Maximizing the value of sparse 3D seismic data by prestack trace interpolation

Ye Zheng, Geo-X Exploration Services Inc., Calgary, AB, Canada; Balazs Nemeth, Christian Escalante, BHP Billiton, Saskatoon, SK, Canada; Andrea Crook, Keith Millis, OptiSeis Solutions Ltd., Calgary, AB, Canada; and Laurie Ross, Geo-X Exploration Services Inc., Calgary, AB, Canada.*

Summary

Prestack trace interpolation (5D interpolation) is widely used in seismic data processing recently to regularize spatial sampling and recover missing traces. There are many successful cases of interpolation helping improve prestack migration images, stabilize AVAZ analysis, and distinguish and attenuate short period multiples.

It is a hot topic if interpolation can help reduce acquisition costs. In this study, two kinds of tests were conducted. The first is a series of decimation tests on a typical orthogonal land seismic survey in combination with 5D interpolation were conducted to investigate the ability to recover missing data by interpolation. The second is a series of upsampling (decreasing CMP bin size) tests. The test results show that (a) 5D interpolation provides an opportunity to reduce acquisition cost with thoughtful design; (b) 5D interpolation can eliminate acquisition footprints and increase the signal-to-noise ratio of final images; (c) with finer CMP grid, 5D interpolation can improve spatial resolution of the subsurface image.

Introduction

Prestack trace interpolation in 5D domain has been widely included in seismic processing sequences to regularize spatial sampling for recovering missing traces while helping improve the quality for subsequent processes, such as prestack migration, AVAZ analysis (Zheng, et al, 2011) and multiple attenuation (Hunt, et al, 2011). One question often asked in the seismic industry is “Can interpolation help reduce acquisition cost”. On one hand, since interpolation has the capability to reconstruct the wavefield from incompletely sampled data, it provides the opportunity for recording less data in the field and recover/fill missing data by interpolation. On the other hand, if the acquisition geometry is too sparse, information from some geological features may not be collected in the field data so that the information lost in the field cannot be recovered by interpolation, since interpolation won’t create information. The purpose of this study is to understand what kind and how detailed of information can be recovered by interpolation and what the limit is of the recovery. A series of decimations were designed to test interpolation until it failed.

The size of the CMP bins is closely related to the amount of spatial smearing of subsurface images. The smaller the CMP bin size, the less spatial smearing. Due to the limitation of seismic acquisition, a CMP bin size smaller than its natural bin size (one-half of shot interval by one-half of receiver interval for an orthogonal geometry) often yields poor images, because of the low signal-to noise ratio and poor sampling in the offset domain within a CMP gather. In this study, a series of upsampling (reducing CMP bin size) were tested and the results show that with the help of 5D interpolation, one may use a finer CMP grid for imaging and get higher spatial resolution images with good quality.

Method

The interpolation algorithm used for the tests is the Anti-Leakage Fourier Transform (ALFT) method (Xu et al, 2004), which works in 5D frequency-wavenumber domain of time, in-line, cross-line, offset and azimuth. By solving Fourier coefficients of the wavefield from irregularly sampled seismic data, ALFT is able to reconstruct the wavefield, regularize spatial sampling and fill missing traces. Unlike other algorithms which snap input traces into bin centres, this algorithm uses true coordinates of each trace, therefore, minimizes spatial smearing.

Decimation tests

A typical orthogonal land seismic survey was used for this study. The survey has shot lines with the line spacing of 300 m and shot station interval of 60 m. Receiver lines are with a line spacing of 180 m, and receiver station interval is 60 m. The normal stacking fold for the natural CMP bin size (30 x 30 m^2) is only 8 at 700 m offset, which is low compared to the average survey design. To maintain the stacking fold at a reasonable level, the processing CMP bin size was defined as 60 x 60 m^2, which is four times bigger than the natural CMP bin size in area. The normal fold at 700 m offset is 29. First, the original data (full data) was processed to get the best processing sequence and the structural stack was used as a bench mark for further tests. Interpolation was applied to the “full data” to test the algorithm itself to make sure the interpolation preserves geological features and enhances the image. Afterward, a series of decimation tests were conducted to investigate the power of interpolation: case 1. removed every second shot line so the remaining data (1/2 data) is only one-half of the "full data"; case 2. removed every second shot and receiver lines so the remaining data (1/4 data) is only one-quarter of the "full data"; and case 3. removed every second shot and receiver lines, and every second shot station from the remaining shot lines so the remaining data (1/8 data) is only one-eighth of the "full data". The same processing sequence developed for "full data" was applied to all three decimated datasets (1/2, 1/4 and 1/8 data).

