Application of Gabor transform to amplitude spectrum matching for merging seismic surveys

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Summary

Traditionally, survey merging is achieved by applying the optimal bulk time shift, phase rotation and a time-varying amplitude scalar obtained to match two or more different surveys. With an increase in demand for seismic reservoir characterization, the amplitude-related seismic attributes are of greater importance. Therefore amplitude-spectrum matching is critical to survey merge processing. In contrast, the use of Fourier Transform in amplitude spectrum matching is often taken for granted, by ignoring the requirement for stationarity of the seismic signal under investigation. Our study presented here shows that ignoring the nonstationarity requirement imposed by the theory of Fourier Transform could be problematic in practice. Using the Gabor transform, a solution to this problem is illustrated by application to real data examples from offshore north-west shelf of Western Australia.

Introduction

Industry trends indicate that amplitude-spectrum matching is necessary to meet the data quality requirement for seismic reservoir characterization. Fourier Transform (FT) and its digital implementation, the Fast Fourier Transform (FFT), have long been powerful tools in the geophysical signal processing industry. It is not an exaggeration to say that FFT is one of the most powerful and important tools in the field of seismic digital signal processing.

However, it is also not surprising that the application of FFT into the seismic data is often inadequate. That is because, by its theoretical definition, Fourier Transform is not suitable for application to a nonstationary signal, and unfortunately, seismic data is nonstationary by its nature.

The requirement for the signal to be processed as a stationary data set for the FT application has long been recognized as a limitation of the FT theory. There have been different methods proposed to overcome this limitation. One of these is the Gabor Transform which is also commonly referred to as Short Time Fourier Transform (STFT) and Wavelet Transform (WT).

In this study, the problem of applying FFT in amplitude-spectrum matching for a seismic survey merge is illustrated by using a real data example. A solution to this problem is also provided through the application of the Gabor transform to the same data.

The problem and the solution

Survey merge is widely used in seismic data processing for either the purpose of creation of a data set by splicing different surveys or vintages, which have some area of overlap, or to borrow some data from adjacent surveys or vintages at the survey boundaries in order to ensure the full migration aperture coverage.

Traditionally, survey merge is achieved by designing an optimal bulk time shift, phase rotation and a time varying amplitude scalar which could be applied to match the surveys that are going to be merged. After applying those estimated time, phase and amplitude adjustments, the surveys or vintages are normally considered to be time, phase and amplitude matched, or even further the spectra are considered to be matched in a loose sense.

A merged seismic data set obtained in this traditional way is generally sufficient to serve the purpose of structural interpretation. However, if the merged seismic data set is going to be used for the purpose of seismic reservoir characterization, such as elastic inversion which is very sensitive to amplitude anomalies, then the spectrum matching is an issue which needs to be addressed. This is particularly true when legacy data are involved in the survey merge because the difference in the data acquisition procedure could be considerably significant.

Figure 1 is a sample seismic section from one of the two surveys used for this study. The global time window (green in color) for amplitude spectrum analysis indicates the spectral analysis is carried out with the whole seismic data section or volume, while the local time window (red in color) indicates that only a portion (or a local part) of the data within the specified time window is used for the spectral analysis.

Figure 2 shows the amplitude spectra (from global window) of two seismic sections taken from surveys A and B to be merged, respectively. The two seismic sections represent the same subsurface line in the area where surveys A and B overlap. It can be clearly seen that there are significant differences between the two spectra. This difference is sufficient evidence for the necessity of a proper amplitude spectrum matching between those surveys. In this case, the spectrum of survey B will be matched to that of survey A.

