Gabor deconvolution: real and synthetic data experiences

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Summary

A new high resolution processing stream comprising multiple passes of Gabor deconvolution is compared to an industry standard approach for high frequency reconstruction. Comparisons are made on both synthetic and real data sets, and algorithm efficacy is assessed based on well-tie analyses and also on interpreter feedback concerning the overall image character.

Introduction

As the search for subtle hydrocarbon traps intensifies, the seismic processing world is driven to extract increasing bandwidth from the raw data. To this end, various high resolution processing schemes have been proposed, all of which seek to restore those high frequency Fourier components of the signal which have been attenuated via earth filtering processes such as anelastic attenuation and stratigraphic filtering. Among these approaches, the one consisting of a single pass of surface-consistent, minimum phase deconvolution followed by multiple passes of prestack and/or poststack time-variant spectral whitening (TVSW) has become quite popular. Although years of experience have shown that the TVSW algorithm is amazingly robust, detractors are quick to point out that it lacks a certain amount of theoretical rigour. This criticism stems from the fact that non-stationary earth filtering processes (whose residual effects TVSW attempts to remove) are *minimum phase*, while the algorithm effectively constructs temporally localized *zero-phase* operators and therefore produces results which may contain residual phase errors. By contrast, Gabor deconvolution (Margrave et al., 2003) constructs temporally localized minimum phase, rather than zero phase, operators, and as such it offers a more theoretically rigorous alternative to this conventional high resolution flow.

Extensive initial testing based on both surface seismic and VSP data suggests that the Gabor algorithm produces excellent results. Still, the question remains as to whether the algorithm's theoretical advantage will always be realized in practice. There are at least two practical considerations which might preclude the Gabor deconvolution flow from routinely outperforming the above conventional high-frequency-enhancement flow in a production environment, First, on many data sets, it's possible that the non-stationary *phase* effect (induced by the earth filtering) is less important than the associated *amplitude* effect. In such cases the conventional flow may produce satisfactory results, with the initial pass of minimum phase surface-consistent deconvolution successfully removing the bulk of the phase imprint, and subsequent passes of TVSW properly compensating for any residual, non-stationary amplitude effects. Second, it's possible that errors in the Gabor deconvolution's estimate of the local minimum phase spectra could have the unintentional (and undesirable) effect of introducing "time-varying phase" errors in the final section. In order to safeguard against this problem, Gabor deconvolution performs a sophisticated smoothing operation in the time-frequency plane prior to estimating the local amplitude spectra associated with the non-stationary earth filters (from whence the local minimum phase operators are constructed), but the approach may break down in certain cases (e.g., local noise bursts).

Because it is unclear whether the above two practical considerations will thwart Gabor deconvolution in its theoretical promise to deliver high frequency sections with improved amplitude and phase handling, we have decided to submit both the conventional and the Gabor approach to extensive testing. In this paper we compare Gabor deconvolution to this conventional high-frequency-enhancement approach on both real and synthetic data sets. In so doing, we hope to build up a sample space of real data experiences, from which we can make meaningful, production-oriented inferences about the Gabor algorithm's efficacy.

Synthetic tests

Extensive synthetic testing was performed in order to optimize Gabor deconvolution parameter selection for the real data examples. Since these synthetic tests help to showcase the theoretical advantages of Gabor deconvolution, we show them here. Figure 1 shows a portion of a noise-free synthetic shot record obtained by taking a real reflectivity series from a well log and performing forward NMO and forward Q filtering (Q = 50; note that Q is spatially and temporally invariant). Figure 2 shows the ideal result obtained by convolving the reflectivity series with a 6/10/140/160 Hz zero-phase bandpass filter. Figure 3 shows the result after a single pass of Gabor deconvolution and Figure 4 shows the result after the conventional high-frequency-enhancement loop of minimum phase trace-by-trace stationary deconvolution followed by a single pass of TVSW (there is no theoretical reason to apply surface consistent deconvolution, nor to perform a subsequent pass of poststack Gabor/TVSW on these noise-free synthetics) . The Gabor deconvolution result is clearly superior, especially in its amplitude and phase treatment of the deep events between 1.4 and 1.6 seconds. It is important to note that the Q value was not supplied as an input parameter to the Gabor deconvolution (such as would be the case for an inverse Q filtering algorithm); rather, the algorithm implicitly performed a data-driven estimate of Q.

