Wavelet processing of seismic data
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Abstract:
In recent years, considerable interest has been generated in the problem of determining the phase characteristic of seismic wavelets accurately, two factors largely account for this, increasing need to extract detailed stratigraphic information from seismic data, and realization the phase assumptions in statistical deconvolution schemes may not generally be valid, and that the resulting deconvolved sections may differ considerably from zero-phase. The purpose of this paper is to demonstrate a method of extracting a seismic wavelet by well log data. From that we concluded that wavelets are powerful tools for analysis of field data, that is coming from analysis data and it is an excellent tool of field data compression.

1 - Introduction:
The processing of a digital seismic section is one of the most widely practiced activities in the field of exploration seismology. Signal deconvolution is a processing step that is ideally carried out after exponential gain recovery and before velocity analysis. The underlying purpose of deconvolution is to improve data resolution [1], by increasing the sharpness of the seismic reflections. In practice, this process attempts to shorten the seismic wavelet, broaden the wavelet's spectrum, remove the change in wavelet shape due to earth filtering, and to stabilize the wavelet from trace to trace. A wavelet is a mathematical function that cuts data into different frequency components and then analysis them according to scale. Data are numbers measured, that carry information, and then the objective of processing them is to sort and rearrange the data by correction and filtering and finally display the outcome. It is worthwhile to mention here one of the applications of wavelets in seismics, that help us to solve problem of extracting a true signal from indirect or noisy data. And the objective of seismic deconvolution, that is the important operation on data, aims to removing the effect of ghost "noise" from seismic trace.
In both academic and industry, seismic data processors tend to focus on the seismic wavelet when considering the deconvolution problem because if the wavelet is reliably estimated, it can generally be deconvolved or sharpened to some desired output with a digital filter. Since the onset of the digital recording, a
time honored tradition has arisen in that statistical estimation method is used to model the seismic wavelet. Although these methods have been in use for several for several decades [ 2 ] , gave a scathing criticism of their theoretical basis. The characteristics of wavelet observed on seismic reflection records depend on the particular seismic source and recording system which used. In general, wavelets in seismic data can be estimated by two different methods. The first one is a deterministic approach (consistency of wavelet extracted by using well-log data) , and second one is a statistical approach ( which estimates the actual wavelet on seismogram after filtering and recording system )[2].

2- Wavelet Processing

The general objective of wavelet processing or deconvolution programs can be summarized as shown in figure 1. in the convolution model an input trace is considered to be result of convolving an input wavelet with earth reflectivity sequence and adding noise. Although both wavelet and noise are generally time variant, it is common practice to consider them as fixed in some window on the trace. Wavelet processing is successful to the extent that three criteria, output wavelet should be zero-phase to ensure optimum resolution and ease of interpretation, output wavelet should be broad-band (or equivalent, of short duration in time, i.e. spiky ) and output signal-to-noise ratio should be high [3].

In seismic exploration a short duration seismic source wavelet (pulse) is transmitted from surface, reflected from boundaries between underground earth

Figure 1. Scheme of wavelet processing after[4].
layers, and received by an array of geophones on the surface. With the assumption that the seismic pulse wavelet is not distorted during its propagation. The deconvolution process involves separation of the components of convolution in the observed trace, satisfactory results were obtained when one component was known. However, when only the observation is known, the problem becomes much more difficult. In this case. However, the minimum phase assumption cannot always be satisfied in the real world. Seeking alternative way for mixed phase wavelet deconvolution has become a topic of great interest in current research [5]. In the convolutional model, the seismic trace can be written:

\[ T = W \ast R + N \] (1)

Where: \( T \) = seismic trace; \( W \) = wavelet; \( R \) = reflection coefficient sequence; \( N \) = noise

