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Simultaneous Source Separation Using an Annihilation Filter Approach

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SUMMARY

Simultaneous shooting increases acquisition efficiency by activating more than one source at the same time. This introduces blending noise that typically needs to be removed before data processing. We present a new deblending algorithm based on iterative annihilation filtering. The strategy attenuates coherent energy using a modified sparse τ -p transform following which the remaining energy is re-aligned to form the deblended output. The method is tested on a numerically blended dataset using real short and long offset narrow-azimuth data. The results show the residual blending noise to be ~ 25 dB down.

Introduction

Simultaneous source acquisition aims to increase acquisition efficiency by activating a second source while still recording the Earth's reflections from a first source. This can provide a cost saving, or allow a denser survey to be acquired in the same time. However, the signal overlap also results in cross-talk noise contamination which must be handled in processing. Unlike land-based acquisition where this technique already is well established, it is not yet commonplace in the marine environment. Nevertheless, potential for towed streamer as well as ocean bottom acquisition has been shown by, e.g., Moore et al. (2012), Davies et al. (2013) and Poole et al. (2014).

One strategy to handle cross-talk noise is to remove it near the start of the processing sequence, a process commonly known as active deblending. This approach normally relies on the introduction of asynchronicity into the source firing times from shot to shot. The use of such firing times ensures that cross-talk noise has an impulsive character in domains other than the common shot. The data can then be deblended, for example, by attenuating the cross-talk noise using impulsive denoising techniques (e.g. Stefani et al. 2007). Other deblending techniques focus on the iterative incremental removal of the cross-talk noise (e.g., Doulgeris et al. 2010) or on simultaneously deriving model representations for both sources based on source firing time information (e.g., Akerberg et al. 2008 or Moore et al. 2008).

This paper describes an iterative annihilation filtering approach to build up a cross-talk model that, when shifted according to the known dither times, represents the non-blended data.

Methodology

Annihilation filters may be defined as filters which attenuate coherent energy. One example of an annihilation filter is a prediction-error filter. In contrast to prediction filters that aim to remove any non-predictable part of a data series, prediction-error filters remove the predictable part of the data, effectively leaving the unpredictable part intact. This process can be expressed as

$$r = f * d$$

where r is the residual, f is the prediction-error filter, d is the input data series, and $*$ indicates a convolution. Examples of prediction-error filters are the multi-dimensional time-distance prediction-error filters introduced by Claerbout (1999) and the plane-wave destruction filter (e.g., Fomel 2002).

The annihilation filter used here is based on a high-resolution sparse τ -p transform that utilises data- and model-domain sparseness weights (e.g., Herrmann et al. 2000 and Trad et al. 2003). The transform was modified so that instead of calculating a sparse τ -p representation of the data by minimising a residual, the time domain residual (i.e., the cross-talk noise) is calculated directly.

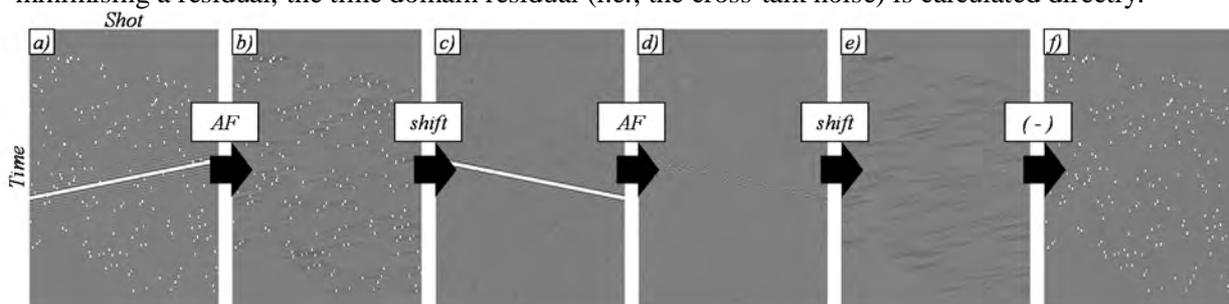


Figure 1 Common-receiver display showing one iteration of the deblending workflow. a) blended data aligned for source #1, b) result of first annihilation filter, c) data aligned for source #2, d) result of second annihilation filter, e) after reversing the dithers, and f) result of subtracting e) from b).

