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# An Investigation of the Tools of Seismic Data Processing

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***Summary***

*The purpose of seismic data processing is to isolate 'signal' i.e useful information and to separate it from 'noise' i.e. unwanted signals. It includes many operations in time as well as frequency domain. The different aspects of important processing operators like auto-correlation, cross correlation, deconvolution and filtering have been illustrated using the synthetic data. The effects of different water level on the deconvolution and different orders of the lowpass and bandpass filters have been illustrated and discussed. The utility of auto correlation and cross correlation in the data processing have been demonstrated on synthetic data. The practical applications of these tools to handle the seismic data have been discussed.*

## Introduction

The objective of seismic data processing is to massage seismic data recorded in the field into a coherent cross section of significant geological horizons in the earth's subsurface (Hatton et al., 1986). These data are contaminated by coherent as well as incoherent noise. In order to isolate 'signal' i.e useful information and to separate it from 'noise' i.e. unwanted signals various types of processing operations are applied on the data. The digital revolution of recording the data has made it possible to use flexible and sophisticated techniques to process the data. The processing of data involves many operations in time domain as well as in frequency domain like windowing, filtering, correlation, convolution, Fast Fourier Transform (FFT), power spectrum, deconvolution etc. The different types of parameters need to be defined before applying these techniques. In this study we have applied some of the processing techniques like autocorrelation, cross correlation, deconvolution etc on the synthetic data and discussed their effects. The consequence of applying filters of different order has been illustrated.

## Correlation

The auto- and cross-correlation play an important role in the processing of seismic data. The auto-correlation measures the degree of similarity between a time series and a shifted copy of itself while cross-correlation gives the quantitative estimate of the degree of similarity between two time series. The discrete auto-correlation ($\phi_k$) of a time series x(n) of N samples is defined as:

$$\phi_k(x) = (1/N)\sum_{n=0}^{N-k-1} x(n)x(n+k) \; ; \qquad k = 0,1,2,\ldots\ldots N-1 \qquad (1)$$

The discrete cross-correlation $\psi k$ of the time series x(n) and y(n) is defined

$$\psi_k(x,y) = (1/N)\sum_{n=0}^{N-k-1} x(n)y(n+k); \qquad k = 0,1,2,\ldots\ldots N-1 \qquad (2)$$

## Convolution

Convolution is a mathematical operation to combine the two time series in a particular way to produce the third series. The convolution of two sequences a(i); i = 0,1,2 . . . . . M and b(j); j = 0,1,2, . . . . . .N is defined as:

$$c(k) = \sum_{j=0}^{M} a(j)b(k-j) \; ; \qquad k = 0,1,2,\ldots\ldots\ldots M+N-1 \qquad (3)$$

c = a*b ; * indicates the convolution.

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In the frequency domain, the convolution is equivalent to multiplication i.e. equation (3) in the frequency domain is written as

$$C(f) = A(f)B(f) \; ; \; f \text{ is the frequency.}$$

**Deconvolution**

Deconvolution is the reverse of convolution. It is used to remove the effect of source from the seismic data. Deconvolution is division in the frequency domain. The deconvolution of the sequence 'a' from the sequence 'c' in the frequency domain is given by:

$$B(f) = C(f)/A(f)$$

**Filtering**

Filtering may be defined as the act of modifying a time series by application of another time series generally have different frequency characteristics.

**Examples**

The concept of signal processing operators like autocorrelation,cross correlation,deconvolution and filtering have been discussed using synthetic data.

