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Exploring two different methods of seismic interpolating operators

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Abstract

3D land data acquisitions are often undersampled along offset and azimuth directions because of large shot and receiver line intervals.
In marine data acquisition, data are well sampled in the inline direction but coarsely sampled in the crossline direction.
These issues can often be alleviated by seismic interpolation, which is an important step in data processing since many processing and migration tools require regularly sampled input data.
We compare two methods of seismic amplitude reconstruction.
Singular Spectrum Analysis (SSA) which is based on rank reduction methods and reduces the rank of Hnakel marix of the signal in each constant frequency.
Minimum Weighted Norm Interpolation (MWNI) which infills missing traces by transforming the data to the Fourier domain and removing sampling artifacts by enforcing wavenumber-domain sparsity.

Introduction

Singular Spectrum Analysis (SSA) implemented with an iterative algorithm can interpolate seismic data.
We can summarize the algorithm in 6 steps:
1-Transforming data from t-x domain to the f-x.
2- Generating a Hankel matrix for each constant frequency.
3- Decomposition of the Hankel matrix via TSVD.
4- Rank reduction of the Hankel matrix.
5- Averaging in the Hankel matrix anti-diagonals.
6- Applying inverse Fourier transform.
Rank of the Hankel matrix in the f-x domain for a noiseless linear event is 1.
In the presence of random noise or missing traces, rank of the Hankel matrix will increase.

Methods

considering the signal S in the frequency slice with some missing traces:

$$S_\omega = [s_1, 0, s_3, 0, s_5, s_6, s_7, 0, 0]^H. \tag{1}$$

The Hankel matrix of S_ω will be as follows:

$$M = \begin{pmatrix} s_1 & 0 & s_3 & 0 & s_5 \\ 0 & s_3 & 0 & s_5 & s_6 \\ s_3 & 0 & s_5 & s_6 & s_7 \\ 0 & s_5 & s_6 & s_7 & 0 \\ s_5 & s_6 & s_7 & 0 & 0 \end{pmatrix}. \tag{2}$$

Defining a sampling operator:

$$T = [1, 0, 1, 0, 1, 1, 1, 0, 0]^H. \tag{3}$$

SSA with the iterative algorithm for noisless data:

$$S_f^i = S_f^{obs} + (I - T) \odot F_{SSA} S_f^{i-1}, \tag{4}$$

SSA with the iterative algorithm for noisy data:

$$S_f^i = \alpha^i S_f^{obs} + (1-\alpha^i) T \odot F_{SSA} S_f^{i-1} + (I-T) \odot F_{SSA} S_f^{i-1}. \tag{5}$$

SSA can be expanded to more than two dimensions, which is called multidimensional singular spectrum analysis (MSSA).

