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OPTIMIZING RESOURCES

The Borga transform and some applications in seismic data analysis

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Summary

Signal transforms form the bases for many seismic data processing and analysis algorithms. We present the adjoint of the Gabor transform, which we call the Borga transform. The Gabor transform uses the operations of first windowing and then Fourier transform while the Borga transform reverses the order so that the window is applied in the frequency domain. The result is a real-valued time-frequency decomposition that is essentially a complete set of filter slices. When summed, the frequency slices exactly recreate the original signal.

The Borga transform can be used in various processing steps. Since surface noise is predominantly low-frequency and high-amplitude, one can separate it from the signal in a raw shot gather. Other types of noise can have a band-limited nature and anomolous amplitudes as well. By assuming local linear behavior of the amplitudes in a CMP NMO-corrected gather, we can design a noise attenuation algorithm. The process can lead to better results in AVO analysis and inversion. The transform can be a natural choice for time-variant spectral whitening as well. By applying an amplitude gain function to frequency slices, one can compensate for time and frequency amplitude attenuation.

Introduction

Signal transforms form the bases for many seismic data processing and analysis algorithms. Examples include the Fourier transform, the Radon transform, the Gabor transform and so on. The basic idea is that in a different domain, various physical events (primaries, multiples, surface waves) and noise a better separable.

In this publication we present a new type of transform, the Borga transform, which can be viewed as adjoin of the Gabor transform. We believe that it can be implemented in various seismic processing and analysis algorithms. Three examples are presented: CMP NMO-corrected gather noise attenuation, high-amplitude data separation, and time-variant spectral whitening.

The Borga Transform

In recent years the Gabor transform (short-time Fourier transform) has seen an increasing usage in seismic data processing, analysis, and interpretation. Example include the Gabor deconvolution (Margrave and Lamoureux, 2001) and spectral decomposition. In this publication, we present the adjoint of the Gabor transform, which we call the Borga transform. The Gabor transform uses the operations of first windowing and then Fourier transform while the Borga transform reverses the order so that the window is applied in the frequency domain. The result is a real-valued time-frequency decomposition that is esentially a complete set of filter slices. When summed, the frequency slices exactly recreate the original signal. Figure 1 is a flow chart of the Borga transform algorithm. First we compute the complex Fourier spectrum of the input signal. Then for each frequency, we multiply (window) the complex Fourier spectrum with a Gaussian window, centered at the frequency. Frequency slices are generated by performing the inverse Fourier transform of the windowed spectrum.

