CORRECTION OF RESIDUAL PHASE DISTORTIONS IN SEISMIC DATA

Sabeur Mansar[1] and François Glangeaud[2]

[1]*TOTAL, TEP/DE/CST/RTS, 78470 Saint Remy les Chevreuses, France*

[2]*CEPHAG/ENSIEG, BP 46, 38402 Saint-Martin-d'Hères Cedex, France*

ABSTRACT

The residual wavelet on a processed seismic section is often not zero phase despite all efforts to make it so. Phase distortions arise for a variety of reasons.

In this paper we deal with phase distortions which arise during the seismic processing.

Constant phase rotation have been used to try to correct phase distortions. We present here two new methods for phase distortion correction. The first is based on Higher Order Statistics and can handle frequency-dependent phase distortions. The second is based on the Continuous Wavelet Transform and can handle time-varying frequency-dependent phase distortions. The application of the two methods on synthetic and real traces has shown their efficiency.

1 INTRODUCTION

The aim of seismic signal processing is to derive the structural and the lithologic information of the subsurface. During processing an effort is made to eliminate the variability of the seismic source and to shape it to a more desirable wavelet: the zero phase wavelet.

A zero-phase signal is a symmetric, non-causal signal. It has a narrow central peak and small side lobes. The maximum of amplitude is at the reflection time. These characters make zero phase signals very suitable for interpretation and automatic tracking on workstations. Furthermore, for a given bandwidth, the zero-phase signal is the one that provides the best resolution.

However, real signals are not zero phase (since they are causal signals) and have to be zero-phased: this is the task of the zero-phasing process.

Perfect zero-phasing is hardly achievable, and final processed data exhibit residual phase distortions. These distortions arise for a variety of reasons.

Dispersion, attenuation, and super-critical reflection introduce phase distortions to the source signature [1]. Deconvolution filters also introduce phase distortions. This occurs because some assumptions on which conventional deconvolution methods are based, are not strictly valid. For instance, the minimum phase condition is only partially met. Even if the initial signature, in the case of an explosive source, is minimum phase, due to sampling [2], recording and processing [3], the resulting wavelet is not minimum phase.

All these complications mean that the phase of the final wavelet is likely to be not zero and an additional effort has to be done to remove the residual phase distortion in the seismic section.

Levy [4] and Fourmann [5] used a constant – phase shift model to emulate phase distortions. The optimal phase shift is found by maximizing an objective function of the data (Kurtosis or Varimax norm).

Haargreaves [6] and Cambois [7] investigated phase errors in the minimum phase computation and showed that these errors can be approximated by a one-parameter function of frequency (the p/f filter). The optimal parameter is found by maximizing the same objective function as Fourmann and Levy (Kurtosis).

In this paper we will present two new methods for phase distortions correction. The first method is based on the allpass model of phase shift filters. Higher Order Statistics (Fourth order moments) are used to estimate the allpass filter. This method can be seen as an extension of the constant phase rotation model. It offers the advantage of handling frequency– dependent phase distortions.

The second method is based on the Continuous Wavelet Transform. This method can handle time-varying frequency-dependent phase distortions.

2 SEISMIC TRACES MODEL

The model adopted here for seismic data is the convolutional model. This model is entirely correct only in the case of a lossless horizontally stratified layered medium. However, modeling the processed seismic trace over a short time interval as a convolution of a wavelet with the series of normal incidence reflection coefficients (reflectivity function) is a good approximation and is the basis of the stratigraphic exploration tool in the oil industry.

The processed seismic trace x(t) can be seen as the output of a pure phase shift filter F derived by the reflectivity function r(t) :

$$x(t) = F\{r(t)\}$$

F : Pure Phase Shift Filter

Phase correction methods estimate the filter F to zero-phase the seismic trace x(t) by applying to it the inverse filter F^{-1}.

3 PHASE DISTORTIONS CORRECTION METHODS

3.1 Constant phase rotation method (CPR)

The idea is to model the filter F by a constant phase rotation. Seismic trace is rotated for a variety of constant phase value to obtain a set of phase-shifted replications of the seismic trace, that is

$$x(\theta, t) = cos(\theta) \times x(t) + sin(\theta) \times \mathrm{H}[x(t)]$$

H[.] denotes the Hilbert transform

The optimal phase is obtained by searching for the maximum of the varimax norm over $\{x(\theta, t)\}$

$$\theta_{max} = arg\left\{ max_\theta \left(\frac{\sum_t x^4(\theta, t)}{\left(\sum_t x^2(\theta, t)\right)^2} \right) \right\}$$

The varimax norm is a measure of the symmetry and the "spikness" of a signal.

