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Attenuation of Turn Noise in Marine Towed Streamer Data with an Anti-leakage Tau-P Method

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SUMMARY

A method for attenuating strong, clustering turn noise, caused by the turning of seismic vessels in marine surveys, is proposed in this work. The critical step of this approach is based on a coherence-preferred anti-leakage Tau-P transform that fits input data by favouring coherent events and excluding strong, incoherent noise energy. After reconstructing the data from the Tau-P transform, most of the turn noise is attenuated.

Introduction

In marine seismic data, the strong noise caused by vessel turning is often clustered in both the channel and shot domains. Statistically, this noise is non-Gaussian in distribution and can be challenging for conventional noise attenuation procedures. Typically, most noise attenuation methods rely on the assumption of Gaussian-distribution of the noise and the predictability of coherent signals. These methods include F-X prediction filtering (Canales, 1984) and projection filtering (Soubaras, 1994), SVD rank-reduction methods (Sacchi, 2009), and anti-leakage Fourier transforms. For erratic noise patterns, robust versions of the rank-reduction method have been proposed (Chen and Sacchi, 2013), in which data points that contain the strong erratic noise are treated as outliers in the processing window. These outliers are then assigned a small weight to make them less significant in the data fitting. Unfortunately, the turn noise patterns are clustered such that the noisy data points do not display as outliers, and therefore can leak into the predicted signals.

I propose a noise attenuation approach based on a novel anti-leakage Tau-P (ALTP) transform to attenuate turn noise. This modified version of the ALTP transform can fit the signal energy while considering its coherence, and avoids fitting the strong, erratic turn noise. The proposed method is discussed first, and then a field data example is used to demonstrate its application.

Method

Raw shot gathers contaminated with turn noise typically contain strong low frequencies and highly dipping linear energy; therefore, the first step of a work flow is usually low frequency cut and F-K domain dip filtering. The filtered shot gathers often contain incoherent and clustering noise patterns with considerably higher amplitudes than the primary signals. To further attenuate this noise, the coherence-preferred ALTP transform is applied.

The conventional ALTP transform (Poole, 2011) is an analogue to the anti-leakage Fourier transform. The process begins with slant stacking on a p (slope) grid. Then, the slope (p) with the maximum energy is selected and the corresponding trace is accumulated to the output. The corresponding linear event is subtracted from the input in the T-X domain, and the residual goes to the next iteration until a certain accuracy criterion is reached. The problem with the conventional ALTP transform is that the process uses only the strength of the energy of a p trace as the criterion when choosing the optimal p component to remove from the input. This can lead to considerable energy leakage from strong, clustering, and erratic noise into the reconstructed signal because, for a high energy p trace, the energy could be noise.

In order to overcome this drawback, I propose a coherence-preferred ALTP transform, which differs from the conventional Tau-P transform in the way that the optimal p trace is selected in each iteration. Instead of directly using the energy of the slant-stacking trace to choose the optimal p, I first use a power of the semblance at each τ along a p to scale the slant-stacking trace at that (τ, p). Then I use the energy of the semblance-scaled p trace, $S^i(p,\tau)T(p,\tau)$, to pick the optimal p, where $T(p,\tau)$ is the slant-stacking trace along p, $S(p,\tau)$ is the semblance along p at τ, and i is the power index. If the power index is zero, this method is equivalent to the conventional ALTP transform. The larger the power index, the more significant the semblance becomes in the p selection. In this method, the iterations will stop when the maximum semblance is under a certain threshold. Once the stopping criterion is met, the signal model is obtained in the Tau-P domain and, after reconstruction by the inverse Tau-P transform, the noise-attenuated data are obtained. This proposed method avoids blindly fitting strong yet incoherent noise patterns with low semblance, making it a promising algorithm for the attenuation of turn noise.

