

5D Reconstruction in the Presence of Residual Statics

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Summary

A modification to the reinsertion step of Projection Onto Convex Sets (POCS) is proposed that allows for the compensation of residual statics during 5D denoising and interpolation of seismic data. The method allows preserving residual statics during denoising, or correction of residual statics in the case of simultaneous denoising and interpolation. We implement the algorithm in a POCS framework but the method could be easily modified to use any other iterative Fourier reconstruction algorithm. An example is shown for a 5D reconstruction of synthetic data with added noise, missing traces and random static shifts. While standard reconstruction struggles in the presence of even small static shifts, reconstruction with simultaneous estimation of statics is able to accurately reconstruct the data.

Introduction

There are a variety of 5D reconstruction methods that can be used to interpolate and denoise seismic data. While many of these algorithms can handle low signal to noise ratios and sparse sampling, they typically fail in the presence of even small static shifts ($\leq \pm 10ms$). A common step in many reconstruction algorithms is a reinsertion step. This step inserts the estimated data into the original data and can be used for both interpolation and denoising. We propose a modification to the reinsertion that allows for the compensation of residual static shifts during this step.

Residual statics are typically attributed to near surface lateral velocity and topographical variations (Ronen and Claerbout, 1984). Because these effects are considered to be surface consistent their correction involves a single static shift for each trace. A common practice for residual static estimation is to use the cross-correlation of unstacked data within a CMP gather compared with the stacked trace, taking the maximum lags for each trace as an estimate of the residual statics. A problem with this method is that it is sensitive to the velocity used to NMO correct the input gathers (Eriksen and Willen, 1990). Traonmilin and Gulunay (2011) tackle the problem by simultaneously estimating the statics during projection filtering for the purpose of denoising seismic data. We propose a similar algorithm that allows for statics to be estimated during 5D trace interpolation and denoising.

Theory

Our method begins with the observation that statics appear to have the same character as noise or missing traces in the Fourier domain. Figure 1 shows a 2D synthetic gather (a) with added noise (b), missing traces (c), static shifts (d), and their respective f-k amplitude spectra (e)-(h). The destruction of the signal observed in the f-k amplitude spectra for each of these three cases are remarkably similar.

The assumption of any Fourier reconstruction method is that the desired noise-free, fully-sampled signal can be sparsely represented in the Fourier domain. In this paper we show that this same sparsity relation can be used for the removal of static shifts within the data.

In the case of 5D POCS reconstruction a Fourier estimate of the data is found by iteratively thresholding the amplitude spectrum of the data (Abma and Kabir, 2006). For a given temporal frequency, ω , the data in the $\omega - m_x - m_y - h_x - h_y$ domain at the k^{th} iteration of POCS are given by

$$D^k = \alpha_1 D^{obs} + (1 - \alpha_1 S) F_D^{-1} T F_D D^{k-1}, k = 1, \dots, N, \quad (1)$$

where m_x, m_y, h_x, h_y are midpoints and offsets in the x and y directions respectively, D^{obs} are the original data with missing traces, and F_D and F_D^{-1} are the forward and reverse 4D Fourier transforms in the spatial dimensions respectively. In this notation $D^k(\omega, k_{m_x}, k_{m_y}, k_{h_x}, k_{h_y}) = F_D D^k(\omega, m_x, m_y, h_x, h_y)$, and T is an iteration dependent threshold operator that is designed using the amplitudes of the input data (Gao and Sacchi, 2011). S is the sampling operator and is equal to one for points with existing traces and zero for points with unrecorded observations. The scaling factor $\alpha_1 \leq 1$ can be used to simultaneously denoise the data. A choice of $\alpha_1 = 1$ reinserts the noisy original data at each iteration, whereas a lower value of α_1 will denoise the volume by averaging the original and reconstructed data.

The modification we propose to allow for statics to be compensated for during the reconstruction is to derive a static shift between the thresholded data and the data from the previous iteration. The data in the $\omega - m_x - m_y - h_x - h_y$ domain at the k^{th} iteration of POCS with statics compensation are given by

$$D^k = \alpha_1 D^{obs} e^{-i\omega(1-\alpha_2)\tau^k} + (1 - \alpha_1 S) F_D^{-1} T F_D D^{k-1}, k = 1, \dots, N, \quad (2)$$

