

G010

Four-dimensional f-k Interpolation of Wide Azimuth Towed Streamer Data

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SUMMARY

We extend the frequency-wavenumber (f-k) interpolation method introduced by Gulunay (2003) into a Four-Dimensional (4D) application. The 4D f-k interpolation is used to interpolate between streamers and shots in Wide Azimuth Towed Streamer (WATS) data. The f-k interpolation method utilizes the low frequency non-aliased portion of data to interpolate aliased high frequencies. Therefore, it can handle highly aliased spatial domains. In addition, the multidimensional nature of the 4D f-k interpolator extracts information from non-aliased spatial axes to interpolate highly aliased axes correctly. Synthetic and real data examples are provided to examine the performance of the proposed interpolation scheme.

Introduction

Reconstruction and interpolation of seismic data is one of the ongoing research topics in exploration seismology. In 3D seismology one works with an areal distribution of sources and receivers given rise to a 5 dimensional data volume: time plus 2 coordinates (x-y or North - East) for each source and receiver. Each seismogram is defined by a time series with a unique spatial label given by its associated source and receiver positions. The time axis is discretized via the acquisition system that can easily meet adequate sampling criteria to preserve information content. On the other hand, the spatial axes often end up either irregularly or coarsely sampled due to the logistic or economical restrictions. The seismic interpolation methods aim to obtain an adequately and regularly sampled seismic data from inadequately sampled data.

Gulunay (2003) introduced the frequency-wavenumber (f-k) interpolation method for 2D and 3D seismic data. This method is the f-k equivalent of the frequency-space (f-x) interpolation method introduced by Spitz (1991). The f-k interpolation method is based on creating a mask function from the low frequency portion of the data and applying it to interpolate the high frequencies. The mask function is created by properly zero-padding and zero-interlacing the original data. The principle of the f-k interpolation remains the same for 3D and higher dimensional data. Recently, multidimensional interpolation of seismic data has attracted particular attentions in the seismic data processing community (Trad, 2009). Simultaneous interpolation of spatial axes can utilize information from properly sampled spatial directions in order to interpolate the inadequately sampled spatial directions.

In this article we will use the f-k interpolation method for simultaneous interpolation of 3 spatial dimensions. The objective is to present a method that natively handles wide azimuth towed streamer (WATS) data. In other words, we avoid the use of intermediate storage or resorting of the input data. Synthetic and real data examples are provided to examine the performance of the proposed 4D f-k interpolation method.

Method

In order to apply 4D f-k interpolation one must perform multidimensional Fast Fourier Transforms (FFTs) on three different types of modified data, which have been obtained by padding, zeros and interlacing zero traces. It can be shown that all these steps have the same effect as the f-x interpolation described by Spitz (1991). Steps to find the interpolator and obtaining final interpolated seismic section for only one spatial direction can be summarized as below:

1. A seismic section window in t-x is the input.
2. Create a section by inserting zero traces between each pair of traces. For this section the number of traces will be twice that of the original traces. Apply 2D FFT to this section and save it for next steps.
3. Create another section by zero padding each trace of the original data. To the obtained section, adhere another section of zero traces of the same size. It means that at the end we will have a section with a number of traces and time samples that is twice the size of the original data. Apply 2D FFT to this section and save it for the next steps.
4. Create another section of data from the time-space domain from an already created section in step 3 by replacing even number traces with zeros. Apply 2D FFT to this section and save it for the next steps.
5. Choose the half part of the frequency axis of the f-k section of step 3. We will choose the frequencies from zero up to half the Nyquist frequency and save this section for next steps.
6. Do the same operation (5) for the f-k section of step 4 and save the results for next steps.
7. Divide the resulted section of step 5 by the resulted section of step 6. The resulted section must have the values between 0 and 2. One can use a whitening parameter to avoid division by zero. This resulted section is the interpolator.

8. Multiply the interpolator obtained from step 7 with the section obtained from step 2. The result of this step is the f-k domain section of the interpolated data.
9. Apply inverse 2-D FFT to the result of step 8. This is the output of the 2D f-k interpolation method.

Notice that for more than one spatial direction the same steps are valid with the exception that now one has to use the multidimensional FFT.

