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Model-based Deblending Workflow and its Application to Multiple Source Acquisition Data

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Summary

Towed streamer acquisition employing more than two sources has been attracting increased interest due to the prospect of denser sampling, particularly in the crossline direction, at a similar or cheaper cost compared to a conventional acquisition configuration. Due to a reduced temporal shot spacing, final data quality depends heavily on processing to separate the energy from different sources; this step is often referred to as deblending. In this paper, we discuss the deblending result of a penta-source marine towed streamer dataset which gives rise to a natural acquisition grid of 6.25 m × 6.25 m. In this dataset the shooting rate is about 4 sec with average random dithering of ±70 ms. The small dithering time renders the cross-talk noise semi-coherent in all domains, making this dataset challenging for existing deblending techniques. To tackle this problem, we propose a new model-based deblending scheme which supplements a previously proposed deblending scheme (Wang et al., 2016). After deblending, broadband processing including deghosting, SRME and Kirchhoff time migration, was applied to validate the effectiveness of the proposed deblending scheme.

Introduction

The use of simultaneous shooting has increased in recent years due to its ability to increase fold and spatial data sampling, often at little or no extra cost (Poole et al., 2014; Peng et al., 2013). An alternative approach to improve crossline sampling is to increase the number of sources beyond the conventional dual-source acquisition (Hager et al., 2016). For such a configuration, the CMP spacing of a single offset along the acquisition direction is $(d_s \times n_s)/2$ where d_s is the spacing between adjacent shots and n_s is the number of sources. Therefore, a larger number of sources could lead to aliasing in the acquisition direction. To overcome this, d_s may be reduced such that $(d_s \times n_s)/2$ is comparable with conventional dual-source acquisition (< 25 m). However, the shorter temporal spacing between adjacent shots leads to higher interference noise in the recorded data. Hence, the success of such acquisition depends heavily on an effective processing algorithm to separate the energy from the different sources. This process is called deblending.

Many deblending approaches have been described in the literature, for example (Peng et al., 2013; Wang et al., 2016; Poole et al., 2014), and the references within these works. Most make use of the randomness of the cross-talk noise in the common channel domain to predict the primary signal. The signal is then used to model cross-talk noise which is subtracted from the data. For low frequencies, however, many of these approaches break down when the cross-talk noise timing is not sufficiently random. While for broadband processing down to 2 Hz a dithering time greater than 250 ms should be allowed (Abma et al., 2012), such dithering is not always possible for a multiple source set up. The dataset presented in this paper was acquired with 5 sources (penta-source). The dithering time of the cross-talk noise was ~±70 ms on average although occasionally increasing to ~±350 ms. To tackle this problem, we propose an extension of the deblending scheme described by Wang et al. (2016). The new flow utilizes the cross-talk noise model, formed by reconstructing the primary signal using neighbouring data, to remove the cross-talk noise layer by layer. This step significantly weakens the cross-talk noise and reduces its coherency, paving the way for other deblending schemes to effectively remove residual cross-talk noise and recover leaked signal.

Acquisition

The data was acquired offshore Australia in 2015 using a 5 source setup (Hager et al., 2016). The crossline source spacing and inline receiver group spacing were both 12.5 m resulting in a natural 6.25 m × 6.25 m subsurface grid, four times denser than a conventional 6.25 m × 25 m grid (Figure 1a). The shot point interval was 9.37 m and the CMP spacing of a single offset along the acquisition direction was ~23.4 m, comparable to a conventional setup. However, due to the spatial shot point interval of 9.37 m, the temporal interval between shots was about 4 s plus an observable random dithering time of ~±70 ms. Figure 1b shows typical common shot and common channel gathers of the raw blended data (after a 2 Hz low cut). As we can see, blended energy from four other sources can be seen on the time-corrected domain of any source. To extend the length of usable seismic data beyond 4 s from water bottom two way time (TWT), cross-talk energy needed to be removed. However, this proved to be very challenging for most existing deblending flows due to the very strong (and only partly random) nature of the cross-talk noise that sits on top of seismic reflection data. This penta-source 3D data covered approximately 400 km^2. However, for this deblending test, only one sail line was utilized. The sail line is ~36 km long with ~27 km of full fold CMPs.

