A simulated Simultaneous Source Experiment in Shallow waters and the Impact of Randomization Schemes

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Summary

In simultaneous source acquisition, seismic data can be recorded with a temporal overlap between the shots. Better sampled data in terms of source spacing, azimuth and/or offset distributions can be obtained in a much more efficient way. These potential benefits can only be realized if the recorded data, with interfering energy from multiple sources, can be handled properly. Common practice is to apply randomized time-delays to the sources during the acquisition of the data. As a result of using randomized firing schemes, coherency measures can be utilized to actively separate the recorded data over the individual sources. In this paper an inversion-based source separation method is utilized to a shallow water data set which may have specific challenges compared to deeper water applications. We will focus a bit more on the randomized firing schemes. It is shown that optimizing these firing schemes, introducing “pseudo randomization”, instead of using random time-delays, can benefit the performance of the source separation.

The separation method is illustrated using a controlled simultaneous source experiment where a shallow water field data set is used to mimic simultaneous recorded data where two sources were located with only a small cross line distance between them (simultaneous FLIP/FLOP acquisition). Results demonstrate that it is advised to utilize “pseudo randomization” of the firing delay-times. The controlled shallow water field data example shows that good separation results are obtained.

Introduction

In seismic exploration, there is continuous drive towards more dense data sampling to better image complex geological structures. Recent advances in acquisition such as Wide-Azimuth, Multi-Azimuth or Rich-Azimuth acquisition can deliver a more diverse range of source, azimuth and offset sampling. To collect such data, multiple source and receiver vessels are deployed, thereby increasing the costs of the survey significantly.

In conventional acquisition, there is zero time overlap between shot records, and data are recorded discontinuously. The source domain is often poorly sampled, leading to aliasing.

In simultaneous acquisition, data can be recorded continuously, and temporal overlap between shots is allowed. Consequently, more sources are fired during the same period of acquisition, which greatly enhances the flexibility in survey geometries. As a result, a more densely sampled data set in terms of source spacing, but also azimuth and offset distributions can be obtained. In terms of efficiency, simultaneous acquisition can contribute by reducing survey times, which is of particular value in critical situations where small acquisition time-windows dominate due to severe safety, environmental or economic restrictions.

As such, from an acquisition point of view, simultaneous acquisition holds the promise of both efficiency and quality improvements. However, unless source separation can be achieved to a sufficiently high degree, the enormous potential benefits of simultaneous sources remain unrealized.

In this abstract, an inversion-driven method is utilized that aims to distribute all energy in the blended shot records by reconstructing the individual unblended shot records at their respective locations. The focus is this paper will be on shallow water applications. The method is explained further in the next section, after which we discuss how the firing schemes can be optimized and finally a controlled field data examples is presented.

Methodology

Inversion-driven methods aim to construct the separated sources through the minimization of a cost function that describes the “data misfit” (see, for example, Akerberg *et al*. 2008 and Moore *et al.* 2008).

Using the well-known matrix notation (Berkhout 1982), seismic data in the temporal frequency domain can be represented by data matrix **P**, where each element corresponds to a complex-valued frequency component of a recorded trace, the columns representing shot records and the rows receiver gathers. In general, source blending can be formulated as follows:

$$\mathbf{D}\,(z_d, z_s) = \mathbf{P}\,(z_d, z_s)\,\mathbf{\Gamma} \tag{1}$$

where **D** is the blended data matrix, z_d and z_s are the detector and source depth level respectively. Blending matrix $\mathbf{\Gamma}$ (Berkhout 2008) contains the blending parameters. In the case of a marine survey with random firing times but equal source strengths, only phase encoding is utilized. As such, elements Γ_{kl} from the blending elements only consist of phase terms $exp(-j\omega\tau_{kl})$

DOI http://dx.doi.org/10.1190/segam2013-1199.1

that express the time delay τ_{kl} given to source k in blended source array l.

To retrieve individual 'deblended' shot records from blended data, a matrix inversion has to be performed. In general, the blending problem is underdetermined meaning that there is no unique solution to the inverse problem. Hence, the blending matrix is not invertible.

In this paper, an inversion based separation method (Baardman and van Borselen 2012, van Borselen et al. 2012) is used that constrains the inversion based on coherency measures (Abma *et al.* 2010). The method is utilized in a mixed common channel / CDP domain. The randomized time-delays applied to the sources during the acquisition ensures that, dependant for which source you align the data, energy for one source will become coherent while all interfering energy from other sources appear as incoherent spikes. In an iterative way all the individual separated gathers are build up simultaneously. In each iteration a multi-dimensional median filter extracts the strongest component of coherent energy for all individual sources. Advantage is that when the strong events are separated first, the weaker events are better accessible and can be better separated.