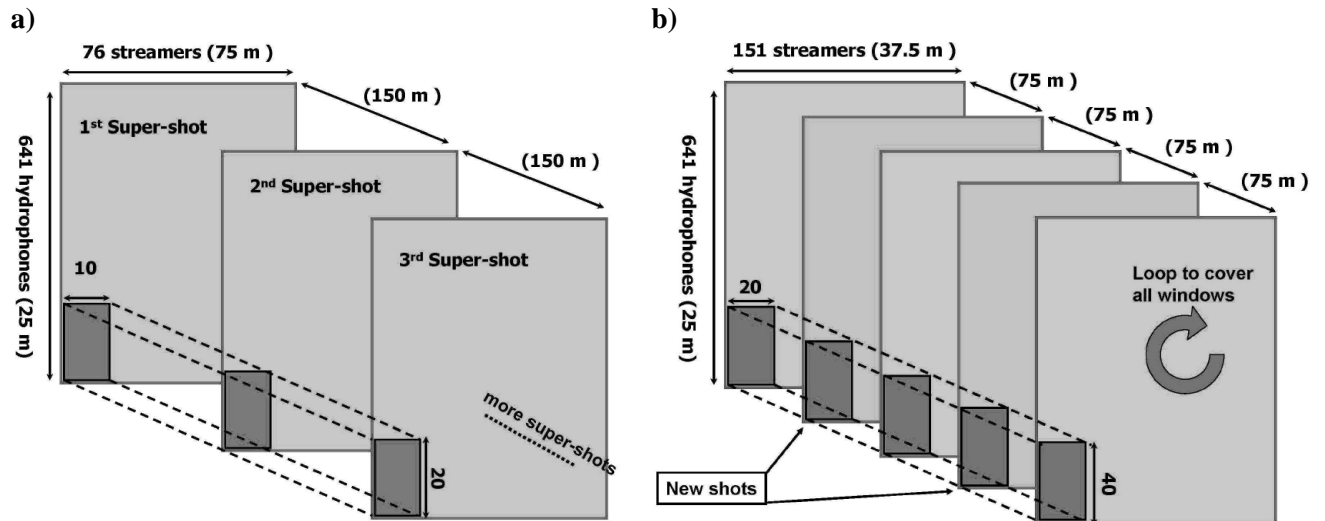


Figure 1 a) The Geometry of the original synthetic data and small spatial windows. b) The geometry of spatial axes after interpolation.

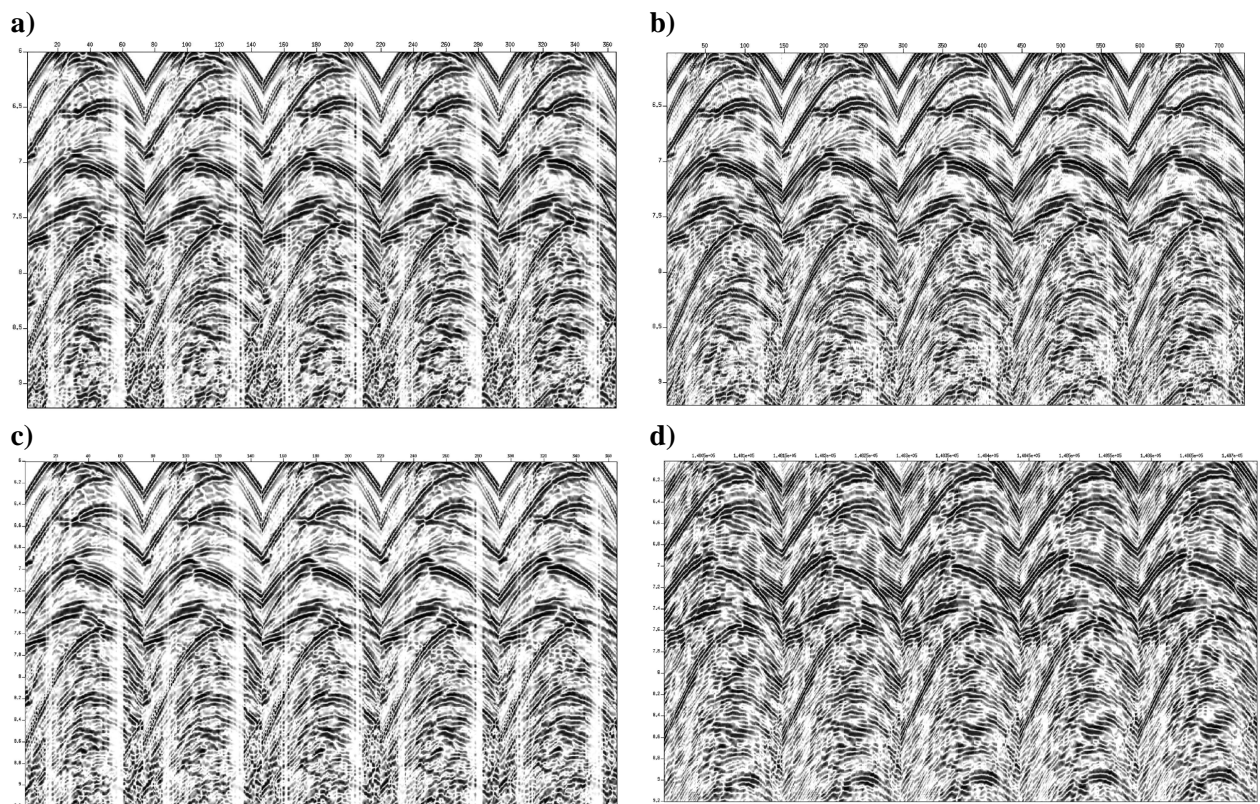


Figure 2 a) Five cross-line (spatial direction perpendicular to streamers direction) sections of an original shot before interpolation. b) Data in (a) after interpolation between each streamer. c) Five original cross-line sections (These data are not used for interpolation). d) Newly interpolated data in the location of original data in (c).

