Advanced Deblending Scheme for Independent Simultaneous Source Data

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SUMMARY

Independent Simultaneous Source (ISS®) technology is an attractive way to provide high acquisition production rates and affordable higher density seismic imaging. In this paper, we propose an advanced deblending scheme to address the source separation requirement of ISS® data. The deblending scheme includes a) 3D low-rank decomposition based iterative noise modelling, and subtraction, b) signal-to-noise ratio map guided residual denoise and c) erratic noise attenuation. The application is tested on actual shallow water OBC dataset, which was pseudo-blended using a realistic dual vessel acquisition plan. The result shows that this advanced deblending scheme can successfully recover individual source responses. The deblended data have a minimal difference compared with the actual unblended data.

Key words: simultaneous shooting; ISS®; OBC; deblending; low-rank decomposition.

INTRODUCTION

Simultaneous shooting has gained increasing attention in recent years, and it remains a hot topic even with the current difficult market. This efficient acquisition technique allows temporal overlap between different sources, termed source interference, which allows a significant increase in source productivity and permits cost efficient increases in acquisition sampling density. Independent simultaneous source (ISS®) acquisition is one of the techniques used either to provide high density data or to reduce the duration of acquisition (Howe *et al*., 2008). Using high fold and wide-azimuth designs, ISS® data still permit high quality AVO products (Paramo *et al*., 2013, Dvorak *et al*., 2013) and have been shown not to hinder land statics (Manning & Ahmad, 2013).

Various deblending methods have been developed to separate the interferences for simultaneous shooting data (Abma *et al*., 2010, Peng *et al*., 2013, Kontakis and Verschuur, 2014, Cheng and Sacchi, 2015, Haacke *et al*., 2015, Abma *et al.*, 2015). Most of them make use of coherency enhancement in proper domains, iteratively modelling cross-talk noise and subtracting it from the data. The coherency enhancement is used to extract a signal estimate and can be accomplished with many approaches, such as median filters, F-XY projection filters and low-rank decomposition. This kind of strategy may seem straightforward; however it may be difficult to separate sources when shots have low signal-to-noise ratios or contain strong data complexity. In these cases, some additional denoise methods can be used to remove residual noise and further improve the final data quality.

In this paper, we propose an advanced deblending scheme to address the source separation problem for ISS® data. The deblending scheme includes: a) 3D low-rank decomposition based iterative noise modelling and subtraction, b) signal-to-noise ratio (SNR) map guided residual denoise and, finally, c) erratic noise attenuation. We perform the proposed deblending scheme on a pseudo-blended OBC dataset (Wolfarth *et al*., 2016) (i.e. actual unblended OBC shots are summed using a dual vessel shot timing simulated on a computer), and the results show this method can successfully recover the original individual source responses. The deblended data have a minimal difference compared with the unblended data.

METHOD

Recorded simultaneous sources data D contain the responses of more than one source. Deblending processes recover the individual source response S by separating out non-signal cross-talk N. Actually cross-talks are signals at other positions, which can be expressed by signals by applying a time delay operator Γ. Equation 1 shows their relationship as

$$D = S + N = S + \Gamma S . \qquad (1)$$

This inversion problem in equation 1 is, unfortunately, underdetermined. Some prior information, such as the signals are sparse in the focal transform domain (Kontakis and Verschuur, 2014) or the signal is coherent in common receiver gathers (Peng *et al*., 2013, Khalil *et al*., 2014), can be utilized. For the latter method, the key problem is how to extract reliable signals from input data gradually. After testing various methods with our data, low-rank decomposition was found to be better at recovering weak signals from noisy data than other approaches such as F-XY projection filtering. Similar observations can be found in Trickett (2008). In low-rank decomposition, the signal is modelled by the principal components of the Hankel matrix formed from the input data. Random noise increases the rank of the matrix, thus signal/noise separation is performed by rank reduction. Using the rank reduction implementation described by Sternfels *et al*. (2014), the strongest and most coherent signals S_i are extracted first, from which the corresponding cross-talk noise $N_i = \Gamma S_i$ can be modelled and subtracted from the data using the known source firing time. The remaining coherent signal can be further predicted in the next iteration from the residuals $R_i = D - \sum_i N_i - \sum_i S_i$. The modelling and subtraction processes interleave iteratively until the signals can no longer be efficiently extracted. The signal and cross-talk estimated from the modelling and subtraction stage can be used to calculate an SNR map. Low SNR means that data segments have strong cross-talk noise and the residual signals can therefore be estimated by nearby data. The SNR map guided denoise (Khalil and Poole, 2014) can be applied on previous residuals R_i to extract residual signals $\tilde{S}$, which can be added back to the previous estimated signals. Then the total deblended data are $\hat{S} = \sum_i S_i + \tilde{S}$.

