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Color Correction for Gabor Deconvolution: A Test with Field Data

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Summary

Conventional deconvolution algorithms usually assume that the spectrum of reflectivity is white. However, the amplitude spectrum of reflectivity calculated from a well log usually demonstrates obvious dependence on frequency, which is referred to as the color of the reflectivity. Consequently, the white reflectivity assumption can lead to distortion of the deconvolution result. A practical color correction method for Gabor deconvolution has been proposed and tested using synthetic seismic trace. This article tests the proposed color correction method using field data. Results of processing field data demonstrate that the seismic data have higher resolution and a better tie to the well log data when color correction is applied.

Introduction

Four conventional deconvolution algorithms, the reflectivity is usually assumed to have a flat (white) amplitude spectrum over the deconvolution frequency band. Such a reflectivity is the so-called white reflectivity. However, in practice, the reflectivity is not white. In the Gabor transform domain, the amplitude spectrum of real reflectivity demonstrates a dependency on both time and frequency, which we refer as temporal and spectral color respectively. This indicates that the reflectivity color is time (actually depth) variant and needs to be corrected in a nonstationary way. Margrave and Lamoureux (2002) proposed a nonstationary Gabor deconvolution method, which makes the nonstationary correction to reflectivity convenient. Cheng and Margrave (2008) proposed a practical way to apply color correction for Gabor deconvolution when reference well log information is available. Their testing on synthetic data showed that a deconvolved seismic trace with color correction has more accurate relative amplitude and smaller phase rotation compared to true reflectivity. In addition, Cheng and Margrave (2009) showed that the amplitude distortion and phase rotation of estimated reflectivity can result from temporal color and spectral color respectively. The purpose of our work is to apply the color correction method to field data and to evaluate the results.

Color correction for Gabor deconvolution

Cheng and Margrave (2008) proposed a practical color correction method for Gabor deconvolution given by

$$R_G(\tau, f)_{est} = \frac{S_G(\tau, f)\overline{|R_G(\tau, f)|}}{\overline{|S_G(\tau, f)|} + \mu A_{\max}} e^{i\varphi_c(\tau, f)}, \qquad (1)$$

where $S_G(\tau, f)$ is the Gabor spectrum of seismic trace, $R_G(\tau, f)$ is the Gabor spectrum of the reflectivity calculated from the reference well log, μ is the stability factor (a small positive number roughly 10^{-4}, $A_{\max}$ is the maximum value of $\overline{|S_G(\tau, f)|}$, and $\varphi_c(\tau, f)$ is given by the Hilbert transform (over frequency)

$$\varphi_c(\tau, f) = H\left(\ln\left|\frac{\overline{|R_G(\tau, f)|}}{\overline{|S_G(\tau, f)|} + \mu A_{\max}}\right|\right). \qquad (2)$$

To apply the color correction to Gabor deconvolution, a smoothed Gabor amplitude spectrum of the reference reflectivity should be available. So, a non-detailed estimation of the time variant color feature of true reflectivity may be sufficient, which means the information of a regional well log can be applicable as well. Cheng and Margrave (2008) developed an effective way to approximate the Gabor amplitude spectral by using low order polynomial curves with time variant coefficients.

When applying the above color correction to field data, some practical issues should be considered. Usually, the available well log spans a smaller time range than the data, and needs to be aligned roughly with the field data. In addition, the amplitude of reflectivity may change significantly with depth/time. So, the color correction should address the alignment error properly. Cheng and Margrave (2009) separated the reflectivity color into temporal color and spectral color, which captures the time variant features and frequency variant features of the Gabor spectrum of reference reflectivity respectively, and showed that neglecting to correct for them can lead to relative amplitude distortion and phase rotation respectively. The spectral color correction, which can be regarded as normalized color correction, is probably more of interest from the point view of deconvolution. Since the spectral color is not sensitive to the alignment error of well log to field data, spectral color correction may be preferable for prestack decovolution. The spectral and temporal color correction can then be chosen for poststack deconvolution. The details about the implementation of color correction to field data using ProMAX is described by Henley et al (2010).