3.2 Allpass method (AP)

The idea is to model the filter F by an all-pass system; its Z-Transform can be written as:

$$F(z) = \frac{B(z)}{A(z)} = \frac{\prod_{i=1}^{n} \left(1 - (p_i^*)^{-1} z^{-1}\right)}{\prod_{i=1}^{n} (1 - (p_i) z^{-1})} \text{ with } |p_i| < 1.$$

The roots of B(z) are the inverse conjugate of those of A(z). Notice that this filter is completely described by its poles $\{p_i\}_{i=1..n}$.

Since second order statistics are blind to this kind of filters, Higher Order Statistics should be used. The poles of the filter are estimated using the Fourth-order moment version of the extended Yule-Walker equation [9] :

$$E_{4,x}(m, l, 0) + \sum_{i=1}^{n} p_i E_{4,x}(m - i, l, 0) = 0 \text{ for } m \geq n$$

$E_{4,x}$ is the fourth order moment of the seismic trace

Remark: the order n is estimated using the maximum Kurtosis properties [8].

3.3 Continuous Wavelet Transform method (CWT)

The two methods presented above consider the seismic signal stationary or work within a short time interval where the seismic signal could be considered as stationary. This is not suitable for handling correctly time–varying phase distortions.

Time-frequency tools were introduced to analyze non-stationay signals. Asfirane et al. [10] showed that the Continuous Wavelet Transform (CWT) can provide a qualitative control of the zero-phase character of seismic data. The method we present here analyses quantitatively the zero-phase character of seismic signal and correct its phase distortions.

Mansar and Rodriguez [11] showed that the phase of the CWT of a seismic signal is related to the phase of its events. Using this relation we derive the following algorithm for phase correction :

- Compute the CWT of trace x(t):

$$W_{a,b}(x) = |a|^{-1/2} \int x(t) h^* \left(\frac{t - b}{a}\right) dt$$

- Pick several isolated events along the trace.
- Compute the phase of the CWT at these events.
- Interpolate between the phase functions at the picked events to obtain a 2D phase grid $\Phi_{corr}(a, b)$.
- Apply the reconstruction process to the function $CWT_x(a, b) \times \exp(-j \times \Phi_{corr}(a, b))$.

The Morlet wavelet (modulated Gaussian) was used as the analyzing wavelet for two reasons:

- The Morlet wavelet is well concentrated in both time and frequency domains.
- The Morlet wavelet is a complex value function. This allows us to analyze both the amplitude and the phase of the CWT of real signals.

4 APPLICATION TO SYNTHETIC AND REAL DATA

4.1 Synthetic data

The first synthetic data set consists of a reflectivity function which have been phase shifted. In this example the phase shift is frequency dependent. Figure 1. shows the results obtained after applying the three methods and their corresponding phase correction function. The AP and The CWT method provide better result than the CPR method because they apply a frequency dependent phase rotation. The CPR method was not able to correct efficiently the frequency dependent phase distortion, however it can be a good approximation in many other cases.

The second synthetic data set consists of a reflectivity function convolved with a time-varying phase-shift filter. Since this kind of signals can not be handled by the CPR nor the AP method, we have applied only the CWT method. Figure 2 displays the result of the CWT method. We can notice the perfect phase distortions correction and the overall noise reduction.

4.2 Real data

The real dataset consists of a portion of land stacked section. In order to evaluate the results of the different methods a well calibration test has been done. The well calibration consists of comparing the real seismic trace with a synthetic trace derived from well-log measurement at the same position as the real trace.

A window of 300 ms was used and the seismic trace at the well position was processed by the CPR, the AP and the CWT method. Tab. 1 shows the correlation coefficient between the real and the synthetic traces. We can notice the increase of the correlation coefficient with the increase of the complexity of the method used. A trade-off between the accuracy of the result needed and the complexity (more computation time) of the method to be used, has to decided.

5 CONCLUSION

Final processed seismic data suffer from residual phase distortions. Conventional methods (e.g., Constant phase Rotation) for estimating and removing the residual phase distortions are efficient only in the case of a frequency-independent phase shift.

We presented two new methods for residual phase correction. The first method is based on Higher Order Statistics and it can handle frequency-dependent phase distortions. The second method is based on the Wavelet Transform, and it can handle time-varying frequency-dependent phase shift.

The application of the two new methods on synthetic and real traces proved their efficiency. However, to choose the method to be used for phase distortion correction, a trade-off between accuracy and rapidity has to be decided.

