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V002

Separating Simultaneous Sources by Inversion

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SUMMARY

Separating overlapping shots after seismic data acquisition using independent simultaneous sources can be done by using an inversion separation process with a set of linear equations that describe the overlap of the shots, the Vibroseis sweeps used, and the similarity of adjacent shots. The similarity of shots is a critical element in this separation. The similarity criteria may be Radon filtering, fx-decon, or some other measures of similarity. This inversion separation should be an improvement over simply ignoring the interference of the overlapping shots or attempting to filter out the interference from other shots. The inversion separation method is demonstrated on synthetic data and on land field data from Algeria. We found that the geometry of the source lines appears to affect the quality of the inversion. Successful application of acquisition with independent simultaneous sources may significantly reduce the cost of seismic surveys.

Introduction

The acquisition of seismic data is expensive, and one method of reducing the cost is to overlap shots. Standard seismic surveys involve setting off a shot and recording the reflected energy from that shot. The next shot is set off after the energy from the previous shot dies away. If a seismic survey could be shot with overlapping sources, where the recorded data from one shot overlaps with data from other shots, the acquisition time could be reduced. We refer to our particular method of shooting with overlapping shot records as Independent Simultaneous Sources (ISS) (Howe, et. al. 2008). The success of this method of reducing acquisition costs will depend largely on our ability to separate the energy of the various shots.

The simplest method of separating the signals from various shots is to set the shots off at random time intervals, correct each shot to its own zero time in processing, and let the stack fold attenuate the interfering energy (Hampson, et.al. 2008, Moore, et.al. 2008, Fromyr, et.al. 2008). Another separation method involves attempting to filter out the energy from the interfering shots (Akerberg, et.al. 2008, Moore, et.al 2008). Filtering will work only if the kinematics of the signal of interest is significantly different from that of the interfering noise and the geology is simple. This method also constrains the acquisition to somewhat fixed geometries to ensure that there will be enough kinematical differences to allow this filtering. For both these separation methods, the strongest energy from interfering shots may still corrupt the resulting images. Additionally, pre-stack uses, such as AVO analysis will be corrupted by the shot interference.

When shots are set off at random time intervals, the data may be reordered to make the energy of the interfering energy appear random. The interference may then be removed by random noise attenuation techniques. A shortcoming of this approach is that while strong energy bursts are attenuated, the residual energy from these strong events is often smeared across several traces by the operators used in the random noise attenuation (Abma 1995). In these cases, it may be better to simply mute out the strongest interference before filtering to avoid spreading energy into the nearby traces.

While the idea of using data with overlapping shots had been considered before (Lynn, et.al. 1987, Beasley et.al. 1998), Berkhout (2008) described the overlap, or blending, as a system of equations. To improve on the methods given above, we propose solving this system of equations to separate the blended shots. We refer to this method as inversion separation. The recorded data may be described by the linear system where

$$\mathbf{d} = \mathbf{\Gamma}\,\mathbf{m} \qquad (1)$$

where **d** is the recorded data, **m** is the data that would have been recorded if there had been no overlap between the recorded data, and **Γ** is a matrix that describes the timing and the overlap of the shot records. Berkhout (2008) refers to **Γ** as the blending matrix. As it stands, Equation 1 cannot produce a useful inversion to calculate **m** from **d**. Equation 1 requires more information to allow a practical separation of the sources. We propose to use the similarity of nearby shots with each other as an additional criterion for separation.

Theory of Inversion Separation

If the recorded data is described by **d = Γ m,** an initial estimate of **m** may be obtained by applying the transpose of **Γ** to **d.** This corresponds to simply correcting each shot to its own time zero. We will refer to the application of the transpose of **Γ** to **d** as straight separation. What we really want is the inverse of **Γ** applied to **d,** but **Γ by** itself does not have a suitable inverse.