Deblending methodology

Due to the low average dithering time, low frequency energy was coherent in all domains, forming well-defined bands in the common channel gather domain. In Figure 1b we can see that just before and after the water-bottom TWT, signal-to-noise ratio is good. Four seconds after the waterbottom TWT, the energy from the next shot arrives and hence degrades the signal-to-noise ratio. By making use of the relatively clean data before the noisy bands, we can model the cross-talk noise and remove it from the data. A schematic of this model-based deblending (MBD) flow is shown in Figure 2. The MBD flow consists of 3 main steps:

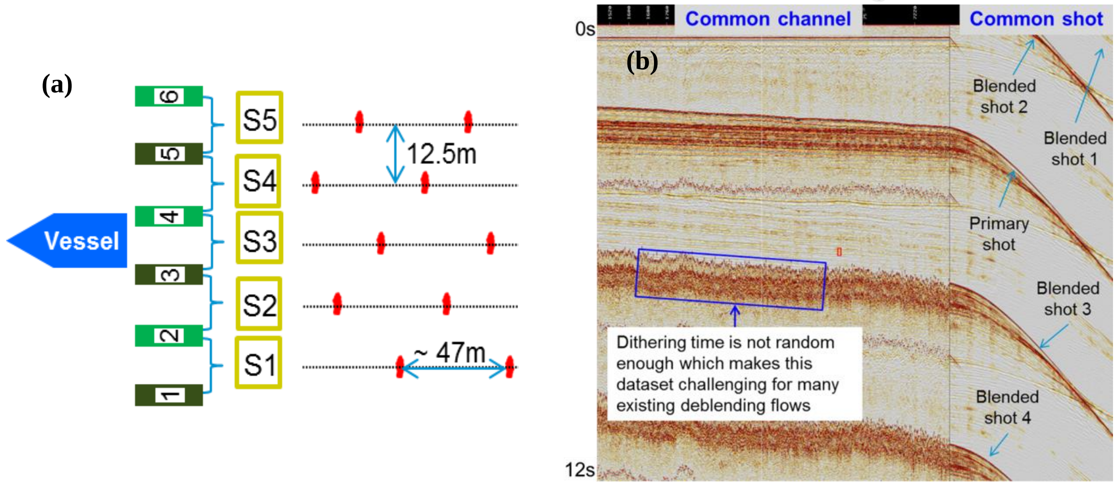

Figure 1. *(a) Simplified schematic of the penta-source acquisition setup. (b) Common channel and common shot gathers of the input blended data. Before deblending, cross-talk noise from 4 other sources can be seen on any source time-corrected domain. On the common channel gathers where the cross-talk noise randomness is key to most deblending flows, the relatively small dithering time (average of ~±70 ms) presents a significant challenge.*

(1) Construct the cross-talk noise model:

In this step we sequentially drop shots from each individual source-cable combination and re-interpolate the dropped shots using the remaining data. As primary signal is more coherent across adjacent shots compared to cross-talk noise, this approach ensures that primary energy will be re-constructed more accurately even in region of low signal-to-noise ratio. Figure 3a shows comparison of a typical shot with its reconstructed data and the difference. The difference panel illustrates an improved accuracy of signal reconstruction relative to cross-talk noise reconstruction.

(2) Adaptively subtract the noise model from input data:

Next we mute the strong cross-talk noise, correct the travel time for the blended energy and then adaptively subtract from the input data (see Figure 2). The subtraction will remove more cross-talk energy compared to primary signal. In Figure 3b, a comparison between conventional coherency driven deblending and the new flow is shown. It is apparent that the new flow successfully removes cross-talk noise and preserves the primary signal.

(3) Remove residual noise and retrieve leaked signal:

After step (2), the energy and coherency of the cross-talk noise has been reduced to a manageable level for other deblending schemes to further attenuate cross-talk noise and recover leaked signal. For residual deblending, we used a low rank reduction scheme to model the signal both from the main data and the residual domain ($R = D - N - S$) where R is the residual, D is the input data, N is estimated random noise and S is the partially deblended signal (Wang et al., 2016).