To illustrate the principle of this modified ALTP transform, Figure 1 compares the noise attenuation flows using the coherence-preferred ALTP transform and the conventional ALTP transform. From Figure 1 (b) and (e), it can be observed that the coherence-preferred ALTP transform has cleaner Tau-

P mode for the input than the conventional Tau-P transform. This leads to minimal noisy energy leakage in the reconstructed image with the coherence-preferred Tau-P transform as shown in Figure 1 (c); for comparison the reconstructed image with the conventional Tau-P transform is shown in Figure 1 (f).

Examples

The proposed method has been applied to field data sets from a full azimuth survey. The vessel turning at the start and end of the lines generates strong clustering noise in almost all channels for the shots when the turning occurred. The turn noise concentrates in low frequencies, but spans a considerable frequency band (approximately the lower third of the Nyquist band; refer to Figure 3).

As mentioned in the previous section, a mild low-cut and F-K dip filter was applied to remove low frequencies and linear noise with high dips. After this step, more than half of the noise energy was removed. However, the remaining noise is still strong and clustering in both channel and shot domains.

Since most of the residual noise energy exhibits low frequencies, I apply the coherence-preferred ALTP transform to only the lower half of the resulting frequency band after the low-cut and F-K filters. After the data reconstruction by the inverse Tau-P transform, most of the residual turn noise is removed.

Figure 2 shows the processing of an entire shot gather that is heavily contaminated with turn noise. Most noise energy was successfully removed during the flow with almost no attenuation of primary signal. Figure 3 shows the change of the frequency spectrum of that gather during different stages of the processing. The majority of the attenuated turn noise concentrates below 10 Hz.

Conclusions

Turn noise in marine surveys is a challenge for seismic data processing due to its high energy, non-Gaussian distribution, and clustering in both the channel and shot domains. Most current noise attenuation methods poorly attenuate turn noise because they either make an assumption that the noise is Gaussian or they fail to classify turn noise as outliers in processing windows.

In this work, I proposed a coherence-preferred ALTP transform to handle turn noise attenuation. Unlike the conventional ALTP transform, which favours events with high energy without taking coherency into account, the proposed coherence-preferred ALTP transform places optimum weight on coherence in addition to energy. This mitigates potential energy leakage from strong clustering noise.