Synthetic data

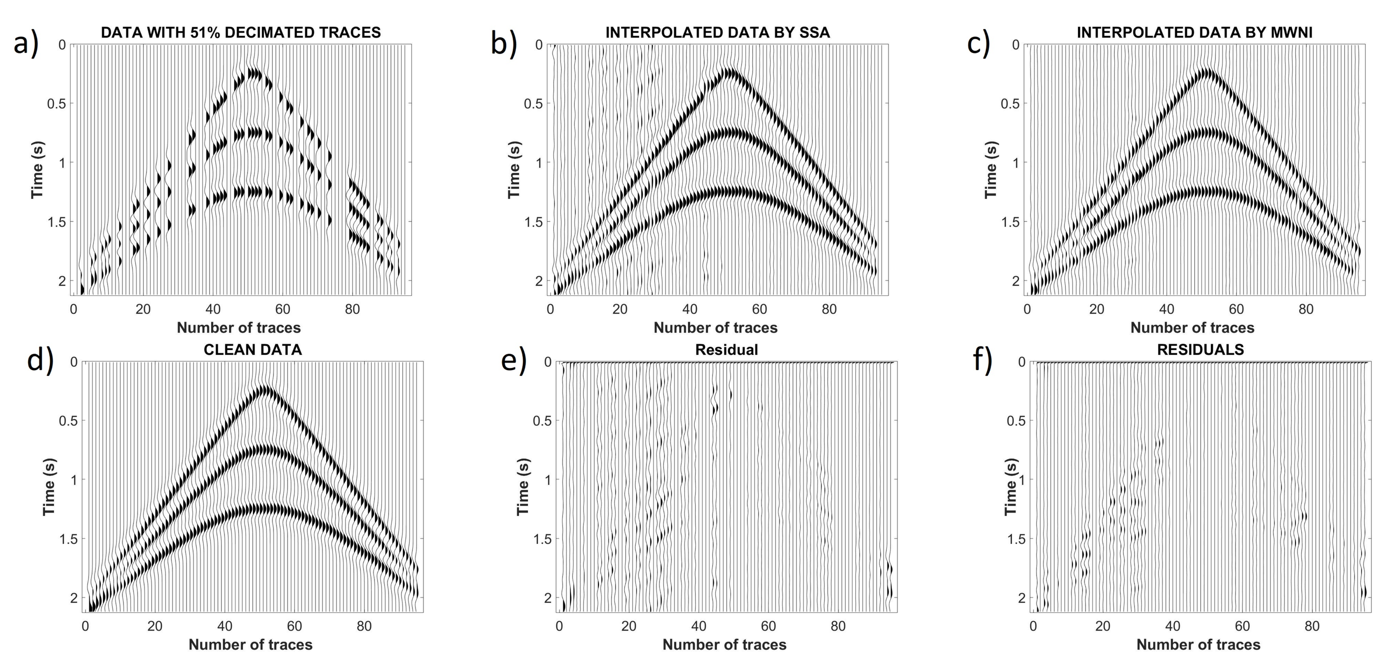

Figure 1: Comparison between SSA and MWNI on 2-D synthetic data with 51% killed traces. a) Input data with quality data ($Q = -0.15\ dB$); b) SSA interpolation ($Q = 10.40\ dB$); c) MWNI interpolation ($Q = 12.45\ dB$); d) expected result; e) and f) residuals of SSA and MWNI respectively.

Synthetic data

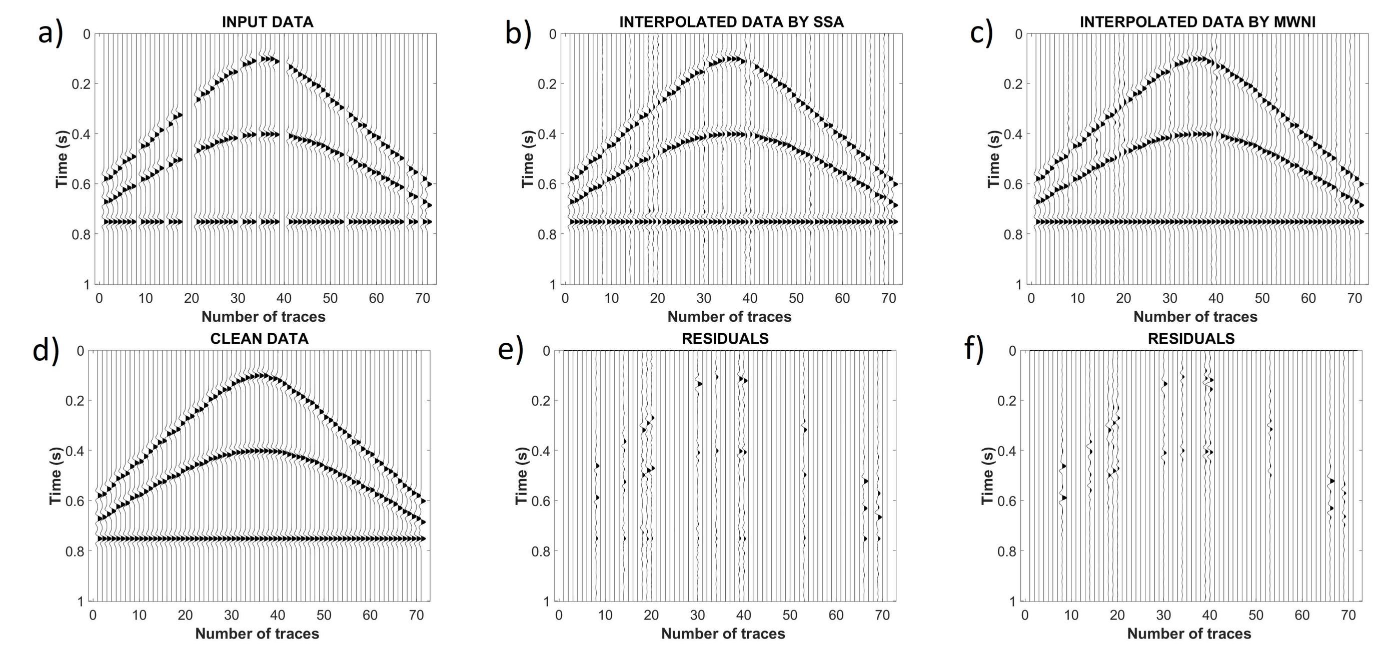

Figure 2: Comparison between SSA and MWNI algorithms applied on 2-D irregular pre-stack synthetic noiseless data with 20% randomly decimated traces. a) Input data with quality data $Q = 6.92\ dB$; b) reconstruction using SSA ($Q = 10.45\ dB$); c) MWNI interpolation result ($Q = 11.12\ dB$); d) expected result; e) and f) difference between expected result and interpolated data by SSA and MWNI respectively.