REFERENCES

[1] Robinson, J. C., 1979, A technique for the continuous representation of dispersion in seismic data: Geophysics, 44, 1345–1351.

[2] Eisner, E., 1984, Tutorial. Minimum phase for continuous time and discrete time functions: Geophysical Prospecting, 32, 533–541.

[3] Ellender, S. A., 1986, Considerations in estimating the minimum-phase properties of sampled data: Geophys. Prosp. 34, 1200.

[4] Levy, S. and Oldenburg, D. W., 1987, Automatic phase correction of common-midpoint stacked data: Geophysics, 52, 51–59.

[5]Fourmann, J., 1985, Estimating phases of mixed-phase wavelets: Geophysics, 50, 722.

[6] Hargreaves, N. D., 1992, Air-gun signatures and the minimum-phase assumption: Geophysics, 50, 263–271.

[7] Cambois, G. and Hargreaves, N. D., 1994, Zero-phase conversion of marine data using one-parameter phase filters and Kurtosis maximization: SEG Expended Abstracts, 1591–1594.

[8] Boumahdi, M. and Lacoume, J.L., 1994, Blind Identification of Non-minimum Phase Systems by Maximizing the Kurtosis: Proc. EUSIPCO: HOS session.

[9] Mansar, S., Boumahdi, M. and Julien, P., 1995, New deconvolution method using higher order statistics: Proc. EAEG' 95, Glasgow, Scotland, 29 May- 2 June.

[10] Asfirane, F., Rodriguez, J. M. and Julien, P., 1995, Phase quality data control using the Wavelet Transform: Proc. EAEG' 95, Glasgow, Scotland, 29 May- 2 June.

[11] Mansar, S. and Rodriguez, J. M., 1996, Analyzing and zero-phasing seismic data using the wavelet transform: Proc. EAEG' 96, Amsterdam, The Netherlands, 3- 7 June 1996.

Table 1 Correlation coefficients of the well calibration.

Before	Phase Rotation	AP method	CWT method
0.60	0.68	0.74	0.77

Figure 1 Phase correction of a synthetic trace. Top: synthetic traces before and after correction. Bottom: the corresponding phase correction functions.

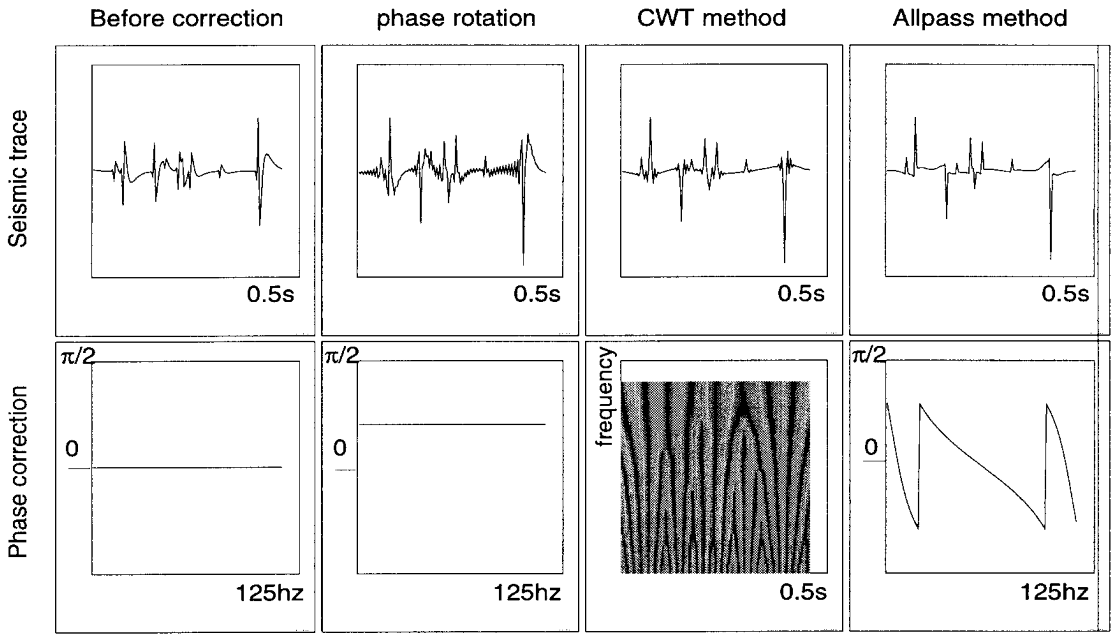

Figure 2 Second synthetic data example. The seismic trace is the convolution of the reflectivity with a time varying frequency-dependent phase shift filters. White noise has been added with a SNR=10.