Deblendable land acquisition

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Summary

Given the success of inversion-based deblending algorithms, simultaneous-source seismic acquisition is now a well-established technology used by many acquisition companies. It allows multiple sources to be fired near-simultaneously in a narrow time interval, which can improve the acquisition efficiency and reduce the cost. To be effective, deblending needs to be performed without compromising data quality. In this paper, we address specific challenges that directly affect the quality and efficiency of inversion-based deblending and provide practical recommendations for future simultaneous-source acquisition.

Introduction

Simultaneous-source seismic acquisition is an increasingly common strategy for improving efficiency and reducing the cost of high trace density seismic surveying. This acquisition method results in data with interference from overlapping shots that should be disentangled before proceeding with a conventional processing and imaging workflow. Deblending is the process of separating the interfering shots and is the key technology that enables simultaneous-source acquisition. To be effective, deblending needs to be performed without compromising data quality. We share several examples of the successful applications of inversion-based deblending of land seismic data and address specific challenges that directly affect the quality and efficiency of inversion-based deblending. We provide practical recommendations for future simultaneous-source land acquisition programs that will both improve the quality and decrease the cost of successful inversion-based deblending without significant additional acquisition costs.

Deblending strategies typically fall into two categories: denoising-based and inversion-based. The objective of denoising-based deblending is to attenuate energy associated with overlapping shots based on unique characteristics of the interfering energy in different domains (Hampson et al., 2008). This strategy is conceptually simple compared to inversion-based algorithms but takes considerable effort to parameterize and may require several passes of different algorithms in multiple domains. Additionally, it is prone to artifacts and signal leakage, particularly in areas with low signal-to-noise ratio and when the interfering signal is coherent in an unexpected domain. Alternatively, inversion-based algorithms take advantage of sparse representations of predictable seismic signals (Akerberg et al., 2008). Kumar et al., (2020b) proposed an inversion-based algorithm to reconstruct the blended shot records from the blended data using a novel iterative relaxation algorithm. The objective is to seek unblended records that can be blended to accurately reproduce the input data. Inversion-based deblending is now widely favoured and it has the advantage of having a strong theoretical basis. In addition, inversion-based deblending naturally increases the signal-to-noise ratio of deblended data compared to unblended data (Beasley et al., 2012), indicating simultaneous-source acquisition is not only cost-effective, but also beneficial. The algorithm has performed exceptionally well on real marine, land and OBN datasets from several basins around the world (Rayment et al., 2020).

Based on our experience, we contend that inversion-based deblending is a mature, robust technology that outperforms denoising-based deblending. Furthermore, we argue that with the right inversion-based algorithms, blended acquisition becomes so effective that it should be considered the default approach to seismic acquisition. However, in order to achieve these high quality results, certain aspects of the survey design and the field operations need to be taken into consideration. It turns out that any modifications in design are readily implemented with barely any additional effort.

Deblending method and challenges

The deblending algorithm proposed by Kumar et al., (2020a, b) is based on an iterative thresholding technique. The efficacy of this algorithm rests upon the novel manner in which the 3D frequency-wavenumber domain thresholding operation is performed and the relaxation of the threshold to iteratively reconstruct the shots as if they had been acquired separately. The objective is to explain all of the input data as a blending of the deblended shot records, therefore, the total energy is preserved. A benefit of this process is that random noise is divided between the number of overlapping shots thus improving the signal-to-noise ratio. Extensive experience has shown that this algorithm is a robust and powerful solution to the deblending problem. However, we have frequently observed that optimization of the acquisition configuration can improve the results even further. With this in mind, we discuss below, several aspects of acquisition design and field procedures that can improve blended land acquisition.

Spatial irregularity

Spatial irregularity between adjacent sources and/or receivers is a pervasive challenge for land seismic data processing and imaging and can impact the quality of inversion-based deblending results. The inversion-based deblending algorithm proposed by Kumar et al., (2020b) does not assume regular trace spacing. It requires only that the signal is predictable, but not necessarily locally coherent. Figure 1 shows an example of a common offset gather of a marine triple source vessel configuration. The triple source signatures can be observed clearly, and it is obvious they are predictable, although not coherent.