* Denotes as the convolution operator

The difficulty in estimating \( W \) or \( R \) stems from the fact that there are three unknowns in this single equation. The noise \( N \) can never be estimated precisely, but must be described statistically. The reflectivity sequence, on the other hand, can be estimated by using the impedance function calculated from a sonic and density log, in the same manner as when calculating a synthetic seismogram. If the reflectivity sequence calculated from the log is close to the true reflectivity sequence in the seismic data and if the noise in the seismic data is low-amplitude, random, and uncorrelated with the other components, then the true wavelet, \( W \) is the one that makes the synthetic seismogram match the seismic trace as closely as possible. Figure 2 illustrates this concept [4]. Mathematically the wavelet extraction problem is formulated as shown in Figure 3. The general least-squares shaping problem is:

Given an input sequence \( A \), and a desired output sequence \( B \), design a filter \( F \) which transforms \( A \) into \( B \).

\[ A \ast F \cong B \] (2)

Such that the error sequence \( E = B - A \ast F \)

Has minimum energy

\[ \sum_{i} E^2(i) = \text{minimum} \] (3)

The ideal case shown in Figure 3, and the input sequence is the well-log reflectivity sequence the desired output is the seismic trace, and the result is the extracted wavelet. Errors in the well-log reflectivity sequence that invalidate the assumption that it is a good estimate of the earth reflectivity sequence, random noise, and long-period multiples, etc. in the seismic data, which may be considered as increasing the noise term in Equation (2), errors in the depth-to-time conversion, cause the most difficulty. Thus, errors in
the transit time from phenomena such as caving, secondary porosity. Additional information from a check-shot survey can be used to calibrate the log. A mathematical measure of the spread of energy in the wavelet is the effective length defined by [6].

\[
L^2 = \frac{\sum X_i^2 (t_i - t_0)^2}{\sum X_i^2} \tag{4}
\]

where \( t_i \) = time corresponding to i-th sample; \( t_0 \) = time corresponding to time zero on the wavelet; \( X_i \) = Sample value at the I-the position.

The sums are over all samples in the extracted wavelet. The computed value \( L \) is in units of time and measures the root-mean-square distance of the samples from time zero. The magnitude of \( L \) depends on the choice of “\( t_0 \)” although for the purposes of comparing several extracted wavelets the actual choice of “\( t_0 \)” is not critical as long as it is chosen consistently on the various wavelets.

![Figure 2. Synthetics correlated with seismic data.](image)

The wavelet extraction procedure, extract wavelets by using a large number of windows with varying lengths and locations, then reorder the wavelets from shortest effective length onward, in the final average those wavelets whose effective lengths are shorter than some specified value. Factors affecting the wavelet are the seismic wavelet is considered to be the result of a series of processes, as following,
each component contribute its own impulse response "wavelet" and the final result is the convolution of the individual wavelets. The basic categories into which the various factors affecting the wavelet could be grouped [4].

The source and near surface, comprising the source signature, near-surface attenuation, ghost-resonse etc, the earth filter, comprising all other earth effects on the wavelet attenuation, multiples, etc, the recording of system response, the processing (especially Deconvolution).

The sequence of reflections observed on seismic reflection records can be represented by a superposition of impulsive waveforms, called wavelets. The wavelet will depend on the particular seismic source and recording system used. Many such wavelets are recorded on a reflection seismogram, and these overlap in a complicated way, but their shape remains effectively constant over limited time intervals. It is the estimation of this basic wavelet, which we call the primary seismic pulse. It is the primary seismic pulse which controls the design and, ultimately the performance of deconvolution and shaping filters. It is also needed for the construction of synthetic seismograms which are to be compared with actual records.

Figure 3. Wavelet extraction by least-square shaping filter.