Real data tests

Not surprisingly, the real data results are less clear-cut. Nevertheless, with a sample space of six data sets (all having good well control), we hope to make some meaningful inferences about the relative pros and cons of the Gabor and the conventional TVSW flows. As of the writing of this abstract, several of the data sets had yet to be analyzed, but one representative result is shown below. Figure 5 shows a portion of a migrated stack from a 2-D land data set from Western Canada. This result was obtained using the new Gabor flow consisting of a single pass of prestack trace-by-trace Gabor deconvolution followed by a single pass of poststack Gabor deconvolution. Figure 6 shows the migrated stack obtained using the conventional high-frequency-enhancement flow consisting of a single pass of (stationary) minimum phase surface-consistent deconvolution plus prestack TVSW followed by poststack TVSW. Although the results have the same approximate frequency content, there are some significant differences in the phase and amplitude of certain events, and the interpreter (marginally) preferred the Gabor result because he felt it gave a slight overall improvement in lateral continuity . Figures 5 and 6 also show well ties at three different wells. The quality of the ties is good for both approaches, although the Gabor ties are arguably slightly superior. Note that a different (global) constant phase rotation was applied to each data set (-70 degrees for the Gabor; -50 degrees for the conventional). The precise reason for these large constant phase rotations is presently unknown, but it is worth pointing out that rotations of this magnitude are routinely applied at the interpretation stage, and moreover, that simple effects like random noise contamination are known to impart an overall constant phase error.

References

Margrave, G.F., Dong, L., Gibson, P., Grossman, J., Henley, D. and Lamoureux, M., 2003, Gabor deconvolution: Extending Wiener's method to non-stationarity: CSEG Recorder, December 2003, 5-12.

Fig. 1: Raw shot.

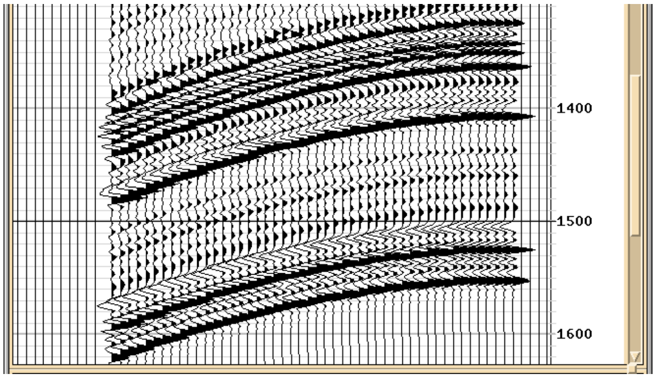

Fig. 2: Ideal result.

Fig. 3: Result after Gabor deconvolution.

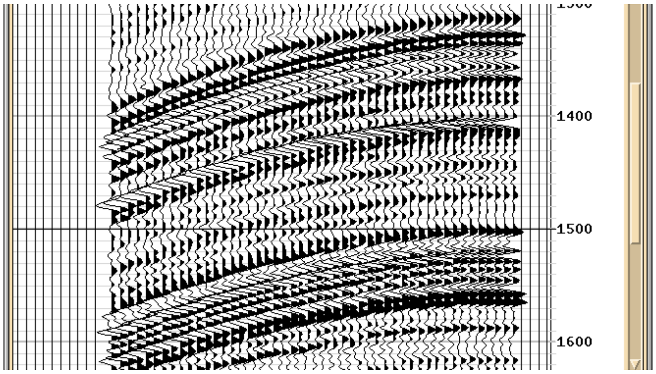

Fig. 4: Result after "standard processing"

