Submission code: QMGV9Q4BK8

See this and other abstracts on our website: https://home.sbgf.org.br/Pages/resumos.php

Irregular-grid Seismic Data Reconstruction Based on Interpolated Tensor Completion

Lieqian Dong (BGP; CNPC), Lixin Zhai (BGP; CNPC), Rongzhi Lin (Department of Mathematics and Center of Geophysics; Harbin Institute of Technology), Yunlei Wang (BGP; CNPC), Xueyong An (BGP; CNPC)

Irregular-grid Seismic Data Reconstruction Based on Interpolated Tensor Completion

Abstract Summary

Field acquired seismic data are typically irregularly distributed and contain missing traces due to the influence of geological conditions and acquisition design. These missing traces and irregularities complicate subsequent processing, making seismic data reconstruction and regularization a critical step. In recent years, multidimensional seismic data reconstruction has gained significant attention for its ability to incorporate more spatiotemporal information, enabling more accurate predictions of amplitude and phase for the missing traces. Tensor-based methods offer an effective way to extend reconstruction techniques to higher dimensions. By introducing interpolation operator and combining with tensor completion algorithm, a 5D interpolated tensor completion algorithm (I-TC) is proposed to simultaneously reconstruct and regularize higher dimensional irregular-grid seismic data and improve the overall signal-to-noise ratio of seismic data. Furthermore, the I-TC method has noticeable advancements in handling curved events, outperforming traditional matrix-based low-rank methods.

Introduction

Due to the influence of geological conditions and acquisition design during field data sampling, seismic data are often irregularly sampled, resulting in missing traces. These missing traces can significantly impact subsequent processing, necessitating the reconstruction of the seismic data. Numerous reconstruction methods have been proposed to address this issue, such as POCS (Abma and Kabir, 2006) and MSSA. Most of these methods employ a binning strategy, in which irregularly sampled traces are assigned to the nearest points on a regular grid before reconstruction. However, the binning process introduces phase and amplitude distortions, which can compromise the accuracy of seismic images. To tackle this issue, some methods has been proposed, such as antileakage Fourier transform (Xu et al, 2005) and I-MSSA (Carozzi and Sacchi, 2021). In recent years, 5D-based reconstruction methods have gained considerable attention due to their potential for higher-quality data reconstruction for multidimensional data. Multidimensional reconstruction improves the prediction of amplitude and phase accuracy, as seismic amplitudes exhibit mild variations, and the decimation can be compensated by other dimensions (Trad, 2009). Tensor decomposition, an extension of vector and matrix operations, provides a robust framework for 5D seismic data reconstruction. By utilizing tensor rank-reduction techniques, the 5D seismic data reconstruction can be expressed as a tensor completion problem which can be solved by HOSVD (Kreimer and Sacchi, 2012) and other methods.

In this abstract, we introduce an interpolation operator combined with a tensor completion algorithm to develop the interpolated tensor completion (I-TC) method, which addresses the 5D irregular-grid seismic data reconstruction problem. To preserve field true coordinates, the I-TC method employs an interpolation operator that maps irregular-grid data onto a regular grid, thereby avoiding the reconstruction errors typically associated with binning and improving reconstruction accuracy. Leveraging tensor rank-reduction techniques, I-TC can simultaneously denoise and reconstruct multidimensional seismic data, both on irregular and regular grids. Notably, I-TC outperforms conventional matrix-based rank-reduction methods, particularly in the reconstruction of non-linear events with large curvature. Experimental results demonstrate that the proposed I-TC method delivers significant improvements in reconstruction performance with high computational efficiency