Optimized design of firing scheme

Since the separation method is based on coherency measures it is of vital importance that the randomized time-delays applied to the sources ensures that there is enough randomness in the utilized domain(s). In case random numbers are generated, it may occur that, within a couple of shots, two or more shots have time-delays that are the same or very similar. Energy from that source, that should appear as incoherent spikes in a gather aligned for another source, can now be misinterpreted as coherent energy for the wrong source resulting in leakage. Figure 1a shows a common offset gather of a simultaneous field data example where, because random time-delays were generated, 3 out of 4 adjacent shots had accidently almost identical time-delays applied to them. As a result, the interfering energy, that should be incoherent, can now easily be misinterpreted and leak into the wrong source. Figure 1b shows the separation result for the same gather and indeed we see that energy has leaked to the wrong source.

Instead of generating the time-delays randomly, it is proposed to do that pseudo-randomly where a priori information of the acquisition, operator window size and geology can be used to constrain the process.

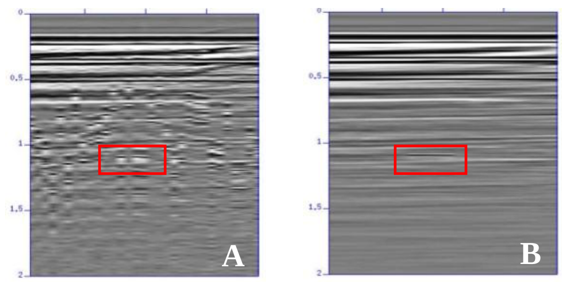

Figure 1: Common channel gather for recorded simultaneous source data (A) and its separation result (B). Notice that (indicated in the red box), the separation result shows leakage because interfering energy, that should be incoherent in this domain, is misinterpreted as coherent energy for the wrong source.

Acquisition and operator window size of the coherency filters can be used to determine a minimal number of adjacent shots (both inline and cross line) for which randomness should be secured. Consider a simple acquisition with 1 recording streamer, 2 simultaneous sources and a coherency filter with an operator length of 20 traces. Considering that only one of the sources is randomized (other will always fire at t=0), one should make sure that within 20 adjacent shots no time-delays are the same or close to each other for the randomized source. One way to do so is to divide the total time range of allowed time-delays (for instance 0 -1000ms) into 20 groups (group1: 0-50ms, group2: 50-100ms … group20: 950-1000ms). Pseudo randomize the order of the groups (group7, group15, group3 ….). For the first shot number, a time-delay is picked from the first group after randomization (group7 in this case) and applied to the randomized source. For the second shot number, a time-delay for the randomized source is picked from the second group after randomization (group 15 in this case). When shot number 21 is reached, the first group (group7) is used again to pick a time-delay. This way it is possible to ensure that there is enough randomness within the operator window to avoid leakage as shown in Figure1. In case more sources are utilized in a simultaneous source experiment (and multiple sources are randomized), it is proposed to first determine the "random seed", the delay-times of all simultaneous sources for shot number 1. Then, define one of the simultaneous sources as reference source and use the system described above to determine the delay-time for this reference source for the second shot number. Change the delay-times for all other sources with the same amount that the delay time for the reference source was changed.

DOI http://dx.doi.org/10.1190/segam2013-1199.1

Shallow water data example

In this example, the proposed method is deployed using a controlled simultaneous source experiment using a shallow water field data set from offshore UK.
In shallow water the following challenges may occur:

- Presence of high amplitude refracted energy
- Presence of many short-period surface multiples

The field data set is blended manually; time shift between 250 – 1000ms are applied to the shots and added to the original data set.

