Deblending seismic data using multi-stage iterative source separation with priors – a case study using streamer 3D data

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Summary

Conventional seismic data acquisition surveys usually require a firing time delay from each source to prevent energy overlaps between the numerous shot records. Recent advancements in continuous seismic recording systems and data separation workflows have enabled us to acquire seismic data from multiple sources simultaneously, thereby significantly reducing operational costs and enhancing data acquisition efficiency. To separate (deblend) the signal from each source, however, the simultaneous source approach introduces new challenges to our data processing workflows. A wide range of source separation technologies exist to deblend the data, but many of these technologies rely on coherent noise attenuation techniques that produce results with a substantial amount of seismic interference residual noise. In addition to the quality limitations, coherent noise attenuation techniques require a considerable amount of additional time to develop the optimal processing workflow for a given dataset. In this abstract, we present an alternative method to deblend the High Point 3D broadband long-offset simultaneous-source towed-streamer data using an innovative algorithm that progressively models the source-separated signal while safely removing interference from the data, yielding significantly improved source-separation results compared to those obtained with the previous algorithm.

Introduction

In conventional seismic surveys, before the development of simultaneous shooting, the delay time used to record the energy from each source is such that there is minimal or no overlap between the energy recorded from each seismic shot. The objective of this method is to independently register each source point or seismic record to prevent source interference or crosstalk among all shots. However, this minimum delay time constraint severely limits the rate at which seismic data can be acquired, increasing acquisition costs and time.

Simultaneous-source acquisition surveys, on the other hand, have proven their capability to enhance data acquisition efficiency (Kumar et al., 2021). Enabling the responses of seismic sources to have a substantial overlap in time minimizes the time necessary to capture all the data and, therefore, the operational cost of seismic surveys. Reducing the (temporal) shot interval, i.e., increasing the number of shots per time interval, may be utilized to decrease overall acquisition time or to enhance fold (angle/offset) and azimuthal variety within the same time frame. It also helps us to use the existing sources more effectively or to leverage a greater number of sources (if available). However, for such data to be usable, a signal-safe method that isolates the source interference from each shot record must be utilized. One solution to solve the interference problem more effectively is to use an inversion-based technique that aims to retain the coherent signal in different domains while removing the interference (Abma et al., 2012).

We implemented a multistage-iterative source separation with priors (MS-ISSP) framework that gradually models the source-separated signal while removing the source interference in a signal-safe manner (Kamil et al., 2021). In each stage, the MS-ISSP algorithm separates different modes of seismic signal, starting with the strongest signal in the data.

In this study, we show that this approach produces high-quality deblended data with little or no residual energy following the data separation. We will present the results of this technology using the High Point 3D broadband, long-offset, simultaneous-source, towed-streamer data collected in the east-central Gulf of Mexico.

Method

MS-ISSP relies on an iterative process that applies a coherency filter to the input data to estimate the signal. The approach assumes that the most coherent energy in the data is the signal. Based on this calculated signal, the coherent noise (interference) is computed. We generate a residual by subtracting the predicted signal and the noise from the input data. Adding this residual to the estimated signal provides the input to the next iteration of the coherency filter. In this subsequent pass, when the input is considered to have less noise (interference), the coherency threshold may be lowered to produce a more accurate signal estimate. As seen in Figure 1, priors may also be used to enhance the coherence of the signal in the sparsity-promoting domain. Additionally, we may also apply multiple passes of ISSP (multi-stage) to get the best results and minimize the need for extensive testing.
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Case study

The High Point survey is located in the east-central Gulf of Mexico. The acquisition of this narrow-azimuth (NAZ) data was completed in 2015. The 10 streamers used to collect the data were 7 km in length and were separated by 120 m. The shotpoint interval was 25 m (flip-flop), and the record length for imaging was 16 seconds. This survey is an expansion of the Four Point survey, and it includes nearly 281 full OCS blocks. Figure 2-a provides a map of the project location. The data were collected using a simultaneous source streamer arrangement. The acquisition used two crews on two vessels. As seen in Figure 2-b, each crew had one vessel towing sources and receivers and a separate source vessel 6 km ahead. This allowed for a reduced streamer tow length of 6 km and a reduced time between shots firing of 4 seconds on average, while collecting far offsets of 13.5 km that would subsequently assist the application of full-waveform inversion (FWI) for earth model building and improved imaging results below the highly complex overburden.

The High Point and Four Point data were reprocessed and reimagined in 2022 to take advantage of advances in signal processing and model-building technologies (the data were previously processed in 2017 and 2018). This included deblending using MS-ISSP. To achieve the best results with the MS-ISSP method, a strategy was adopted in which the data were divided into two frequency bands to allow for a frequency-dependent process parameterization. Processing across frequency bands enhances data sparsity, making it...
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simpler to differentiate between signal and interference noise. We decided to process the frequency bands independently so that the spectrum was not excessively biased by excessive low-frequency interference noise, which may result in inferior deblending at high frequencies. In addition to frequency splitting these data, multiple iterations of ISSP were applied to each frequency band to enhance the deblended output quality. Figure 3-b shows a shot record from our previous 2018 reprocessing project after using our earlier deblending technology based on a tau-p sparse inversion approach (Moore et al. 2008).

Figure 3: Comparison between input (3-a), deblended data (3-b) using tau-p based sparse inversion approach and deblended data using MS-ISSP (3-c).

As shown in Figure 3-c, the results from the MS-ISSP algorithm show significant improvement in the separation of the source energy in terms of removing interference and preserving signal.

Figure 4-a shows shot records from near and far sources. Both records include interference from far and near sources. Figure 4-b displays the near (left) and far (right) source records after deblending using MS-ISSP.

Figure 4. Seismic data in shot domain before (4-a) and after (4-b) the simultaneous source separation using MS-ISSP.

Figure 5-a shows the randomization of the interference signal in the common-channel domain. Interference at the top level corresponds to the energy from the near source record, while interference at the lower level belongs to the next shot (n+1 shot). Figure 5-b shows how MS-ISSP preserves the coherent energy from the far source while removing the random interference from the nearby source and the n+1 record. Figure 5-c shows the difference between the blended data and the deblended data. This data represents the interference from the other sources. Notice that there is no coherent signal in this dataset domain.
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Figures 5-a, 5-b, and 5-c show the common-channel domain before (5-a), after (5-b), and difference (5-c) source separation using MS-ISSP.

Figures 6-a and 6-b show the raw stack image before and after deblending.

Figure 6. Premigration stack before (6-a) and after (6-b) the simultaneous source separation using MS-ISSP.

Conclusions

Using the multi-stage iterative source separation with priors (MS-ISSP) framework, we successfully implemented deblending of the data, leaving minimal residual deblending noise. The results have shown the algorithm's ability to separate data acquired in this acquisition configuration with a separate source vessel ahead of the recording vessel, used to simulate a longer-length streamer acquisition. The frequency splitting and multi-stage approach were key additions to our deblending workflow, that enabled us to obtain a superior separation of the simultaneous sources compared to the results generated from our previous sparse-inversion algorithm.

Acknowledgements

We thank SLB for giving permission to publish this work. Also, we would like to thank our colleagues at Schlumberger SLB for their helpful recommendations and comments that made this project successful.