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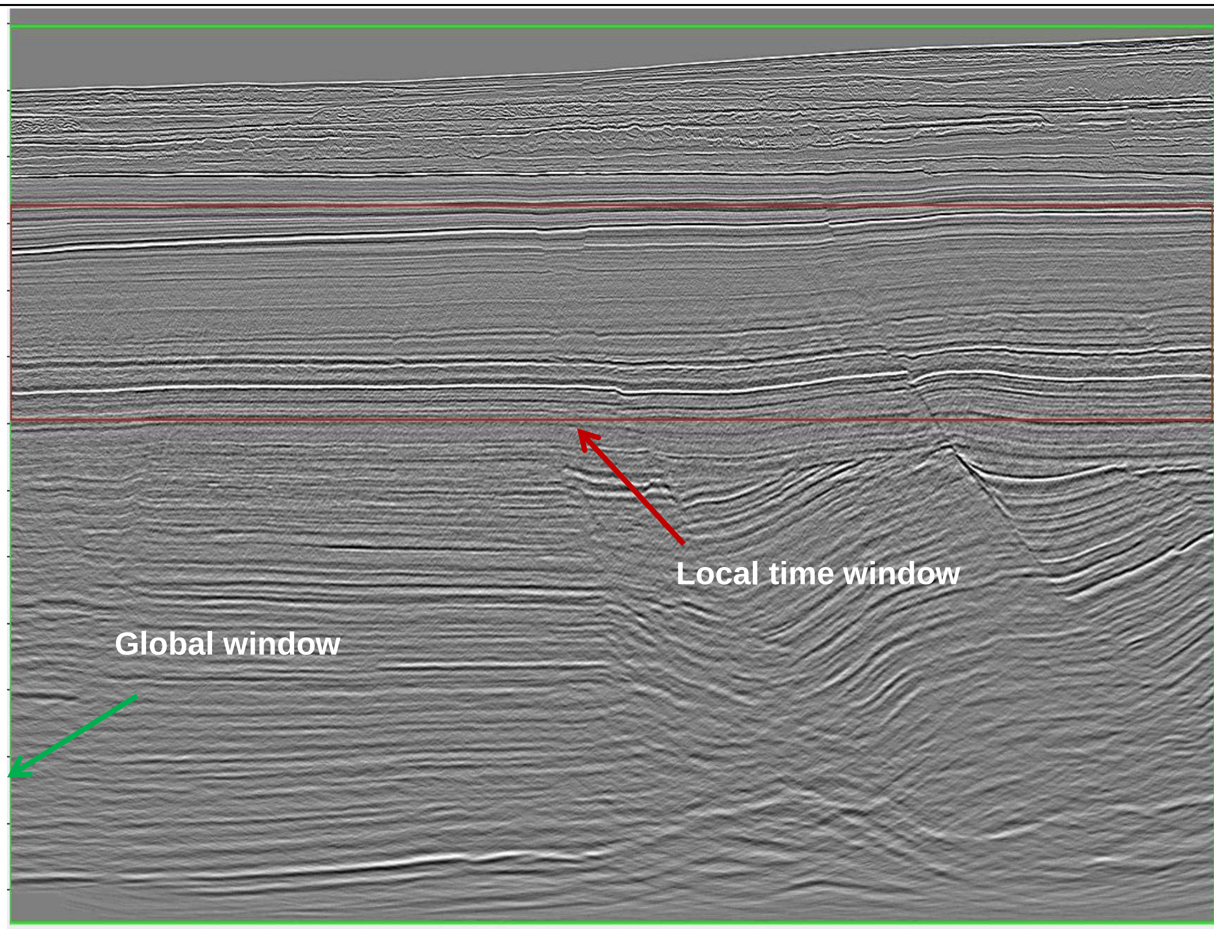

Figure 1: *Example of seismic section used in the survey merge being discussed. The Global and Local time windows shown here are the spectral analysis windows used in the discussion.*

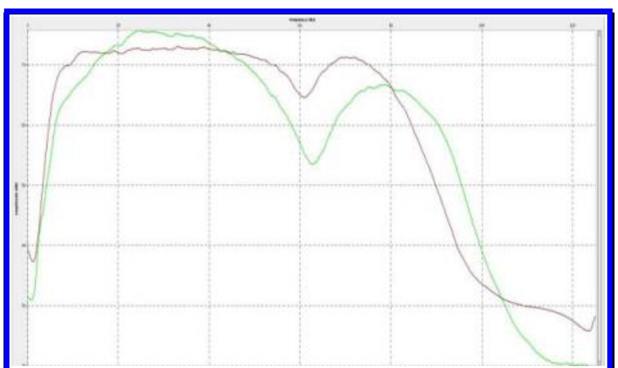

Figure 2: *Spectra of surveys A and B to be merged. Significant differences in the spectra suggest the necessity of spectrum matching between the two surveys.*

Amplitude spectrum matching is a routine process in seismic data processing. Conventionally, it consists of the following steps:

1. Compute the FFT of the global windows from both surveys.

2. Design a matching operator in the frequency domain.

3. Apply the obtained operator to survey B in order to match it to survey A.

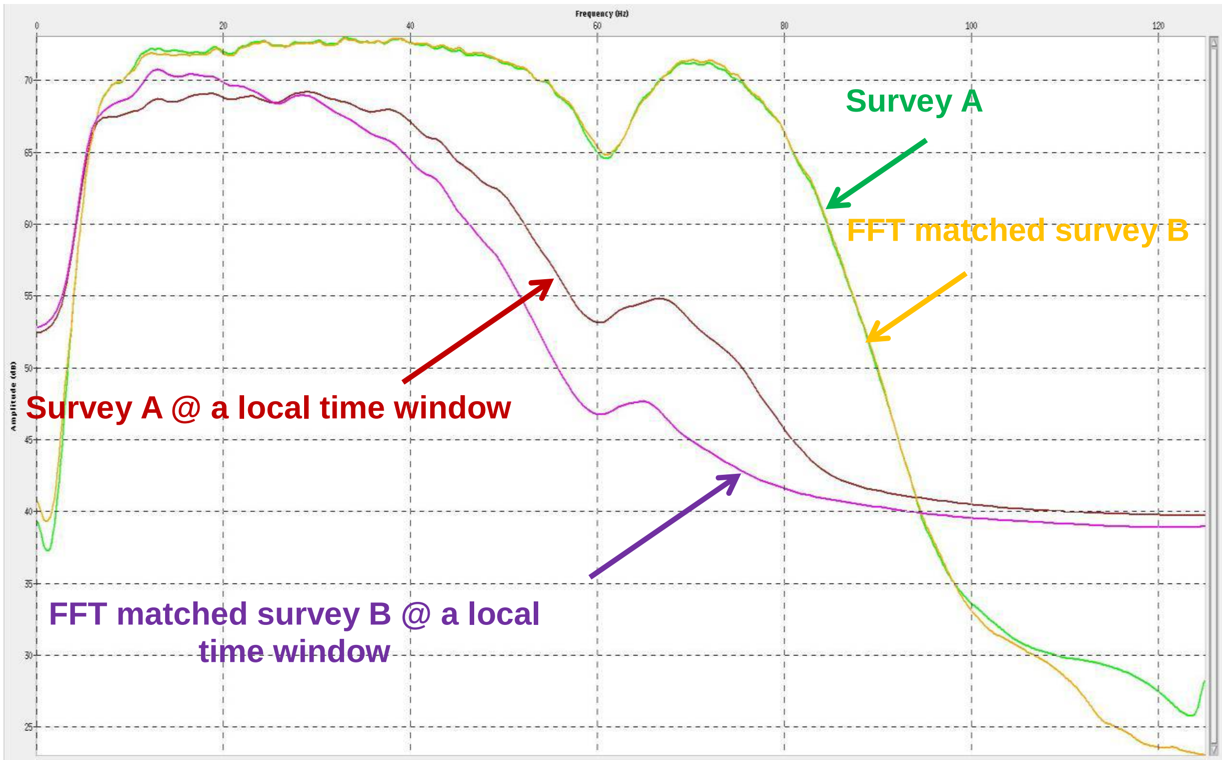

Figure 3: *Spectra of survey A and survey B after spectrum matching applied by conventional FFT method. The spectra in green and yellow colors are from global window.*

Figure 3 shows the spectra of both surveys after spectrum matching using the above procedure. It can be seen that the spectra (green and yellow in color) obtained in the global window are almost perfectly matched. However, the spectra from a local time window (red and pink in color) are not matched satisfactorily. This local time window includes the target reservoir zone. It is obvious that the amplitude spectral mismatch at the local time window shown here does not allow the merged seismic data to serve the purpose of accurate quantitative interpretation for reservoir characterization.

The Fast Fourier Transform is an important tool in modern geophysical signal processing, particularly in the spectral analysis application. However, one of the fundamental limitations of Fourier transform, which is often neglected in practice, is that the application of the Fourier transform is inadequate when the signal exhibits nonstationarity.

Nonstationary signals are those whose frequency components vary with time. Different methods for overcoming this limitation of FFT in dealing with nonstationary signals have been proposed. One of those is the Gabor transform proposed by Dennis Gabor in 1946 and it is also widely referred to as Short-Time Fourier Transform (STFT). The Gabor transform copes with the nonstationarity phenomenon by defining short time windows over the signal. With the window moving along the time axis, the relationship between the variance of frequency and time can be identified. If the time window is sufficiently short, the signal within the time window can be viewed as stationary, so that the application of the Fourier transform remains valid.