In low-rank decomposition, when signals are coherent, the signal subspace supported by the principal eigenvectors is orthogonal to the noise subspace. However, when there are irregular shots in field acquisition, the signals may also have some incoherent components. In this case, the principal eigenvectors are no longer pure signal, and residual cross-talk may still exist in the low rank deblending results. To deal with this problem, we propose to rebuild a signal model from the cross-talk by reverse blending

$$\bar{S} = \Gamma^{-1}(D - \hat{S}) \qquad (2)$$

For irregular shots, if $\hat{S}$ is not clean, we use the interference shot to reconstruct the signal shot $\bar{S}$ as the final deblending output. The deblending scheme, including low-rank decomposition, SNR map guided denoise and erratic denoise, is practical and effective for simultaneous shooting data, and applicable to varied acquisition geometry. In the following section, we will apply it on an OBC dataset to illustrate the effectiveness.

APPLICATION ON ISS® OBC DATA

A shallow water OBC dataset acquired with a single source and no blending, was used as a noisy and complex dataset to test deblending schemes. A realistic blending strategy is simulated to match an acquisition with two independent source vessels (Wolfarth *et al*., 2016). Figure 1 shows the proposed parallel acquisition geometry: two boats traveling in parallel directions either side of an ocean bottom receiver spread with a fixed crossline separation. Shot firing times were randomised using a normal distribution with a standard derivation of one second – this is provided to the air-gun control software in real acquisition cases. As shown in Figure 2a, the cross-talk appears random in the common receiver domain (shot axis), but stays coherent within the common shot domain (receiver axis). The deblending is done in the common receiver domain but results are also displayed in the common shot domain to evaluate the result. The iterative deblending algorithm and SNR map guided residual denoise are applied to the blended data, with results shown in Figure 2b for the deblended results and 2c for the separated cross-talk. For quality control, Figure 2d shows the difference between the unblended data and the deblended data. Frequency-domain analysis shows most of the leaked energy is above 40Hz, far from the target zone. When we compare receiver gathers before and after deblending, shown in Figures 3a and 3b respectively, it can be observed that the weak diving waves are well preserved which is important for FWI work. Figure 3c displays the SNR map used for guiding residual denoise, where low SNR means that data segments have strong cross-talk noise and the residual signals can therefore be estimated by nearby data. The 3D low-rank decomposition based approach and guided residual denoise work well for most areas and produce a reasonable deblending result: the cross-talk is well separated from the input data.

As mentioned in section 2, the initial deblending results by low-rank decomposition may have cross-talk-residuals near irregular shots. In Figure 4a, we present a shot gather of the initial deblending near an obstacle area with no shots (denoted by the red arrow in Figure 1). Strong cross-talk-residuals are observed there. However, a related interference shot, located at a regular area (denoted by the blue arrow in Figure 1) is well deblended by the low rank decomposition, as shown in Figure 4b. Equation 2 uses the cross-talk in shot 3b to rebuild the signal in shot 4a, and update the deblending result as shown in Figure 4c, thereby removing most cross-talk-residuals. For the regular shot 4b, nothing needs to be updated, and so yields an output (4d) similar to 4b. With this erratic denoise, the deblending quality is improved especially around the area having the irregular shots.

