Gabor Deconvolution: Surface-Consistent and Iterative

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Summary

Nonstationary deconvolution has emerged as a tool for extracting the most realistic earth reflectivity from seismic traces, because of its adaptability to the characteristics of a given data set. Recently, deconvolution using the Gabor transform has been extended to yield deconvolution operators that are not only nonstationary in time, but also surface-consistent. We describe here a further extension of the surface-consistent Gabor algorithm in which both source-receiver offset and midpoint are used to parametrize the Q-function component of the deconvolution operator, and which iteratively improves the estimates for the four components of the deconvolution operator constructed for each trace. Each iteration requires a complete re-analysis of the raw input data. We demonstrate on real data.

Introduction

The purpose of deconvolution in seismic data processing is to recover as accurate an estimate of the earth's reflectivity function as possible by estimating and removing the effects of filtering and attenuation in the earth and seismic recording system. The Gabor deconvolution method introduced by Margrave et al (2002, 2004) is based on the assumption of nonstationarity of the recorded seismic signal, due to absorption and other attenuation effects in the earth. It attempts to estimate the time and frequency variant Q function (attenuation function) for each seismic trace, via the Gabor Transform, and to incorporate the estimate in the deconvolution operator in order to remove the effects of Q from the seismic trace simultaneously with inverting the source waveform.

An extension of the standard single-trace Gabor algorithm is the surface-consistent Gabor algorithm, introduced by Montana and Margrave (2006), which factors the high-frequency part of the trace Gabor Transform into source and receiver components and attributes the Q function to the midpoint. Deconvolution operators are formed from the ensemble-averaged source, receiver, and midpoint components.

A further extension of the Gabor algorithm involves the introduction of a fourth deconvolution component, parametrized by the source-receiver offset, and estimated from the Q-function. The

four-component version of Gabor deconvolution, implemented in ProMAX, also has provision for iteration of the first estimates of the components.

Details of the Method

The theory and details of Gabor deconvolution can be found in the references given; we describe here only the details pertaining to the four-component algorithm.

Since ensemble averages are an integral part of the algorithm, an input data set must be read once simply to enable the appropriate averages to be computed. Only with the second and subsequent reading of the input data set can deconvolution operators be constructed and applied to the individual traces from the stored, ensemble-averaged arrays of deconvolution components. The step-by-step algorithm proceeds as shown below. Here we refer to "raw data" by which we mean the data as input to Gabor deconvolution. Typically, such data may have had some processing (like coherent noise attenuation) and so is not in a truly "raw" state, so we use this term for convenience. Also, the various mathematical symbols all refer to arrays that are two dimensional, the dimensions being both time and frequency. The smoothing processes mentioned are also two-dimensional. Detail of these spectra and operators is not given here but is found in our references.

- Read a raw seismic trace, perform the Gabor Transform to obtain the Gabor magnitude spectrum, $|G|$.

- Apply hyperbolic smoothing (e.g. Margrave et al., 2004) to $|G|$ to derive a Q-function, $Qf = h(|G|)$, where $h(\cdot)$ indicates the hyperbolic smoothing operation, and to separate out the smoothed residual Gabor magnitude spectrum, $s(|G|/Qf)$, where $s(\cdot)$ indicates another (not hyperbolic) smoothing operation.

- Factor the Q-function (square root) and sum the result, $\sqrt{Qf}$, to deconvolution operator arrays indexed by source-receiver offset, D_o, and by midpoint (CDP), D_m.

- Factor the smoothed residual Gabor spectrum (square root) and sum the result, $\sqrt{s(G/Qf)}$, to deconvolution arrays indexed by source, D_s, and receiver, D_r.

- Repeat these steps until the entire data set has been read. Begin to read raw data again

- Read a raw seismic trace, perform the Gabor Transform to calculate anew the Gabor spectrum of the trace, G.

- Apply hyperbolic smoothing to re-estimate $Qf = h(|G|)$ and $s(|G|/Qf)$.

- Divide product of Q-function and residual magnitude spectrum by normalized products of three at a time of the four components estimated during the first pass. This provides new (iterated) estimates of each of the components in turn. For example, the updated source operator is $D'_s = s(|G|/Qf)Qf/(D_r D_o D_m)$ and similarly for the other components. These new estimates are summed into arrays indexed by source, receiver, offset, and midpoint.

- Retrieve the four component estimates from the first pass, whose source, receiver, offset, and midpoint correspond to those of the current trace, and combine into a the magnitude

of a deconvolution operator $|D| = D_s D_r D_m D_o$. Estimate the phase of the deconvolution operator by the usual Hilbert transform formula $\phi_D = H\left(\ln\left(|D|\right)\right)$, where the Hilbert transform, H, is applied over frequency at constant time and the usual precautions are taken to avoid the log of zero.apply the inverse Gabor transform to provide an output trace. At this time, we have assumed that all four components are minimum phase; however, this assumption could be modified by making any selected component zero phase for example.

- Repeat these steps until the data set has been read a second time.
- Modify initial component estimates by averaging with with iterated estimates.
- Repeat as many iterations as desired. Each iteration deconvolves the raw data with a revised operator.

