Filter-Bank Strategies for Efficient Computation of Radon Transforms for SNR Enhancement

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Introduction

Radon transforms are a family of transformations utilized to enhance the signal-to-noise ratio of seismic records. They operate within the framework of a very simple concept: data and noise are mapped to different areas in the transform domain and therefore, filtering becomes an easy task. Our current efforts in Radon data processing entail the development of multi-parameter Radon transforms to process 2D and 3D gathers. In particular, we are interested in two chief problems: ground roll suppression and seismic wave field reconstruction.

To gain flexibility at the time of processing waveforms that do no conform to conventional Radon strategies (one single type of waveform in the full aperture) the Radon transform can be extended in two ways: by improving focusing with multi-path Radon operators (Trad et al., 2001) or via local Radon operators that attempt to model the waveforms in a small aperture (Sacchi et al., 2004).

Following the work of Trad et al. (2001), the Radon transform can be implemented with more than one integration path (multi-path transform). This is often referred as the "Hybrid Radon Transform". In general, the two typical integration path families are linear and parabolic paths (for a frequency domain implementation) and linear and hyperbolic paths (for a time-variant/time domain numerical implementation). The basic idea is to have a transformation that can simultaneously focus linear and hyperbolic events. This is in line with earlier work by Harlan et. al (1984) on focusing with imaging operators. It is important to mention that the concept of focusing is central to our discussion and in many ways a recurrent theme in seismic research.

The core of this paper is to examine new ways to gain efficiency in the computation of time-variant Radon transforms. In particular, time-variant multi-parameter Radon transforms can be quite demanding from the computational point of view when used for noise attenuation in 3D shot gathers. An important gain in efficiency can be obtained by combining Radon transform de-noising strategies with filter banks.

Ground Roll Attenuation

Linear coherent noise produced by surface waves (ground roll) exhibits low-pass character when analyzed in the frequency domain. It is desirable to try to exploit this feature when designing a processing strategy based on the Radon transform. I have constructed a hybrid Radon operator (linear and hyperbolic) with the addition of band-pass operators to increase the separability of coherent noise from reflections. Noise estimation using the Hybrid Radon Transform involves solving the following equation for the unknown Radon panels m_h and m_h

$$D = L_h B_h m_h + L_l B_l m_l + n.$$

Where L_h and L_l are the hyperbolic and linear Radon forward operators; B_h and B_l are band-pass convolutional operators for the hyperbolic and linear events, respectively. The inverted Radon panel m_l is used to model the coherent linear noise. I have designed filtering operators with a narrow low frequency band for the ground roll and with a fairly broad band for the hyperbolic part. Concatenating the Radon forward modeling operator with band-pass filters is a simple task from the algorithmic point of view. We basically extend the definition of our forward and adjoint operators (functions) to include a band-pass filtering stage applied in the flight. A drawback of the aforementioned strategy is that we are working with data that contain information of no interest for modeling the noise (information outside the band of B_l). In addition, we have increase the computational cost the iterative inversion due to the incorporation of the band-pass filtering stage in each iteration of the conjugate gradients method.

Filter Banks and Radon Transforms

In the following example, I have combined filter banks with Radon transform filtering to find an efficient way of estimating a noise model. The amount of decimation that one can achieve for this particular example without loosing the ability to model the noise is quite remarkable. The field data are decomposed into low/high frequency components with a system of filter banks (Mallat, 1998). The original data contains 55 traces of N=1024 points each, the data were decomposed into two components: a low-pass component of length N=512 and a high-pass component of length N=512 (**s1** and **d1**). Notice that the component **d1** does not contain much energy and therefore it can be removed from the analysis. The component **s1** can be treated as new data and further reduced to two new components of length N=256 each. These new components, which I have denominated **d2** and **s2,** are portrayed in Figure 1. Again, by inspecting the new data in Figure 2, one observes that **s2** seems to be capturing the linear coherent noise and part of the reflections. We take **s2** as our new data set and break it down into two new components of length N=128 each. The new components (**d3** and **s3**) are displayed in Figure 1. At this stage, I apply the Hybrid Radon Transform to **s3** and modeled the ground roll. Figure 2 portrays the data, the modeled ground roll and filtered data at a sampling interval of 16msec (the data underwent 3 decimations). Finally, we transform the estimated coherent noise to the original sampling rate and subtract it from the original data. The resulting model of linear noise, and data after noise attenuation is also portrayed in Figure 2.