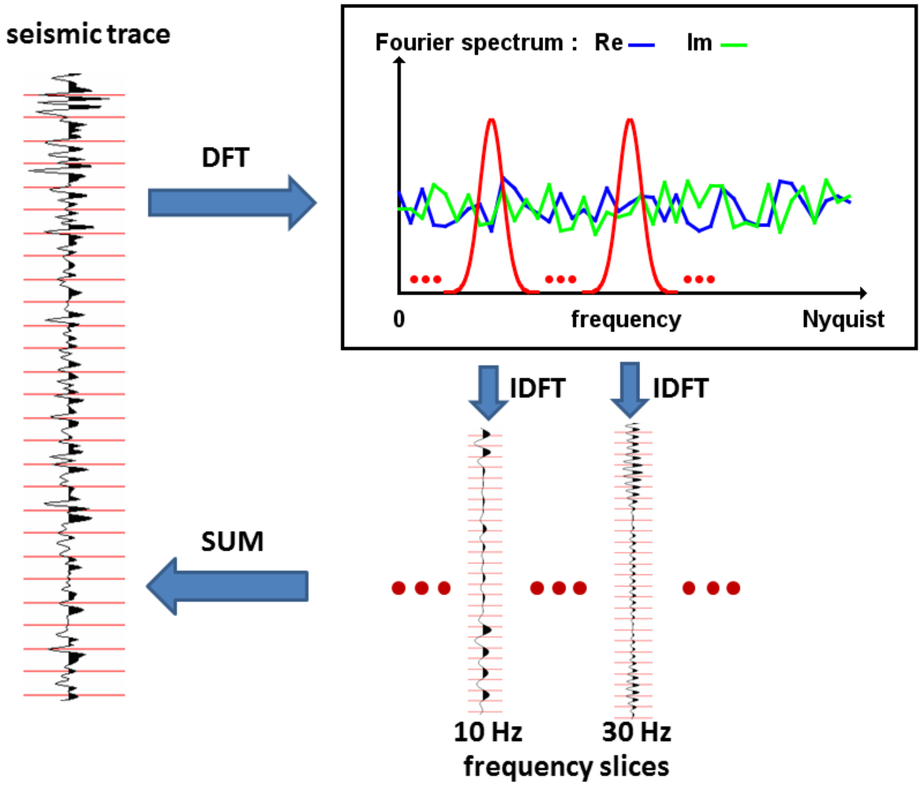


Figure 1: Flow chart of the Borga transform. A seismic trace can be decomposed into frequency slices by performing DFT, multiplying the complex Fourier spectrum with a Gaussian window and applying IDFT. The inverse Borga transform is perfomed by summing all the frequency slices.

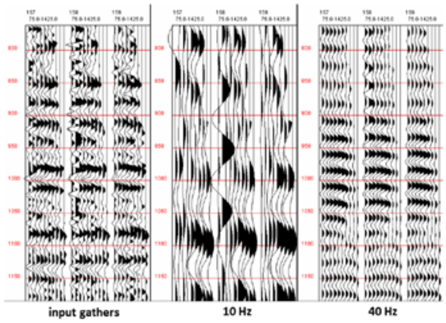
Applications

CMP gather noise attenuation

Figure 2 shows three CMP NMO-corrected gather from the Blackfoot 3D survey (Lawton at all., 1996) and two Borga frequency slices at 10 Hz and 40 Hz. The gather in the middle contains a noisy trace. From the frequency slices we can conclude that the noise is mainly present at the 10 Hz frequency slice, while the 40 Hz looks relatively clean. It is obvious that noise can be band-limited in nature and have abnormal amplitudes at particular Borga slices. For example ground roll is relatively low frequency, while the power line noise has a very narrow, mid-range bandwidth. Aki and Richards (1980) have shown us that within reasonable assumptions the amplitudes for a particular time change in a linear fashion with offset. AVO intercept and gradient analysis are based on the linear assumption. Based on the above assumptions we can design a noise attenuation method:

1. Start with a CMP NMO-corrected gather
2. Using the Borga transform, generate frequency sliced gathers
3. For each frequency:
    a. For each time:
    b. Estimate the amplitude of all samples, based on a local least-squares fit of nearby samples (the predicted sample is not used in the least-squares)
    c. Compute the absolute error between the actual and estimated amplitudes
    d. Correct the amplitude of the sample with the largest error
    e. Repeat until error is small
4. Sum noise attenuated frequency sliced gathers to obtain the final result

Figure 3 shows an example of the process. The input data are CMP NMO-corrected gathers from the Blackfoot 3D survey. The noise attenuated gathers show better signal-to-noise ratio and they are better suited for AVO analysis, inversion, and interpretation.



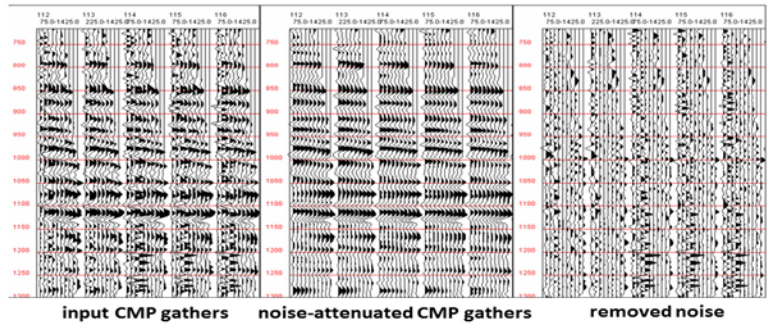


Figure 2. Blackfoot CMP NMO-corrected gathers and two Borga frequency slices at 10 Hz and 40 Hz.