Examples

The field example used to test our color correction method is a 2D seismic line with 159 shots and 151 receiver stations, which was acquired over Blackfoot field near Strathmore, Alberta in 1995. As shown in figure 1, the reference well log is well 14-09 with a recorded depth range from 218m to about 1700m, which is about 600 meters away from the seismic line. Figure 2 shows the Gabor spectrum of the nonwhite reflectivity, whose amplitude depends on both time and frequency. Here an initial time of 210 was employed to align well log data to the field data. In general, the true reflectivity calculated from well 14-09 has obvious spectral and temporal color.

The Blackfoot seismic data were processed using ProMAX with a processing flow consisting of static correction, prestack Gabor decon, stacking, poststack Gabor decon, and Kirchhoff time migration. For the plain Gabor deconvolution case, both prestack and poststack deconvolution were applied using conventional Gabor deconvolution. For the spectral color correction case, both prestack and poststack deconvolution were conducted using Gabor deconvolution with spectral color correction. For the full color correction case, Gabor deconvolution with spectral color correction and Gabor deconvolution with full color correction were used for prestack deconvolution and poststack deconvolution respectively. The migrated seismic data for these three cases are shown as Figure 3, Figure 4 and Figure 5. We can observe the separated events at 820 ms and 960ms in figure 4, which are not clear in Figure 3. Compared with Figure 4, there is a lower amplitude zone around 700ms in Figure 5, which corresponds to the low amplitude zone around 0.7s in Figure 2. The average amplitude spectrum of the traces with CDP number was calculated and compared with a synthetic trace computed from the well 14-09, as shown in Figure 6. The seismic data with color correction applied have higher amplitude for those frequency components over 30Hz. From the above comparison in time domain and frequency domain, we can see that spectral color correction strengthens the high frequency components of seismic data. Compared to spectral color correction, full color correction modifies the temporal amplitudes of the seismic trace according to well log information as well.

Color correction enriches the high frequency components of seismic data. To verify whether such an effect enhances the data or boosts the noise, it necessary to tie the migrated data to well log data. The target zone for the Blackfoot seismic data is around 1050ms, which corresponds to the end the well log. Considering the near surface part of the seismic data is highly contaminated by noise, we use the lower part of the well log to tie the seismic data. The synthetic seismic trace was created using a Ricker wavelet with a dominant frequency of 40Hz. The last event of the synthetic seismic trace is generated by the single spike of the P wave velocity at the very end of well log, which is unrealistic because there are no later events. So, we use the events from 750ms to 950ms to correlate with the migrated data. According the X-Y coordinates of the well log location, the well log is mapped to the seismic trace of CDP 37 that has nearly the same X coordinate. The correlation of the synthetic trace to the migrated seismic data is shown as Figures 7, 8 and 9. We can see that the spectral color correction and full color correction have similar results. With color correction applied, the seismic data have higher frequency components for the events around 920ms and 950ms, all of which roughly match the synthetic seismic trace. For the correlation time range from 800ms to 1000ms, the phase rotation between the migrated seismic traces and synthetic seismic trace was measured and shown in Figure 10. The phase rotation for the spectral color correction case and full color correction case is similar and comparable to the conventional Gabor deconvolution case. So, with color correction applied, seismic data have more high frequency component and roughly tie better to the well log data. In other words, color correction can improve the resolution of our seismic data.

Conclusions

In practice, the earth reflectivity function is usually nonwhite, and this color characteristic is time-variant. So, seismic deconvolution needs to be corrected in a nonstationary way. Color correction for Gabor deconvolution can be applied to shot records directly when reference well log information is available. Testing on field data indicates that color correction can improve the resolution of seismic data, to some degree, and obtain a better tie to the well log data.

Acknowledgements

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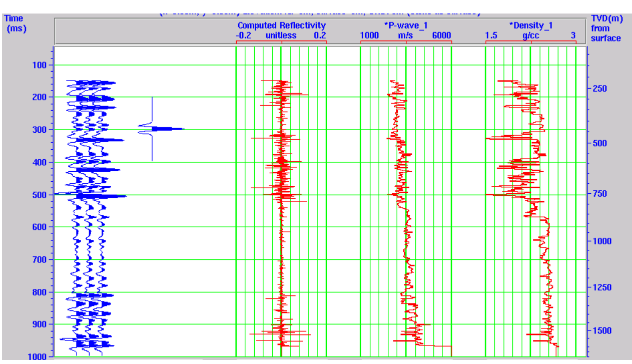

Figure 1. Well log 1409. From left to right: synthetic seismic trace, Ricker wavelet with a dominant frequency of 40Hz, computed reflectivity, P wave velocity and density.