Interpolated Tensor Completion Algorithm

The seismic data of midpoint-offset frequency-space domain is widely used for prestack seismic reconstruction. This fully sampled seismic data have a low-rank structure and can be represented a 5-order tensor by $\mathrm{D}(\mathrm{w}, \mathrm{x}, \mathrm{y}, h_{\mathrm{x}}, h_{\mathrm{y}})$, where w represents frequency, x and y represent the midpoints spatial coordinates and h_{x} and h_{y} represent the inline and cross-line offsets, respectively. The rank of a seismic matrix (or tensor) is influenced by the number of seismic events with different curvatures, and the decimation of seismic data can increase the rank of the matrix (or tensor). For simplicity, we can express the seismic data reconstruction problem as a 5D seismic tensor completion problem under the assumption of low rank:

$$\mathrm{J} = \left\|\mathcal{D}^{\mathrm{obs}} - \mathcal{W}\mathcal{D}\right\|_{\mathrm{F}}^{2} \quad \mathrm{s.t.} \quad \mathrm{rank}(\mathcal{D}) \le \mathrm{k} \tag{1}$$

where $\mathcal{W}$ is the interpolation operator that symbols mapping irregular-grid data to regular-grid data, $\mathcal{D}^{\mathrm{obs}}$ denotes the observed irregular-grid seismic data and $\mathcal{D}$ denotes the desired reconstructed regular-grid data. Using the projected gradient descent, we can solve problem (1) by:

$$\begin{cases} \mathrm{Z}^{\mathrm{k}} = \mathcal{D}^{\mathrm{k}} - \lambda\mathcal{W}^{*}\left(\mathcal{W}\mathcal{D}^{\mathrm{k}} - \mathcal{D}^{\mathrm{obs}}\right) \\ \mathcal{D}^{\mathrm{k+1}} = \mathrm{P}_{\mathrm{TC}}\left[\mathrm{Z}^{\mathrm{k}}\right] \end{cases} \tag{2}$$

where $\mathcal{W}^{*}$ is the adjoint operator of $\mathcal{W}$. The parameter λ is the step length. The symbol P_{TC} is the projection operator (Lin et al., 2022) of tensor completion algorithm. Including interpolation operator $\mathcal{W}$, we refer this method as interpolated tensor completion algorithm (I-TC). In summary, the process consists of two main steps: The first step involves a gradient descent process that maps irregular-grid seismic data to the desired regular-grid data. The second step is a projection process, which reconstructs the decimated seismic data using the tensor completion algorithm. This approach not only preserves the true spatial coordinates of the seismic acquisition, but also maintains the effectiveness of tensor completion methods.

Field Seismic Data Reconstruction

In this section, we evaluate our method using irregular-grid acquired 5D field data. Both the sources and receivers are reconstructed simultaneously. Figure 1(a) illustrates the irregular-grid geometry of the field data, which contains 83,861 traces. Figure 1(b) shows the desired regular-grid geometry, consisting of 625 sources and 260 receivers. For this test, the decimation rate is approximately 48.4%. In this example, we employ the Sinc-Kaiser interpolation operator and its adjoint operator, denoted as $\mathcal{W}$ and $\mathcal{W}^{*}$, respectively. The maximum number of iterations for the I-TC method is set to 30, and the step size is exponentially decreased. Figure 2 presents the different reconstructed slices of the field data using the I-TC method. Figures 2(a-d) display the field data with noise and missing traces across different slices, while Figures 2(e-h) show the corresponding reconstruction results obtained with I-TC. Qualitative analysis reveals that the missing traces have been accurately reconstructed, resulting in a more coherent spatial representation of the seismic waveform. Additionally, the noise is significantly attenuated, and the seismic events are continuous, revealing that the I-TC method effectively performs both denoising and reconstruction simultaneously.

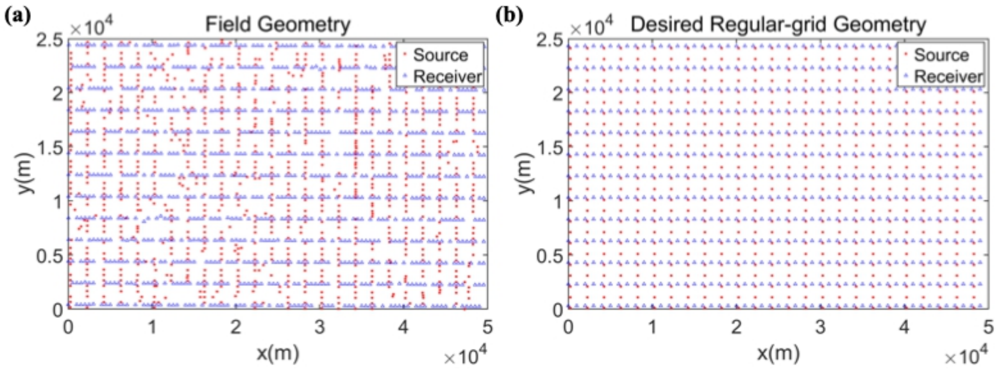

Figure 1: The sampling field data geometry and the desired regular-grid geometry. (a) Sampling field data geometry. (b) Desired regular-grid geometry.