We perform Kirchhoff migrations to further evaluate the effectiveness of this proposed deblending scheme. Figures 5a and 5b show deblended data and unblended data respectively, at target zone. The differences, in Figure 5c, are minimal and show that the signals are well separated. To provide overall QC for the whole survey, an NRMS map (Figure 6) is extracted between unblended and deblended datasets within the time window of 1s to 2s. The dominant value is 0.07 which indicates that the cross-talk noise has been greatly attenuated via the deblending process.

CONCLUSIONS

Deblending is required to maximise the value of simultaneous shooting acquisition. 3D low-rank decomposition based iterative modelling and subtraction can extract most of the coherent energy including weak diving waves, while SNR map guided denoise brings back residual energy. Finally, erratic denoise tackles the real-world problems of acquisition such as irregular shot distributions. The advanced deblending scheme is practical and effective for ISS® data, and provides reliable deblending results to a level around 7% NRMS compared with equivalent unblended data.

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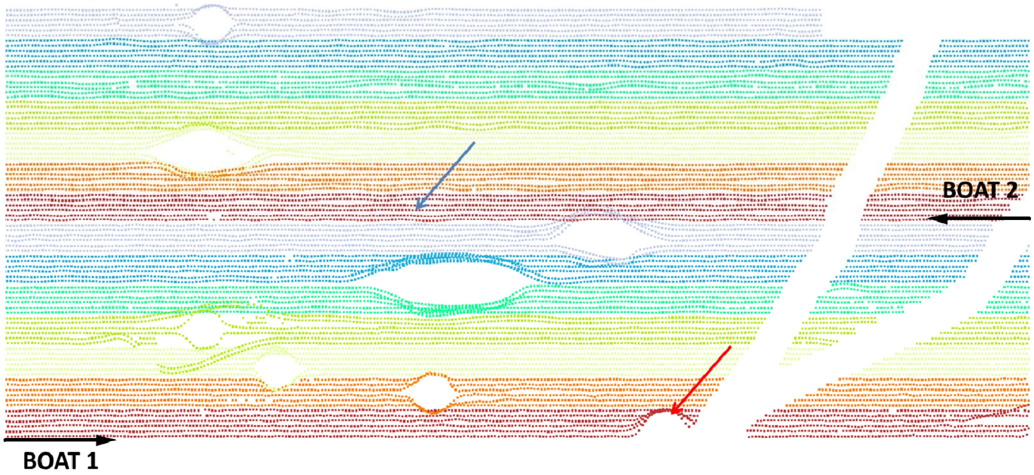

Figure 1: Simulated simultaneous acquisition with two boats firing in each swath (denoted by colour).