Each iteration of the deblending workflow contains two applications of the annihilation filter per source. The sketch in Figure 1a shows a coherent event (energy related to source #1) and incoherent cross-talk noise (energy from source #2). Applying an annihilation filter to the data significantly attenuates the coherent source #1 energy as can be seen in Figure 1b. The cross-talk noise remains mainly intact but is also affected by the filter application (smearing of the impulsive noise). To mitigate this effect, an estimate of the introduced error is calculated through a second application of an annihilation filter. To do this, the data is shifted according to the known dithers. Energy related to

source #2 now becomes coherent while the attenuated source #1 energy appears as incoherent cross-talk noise (Figure 1c). The second annihilation filter is applied, attenuating the coherent source #2 energy while leaving the attenuated source #1 cross-talk noise mainly intact (Figure 1d). The application of the dithers is then reversed (Figure 1e) and the result is subtracted from the output of the application of the first annihilation filter. The result shown in Figure 1f is characterised by improved attenuation of the coherent energy while minimising the effect on the cross-talk noise.

This process is repeated after aligning the input data for source #2 to calculate an estimate for the cross-talk of the other source. The results for both sources are subtracted from the input data, effectively leaving the residual as input for the next iteration. This process is repeated, summing the results from every iteration until the residual is sufficiently small.

Data example

The data example is a numerically blended dataset using two variable-depth streamer datasets acquired offshore Gabon. Both datasets were conventionally acquired with two sources shooting in flip-flop mode with a shot interval of 50 m for each source. Dataset #1 contains offsets between 0 and 10 km while dataset #2 contains offsets ranging from 5 to 15 km (see Figure 2). We show the results for one source and a single inner cable. The long-offset data were dithered using a pseudo-random sequence within ± 2000 ms before being summed with the short-offset data to simulate blended data (see Figure 3b). The large range of dithers ensured that the noise was well spread-out, allowing for accurate separation of low frequencies (Abma et al. 2012).

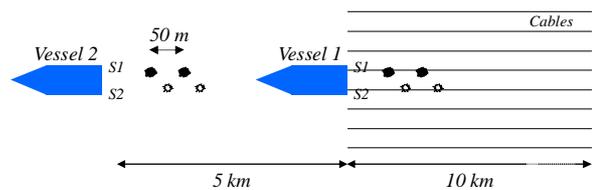


Figure 2 The acquisition set-up. Short- and long-offset data were acquired by simultaneously activating source S1 (black) or source S2 (white) on both vessels.

Near-channel data for the non-blended data, after blending, after deblending and a difference between raw and deblended data are shown in Figure 3. The blending delays were designed to spread the cross-talk noise throughout the gather. Cross-talk from the current shot is clearly visible near the bottom of Figure 3b, while cross-talk noise from the previous shot is much lower in amplitude and is present at the top of the gather. The minor difference between the deblended and the non-blended data shows that the method effectively removed the cross-talk noise while keeping the signal intact.

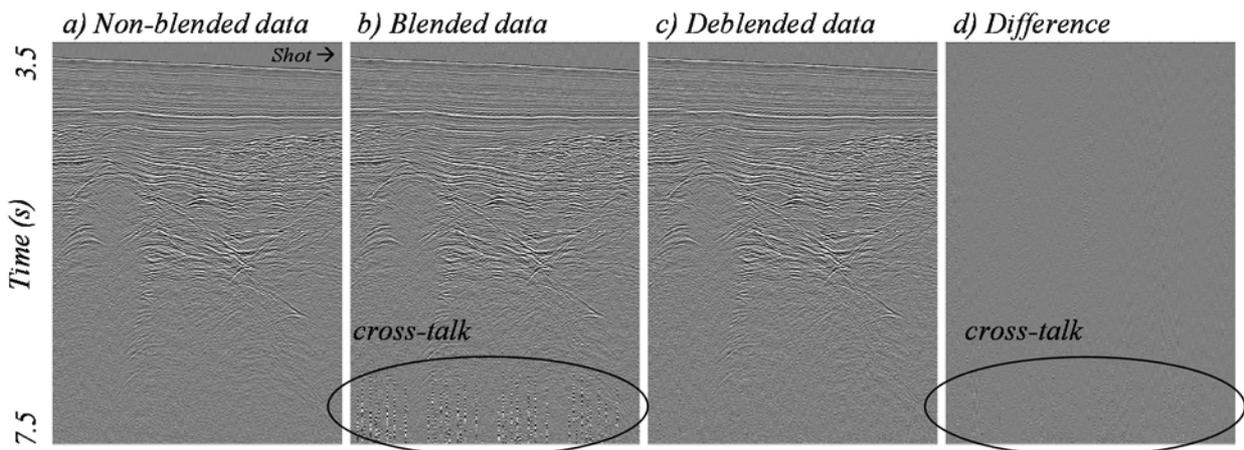


Figure 3 Common-channel displays aligned for one source of a simultaneous source experiment. a) before blending, b) after blending, c) after deblending, and d) the difference between the non-blended and deblended data.