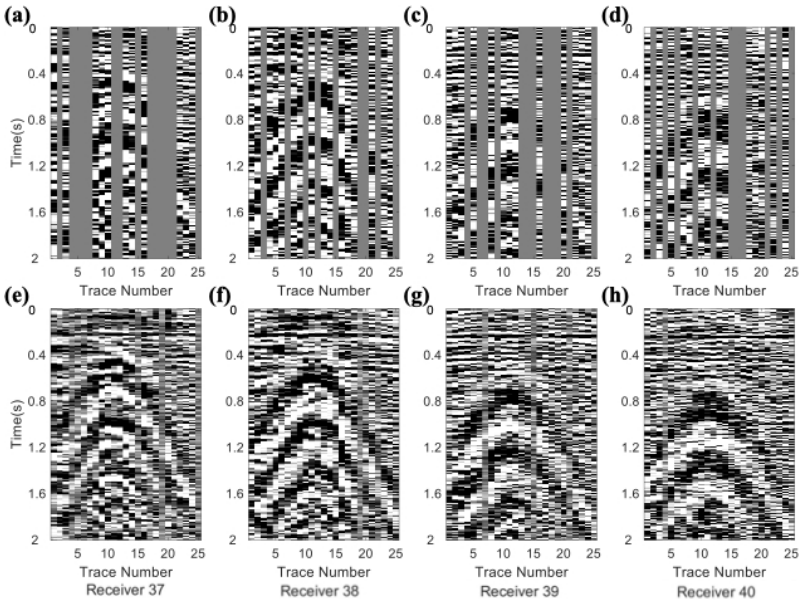

Figure 2: The comparison slice of the field data and the reconstruction results. (a-d) Field data contains 183,861 traces. (e-h) Reconstruction results via I-TC.

Conclusions

In this abstract, we propose an interpolated tensor completion (I-TC) method to simultaneously denoise and reconstruct 5D irregular-grid seismic data. Both synthetic and field data experiments demonstrate that the I-TC method realizes to reconstruct and denoise irregular-grid seismic data. By utilizing an interpolation operator to map irregular grid data onto a regular grid, the I-TC method honors the true coordinates and reduces amplitude and phase errors. For curve-event examples, the I-TC method shows significant improvements in mitigating signal leakage. Future research will focus on developing algorithms to enhance reconstruction quality for highly missing seismic data and to accelerate the reconstruction process.

References

Abma, R. and N. Kabir, 2006, 3D interpolation of irregular data with a POCS algorithm: Geophysics, 71(6), E91-E97.

Carozzi, F. and M.D. Sacchi, 2021, Interpolated multichannel singular spectrum analysis: A reconstruction method that honors true trace coordinates. Geophysics, 86(1), V55-V70.

Kreimer, N. and M.D Sacchi, 2012, A tensor higher-order singular value decomposition for prestack seismic data noise reduction and interpolation: Geophysics, 77(3), V113-V122.

Lin, R., Guo, Y., Carozzi, F. and M.D. Sacchi, 2022, Simultaneous deblending and source reconstruction for compressive 3D simultaneous-source acquisition data via interpolated multichannel singular spectrum analysis: Geophysics, 87(6), V559-V570.

Trad, D., 2009, Five-dimensional interpolation: Recovering from acquisition constraints: Geophysics, 74(6), V123-V132.

Xu, S., Y. Zhang, D. Pham, and G. Lambaré, 2005, Antileakage Fourier transform for seismic data regularization: Geophysics, 70(4), V87-V95.