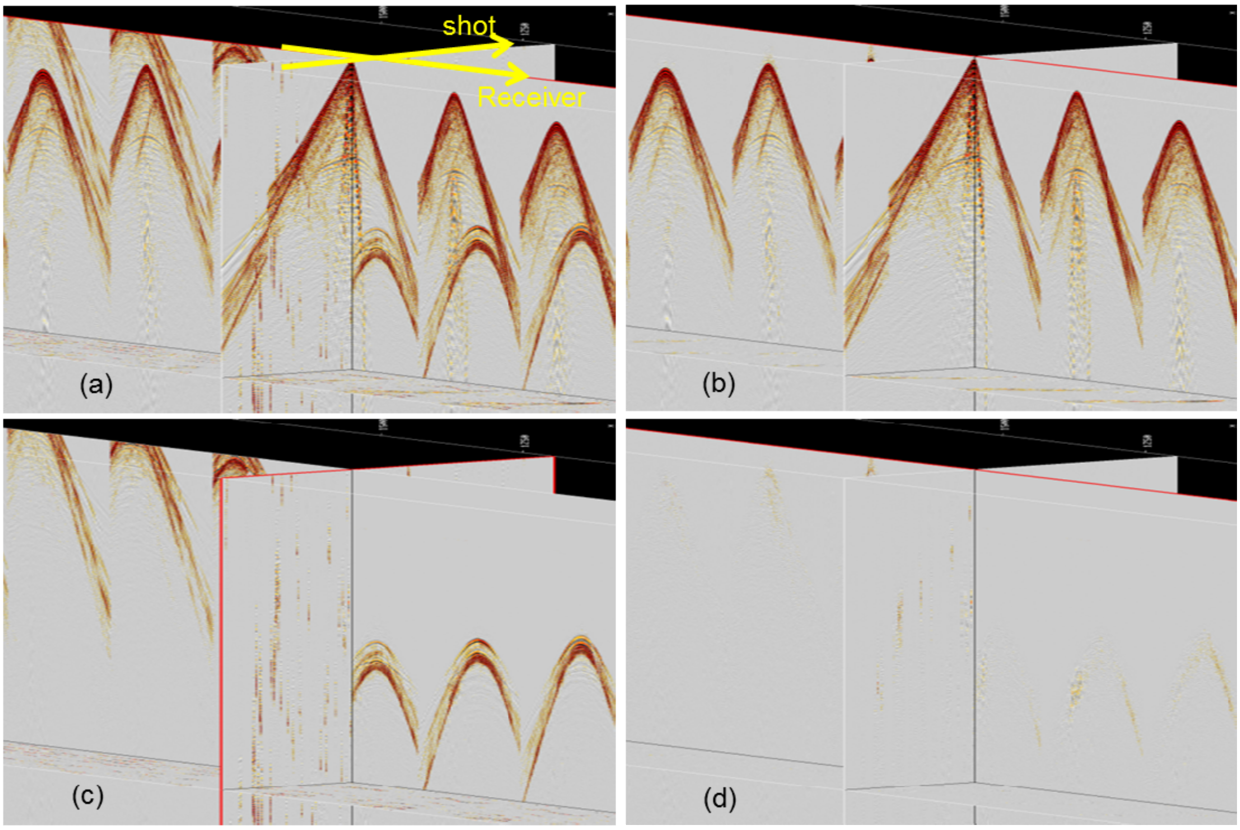

Figure 2: 3D view of cross-spread gathers for (a) blended data, (b) deblended data, (c) cross-talk noise and (d) difference between unblended data and deblended data.

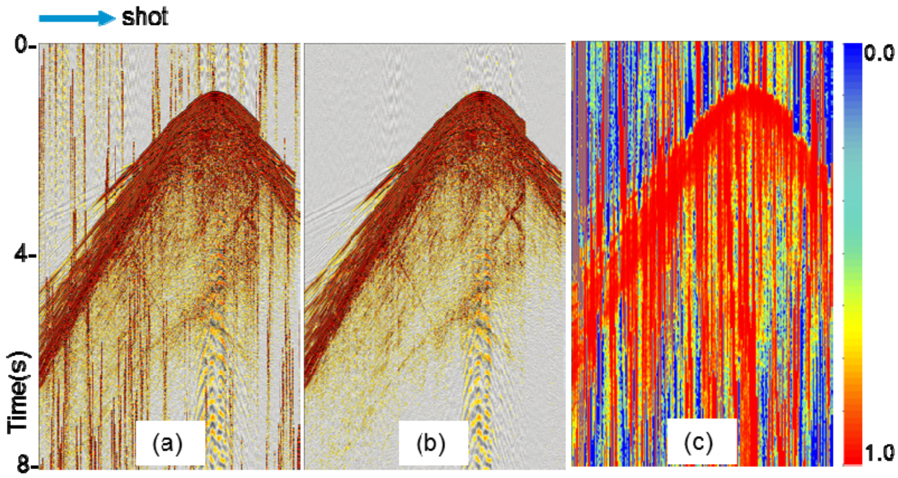

Figure 3: Receiver gathers of (a) blended, (b) deblended and (c) SNR map used for guided residual denoise.