where $\tau^k(m_x, m_y, h_x, h_y)$ are the estimated static shifts at the k^{th} iteration and are constant for all frequencies, ω . The scaling factor $\alpha_2 \leq 1$ can be used to control the level of static correction. A choice of $\alpha_2 = 1$ can be used for data with little to no residual statics, whereas a value of $\alpha_2 = 0$ will remove statics more aggressively by fully applying the estimated static shifts at a given iteration. The time shifts $\tau^k(m_x, m_y, h_x, h_y)$ are the lags given by the maximum values of the cross correlation of the static corrected input data from the previous iteration, $D^{obs} e^{-i\omega(1-\alpha_2)\tau^{k-1}}$ (where $\tau^{k-1} = \sum_{n=1}^{k-1} \tau^n$), with the thresholded data from the current iteration, $F_D^{-1} T F_D D^{k-1}$. This allows for the iterative application of noise attenuation, missing trace interpolation, and static correction.

Considerations

In the case of noise attenuation given data that is fully spatially sampled one may wish to denoise the data while preserving residual statics. The total residual static corrections applied during the denoising are contained in $\tau^N(m_x, m_y, h_x, h_y)$ allowing for them to be removed from the data. In the case of interpolation it is preferable to leave the static corrections applied to avoid static shifts between interpolated and original traces. The fact that the algorithm produces a tensor of time-shifts $\tau(m_x, m_y, h_x, h_y)$ could offer an advantage for other processing steps. Converting this tensor to shot and receiver coordinates, $\tau(s_x, s_y, g_x, g_y)$, the time shifts could then be used for further processing or to gain a better understanding of the near surface.

Example

We apply the algorithm to a 5D synthetic dataset with dimension 100x12x12x12x12. The data has hyperbolic moveout in all four of the spatial directions as seen in figure 2. This figure shows one central bin location out of a total of 144 bins that comprise the complete data. The complete noise free data is shown in figure 2 (a). Before reconstruction random noise was added to the data giving a signal to noise ratio of 2. Random traces were then decimated from the data leaving 50% of the original traces. Random static shifts between ± 10 ms were then applied to the data producing the data seen in figure 2 (b). Standard 5D POCS reconstruction was applied to the data resulting in the data shown in figure 2 (c). The static shifts cause a very low quality reconstruction that smears the

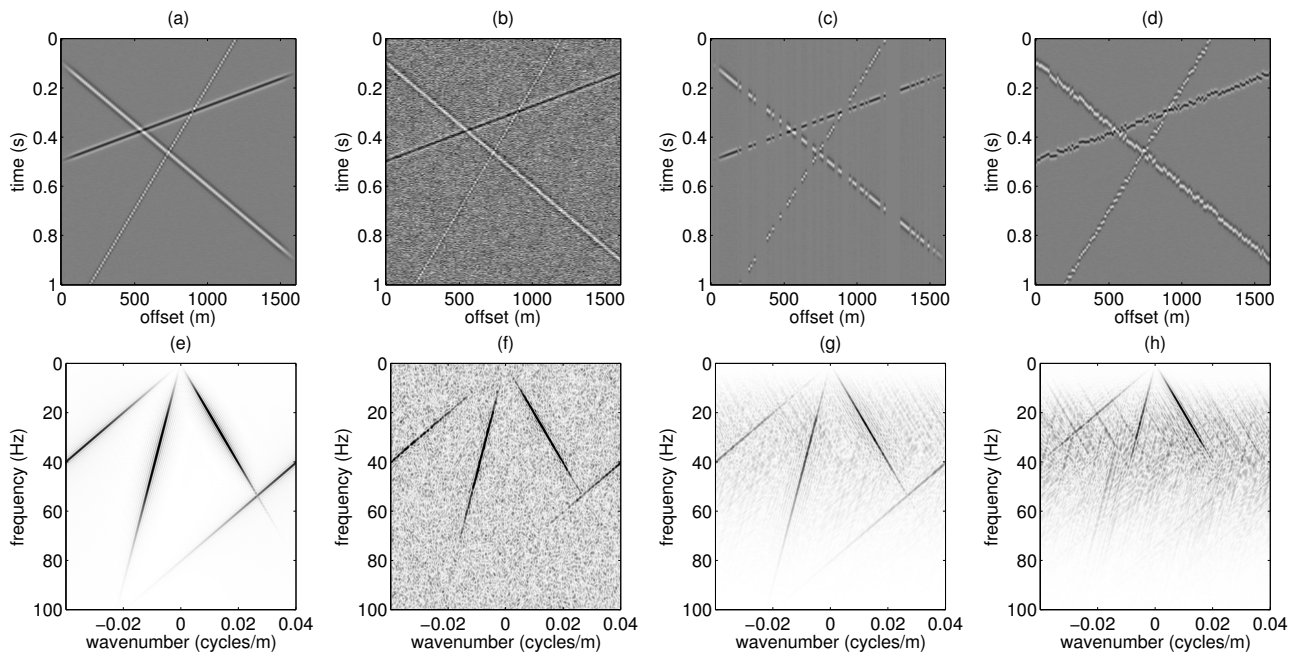


Figure 1 : a) Original 2D synthetic data. b) Data with random noise. c) Data with random missing traces (50%). d) Data with random ± 10 ms statics shifts. e-h) Are the f-k amplitude spectra of a-d.