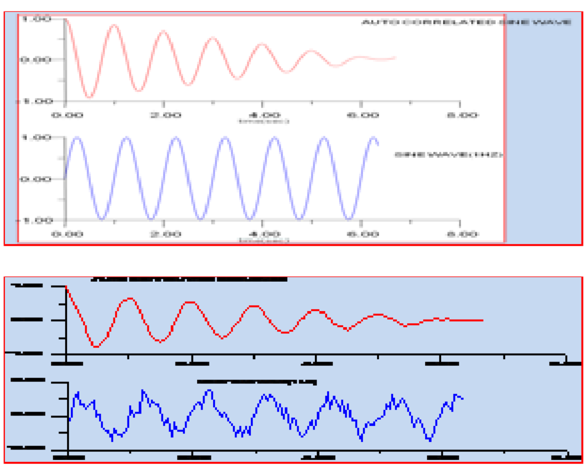


Figure 1: Autocorrelation of the sinusoid (a) without noise (b) with noise

The analysis has been done using the software PITSA. Figure 1 shows the autocorrelation of sinusoidal wave without and with noise. The periodicity can clearly be seen in case of sinusoidal wave with noise also. This property of autocorrelation to detect the inherent periodicity is generally used in seismic data processing.

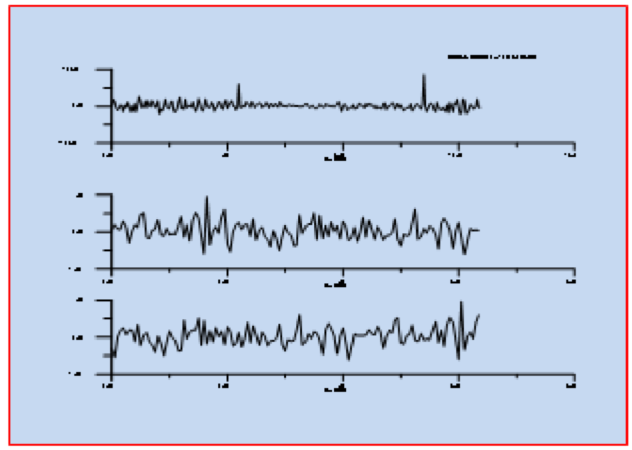


Figure2: Cross correlation of two randomly generated time series.

The peaks in the cross-correlation function show that two sequences correlate well at a shift equal to the time of peak. This time shift is easier to choose.

Ricker wavelet has been convolved with the reflectivity series to generate the synthetic seismogram as shown in the figure 3 below

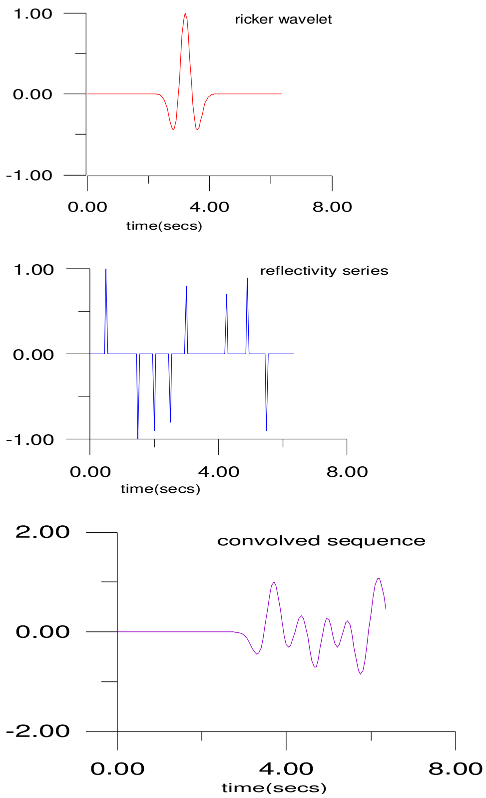



Figure 3: Ricker wavelet convolved with reflectivity series to generate synthetic seismogram.

The analysis has been done using the software.

A common problem arises when deconvolution is applied by division in the frequency domain due to small spectral values of the denominator function. In order to stabilize the division a water level is defined to replace the smaller values. We have tested the different water levels to deconvolve the effect of Ricker wavelet from the synthetic seismogram generated above. The results of different water levels are shown in the Figure 4.