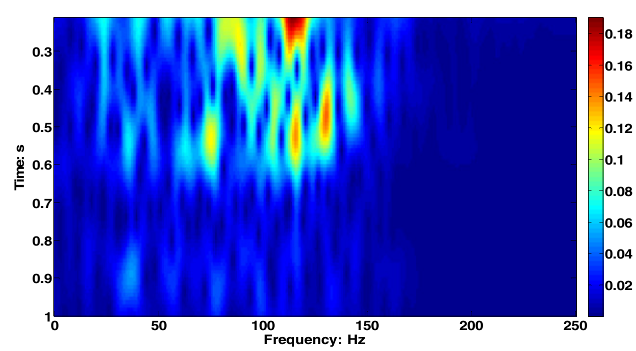

Figure 2. Gabor amplitude spectrum of the nonwhite reflectivity shown in Figure 1.

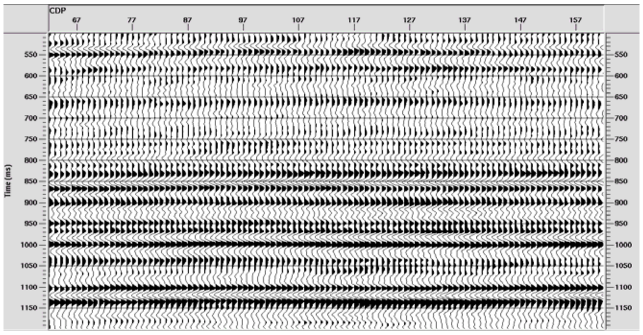

Figure 3. Migrated seismic data with plain Gabor decon (zoomed).

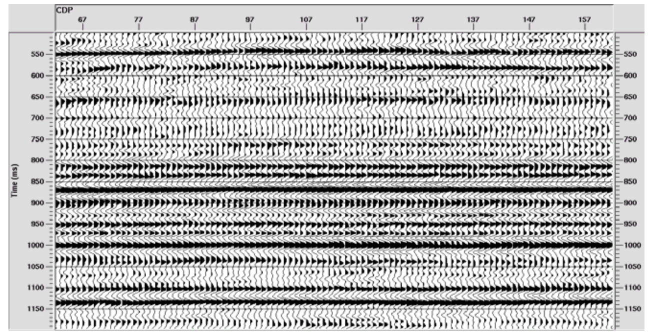

Figure 4. Migrated seismic data with spectral color correction (zoomed).

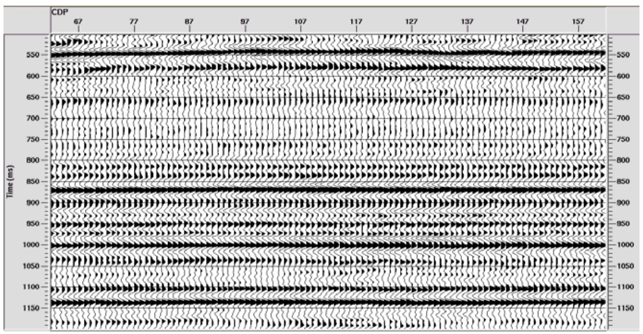

Figure 5. Migrated seismic data with full color correction (zoomed).

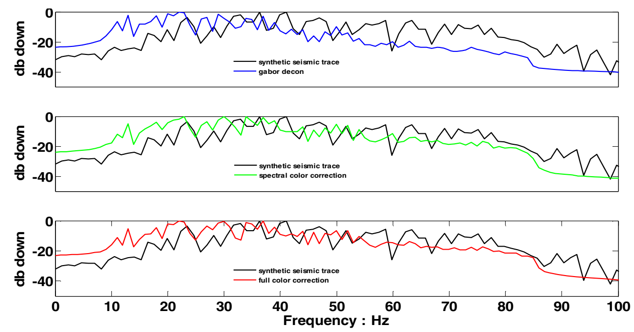

Figure 6. The average amplitude spectra of the seismic data (CDP 50-250, time: 500ms-1500ms) shown in Figure 10 Figure 11 and Figure 12 and the amplitude spectrum of the synthetic seismic trace shown in Figure 1.