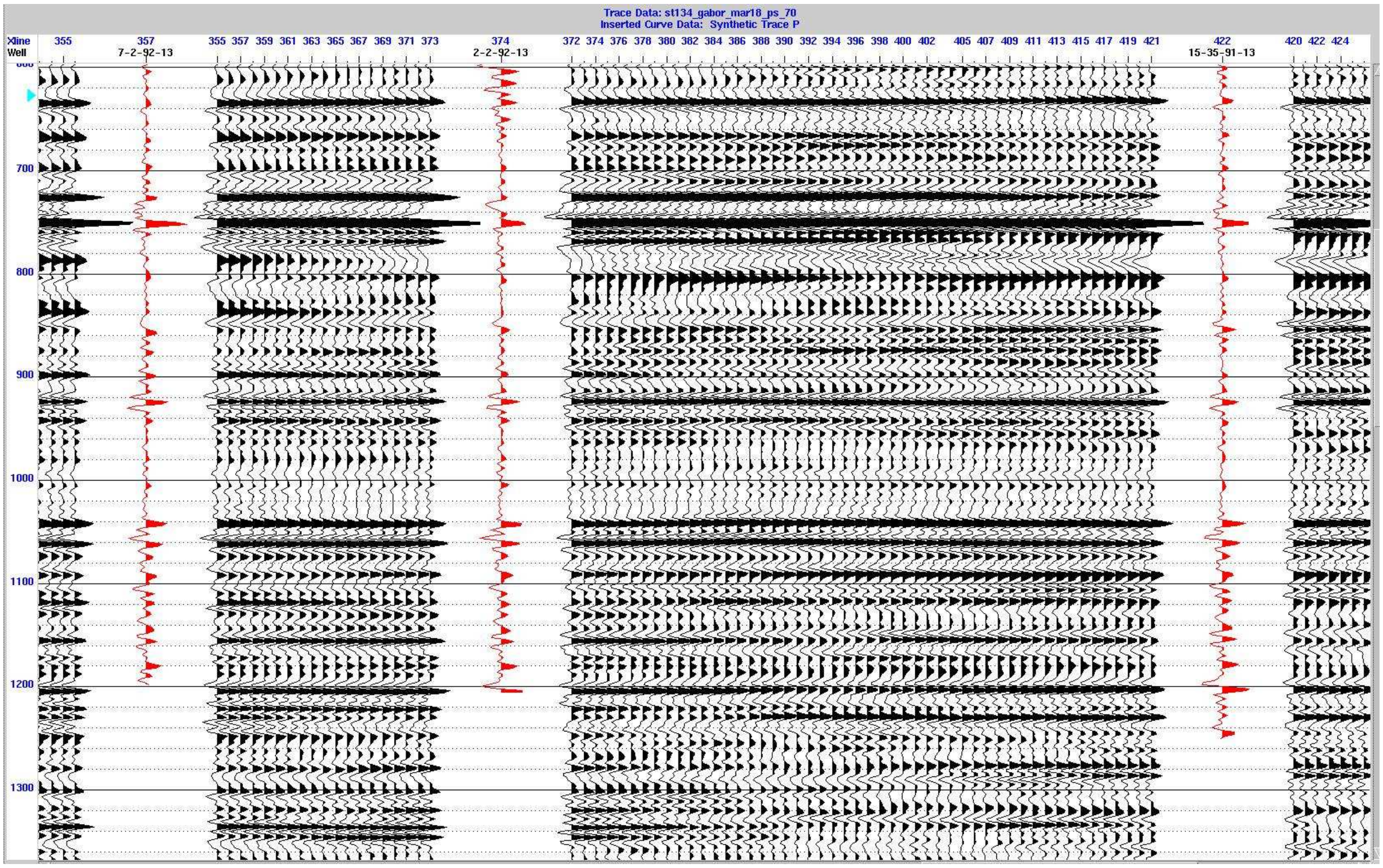

Fig. 5: Migrated stack after Gabor decon. A constant phase rotation (-70 degrees) has been applied to the real data (black). Well ties are shown at three different well locations. Synthetic traces (red) were created by convolving a zero phase bandpass wavelet (7/23/125/135 Hz) with the reflectivity series from the well.