Conclusions

I have implemented the Hybrid Radon transform in conjunction with a system of filter banks to model ground roll. What was the advantage of this process? First, it allows computing Hybrid Radon transforms on a smaller data set and therefore, an important saving in computational cost is achieved. Second, the strategy is in line with the idea of divide and conquers often used to annihilate noise. We are breaking down the data in components where the offending coherent noise becomes more dominant and therefore, the Radon transform will require less effort to separate the coherent noise from signal components. Finally, it is important to mention that the process is quite simple and can be implemented via extremely simple signal processing tricks that involve low/high pass filters.

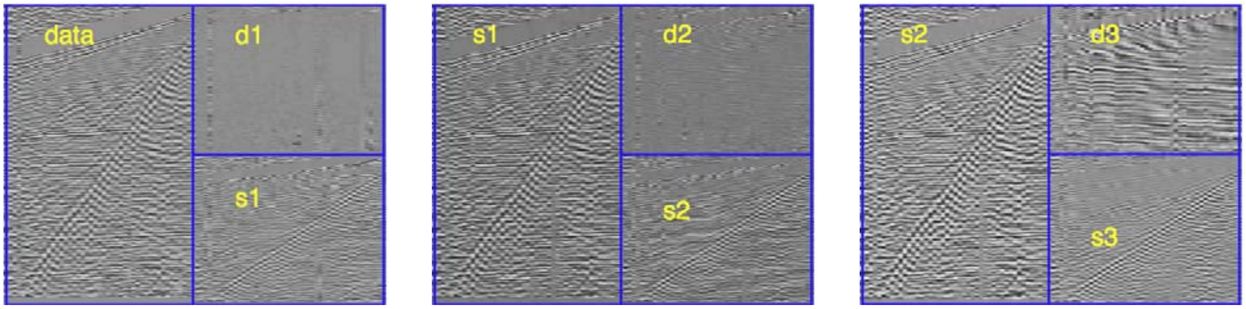

Figure 1. Decomposition of the input signal in low and high pass components via filter banks. **s3** is the component isolating the ground roll.

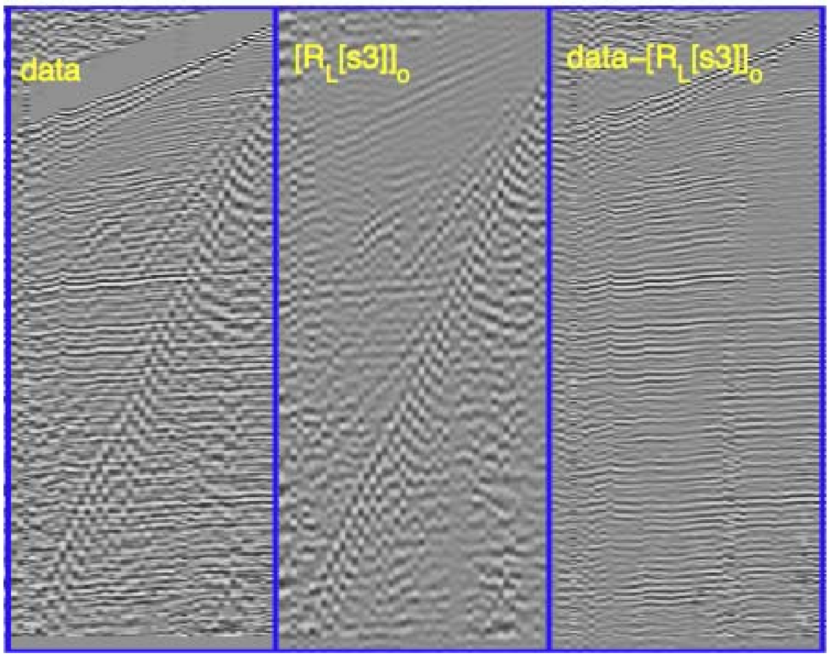

Figure 2. Input data, estimated coherent noise, and data minus estimated noise model. The linear noise model is extracted via the Hybrid Radon Transform from **s3** and interpolated to the original sampling rate before subtraction from the input data.

Acknowledgments

I would like to acknowledge the industrial sponsors of the Signal Analysis and Imaging Group for their continuous support.

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