Example

The new version of Gabor deconvolution has been tested on both model and real data. In both cases, when compared with single-trace Gabor deconvolution, or with ensemble-average Gabor deconvolution; the single-trace Gabor algorithm produces the broadest band result on any given individual trace, but trace-to-trace phase within an ensemble can vary, due to differing amounts of noise on the individual traces. The ensemble-average Gabor process, on the other hand, shows the most phase stability over an ensemble, but has the lowest bandwidth. The four-component Gabor result is typically not as broadband as single-trace deconvolution, or as bandlimited as the ensemble-average version, but has good phase stability within an ensemble. The iteration of this algorithm appears to improve the early estimates.
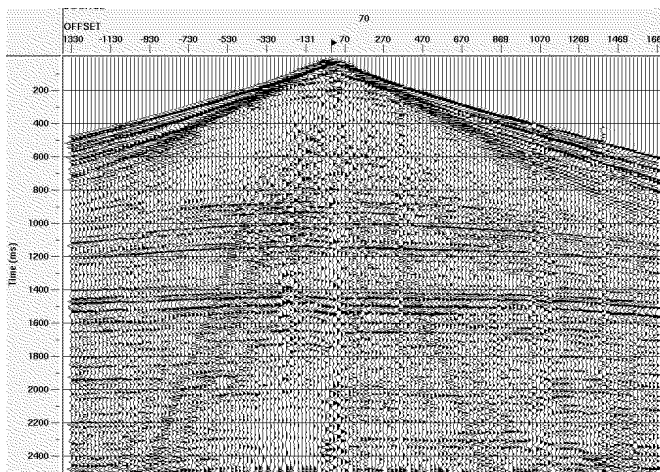

Figure 1: Blackfoot shot gather after single trace
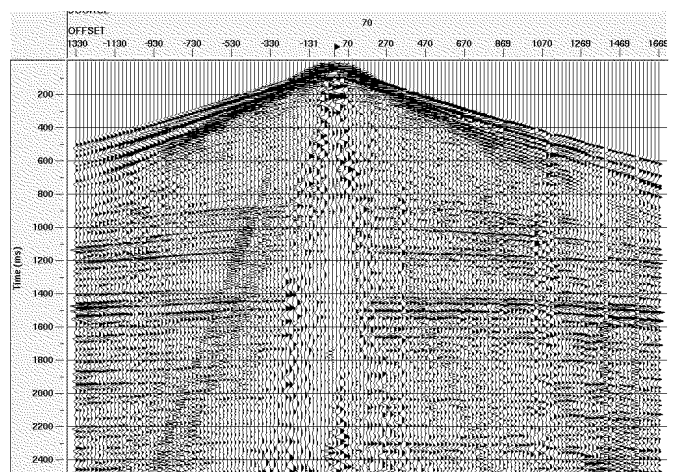Gabor deconvolution

Figure 2: Blackfoot shot gather after ensemble
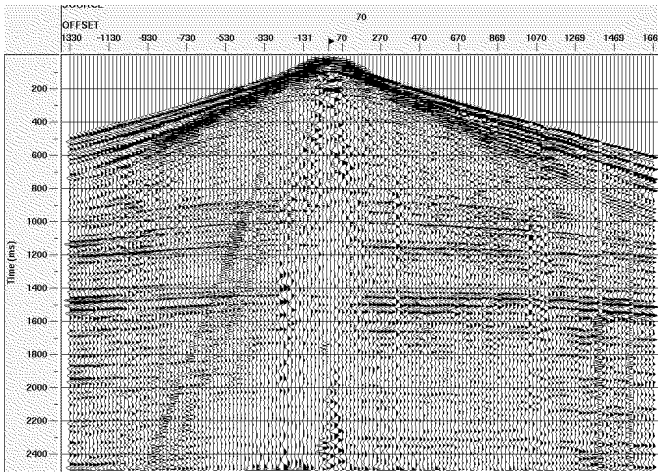average Gabor deconvolution

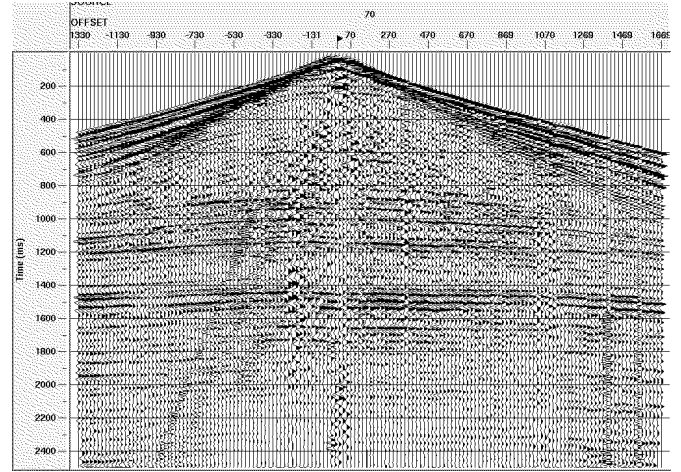Figure 3: Blackfoot shot gather after four-component Gabor deconvolution—first pass

Figure 4: Blackfoot shot gather after four-component Gabor deconvolution—second pass

Figure 1 shows an example of a shot gather from our Blackfoot data set after application of single-trace Gabor deconvolution, while Figure 2 shows the same gather after ensemble-average Gabor deconvolution. Compare these with Figure 3, which shows the initial results from the four-component Gabor algorithm, and Figure 4, which shows the results after the first iterative improvement of the component estimates.

Conclusions

With our new version of four-component Gabor deconvolution, we have provided a tool with which surface-consistent Gabor deconvolution can be applied, and which additionally allows variation of the deconvolution operator with offset. We also have the flexibility to iterate our initial estimates of the deconvolution operator components, which were initially obtained through simple factorization of the smoothed Gabor transform, followed by ensemble average. The iteration process is an area of ongoing research. Judging the results on real data will lie primarily in the domain of the interpreter.

Acknowledgements

References

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