Figure 4 shows CMPs, stacks and amplitude spectra from the dataset. Figures 4e and 4f show the difference between the non-blended and the blended and deblended data, respectively. Comparing the two differences shows that the majority of the cross-talk noise was removed with no/negligible signal

damage. The amplitude spectra in Figure 4b show that the difference between the non-blended and deblended data is on average between 25 and 30 dB lower than the signal. Figure 5 shows the stacks after migration for reference.

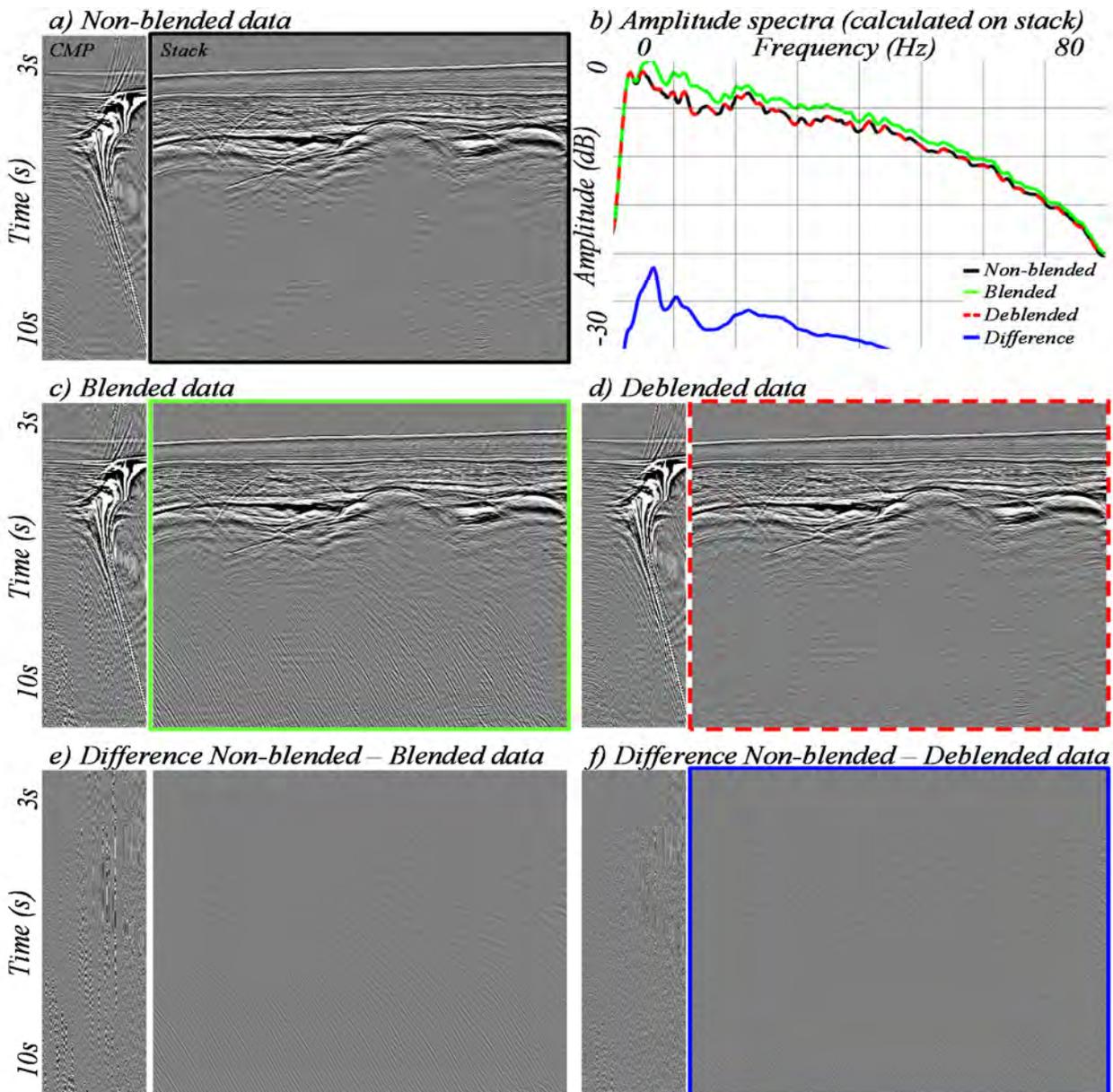


Figure 4 CMPs and stacks a) before blending, c) after blending, d) after deblending, e) difference non-blended minus blended, f) difference non-blended minus deblended and b) amplitude spectra.

Conclusions

We have introduced a new deblending approach based on annihilation filtering. The approach uses a modified high resolution sparse τ -p transform utilising data- and