Further, it supplies information concerning the physics of the seismic source and the absorption of seismic waves in the earth, as providing estimates of the reproducibility and the resolution obtainable from a particular seismic source. There are two approaches to estimating the primary seismic pulse. One approach is to make direct near-source measurements of actual radiation seismogram itself. These
measurements exclude the filtering effects of the recording system and the earth; they could not be routine in land surveys. The other approach, the derivation of basic wavelets from seismograms, called the statistical approach. This statistical approach estimates the actual wavelet on the seismogram, that is the actual pulse after filtering by the earth and the recording system, but it brings in several assumptions. Steps and assumptions to derive a basic wavelet from a field seismogram are, the sequence of reflection must somehow be separated from any noise. Also the better the signal-to-noise ratio on the reflection seismogram, the better are the signal spectrum estimates [7], generally the change in shape due to absorption is comparable with the error of measurement. The third assumption is that the reflection spike sequence is white, in other word assumption of whiteness is a critical assumption in most wavelet estimation methods, for the amplitude spectrum of the reflection response is normally not known.

Figure 4. Wavelet construction Methods: (A) Hilbert transform method, (B) Z-transform method, (C) Inverse of the inversion method.

The assumption is critical in both conventional least-squares spiking deconvolution and in MED. It is sometimes assumed [ 8 ], that the randomness of the reflection coefficients has something to do with the assumed whiteness of the reflection response. The methods for constructing minimum-phase wavelet are three common methods for constructing minimum-phase wavelet Hilbert transform method, in this method the phase spectrum is computed from the amplitude spectrum and the wavelet constructed by Fourier synthesis. The phase spectrum is synthesized from the resulting coefficient by means of a sine transform Figure 4A, and the Z-transform method, it’s an exact method for wavelets of finite length, zeroes
outside the unit circle are selected and the minimum-phase wavelet is constructed from these zeroes Figure 4B, and the Least-Squares inverse method, this is a straightforward method and the inverse of the wavelet is determined from the wavelet autocorrelation as in conventional. The inverse of this inverse is an approximation to the lengths of the actual wavelet. Figure 4C, All three methods of wavelet construction give similar results when good spectral estimates are available but in the hazy area into which much seismic data falls, the Hilbert transform method is the least troublesome [9].

The best way of estimating the basic recorded seismic pulse is to fit a wavelet model to the observed spectral values and from this model compute the wavelet.

3- Wavelet estimation techniques

There are three techniques for estimating seismic waveforms, statistical in nature and directly estimate a wavelet from portions of the seismic trace. Statistical approaches are generally used for estimating wavelets from such data. The wiener-Levinson double inverse method can use the wavelet autocorrelation rather than the wavelet itself. If the desired output is set to a spike at zero delay (which will be the optimum only if the wavelet is minimum phase) then the inverse filter for minimum phase wavelet is obtained. To obtain the wavelet estimate, another Wiener filter is applied to invert the inverse filter and thereby estimating the minimum phase wavelet from its autocorrelation. Theory has been described by [12], and Wold-Kolmogorov factorization, This method which is described in detail by [12 ], Determining the phase spectrum for a given amplitude spectrum[ 12 ], deduces the minimum phase spectrum from the amplitude spectrum by comparing the logarithm of the wavelet’s amplitude spectrum, with the logarithm of the wavelet’s Fourier transform, the other one is Homomorphic Deconvolution wavelet estimates, this method does not require the restrictive conditions imposed by the previous methods of wavelet estimation. In using homomorphic deconvolution, a characteristic transformation is applied to a time sequence in order to yield the complex spectrum. The complex spectrum defined as the inverse transform of the logarithm of the sequence’s Fourier transform.

4- Design of inverse filters for the wavelets.