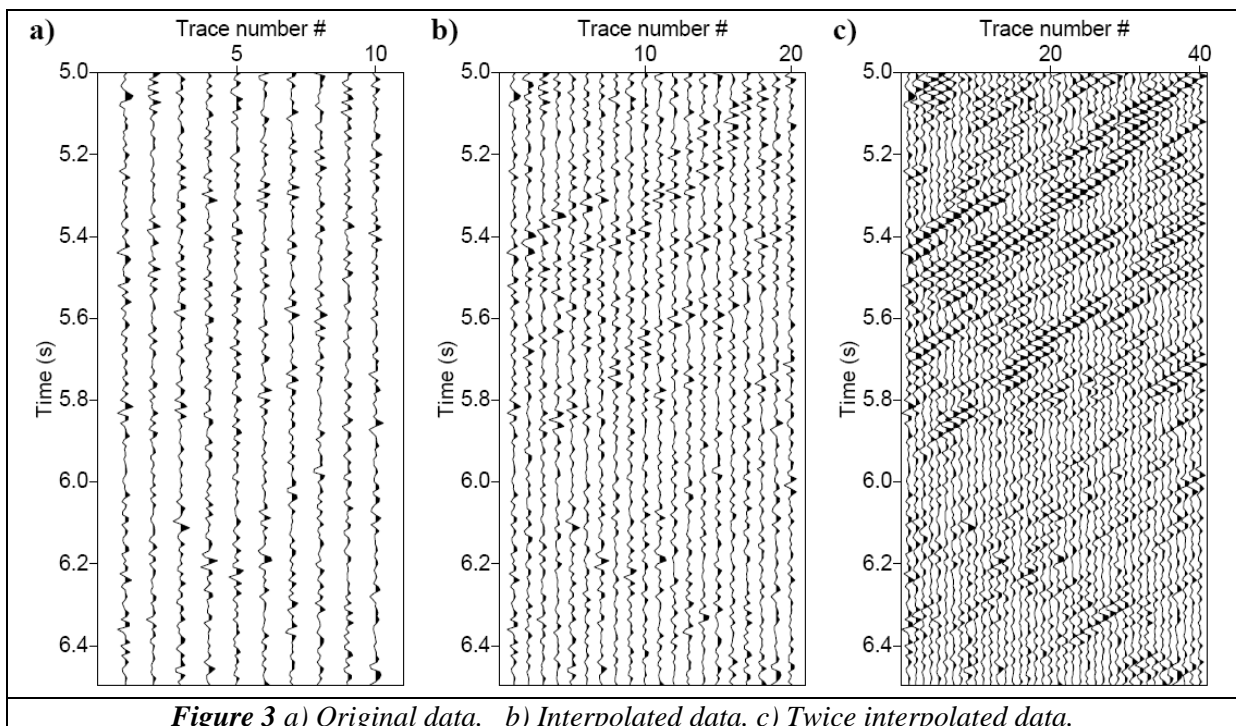
Synthetic example

The synthetic data from 5 super-shots each with 76 streamers and 641 hydrophones per streamer are used to test the performance of the 4D f-k interpolation method. The interpolation is carried out in small spatial windows of 10 streamers, 20 hydrophones and 5 shots. The spatial windowing is required in order to honor the linear events assumption. Figures 1a and 1b show the geometry of the original and interpolated data, respectively. Each neighboring spatial windows has 3 and 5 sample overlaps in the streamer and hydrophone direction, respectively.

Figures 2a and 2b show part of data from one of the original super-shots before and after interpolation, respectively. In these plots new streamers are added between the original streamers. One can see the better resolution of events as well as the removal of aliasing in the interpolated sections. As it was explained, the purpose of the proposed algorithm is to interpolate between streamers as well as shots. Figure 1c shows a part of an original super-shot which was located in the location of the interpolated super-shot (Figure 1d). Notice that the data in Figure 1c were never used during interpolation. There is a nice match between the interpolated super-shot and the original super-shot at this specific location.