Figure 1 shows time slices of structural stacks for the full data and three decimation tests without interpolation. All four datasets have obvious footprints. The slice of 1/8 data is very noisy. Geological features in the yellow box can be seen in the full data, but not in the decimated datasets. Large structure in the blue box can be seen in the full data, 1/2 data and 1/4 data, but not clear in the 1/8 data. Interpolation was applied to all four datasets and Figure 2 shows the slices of the stack of all four datasets after interpolation. Footprints were eliminated by the interpolation, the signal-to-noise ratio is higher and images are cleaner for all four datasets compared to their own counterpart in Figure 1. Geological features in the yellow box were enhanced by interpolation for the full data; well recovered by interpolation for 1/2 data; recovered mostly for 1/4 data except some small details; but not able to be recovered for 1/8 data due to the extreme sparseness of the input to interpolation. However, the large structure in the blue box was successfully recovered by interpolation for even the1/8 data.

From the tests for this survey, interpolation recovered small geological features as small as 2-3 CMPs, which is close to the original receiver line spacing and 1/2 of the original shot line spacing, from slightly decimated data (1/2 data), but only recovered large scale geological features, >5 CMPs, from the heavily decimated data (1/8 data). Roughly speaking, images with interpolation can provide as much detail as that from a twice-denser survey without interpolation. Please note that these numbers are based on this particular 3D survey solely, and may vary in some degrees for other surveys. However, the principle remains that interpolation is able to recover some missing information and the sparser the acquisition geometry is, the larger the size of geological features can be recovered by interpolation.

Upsampling tests

Three different CMP bin sizes were used for the tests, (A) 60 x 60 m^2, (B) 30 x 30 m^2, and (C) 15 x 15 m^2. The average CMP fold decreased dramatically from 29 for size A to 8 for size B and only 2 for size C. Figure 3 shows the time slice of the stacks without interpolation for different CMP sizes. For this figure and Figure 4, screen pixel interpolation provided by the visualization tool was turned off on purpose in order to show the actual spatial resolution of the seismic data. There is no doubt the large bin size data provides blockier (or less spatial resolution) display. The image from size C (15 x 15 m^2) shows poor image quality, blurred geological features, and severe acquisition footprints.

Figure 4 show the time slices after 5D interpolation at the same time level as that in Figure 3. For the smallest bin size (size C), the quality of the image improved significantly from the non-interpolated data, and it shows more fine details compared to the image from size A.

Another benefit of interpolation is that it can eliminate acquisition footprints, remove random noise and improve the quality of seismic image, besides recovering missing geological features,

Conclusions

Through the decimation and upsampling tests, interpolation shows its power to improve the quality of the seismic image and recover some of missing data. The benefits of interpolation are: 1. elimination of acquisition footprints; 2. increase of signal-to-noise ratio and sharpness on final images; 3. most importantly, recovery of some geological features. The ability of structure recovery is largely dependent on the severity of the decimation. Interpolation can recover small features from lightly decimated dataset, but is only able to recover large structures from heavily decimated dataset. With a finer CMP grid incorporated with 5D interpolation, stacks in higher spatial resolution can be achieved due to minimization of spatial smearing.

Depending on the size of the features of interest, seismic surveys might be shot with a coarse geometry, e.g. regional surveys, to reduce the cost of acquisition. During the processing stage, 5D interpolation can be used to recover the structures that cannot be well imaged from conventional processing. From this decimation study, it is suggested that by using 5D interpolation, one can shoot less shots (1/2 – 2/3 total number of shots) compared to conventional acquisition design, and still get similar quality of final image. Crook et al (2013) discussed in detail the strategy of field acquisition design in combination with 5D interpolation in processing.

Acknowledgments

Thanks to BHP Billiton for the permission to use the data and publish this abstract.