Single channel Wiener deconvolution using a wavelet estimate as input and choosing a spike as a desired output allows us to design an inverse filter [10,11], pointed out that
filters which shape the wavelet to some form other than a spike may also prove useful in deconvolution. The performance of a single channel Wiener filter will improve as the length of the filter increase [10]. Although the choices of a suitable length for the single channel Wiener filter is subjective, it is instructive to monitor the normalized mean square error, which for a filter of length . and comparison of Single Channel and Multichannel Deconvolution, application of multichannel deconvolution involves estimating source wavelets from the trace in a single channel fashion and then designing a multichannel inverse filter, which will convert these wavelets to a single channel spike. When convolved with the seismic trace, this multichannel filter should estimate the reflectivity sequence of a layered earth [13]. To demonstrate the wavelet extraction method on real data, the two well data were processed through the standard processing operation that affects the phase of seismic wavelet is deconvolution, first one is Wavelet extraction for field data, in all seismic processing now a day. The main unit involved in the processing of data is of course the digital computer. It is important to realize that the acquired the primary data cannot be improved and the data processing is not a reformation for bad field procedures or originally poor data quality. Data are numbers measured acquired that carry out information but this data are usually severely contaminated with various kind of noise, and the object of processing is to sort (correction) and/or reject some data (filtering) and finally display the outcome. However from a practical point of view, we may classify the activities in the field as data acquisition and those based on processing and interpretation, and the goal of seismic data processing is to render the seismic data interpretable. the field data which are used in this work were obtained from two different wells as final data after some seismic processing. Coming to field data and to continuation advantage comparison of two options that are present in ProMAX system. Wiener option and MED option. figure (5) shows the results of wavelets extraction and dephasing on field data around CDP’s from 270-279. The traces which numbered 1,2, and 3, show wavelets extracted by using DAW procedure with Wiener option, using minimum phase signals in different time gate 700-1460 ms for trace 1, 700-1000 ms for trace 2, , and 1300-1500 ms for trace 3. Whilst traces 4,5, and 6 shows wavelets extracted by using DAW procedure with MED option also applied in different time gate 700-1460 ms for trace 4, 700-1000 ms for trace 5, and trace 6 show time gate from 1300-1500 ms. And the traces which numbered 7,8, and 9 shows the wavelets
illustrated on traces 1,2, and 3 respectively after dephasing. Traces 10, 11, and 12 also are the same wavelets, which appears on traces 4, 5, and 6 but after dephasing. However from this figure it’s clear that the dephasing operations which applied on the signals yield zerophase signals. The discussed options Wiener and MED. Shows the significance of their using, but its obvious from the figure, that the signals which on traces 7, 8, and 9 are a little closer in the shapes to the ideal zerophase. Furthermore, their effectiveness can be seen in the following figures representing seismic sections.

figures 6, 7, and 8 are presented field data. They show the parts of seismic sections near the 270-279 CDP’s, the first one 6 before dephasing and the second one 7 after dephasing using DAW-Wiener minimum phase option, and the third one 8 after dephasing using MED option. The effectiveness of this option can be easily seen in figure 7 specially for some times 840 s, and 1400 s. Can observe much better of reflections than before dephasing. In the figure 8, we can see also the same improvement of continuity using DAW-MED option figure 8. For the same time 840 s, and 1400 s. But the results indicate not so good correlation as in the previous case, specially in the gate 1200-1400 ms for CDP’s 304-324. To confirm this let’s look at the figure 9. This figure illustrates the comparison between the two options on the same part of seismic section.

![Figure 5](image)

**Figure 5** Results of wavelet extraction and dephasing on field data at CDPs 270-279.

From figure 5, the traces 1-3 show wavelets extracted using DAW-Wiener option, minimum-phase in different time gates, and trace 1 at 700-1460 ms, trace 2 at 700-1000 ms, and trace 3 at 1300-1500 ms; whilst traces 4-6 show wavelet

extracted using DAW-MED option in different time gates, trace 4 at 700-1460 ms, trace 5 at 700-1000 ms, and trace 6 at 1300-1500 ms, traces 7-9 show the same wavelets on traces 1-3 but after dephasing, and traces 10-12 show the same wavelets on traces 4-6 but after dephasing.

Figure 6. Part of seismic section near the 270-279 CDPs before dephasing.

Figure 7. Part of seismic section near 270-279 CDPs after dephasing using DAW-Wiener minimum-phase option.
Figure 8. Part of seismic section near 270-279 CDPs after dephasing using DAW-MED option.