Figure 3. CMP NMO-corrected gathers noise attenuation example from the Blackfoot survey. The result is better suited for AVO analysis, inversion and interpretation.

Frequency-dependant high-amplitude data separation

The Borger transform decomposes the single sample seismic amplitude into frequency dependant amplitudes. The ground roll will be present as band-limited high amplitudes. One can separate the data into anomalously high-amplitudes and reasonable amplitudes based on the following process:

1. Apply the Borga transform to a seismic trace
2. For each sample, sort the frequency-dependent amplitudes in decreasing order
3. Define a cutoff value: pick a reference value at the sample index that is, let say, 10 % from the start of the array and multiply it by a scaler, let say 2
4. Sum all the amplitudes, if an amplitude is above the cutoff value, replace it with the cutoff value, the difference is defined as high-amplitude data

Figure 4 is an example of the process.

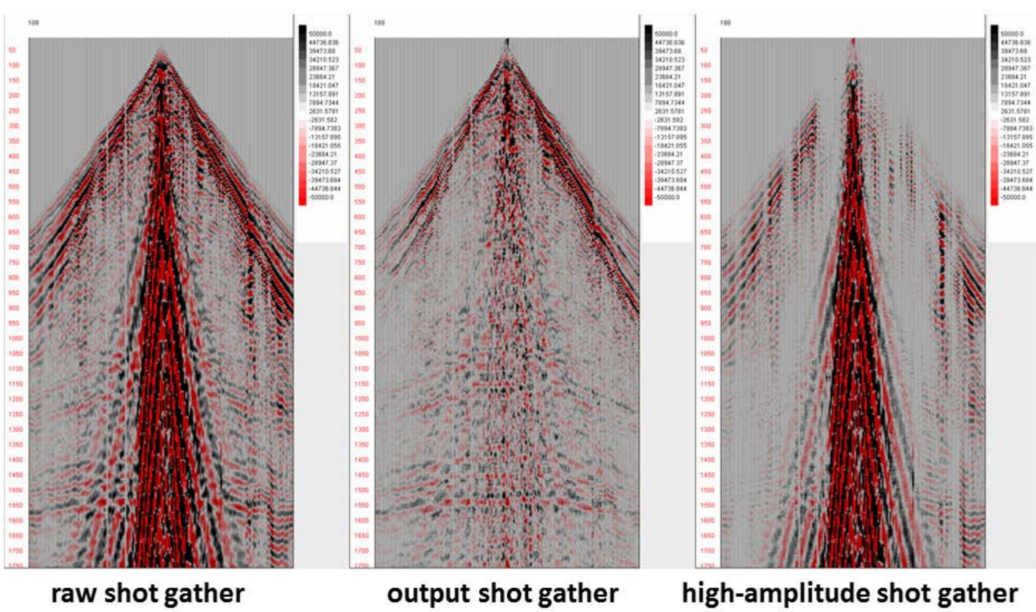


Figure 4. High-amplitude data separation applied to a shot gather from the Blackfoot 2D survey. The input data has been separated into two shot gathers, one with reasonable amplitudes and one with high-amplitudes, mostly ground roll.