Real data example

A data set from Gulf of Mexico including 30 shots recorded by $4 \times 2 \times 10$ streamerlines are used to test the feasibility of 4D-FKI method for real data application. The test is carried out on a spatial window of data including 5 shots, 10 streamers, and 20 hydrophones and time window from 5 (sec) to 6.5 (sec). Figure 14a shows the original data for the first hydrophone and all 10 streamers. The coarse sampling between streamers make almost impossible to see the direction of events. Figure 14b shows the section in Figure 14a after interpolating between streamers. One can interpolate the interpolated section in Figure 14b to get Figure 14c. In Figure 14c 3 streamers are added between each original streamer. Figures 15a, 15b, and 15c show the f-k panel of Figures 14a, 14b, and 14c, respectively. It was almost impossible to detect the orientation of event in the original data but after interpolation and removing the alias the direction of events is clear. Notice that this clear image can not be achieved if we were just using the streamers direction only. The multidimensional nature of the 4D f-k interpolation method uses information from all spatial directions to interpolate between streamers.



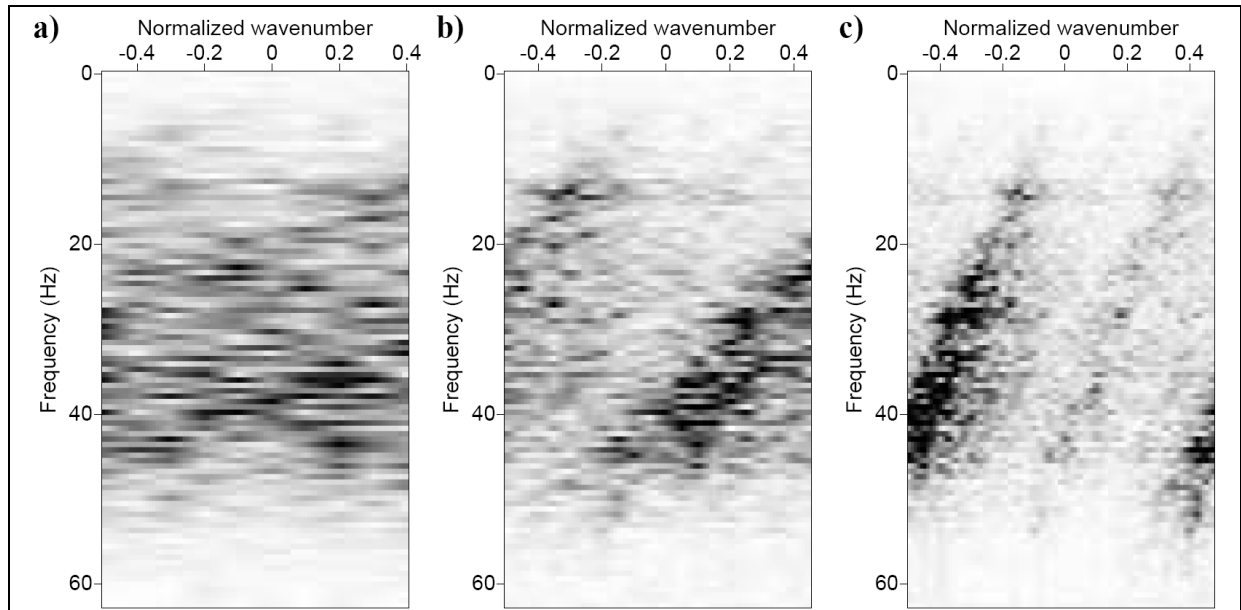


Figure 4 a), b), and c) are the f - k domain representation of data in Figures 3a, 3b, and 3d, respectively.

Discussion and Conclusions

The proposed 4D F-K interpolation proves to be an efficient tool for multidimensional interpolation of WATS data. It can also handle highly aliased data and can be potentially extended to the 5D situation. Although the implementation was designed to handle WATS data, it will, by its kinematics, be applicable to narrow and multi azimuth towed streamer as well as ocean bottom cable configurations. The method is highly scalable in a High Performance Computing (HPC) environment. In wide and multi azimuth cases, the mere size of the acquired data makes it impractical to use intermediate storage for interpolated data. The described algorithm is designed to run over windows and thereby enabling an “on-the fly” interpolation of needed data, a critical aspect of processing WATS data. The range of applications for this method is general in terms of seismic data processing, however, the specific scope of the project was to implement a stable interpolator for SRME and WE based demultiple methods for WATS data.

Acknowledgements

We would like to thank WesternGeco for providing E-Octopus-3 real dataset and Statoil ASA for the use of the synthetic data and the permissions to publish this work. We thank Dmitri Lokshtanov for constructive discussions about this research. We also express our gratitude to Hans Kristian Helgesen for preparing the synthetic WATS data.

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