Acknowledgements

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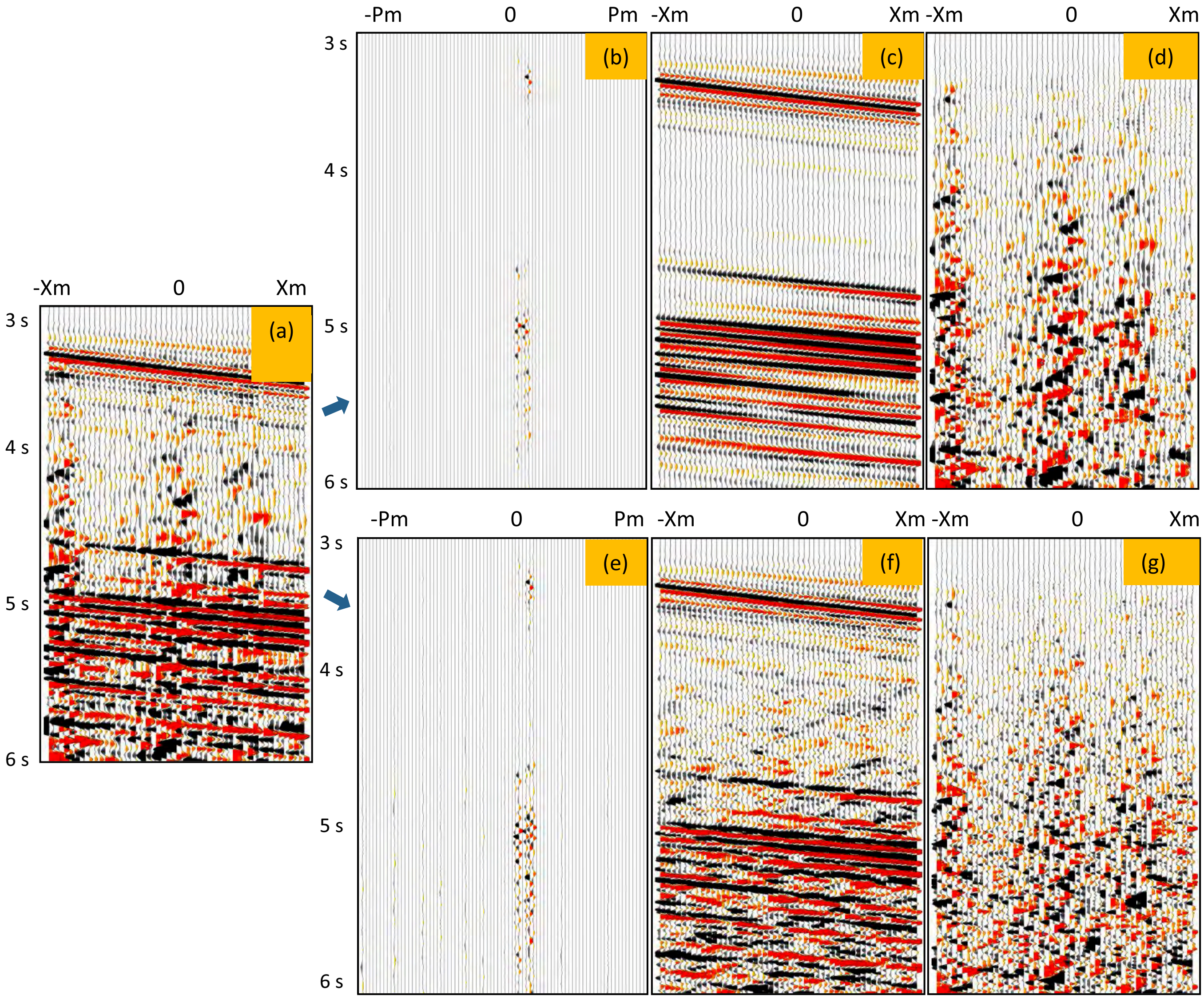

Figure 1: *(a) An input processing window contaminated with strong clustering turn noise, (b) the coherence-preferred ALTP transform domain of the input, (c) after the inverse Tau-P transform of (b); this is the noise attenuated version of the input, (d) the removed noise by the coherence-preferred ALTP transform, (e) the conventional ALTP domain of (a) as a reference, (f) after the inverse Tau-P transform of (e); energy leakage from the noise can be observed, (g) the removed noise by the conventional ALTP transform.*