Time-variant spectral whitening (TVSW)

Time-variant spectral whitening (Yilmaz, 2001) is a common seismic process, used to compensate for frequency dependant amplitude decay. It is commonly applied after spiking deconvolution (Yilmaz, 2001) to improve the flatness of the amplitude spectrum. The properties of the Borga transform make it a natural choice to perform TVSW. The process is applied as follows:

1. Pick a desired frequency bandwidth to be whitened, for example 8-70 Hz
2. Compute the Borga frequency slices covering the desired bandwidth
3. Compute and apply a time-dependant gain function for each frequency slice
4. Sum the frequency slices
5. Optional (amplitude friendly): remove the sum of the gain functions from the final result

Figure 5 is an example of the TVSW with Borga transform frequency slices in the range of 8-60 Hz on a raw shot gather from the Blackfoot survey. This is a simple way to reveal the events hidden by the ground roll and QC the data.

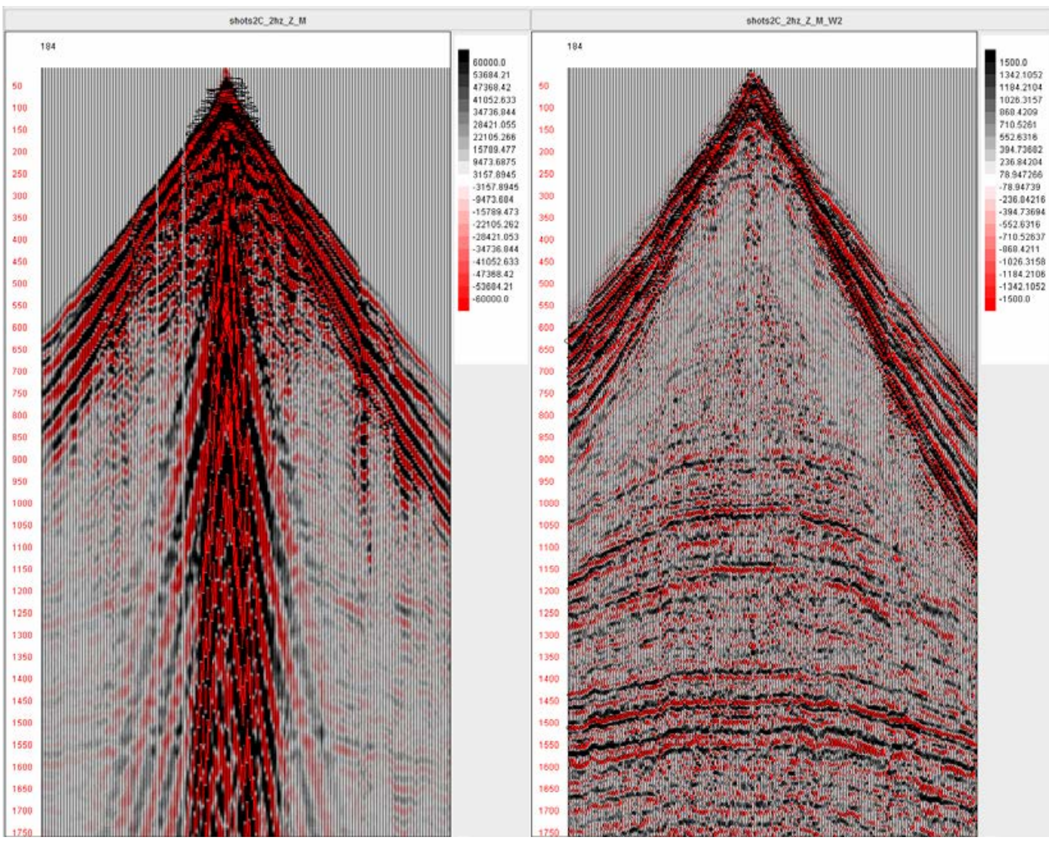


Figure 5. Blackfoot raw shot gather record before and after TVSW 8-60 Hz with the Borga transform.

Conclusions

The Borga transform decomposes the seismic signal into a complete set of filter slices. This property makes the transform a usuful tool for designing seismic data processing and analisys algorithms. The presented three processis in this publication show its successful implementation, however we believe that more can be designed and this is a topic of futher research.

Acknowledgements

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