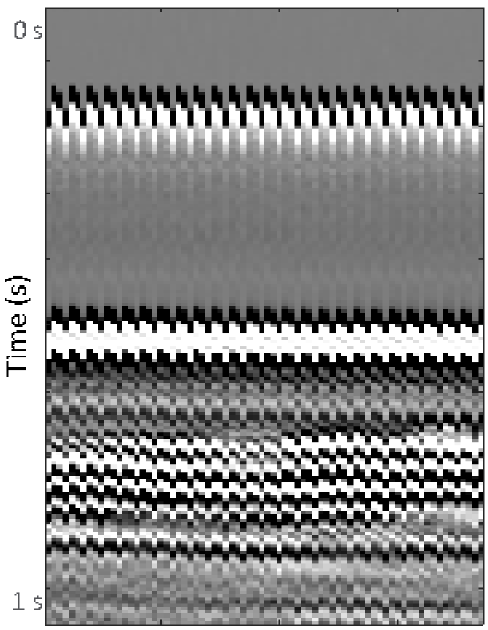

Figure1: A common near-offset gather from the marine triple source vessel configurations. The shots appear to be predictable (not locally linear events).

Therefore, this inversion-based deblending algorithm is effective for data with modest skips due to surface obstructions or compressive sensing acquisition (Candes et al, 2006; Bougher, 2015). However, stub-lines or erratic off-line skids commonly associated with surface obstructions reduce the sparsity of the predictable signal which can degrade deblending results. In cases where deviations from the nominal line geometry are required, we find inversion-based deblending performs best when off-line skids vary smoothly over several stations to better preserve the sparse representation of the predictable signal. When erratic off-line skids are unavoidable, enlarging the spatial and temporal windows used in deblending may help to mitigate artifacts, but at increased computational expense.

The predictability of the signal is directly related to the spatial arrangement of the shots/receivers, the consequential offsets and the geology. The spatial irregularities in both directions (shots/receivers) result in substantially undulating offsets to relatively-near receivers and thus degrade the deblending result. Therefore, it is beneficial for a source to traverse a single line for as long as possible, as opposed to a serpentine pattern. This typically leads to a single Vibroseis unit being assigned to an entire source salvo. In the case that multiple Vibroseis units work on the same source salvo, they should do so in a predictable sequence. However, it is more important to satisfy the fundamental assumptions of deblending, including the spatio-temporal randomness of shots.

Ultra-far offsets

Advances in deblending technology enable increased source productivity for simultaneous-source acquisition that often remains unrealized. For example, the objective of the popular DS4 (distance-separated simultaneous slip sweep) technique is to maximize productivity while minimizing interference between overlapping shots. To minimize interference between overlapping shots, concurrent sources are constrained to have significant spatial separation and co-located sources are constrained to have significant temporal separation (Bouska, 2008). Modern interpretations of the DS4 concept enforce the concurrency of widely separated shots less strictly and instead allow entirely unconstrained activation among sufficiently distant sources. The recently proposed xDSS method further reduces the distance and time separation constraints and eliminates a central controller in favor of multiple decentralized controllers (Tellier et al., 2022). These strategies require large active receiver arrays and result in enormous data volumes with excessively far offsets (> 20 km in some cases). These spatial and temporal constraints were originally imposed on acquisition designs to mitigate the sub-optimal performance of denoise-based deblending algorithms. However, for inversion-based deblending ultra-far offsets significantly increase the cost of deblending. Successful deblending of a given shot requires consideration of all shots fired into all active receivers in a given temporal window (typically *sweep_length* + *max_offset*/*min_velocity*). If the maximum offsets are excessively large, inversion-based deblending may not be computationally affordable by current standards. However, it is possible to reduce the computational cost of the inversion by not deblending ultra-far offset traces that satisfy certain timing criteria. This strategy only retains ultra-far offset traces that interfere with traces inside the desired patch of temporally proximal sources. These ultra-far offset traces may be discarded after deblending.

We show an example of applying this strategy from the West Spring Gully 3D data that was acquired with virtually all the receivers active during the entire acquisition time (Figure 2). As a result, the raw seismic data has offsets up to 20 km, however, the project imaging targets imply the requirement of offsets less than approximately 4 km. The cost of deblending the whole datasets (up to 20 km) might be almost prohibitive. Alternatively, limiting the input to the deblending algorithm to 4 km offset would lead to incomplete deblending of some shot records (Figure 2b). However, using the approach described above, allowed us to achieve a high quality deblending result without incurring excessive computational costs (Figure 2c).