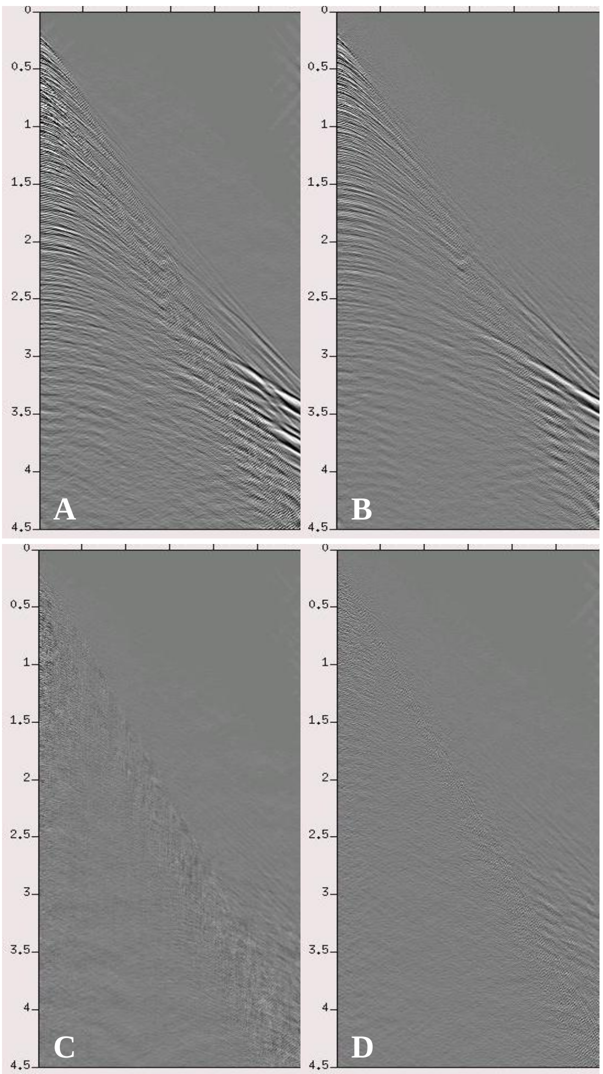

Figure 2: Shot gather of A) Blended input data, B) Separation result for source 1 C) Residual energy and D) Difference between separation result and reference data for source 1.

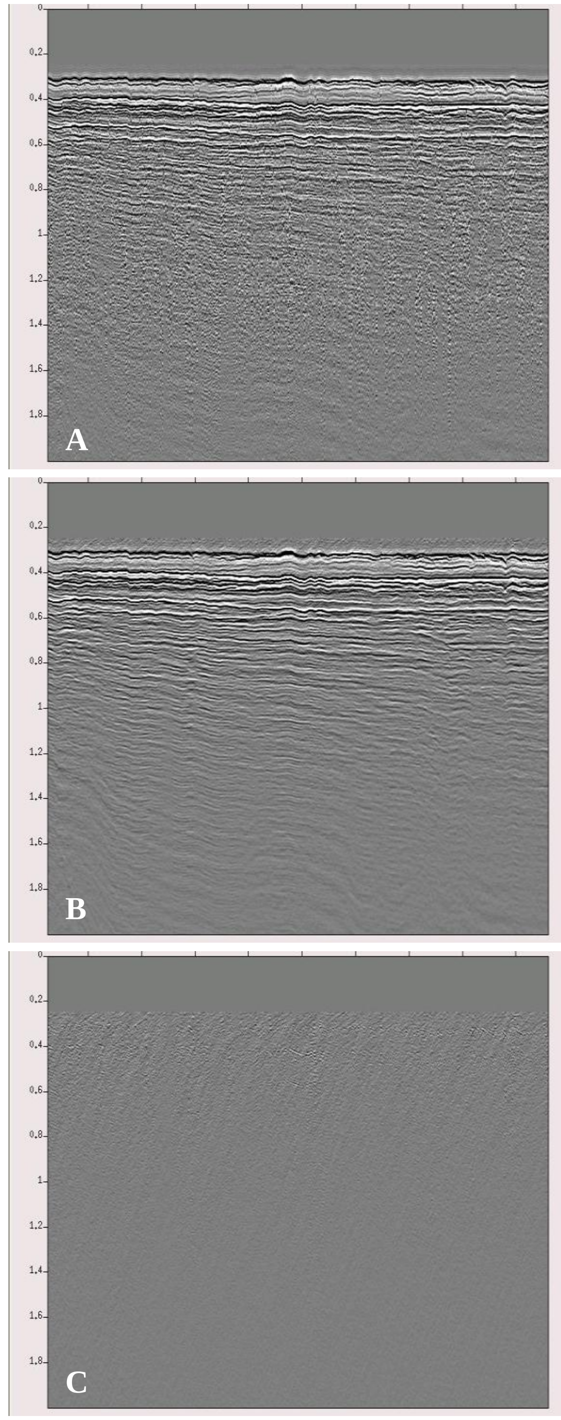

Figure 3: Common near offset channel of A) Blended input data, B) Separation result for source 1 C) Difference between separation result and reference data for source 1.

