arrows indicate a fault that does not appear to be blurred.
2D Stationary Wavelet Transform based Acquisition Footprint Suppression

Figure 4. Vertical seismic line A-A’ through the 3D data volume before (left) and after (middle) 2D SWT filtering, and the difference (right) between the two. SWT rejection levels vary from 2.5 at the top to 1.5 at the bottom of the image. Almost all of vertical random noise and migration artifacts are being removed from data. White arrows show removed acquisition footprint events and yellow arrows depict effect on sub vertical fault.
EDITED REFERENCES
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