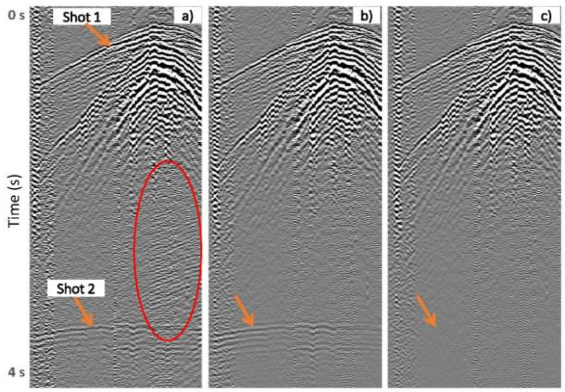

Figure 2: a) A blended shot record from the West Spring Gully survey (red elliptical area shows harmonics from later shots), b) results of limiting the input to deblending algorithm by 4 km offset (the orange arrow shows shot 2 energy is not deblended, only harmonics from later shots are removed), c) deblending results of including ultra-far offset traces that interfere with traces inside the desired patch of temporally proximal sources (shot 2 energy has been successfully deblended).

Alternatively, the cost of inversion-based deblending can be reduced (often by an order of magnitude) without compromising quality, by constraining the independent sources to shoot over smaller areas of the receiver array, as opposed to shooting over the entire array simultaneously. In other words, we recommend eliminating minimum distance and timing constraints in favor of maximum distance constraints to improve the efficiency of inversion-based deblending.

Navigational data

Some survey characteristics are common to all deblending approaches. Because inversion-based deblending is entirely data-driven, good input data quality is important to ensure optimal performance. Accurate positioning and timing of both sources and receivers are crucial. "Test" or "voided" shots that are recorded along with production shots must also be documented for their energy to be successfully deblended from the primary data. Figure 3 shows a deblending example with incorrectly and correctly documented acquisition shot times. It can be clearly seen in Figure 3b that the overlapping shot was unsuccessfully deblended when inaccurate timing information is provided whereas Figure 3c shows the successful deblending of the overlapping shot when using the correct shot timings.

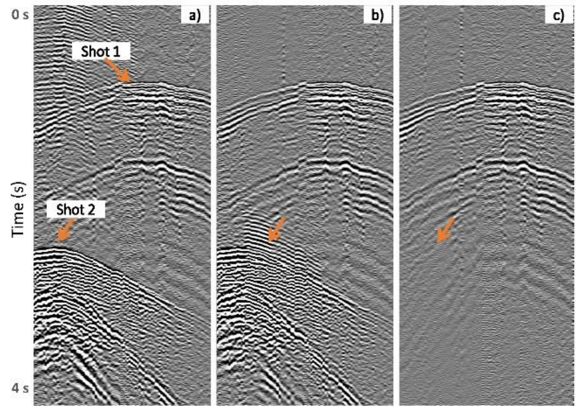

Figure 3: a) A blended shot record from the West Spring Gully survey, b) the results after deblending with incorrectly documented shot timings, c) the results after deblending with corrected shot timings.

Bad traces with anomalously high or low amplitudes degrade the inversion-based deblending results. The reason for this can be explained by looking at the frequency-wavenumber (*f-k*) spectrum of a shot/receiver gather with and without bad traces. Figure 4 shows such an example of an *f-k* spectrum becoming corrupted by including just 1 bad trace with high amplitude. It follows that editing of bad traces is a necessary step for a successful deblending result. We note, however, that inversion-based deblending is more robust than denoising-based methods when faced with poor signal quality.

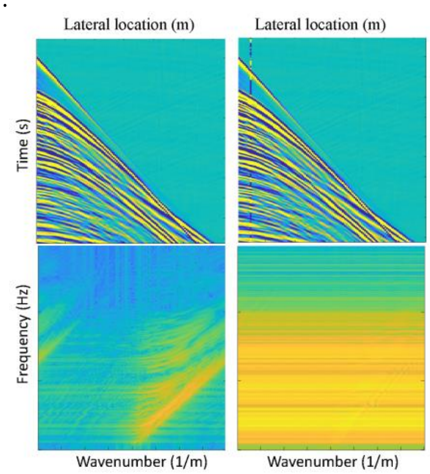

Figure 4: The effects on the *f-k* spectrum (bottom row) by including just 1 high amplitude bad trace in the shot gather (top row). The *f-k* spectrum is severely corrupted with just 1 bad trace (bottom right).

Figures 5 and 6 show a land data deblending example from a 3D broadband survey onshore Egypt, where none of the issues highlighted above have been present. This demonstrates that the absence of these problems leads to very high quality deblending.

Conclusions

The potential of simultaneous-source seismic data acquisition cannot be fully realized without reliable and affordable deblending. The inversion-based deblending algorithm proposed by Kumar et al. (2020b) has performed exceptionally well on land datasets from several basins around the world. Conventional time and distance constraints on simultaneous-source acquisition are an artifact of the sub-optimal historical performance of denoising-based deblending algorithms. These constraints are not required for inversion-based deblending.