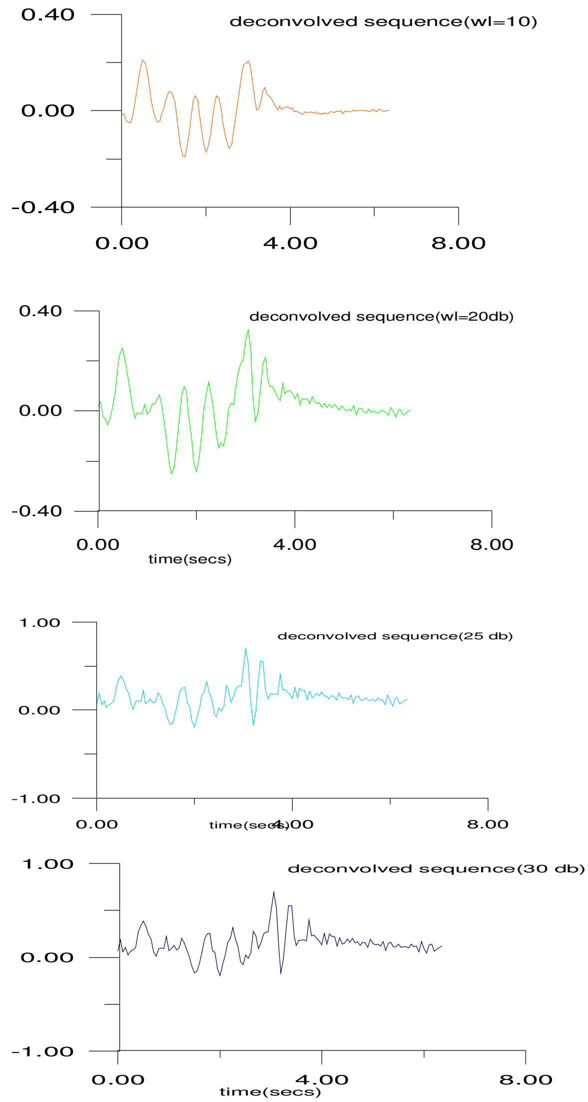



Figure4: Effects of different water levels on Deconvolution of synthetic seismogram

We note that resolution of different peaks become clear as water level increases. A further increase in the water level corrupts the signal. A water level of 25-30 dB is appropriate in this case.

Next we examine the effect of order of the filter on amplitude spectrum of low pass as well as band pass filter. This has been illustrated in the Figure 5.

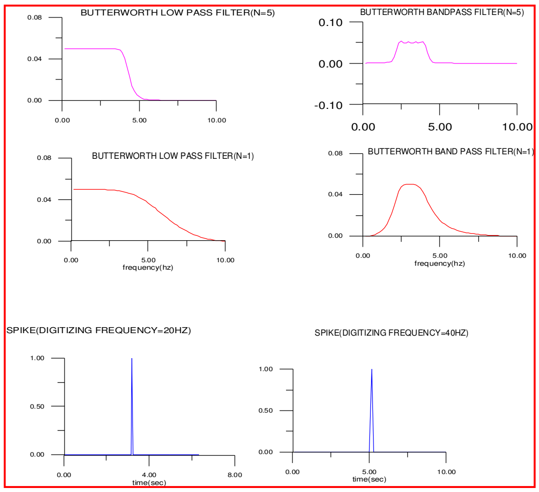



Figure 5: Effect of order of the filter on amplitude spectrum for low pass and band pass filter

We note that as the order of the filter increases from 1 to 5 transition zone between pass band and stop band decreases.

**Applications**

The tools discussed here have wide applications in seismic data processing. We note that the random noise embedded in the signal contributes at zero-lag of the auto-correlation and periodicity present in the signal can clearly be estimated at non zero lags of autocorrelation function (Figure 1). Also the statistical expectation of auto correlation of N- point random series is 1/N (Kendall and Stuart, 1966). This behavior of the autocorrelation function can be used to detect the non-random noise present in the signal. This property of autocorrelation is used to detect the inherent periodicity of multiples in the pre-stack seismic gather. A common problem with the seismogram is that it contains signal plus noise while we want to enhance a ratio i.e. signal to noise (S/N) ratio. The use of large arrays of sources to increase S/N ratios is not recommended as it also increases the source generated noise (Larner et al., 1983; Newman, 1984). It has been found that the correlation functions are related to signal to noise ratios (Hatton et al., 1986 ). The traces with poor S/N ratios give high zero-lag autocorrelation functions.