Figure 9. Comparison of parts of seismic section near 270-279 CDPs after dephasing using Wiener minimum-phase and MED options.
The same two options of dephasing were used in figure 5. Figure 10, shows the result of wavelet extraction and dephasing on field data around CDPs 1050-1059. Trace 1 shows the wavelet extracted with the use of DAW Procedure with the Wiener Option, using minimum-phase signal in time gate of 700–1460 ms. Trace 2, shows the wavelet extraction using the DAW procedure with the MED options, also applied in the same time gate of 700–1460 ms. Trace 3, shows the wavelet on trace 1 after dephasing. Trace 4, shows the wavelet on trace 2 after dephasing as well. However it is also clear from this figure, that the dephasing operation applied to signals yielded Zero-phase signals. Can be seen from the figure the advantage of using Wiener and MED options. Can also point out the signal which on trace 3, is a little close in the shape to the ideal Zero-phase than the signal on trace 4, this is advantage of using Wiener option. Will see the effectiveness of both options in the following figures presenting seismic sections. More field data are shown in figures 11, 12 and 13 they show part of seismic sections near the 1050–1059 CDPs, before dephasing, figure 11, and after dephasing using the DAW procedure with the Wiener minimum-phase option figure 12. Figure 13 gives also an example of seismic section after dephasing with the same MED option. It is easy to see the advantage of the option in second figure, specially at time 800 ms, and 1050 ms, where it can be better observed reflections than before dephasing. It also can be seen that the same improvement of continuity in the same time of (800 and 1050 ms) in figure 13, but the results do not indicate so good correlation as in the previous case, especially in the gate 800–1050 ms for CDPs 1064–1104. To confirm this let us look at figure 14. This figure illustrates the compression between the two options for the same part of seismic section. Generally, in most practical cases can obtain a significant improvement in the quality of seismic data using those options.

From figure 10 the trace 1, shows the wavelet extracted using DAW-Wiener option minimum-phase in time gate 700-1460 ms, and trace 2, shows wavelet extracted using DAW-MED option in time gate 700-1460 ms, trace 3, shows wavelet on trace 1 after dephasing, trace 4, shows wavelet on trace 2 after dephasing.
Figure 1. Wavelet extraction and dephasing on field data about 1050-1059 CDPs.

Figure 1. Parts of seismic section near 1050-1059 CDPs before dephasing.
Figure 12. Parts of seismic section near 1050-1059 CDPs after dephasing using DAW-Wiener minimum-phase option.

Figure 13. Parts of seismic section near 1050-1059 CDPs after dephasing using DAW-MED option.
5- CONCLUSION
It has demonstrated that, the most common meaning refers to estimating the basic wavelet embedded in the seismogram, is designing a shaping filter, which converted the estimated wavelet to a desired form. The main effects of wavelet processing in seismics includes, much better vertical resolution of the section, much easier identification of small fault, and much better tying of seismic section to the well data, and improvement in tying to the well data (dephasing). The method depends on finding optimum windows for the extraction process, and results in an average wavelet for some time and space interval, This because the wavelets must have as many samples in the frequency domain as they do in the time domain. The longer wavelet we have, the more detail we will see in the spectra display. If the shorten wavelets by applying tapers, there will be less time and frequency domain samples.

- Using accurate measure it makes the possibility of improvement of the quality control procedure.
- The wavelets are powerful tools for analysis of field data
- Wavelet analysis is an excellent tool of field data compression. To be use to evaluate the results of various processing sequences, and correct the phase errors introduced by each sequence.
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الملخص
في السنوات الأخيرة نصب الاهتمام حول مشكلة التحديد الدقيق لطور وخصوصية الرويد السيزمية، وذلك لسببين رئيسين أولهما الاهتمام باستخراج تفاصيل للمعلومات الطبقية "الاسترداد" من خلال البيانات السيزمية، وثانيهما حقيقة صورة تطور التلافيف، وثانيهما حقيقة صورة تطور التلافيف قد يكون مختلف عن طور Deconvolution، وثانيهما حقيقة صورة تطور التلافيف قد يكون مختلف عن طور وثانيهما حقيقة صورة تطور التلافيف قد يكون مختلف عن طور Zero-phase.

6- References