Implementation of our practical recommendations - including smoothly varying deviations from nominal line geometry, shooting over smaller receiver arrays, and ensuring the accuracy of navigation data and field logs - will reduce the cost of inversion-based simultaneous-source deblending and ultimately improve the quality and fidelity of seismic images.

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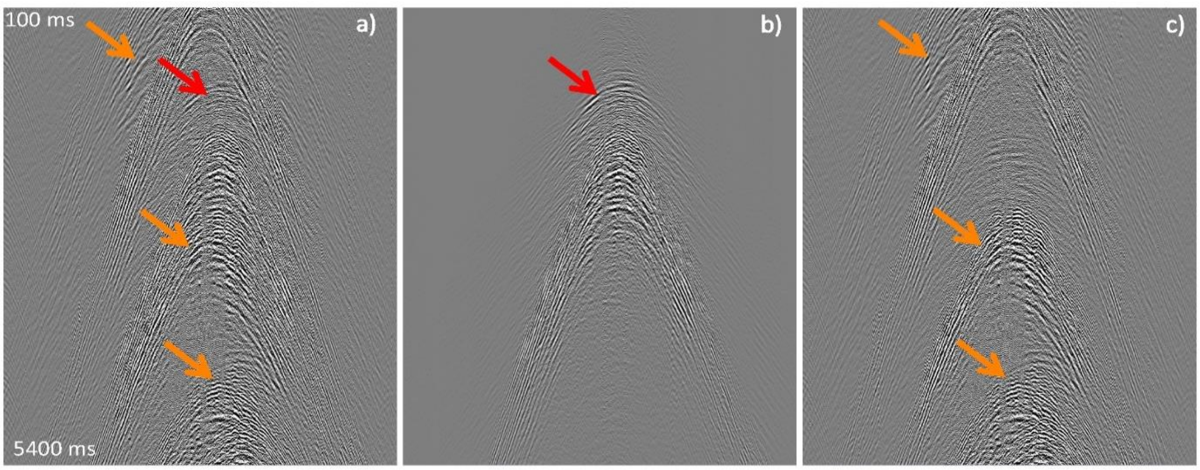

Figure 5: A shot record from a 3D land survey: a) input data before deblending; b) deblended output; c) difference between a) and b). The red arrow shows the primary shot, whereas the orange arrows indicate all the overlapping shots. (Data courtesy of Apache)

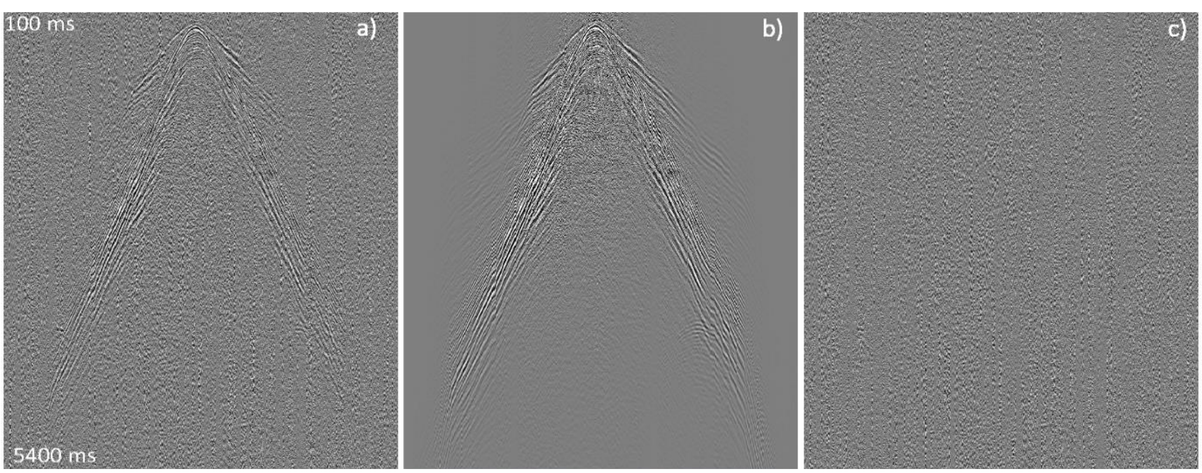

Figure 6: A common receiver gather from a 3D land survey: a) input data before deblending; b) deblended output; c) difference between a) and b). The overlapping shots in this domain appear to be unpredictable. (Data courtesy of Apache)

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