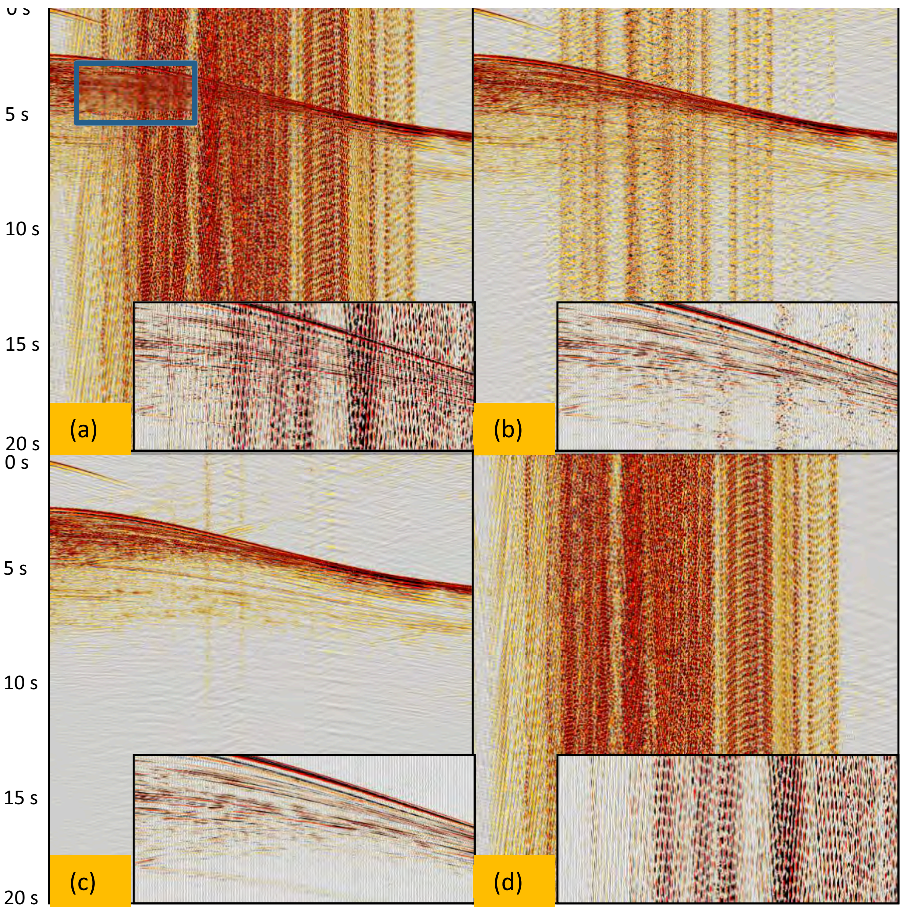

Figure 2: *(a) A raw shot gather with strong turn noise, (b) the result after low-cut and F-K dip filtering, (c) the result after the coherence-preferred ALTP noise attenuation, (d) the attenuated noise. The subplots are zoomed in displays of a shallow window indicated by the square in (a).*

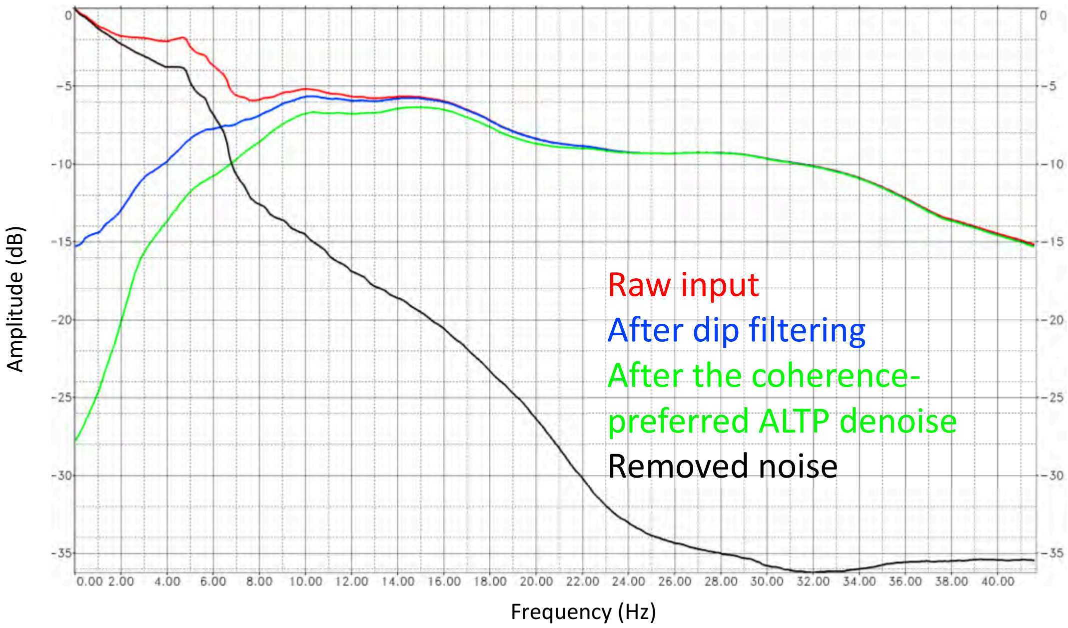

Figure 3: *The frequency spectrum of the raw input (red), the spectrum after dip filtering (blue) (includes a mild low-cut filter), the spectrum after coherence-preferred ALTP denoise (green), and the spectrum of the removed noise (black).*