We can improve the inversion by using the similarity of nearby shots to each other. There are several methods of quantifying this similarity, for example, Radon and fx-decon filters. Incorporating this similarity can be described by a system of equations:

$$\begin{pmatrix} d \\ 0 \end{pmatrix} \approx \begin{pmatrix} \mathbf{\Gamma} \\ S' \end{pmatrix} m \qquad (2)$$

where **S'** removes any coherent data, that is, **S'** passes only non-coherent energy. An alternative to Equation 2 is:

$$\mathbf{d} \approx \mathbf{\Gamma}\, \mathbf{S}\, \mathbf{m} \qquad (3)$$

where **S** passes only coherent data. We have found that the solutions to both systems in Equations 2 and 3 are very similar.

For Vibroseis recording, Equation 3 becomes:

$$\mathbf{d} \approx \mathbf{\Gamma}\, \mathbf{C}\, \mathbf{S}\, \mathbf{m} \qquad (4)$$

where **C** is the convolution of the sweep with the signal.

In the case of the field data shown in Figures 3 and 4, the field recording system had a limited time length that it could record continuously, producing short gaps in the otherwise continuously recorded data. While this limitation no longer applies, the field data here was processed with an additional term in the system.

$$\mathbf{d} \approx \mathbf{M}\, \mathbf{\Gamma}\, \mathbf{C}\, \mathbf{S}\, \mathbf{m} \qquad (5)$$

The **M** term in the equation above, referred to as the mute matrix, describes where the data was recorded and where it was missed. Typically the recorded time is almost continuous, with only a few portions missing. It is interesting to note that the solution for **m** in Equation 5 allows the shots taken in the missing areas to be interpolated. The system in Equation 5 was solved iteratively, and the solution generally required from 10 to 30 iterations.

Synthetic Examples and Acquisition Geometry

Several synthetic examples were generated to test this inversion separation method. The example shown in Figures 1 and 2 has a set of fixed detectors with sources moving in opposite directions. The two sources pass each other in the center of the set of detectors. The result of applying straight separation, that is, the transpose of **Γ,** is shown in Figure 1, where the interfering energy is clearly seen. Figure 2 shows the result of inversion separation, that is, solving Equation 5 for **m**. Note that the interfering noise is significantly reduced.

Other similar synthetics were generated with different shot line geometries. Two interesting cases had the sources moving in the same direction, one with a significant offset between the sources and one with the sources coincident in space. Using inversion separation, both these cases showed poorer separation than the case with the sources moving in opposite directions, and the case with the sources coincident in space showed the poorest separation.

Figures 3 and 4 show the results of the straight separation and the inversion separation methods on land Vibroseis data from BP's ISS acquisition. Some of the interference is marked in red. Notice that the interfering noise is not impulsive here as it was in the synthetic cases, since the real data used different sweeps for different shots.

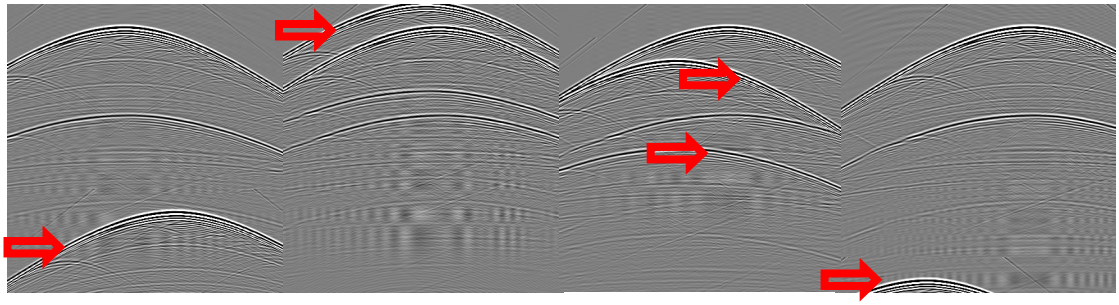

Figure 1 *Four synthetic shots using straight separation with the sources moving in opposite directions. Interference is marked with arrows.*