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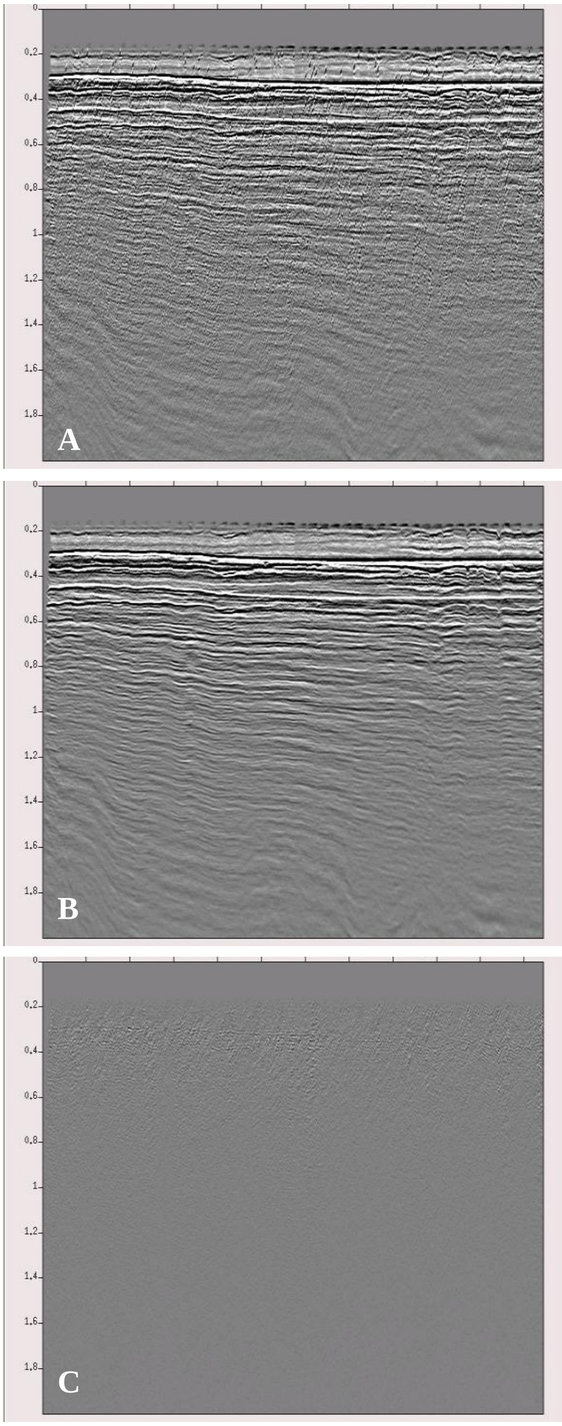

Figure 4: Stacked section of A) Blended input data, B) Separation result for source 1 C) Difference between separation result and reference data for source 1.

This way, we simulate a simultaneous source experiment with 2 sources, one always fired at zero time and one randomized. Because it is a controlled experiment we can compare the separation results to the optimal separation result, the reference data. Figure 2a shows an arbitrary shot record of the blended input data. In Figure 2b the separation result for source 1 is plotted. Figures 2c,d show the residual energy after separation and the difference between the separation results and the reference data for source 1. Similar separation results were obtained for the second source. Figure 3a shows a common near offset channel for the blended input data. The separation result for source 1 is shown in Figure 3b. Note the very good signal preservation of the events after separation, retaining all events optimally. The difference plot to the reference data is plotted in Figures 3c. The absence of coherent energy shows again the good signal preservation while the residual interfering noise from the secondary source is limited. Note also that no additional filtering was applied to achieve these results: only the inversion-based source separation method was utilized. Figure 4 show some stacked sections of the separation results for source 1. In Figure 4a the blended input data, aligned for source 1, is plotted. Figure 4b,c show the separation result and difference to the reference data for source 1. Similar conclusions can be drawn from these results; good signal preservation with acceptable residual noise level is achieved.

Conclusions

In this paper we revisited an inversion-based source separation approach. The use of randomized firing schemes in the acquisition allows the method to utilize coherency criteria to solve the source separation inverse problem. It is shown that generating the time-delays pseudo-randomly instead of randomly, will benefit the separation process. With random time-delays the possibility is not excluded that interfering energy, that should appear as incoherent spikes, can accidently be misinterpreted as coherent energy for the wrong source. Selecting the time-delays pseudo-randomly using minimal a priori information helps to prevent leakage of this kind. Results from a controlled shallow water field data experiment indicate that the separation performs very well. The challenges with shallow water do not seem to be an issue in this particular application. Very good signal preservation is achieved with minimal residual energy from the interfering sources.

DOI http://dx.doi.org/10.1190/segam2013-1199.1

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EDITED REFERENCES

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