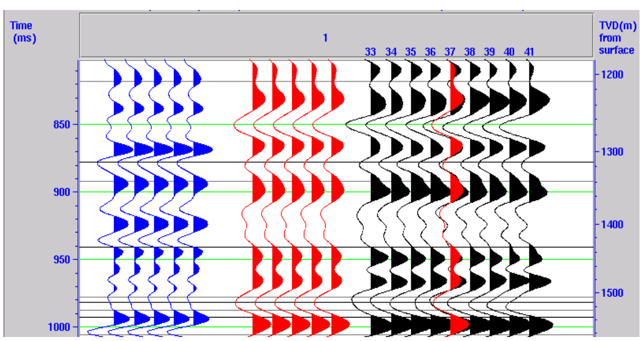

Figure 7. Correlation of synthetic seismic trace and migrated seismic data with plain Gabor decon. Blue: synthetic seismic trace; Red: migrated seismic trace with CDP 37; Black: migrated seismic traces around CDP 37.

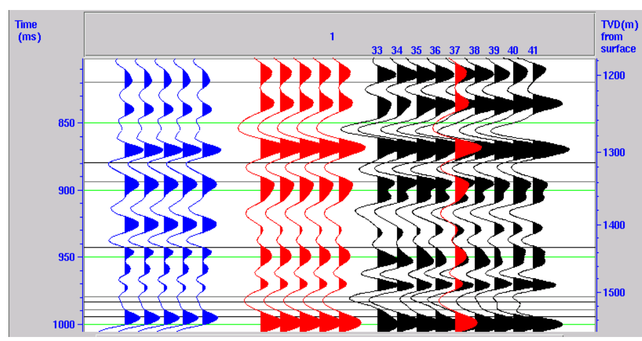

Figure 8. Correlation of synthetic seismic trace and migrated seismic data with spectral color correction. Blue: synthetic seismic trace; Red: migrated seismic trace with CDP 37; Black: migrated seismic traces around CDP 37.

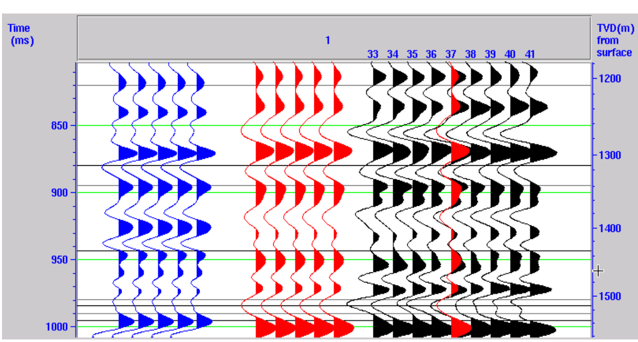

Figure 9. Correlation of synthetic seismic trace and migrated seismic data with full color correction. Blue: synthetic seismic trace; Red: migrated seismic trace with CDP 37; Black: migrated seismic traces around CDP 37.

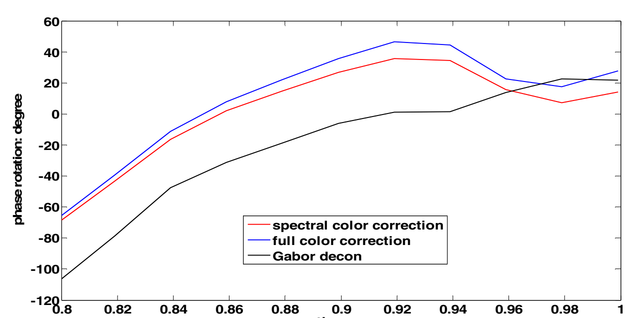

Figure 10. Phase rotation between synthetic seismic trace and migrated seismic trace of CDP 37 from 0.8s to 1s.