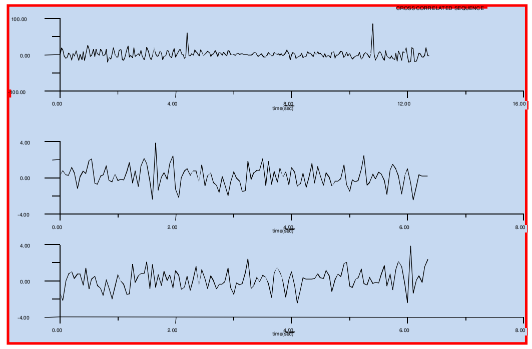
The autocorrelation and cross correlation functions are used to design the important tools of seismic data processing i.e. predictive deconvolution and Wiener filter. For example, the auto correlation function is used to estimate the prediction distance or lag in the designing of prediction filter which is used to suppress the predictable multiple energy from the seismic section. The specification of minimum and maximum autocorrelation lags determines the active region of the operator (Hatton et al., 1986). The cross correlation is very effective with vibroseis data. The cross correlation function of vibroseis source with seismograms gives peaks at the time when reflections occur (Stein and Wysession, 2003).

Filtering in the data processing is useful when signal and nose have different frequency characteristics. Reflections are enhanced by filtering in the frequency domain to enhance certain frequency ranges and reject others. The S/N ratio varies significantly as a function frequency and therefore filtering improves reflection quality. Theoretically, we need filters that should have zero amplitude spectrums outside the pass band and unity in side the pass band. This sharp discontinuity can not be achieved due to well known Gibbs's phenomenon (Gubbins, 2004). Here the order of the filter is important to decide the compromise required. We have shown here that the higher order filters are appropriate (Figure 5).

The seismograms are considered as convolution of source pulse and earth structure (reflectivity series). For a better resolution of reflection times on a section the source pulse should be a delta function. As the physical source wavelet is not a delta function, deconvolution is applied by dividing the Fourier transforms of seismogram and inverse filter. This division in the frequency domain can be problematic when low amplitudes are there at some frequencies in the denominator. This problem can be avoided by choosing an appropriate water level that helps to set a minimum amplitude threshold. The appropriate water level in such deconvolution procedure has been described in this study.

**Conclusions**

The different aspects of signal processing operators like correlation, deconvolution and filtering has been illustrated using synthetic data. It has been found that autocorrelation maintains the periodicity even in case of noisy data. The two time sequences correlate well at a shift equal to the time of peak in the cross correlation function. A water level of 25-30 dB is found to be appropriate for the decovolution by division in the frequency domain. The width of the transition zone between the pass band and stop band decreases as the order of the filter increases. Therefore higher order filter may be used in the processing of data.

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**References**

Claerbout, J.F., 1976, Fundamentals Of Geophysical Data Processing: McGraw-Hill Book Co.

Gubbins, D. ,2004, Time series analysis and inverse theory for Geophysicists, Cambridge University Press, 255p.

Hatton, L., Worthington, M.H. and Makin, J., 1986, Seismic Data Processing: theory and practice, Blackwell Scientific publications, Oxford.

Kendall, M.G. and Stuart, A., 1966, The advanced theory of statistics 3, Charles Griffin, London

Larner, K., Chambers, R., Yang, M., Lynn, W. and Wai, W. ,1983 , Coherent noise in marine seismic data, Geophysics, 48, 854 – 886.

Newmann, P., 1984, Seismic response to sea-floor diffractors, First Break 2, No. 2, 9 – 19.

Stein, S. and Wysession, M. ,2003, An introduction to seismology, earthquakes and earth structures, Blackwell Publishing, 497p.