Maximizing the value of sparse 3D seismic data by prestack trace interpolation

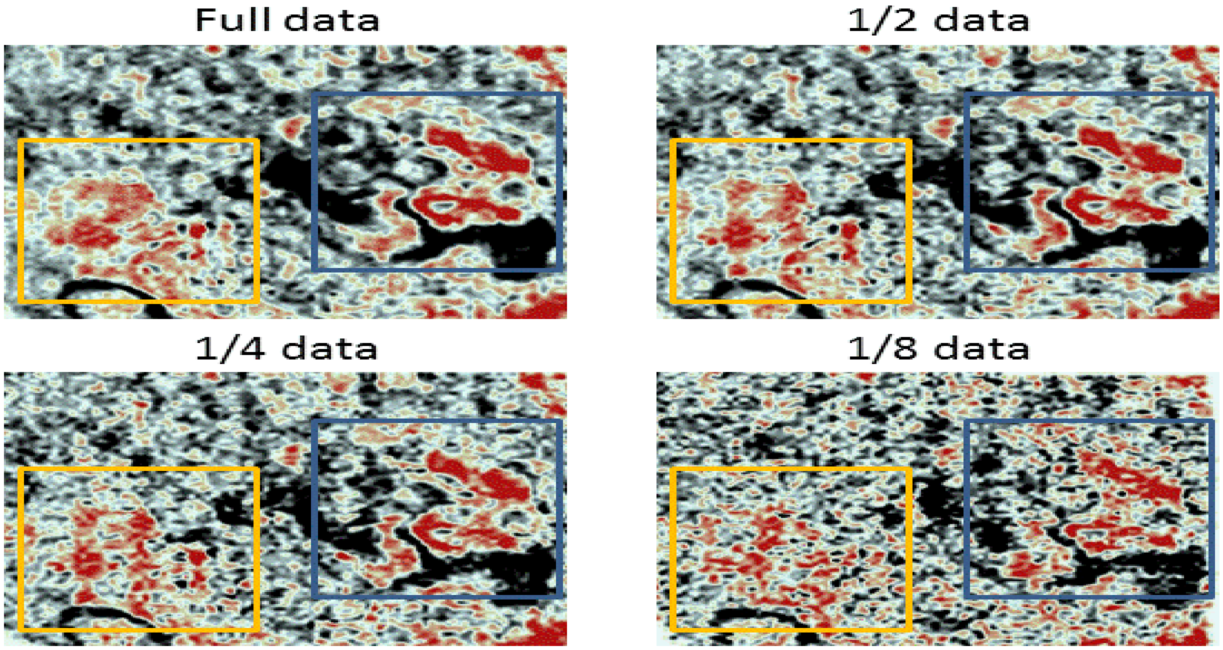

Figure 1: Slices of the stack of all four datasets without interpolation. All four slices have footprints to different degrees. The slice of 1/8 data is very noisy. Geological features in the yellow box can be seen in the full data but not in decimated datasets. Large structure in the blue box can be seen in the full data, 1/2 data and 1/4 data, but not clear in 1/8 data.