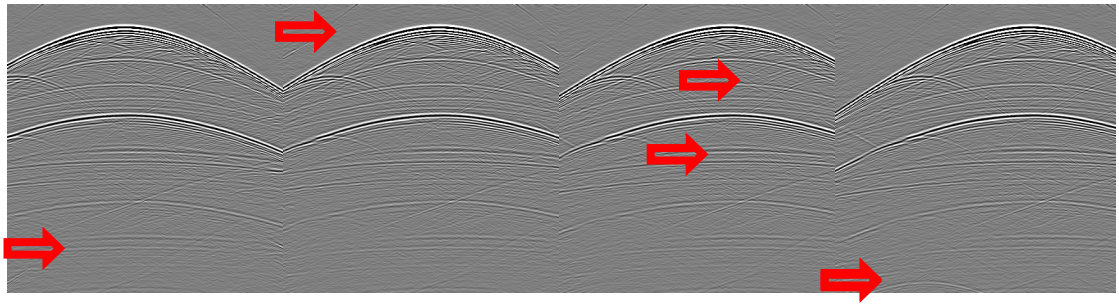

Figure 2 *The shots from Figure 1 using inversion separation with the sources moving in opposite directions. Note that interference marked in Figure 1 is reduced.*

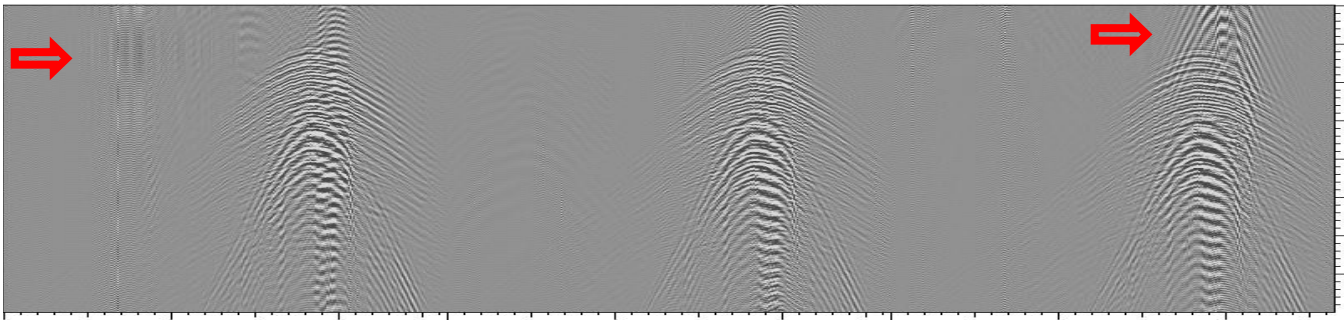

Figure 3 *Straight separation of Vibroseis field data from BP's ISS acquisition.*

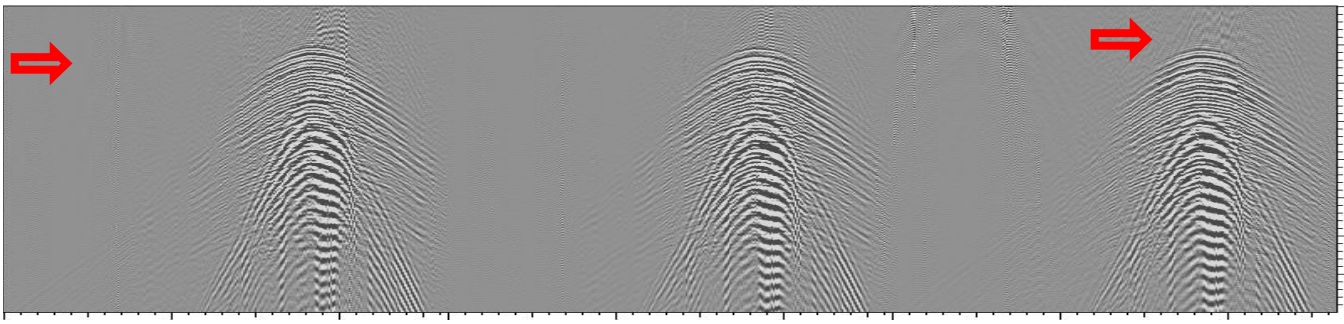

Figure 4 *Inversion separation of Vibroseis field data from BP's ISS acquisition.*

Conclusions

Inversion separation allows improved separation of interference noise for simultaneous shooting of seismic surveys. The geometry and direction of the shot lines appear to impact the result of the separation process. While the process is computationally intensive, the improvement in the survey quality and decreased acquisition time may make the process practical.

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