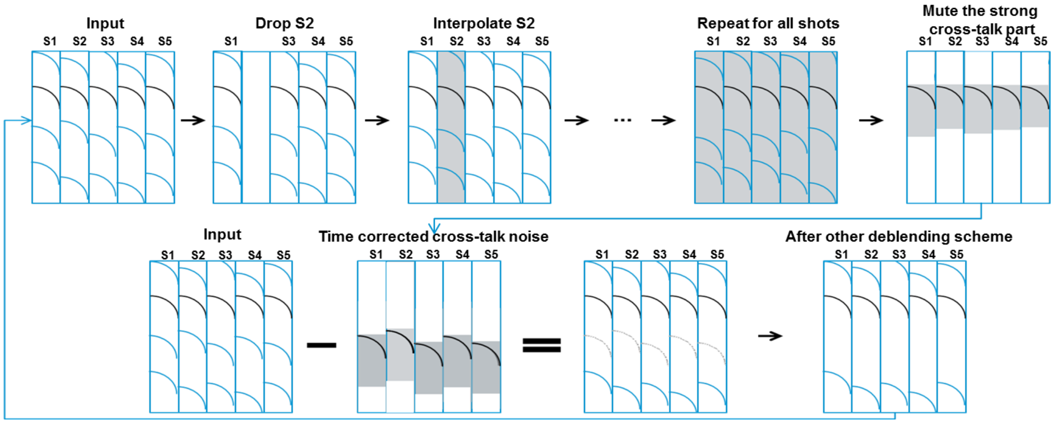

Figure 2. *Schematic of the iterative model-based deblending scheme employed here.*

After step (3), one layer of strong cross-talk noise is removed, revealing a longer section of good signal-noise-ratio data. We then go back to step (1) of cross-talk noise modelling, utilizing the new input to recursively remove the remaining layers of cross-talk noise. This layer stripping flow is particularly effective for data with a low randomness of cross-talk noise. We have found that as the randomness increases, the band of strong cross-talk noise becomes more diffuse. Consequently the region of good signal-to-noise ratio shrinks, making modelling of the cross-talk noise more difficult using the flow described above. However, for such cases, existing/traditional deblending techniques can be effectively applied.

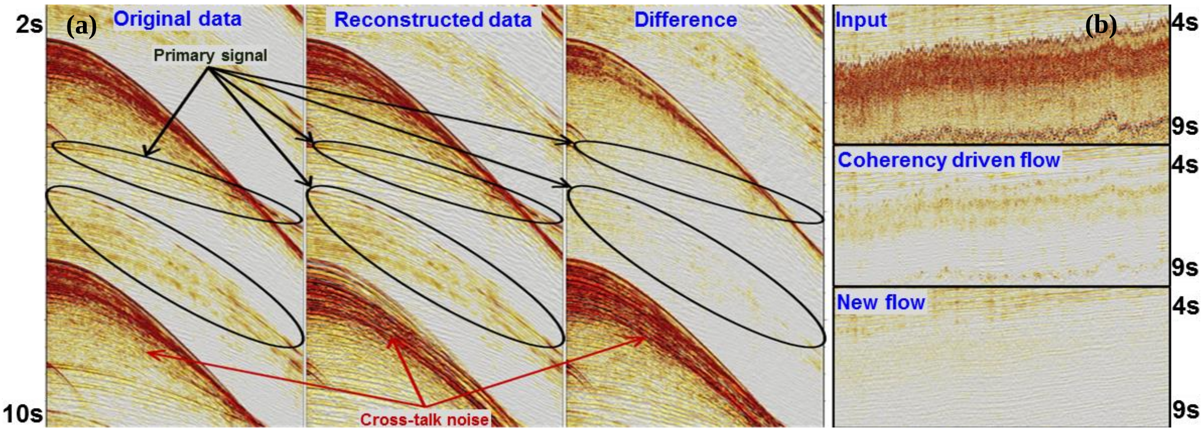

Figure 3. *(a) An example of original shot, reconstructed shot and the difference (original data – reconstructed data). Most of the remaining signal on the difference comes from cross-talk noise making the reconstructed data a good model for the cross-talk energy (after firing time correction). (b) Comparison of input raw data; data after conventional coherency driven flow and new flow. By integrating the MBD into existing deblending scheme, the output is cleaner with less signal leakage.*