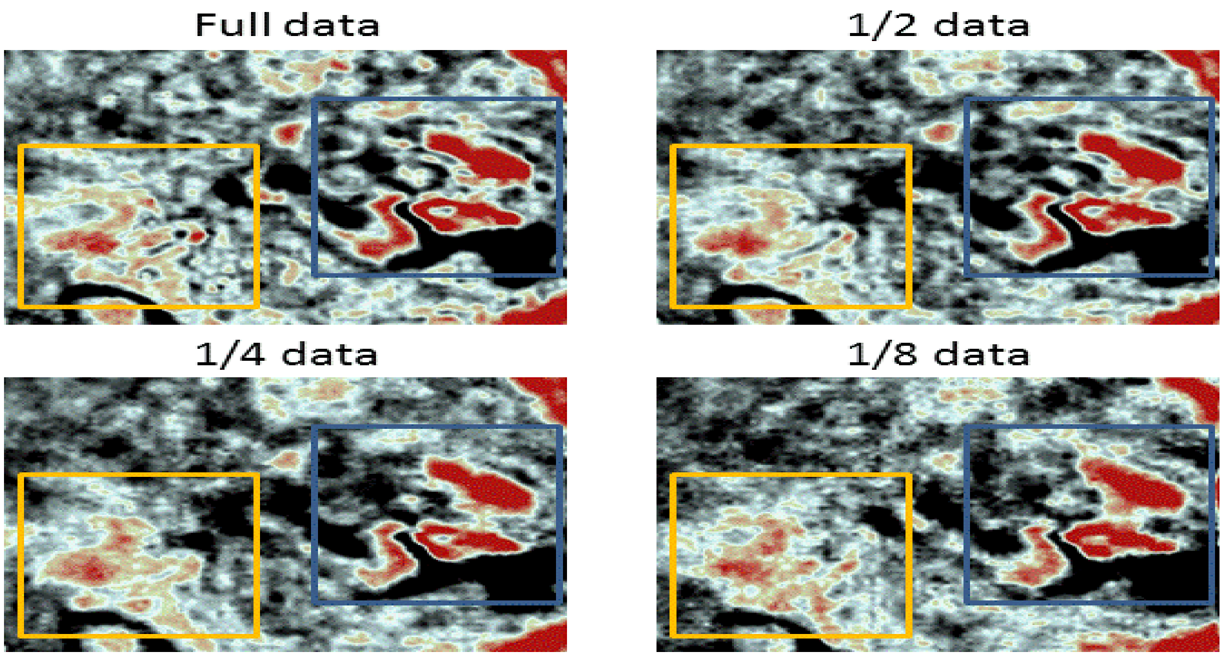

Figure 2: Slices of the stack of all four datasets after interpolation. Footprints were eliminated by interpolation; signal-to-noise ratio is higher and images are cleaner compared to Figure 1. Geological features in the yellow box were enhanced for the full data; well recovered by interpolation for 1/2 data; recovered mostly for 1/4 data except some small details; but not able to be recovered for 1/8 data. Large structure in the blue box was successfully recovered by interpolation for 1/8 data.

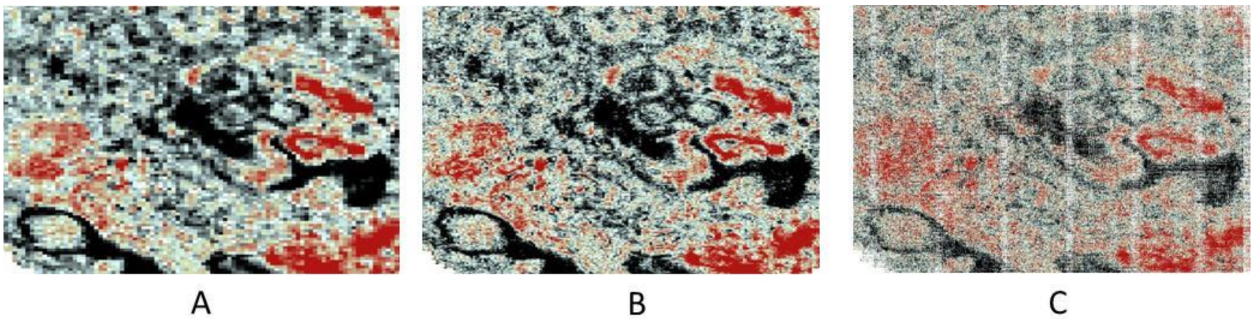

Figure 3. Time slice of the images before interpolation from different CMP bin sizes. A: 60 x 60 m^2; B: 30 x 30 m^2; C: 15 x 15 m^2. The screen pixel interpolation provided by visualization tool was turned off on purpose in order to show the actual spatial resolution of the seismic data. As the CMP size decreases, the noise level on the stacks increases. The image quality on the 15 x 15 grid is poor and has severe acquisition footprints.

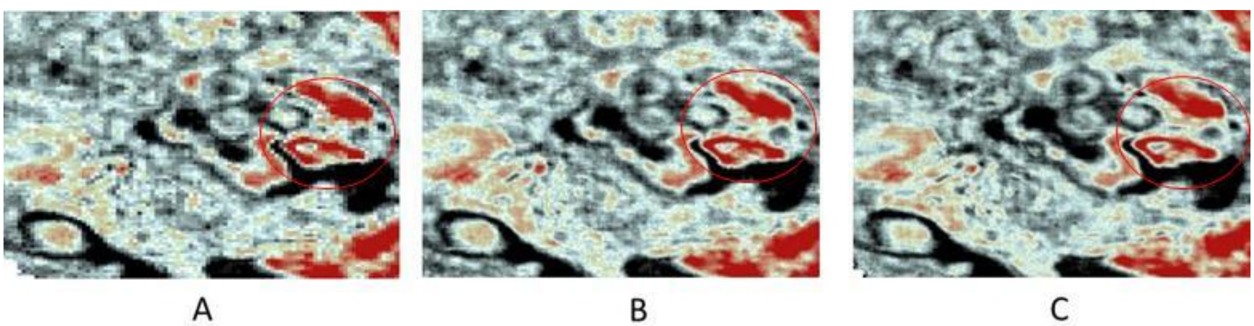

Figure 4. Time slice of the images after interpolation from different CMP bin sizes. A: 60 x 60 m^2; B: 30 x 30 m^2; C: 15 x 15 m^2. As Figure 3, the screen pixel interpolation provided by visualization tool was turned off on purpose in order to show the actual spatial resolution of the seismic data. After interpolation, images from all grid sizes are cleaner compared to that in Figure 3. Acquisition footprints were largely removed. The image from the finest grid (C) shows more detailed geological features (see inside of the red oval) compared to the images from A and B.