The Gabor Transform performed on a time sequence $\{x(n)\}$ can be mathematically expressed as:

$$STFT\{x[n]\} \equiv X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n]w[n-m]e^{-j\omega n}$$

Where $w(n)$ represents the moving window that emphasizes the local frequency component within it.

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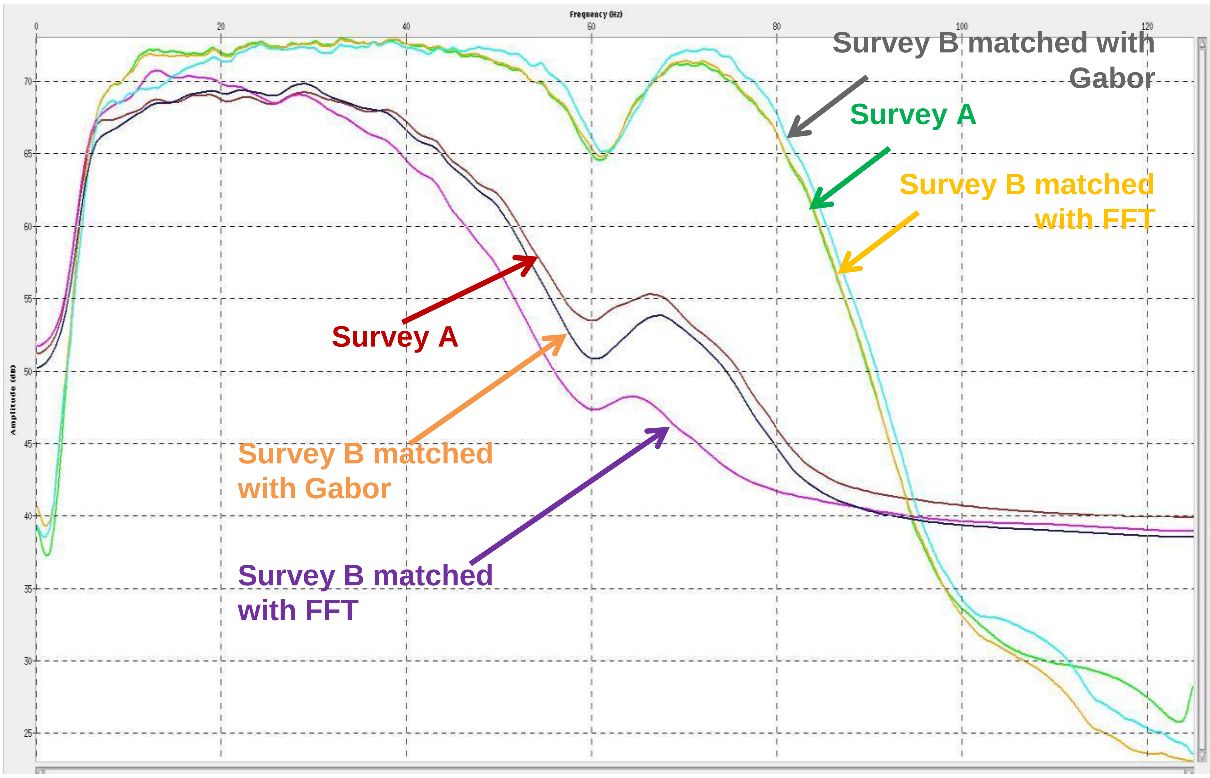

Figure 4: *Comparison of spectra at both global and local time windows from survey A and survey B with application of different methods for spectrum matching.*

We take the following steps to utilize the Gabor transform for spectrum matching:

1. Divide the seismic data of both survey A and survey B into segments by Gabor windowing adapted from the actual seismic data, and perform Gabor transform.

2. Design spectrum matching operator in Gabor domain.

3. Apply the operators to the Gabor windowed seismic data of survey B

Figure 4 shows the spectra from surveys A and B with conventional FFT and Gabor transform spectrum matching. It can be observed that with the utilization of the Gabor transform the spectral matching at the local time window level has been significantly improved. For the purpose of comparison the spectra from global window are also shown here, although a global spectrum for a nonstationary signal is not of great interest.

Conclusion

Due to the nonstationarity nature of seismic data, a satisfactory result may not be obtained by using the conventional method of amplitude spectrum matching where classic FFT is utilized for the amplitude spectrum analysis. A more convincing amplitude spectrum matching result has been achieved with the application of Gabor transform in the amplitude spectrum analysis.

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REFERENCES

No references.