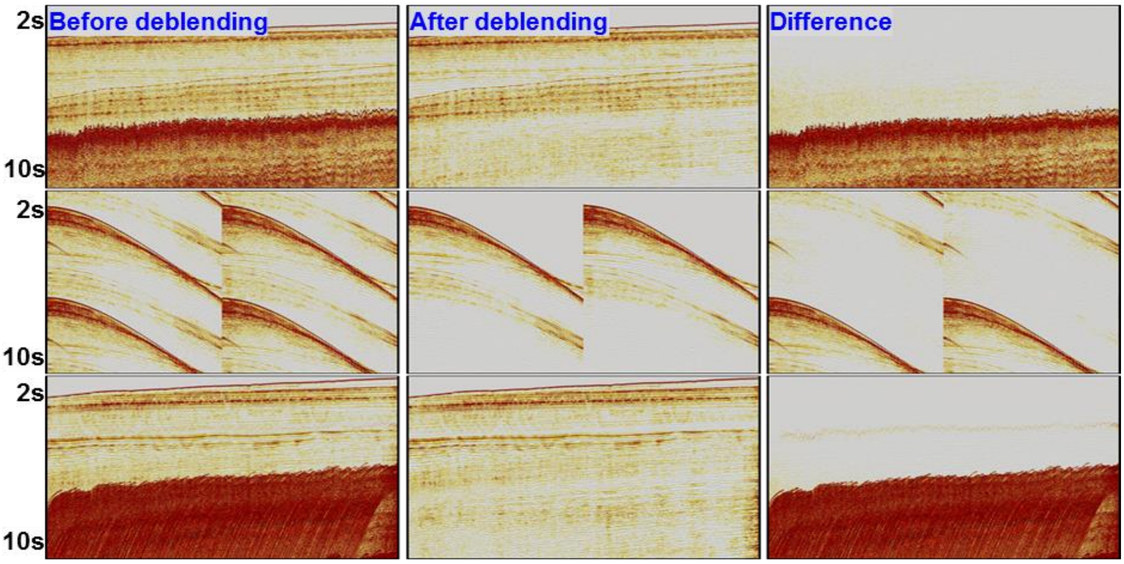

Figure 4. *From left to right: before deblending, after deblending and difference. From top to bottom: selected common channel gathers; selected common shot gathers and stack gathers.*

Results and discussions

Based on the deblending result in Figure 4, it can be seen that most of the cross-talk noise has been effectively removed without any obvious damage to the primary signal. In addition the primary signal has been recovered in the region of very low signal-to-noise ratio as seen quite clearly from the stack (bottom row) and the common channel gather displays (top row). To further validate the result, we continued with a typical broadband processing flow on the deblended data. The flow included receiver deghosting, 2D SRME and 2D Kirchhoff pre-stack time migration (since only one sail line was used for this deblending) as shown in Figure 5. Comparing the stack image of the migrated result with nearby 3D data, we can see that good primary energy within the region of very strong cross-talk energy (below the blue line in Figure 5) has been recovered. The success of the proposed approach was due to a combination of the MBD flow which reduced the strength and coherency of the cross-talk noise layer by layer followed by a low-rank reduction deblending method which effectively removed residual cross-talk noise and recovered leaked signal.

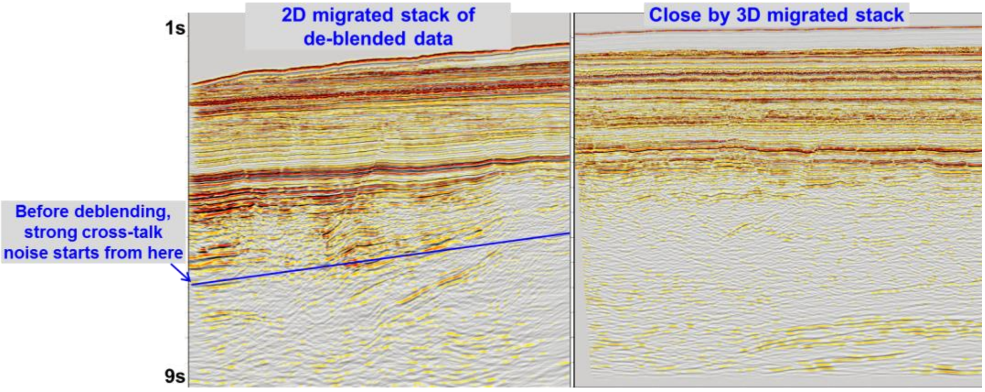

Figure 5. *Comparison of migrated stack of de-blended data and close by 3D migrated stack data. Good signal has been obtained in the region of strong cross-talk noise (below the blue line).*

Conclusion

In this paper we have presented a model-based deblending (MBD) workflow based on cross-talk noise modelling and removal using reconstructed data. After each layer of cross-talk noise was attenuated, a low-rank reduction deblending scheme was utilized to further attenuate residual cross-talk noise and recover leaked signal. The flow was applied to the Baxter 3D penta-source data. The final result showed that cross-talk noise had been effectively removed while primary signal remained intact. A 2D migration result showed that primary energy in the region of very strong cross-talk noise had been recovered. The MBD flow was capable of handling low incoherency of the cross-talk energy, making multiple source marine acquisition more attractive.

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