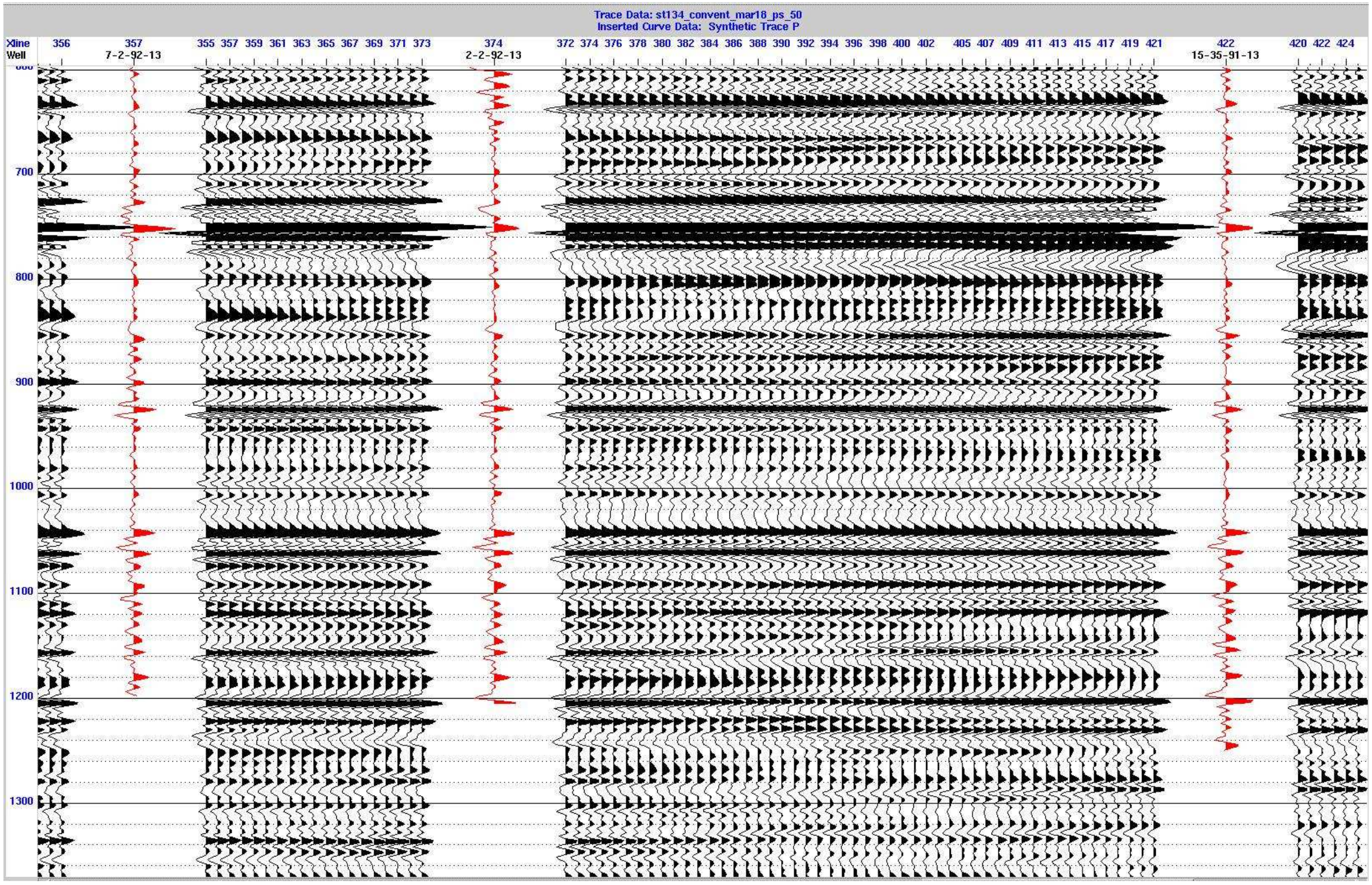

Fig. 6: Migrated stack after “standard processing”. A constant phase rotation (-50 degrees) has been applied to the real data (black). Well ties are shown at three different well locations. Synthetic traces (red) were created by convolving a zero phase bandpass wavelet (7/23/125/135 Hz) with the reflectivity series from the well.