signal. 5D POCS Reconstruction with static compensation gives a much higher quality result as seen in figure 2 (d).

Conclusion

We presented a method to perform 5D denoising and interpolation of seismic data in the presence of residual statics. The method is able to preserve the static shifts in the case of denoising data, or to compensate for the shifts in the case of simultaneous denoising and trace interpolation. The method makes use of the fact that residual statics have a similar character in the Fourier domain as both random noise and missing traces, but requires a different method of correction during the reinsertion step of the reconstruction.

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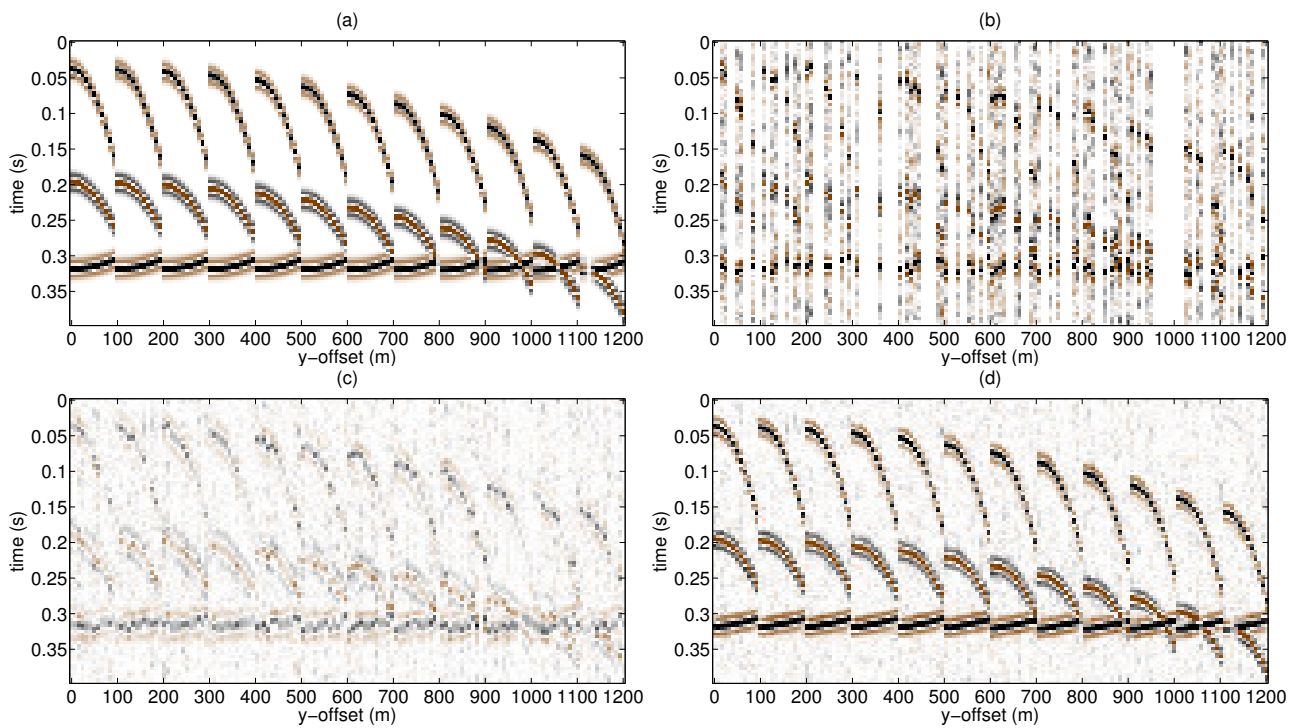


Figure 2 : a) A portion of noise-free, static-free, fully sampled 5-D synthetic data. b) Data after adding random noise ($SNR = 2$), random $\pm 10ms$ static shifts, and randomly removing traces (50%). c) Data after standard 5D reconstruction d) Data after simultaneous 5D reconstruction and statics computation