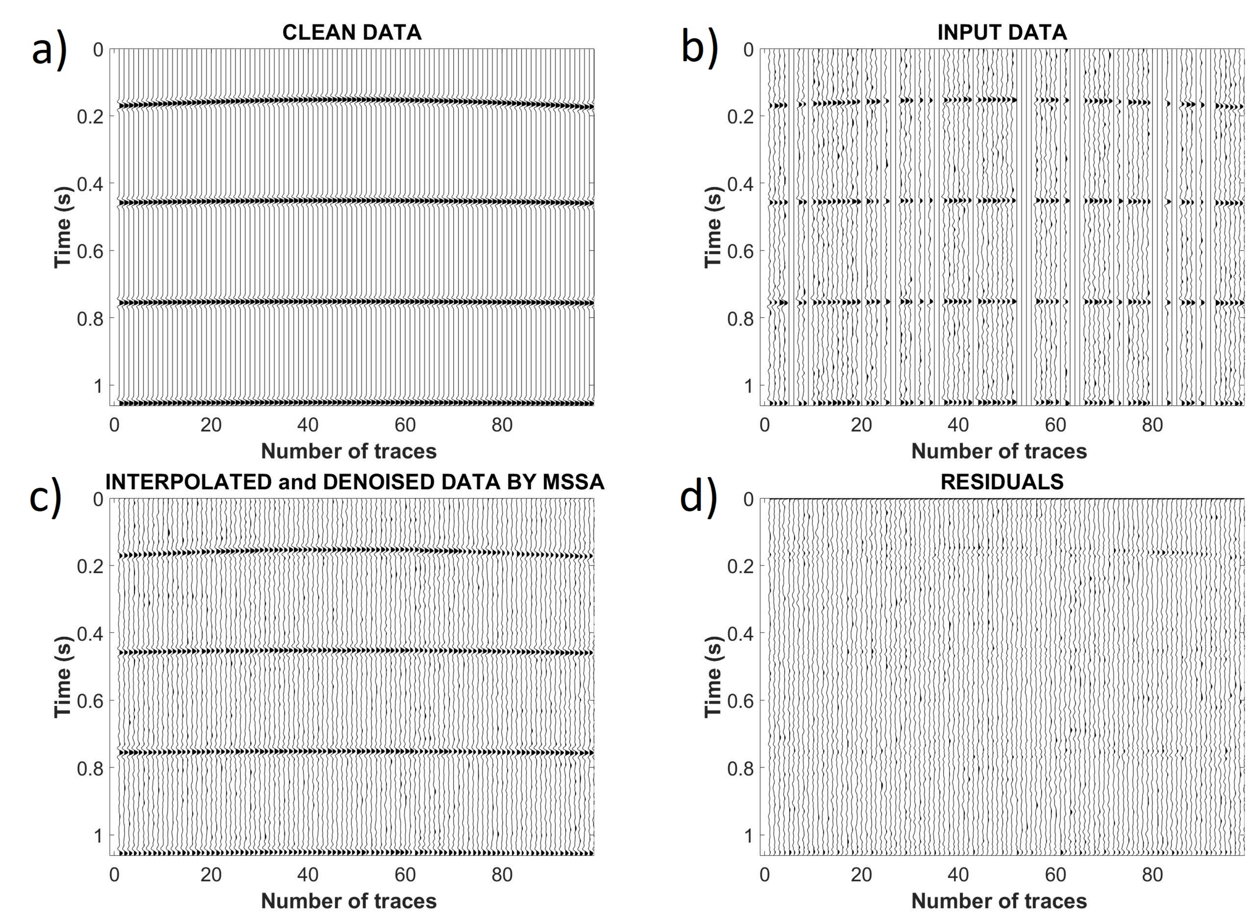

Figure 3: A slice of a 3D noisy cube at y=2. a) Expected data; b) input data with 31% randomly missing traces and contaminated with random noise ($Q = 1.06\ dB$); c) result of the simultaneous interpolation and denoising using MSSA ($Q = 5.48\ dB$); d) difference between the result and expected data.

Conclusions

- SSA with an iterative algorithm interpolated irregular and coarsely sampled data, but not the regularly decimated data.
- MWNI interpolated well the regularly decimated data with fine binning using a FK filter mask.
- Results for MWNI can be improved by using finer binning and more dimensions (3D, 4D or 5D interpolation).
- For SSA we couldn't improve the results with finer binning but it would probably get better for more than 3 dimensions.

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