model-domain sparseness weights to iteratively remove the coherent signal. The remaining cross-talk is then aligned to construct the output data. We have tested the algorithm on a simulated simultaneous source acquisition using short- and long-offset data. Our results show very little leakage of signal and low levels of remaining cross-talk noise. The ability to attenuate the cross-talk noise to an acceptable level makes the simultaneous acquisition of short- and long-offset data without significantly increasing the acquisition time a viable option.

Acknowledgements

We thank CGG Data Library for the data examples, CGG Crawley, especially Matthew Taylor, for processing the data, and Ross Haacke for helpful discussions and input.

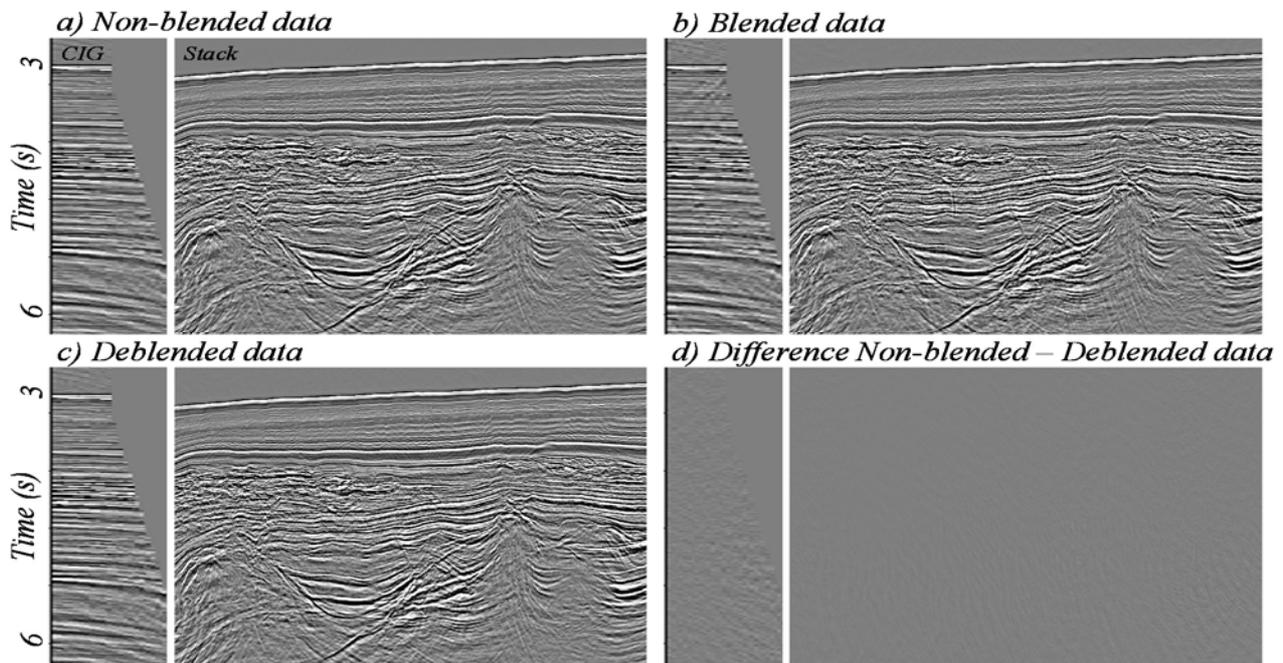


Figure 5 Migrated stacks and CIGs a) before and b) after blending, c) deblended, and d) difference.

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