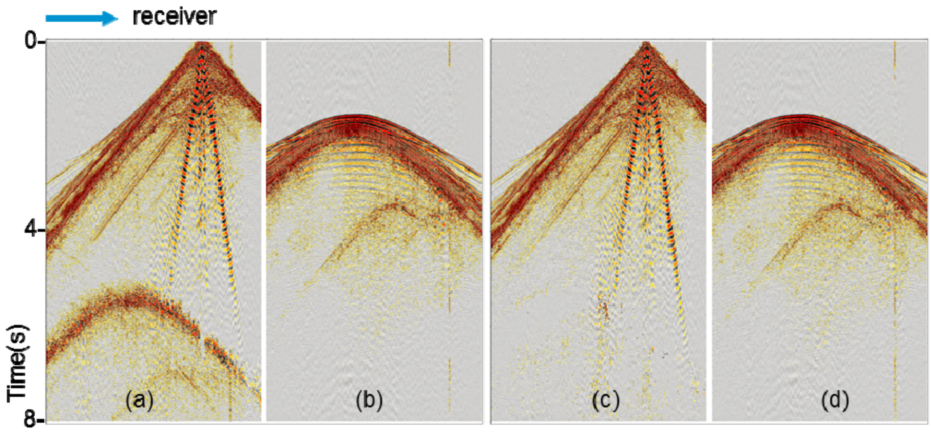

Figure 4: Initial deblending by low rank decomposition: shot gather (a) is located near an area of missing shots, while shot gather (b) is at a regular shot area. (c) and (d) are the denoise results of (a) and (b) respectively.

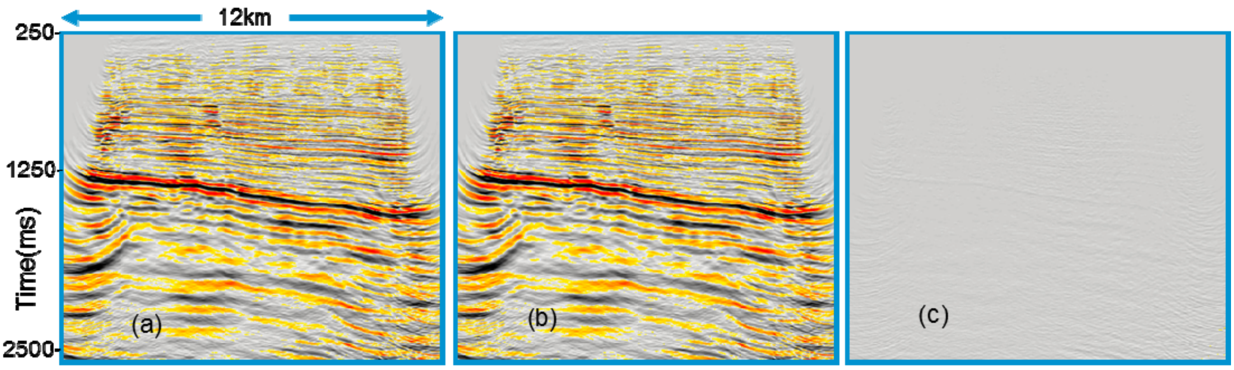

Figure 5: Migration stacks of (a) deblended, (b) unblended data and (c) difference between (a) and (b). Zoom in to show the target zone.

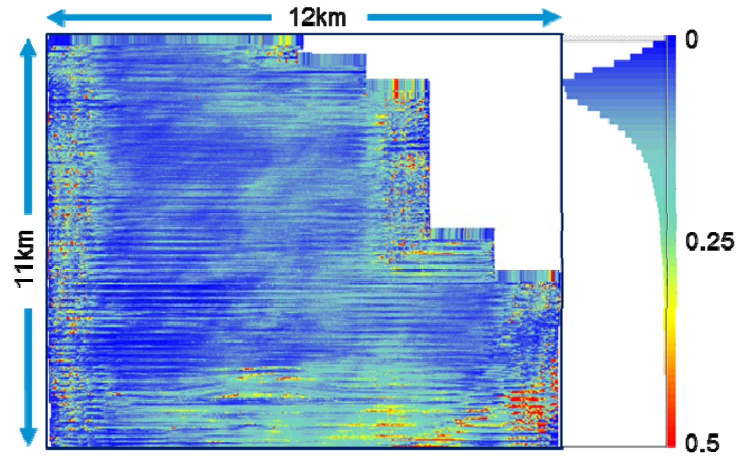

Figure 6: NRMS map between unblended and deblended data with dominant value of 0.07.

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