Prestack Interpolation of a Sparsely Acquired and Heavily Structured 3D Land Data Set

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Summary

Two different prestack interpolation methods, 5D interpolation by Fourier reconstruction and dip-scan-based data synthesis, are contrasted, compared, and cascaded on a sparsely acquired and heavily structured 3D land data set. Systematic testing reveals that cascading the two approaches gives good results which provide a combination of (i) regular upsampling along the crossline midpoint coordinate and (ii) gap-filling along certain shot and receiver lines which were truncated in the field because of the rugged terrain.

Introduction

Multi-dimensional interpolation by Fourier reconstruction, an algorithm originally conceived by Liu and Sacchi (2004) and first implemented in industry under the banner "5D interpolation" by Trad (2008), has begun to enjoy routine production use. In light of some recent well-documented successes (e.g. Perz et al., 2009; Hunt et al., 2008; Downton et al., 2010), there is a tendency within the industry to accept its output as a good reconstruction of the true traces that would have been recorded in the field in the ideal case with sources and receivers deployed at all missing data locations. While there is no question that 5D interpolation is an excellent technology, we emphasize that it is not different than any other processing algorithm in the sense that it is founded on a set of mathematical assumptions and therefore carries a set of limitations. Another very good prestack interpolation algorithm is based on a dip-scan analysis of coherent energy on neighbouring traces in shot and receiver gathers (Bardan, 1987). This dip-scan algorithm (which we term "DSINTERP") carries a different set of assumptions and limitations, and fortuitously enough it may work well in cases where 5D interpolation breaks down and vice-versa. The following real data example (to be bolstered by synthetic testing in the oral presentation) illustrates the relative algorithmic pros and cons of 5D interpolation and DSINTERP, and also shows how judicious cascading of the two approaches can give excellent results-- in effect combining the best of both worlds.

Theory and/or Method

5D interpolation entails posing an inverse problem which essentially seeks to compute an optimal set of spatial Fourier coefficients that at once reconstruct the existing (i.e., sparsely acquired) input traces and also exhibit certain properties of coherence in the frequency-wavenumber domain, where "wavenumber" is understood to comprise multiple spatial dimensions. At each temporal frequency, a separate inverse problem is posed in which the data space comprises the input traces described in four spatial dimensions (cmp-x, cmp-y, azimuth, offset, or cmp-x, cmp-y, offset-x, offset-y) , and the model space comprises the associated spatial Fourier coefficients. Once these coefficients are computed, the algorithm reconstructs traces at the missing locations. The main theoretical limitation of interest in this paper is the fact that the algorithm has problems performing regular upsampling along the midpoint coordinates in the case of spatially aliased data (e.g., Naghizadeh, 2010; Wang et al., 2010). Fortunately, this theoretical limitation is not always manifest on real data, possibly because the spatial sampling exhibits a random, as opposed to systematic, character in at least one of the four dimensions and/or because the data submitted to upsampling experiments often lack sufficient structure to exhibit the aliasing condition which gives rise to the problem. Our sparse real data example is an excellent candidate for probing the severity of this algorithmic limitation because the survey exhibits regular sampling in some places, and irregular sampling in others; moreover, the data are highly structured.

DSINTERP is a coherence-guided time-space algorithm which improves the sampling of 3D volumes by inserting new shots and receivers along existing shot and receiver lines. The algorithm identifies dominant dip directions via trial dip scan across neighbouring traces, and interpolated data segments are constructed by local slant stack along these dominant directions. Unlike 5D interpolation, DSINTERP is naturally suited for upsampling along midpoint coordinates; however, because it is a local technique which uses only a small number of adjacent input traces, it cannot infill large gaps along shot/receiver lines. By contrast 5D interpolation is a global technique which uses information from many traces across many spatial dimensions, so it can often do a good job of extending missing portions of acquisition lines.

Examples

The real data set under investigation is a sparsely shot 3D from the Canadian foothills. The sparse acquisition geometry suffers from two main problems: (i) the shot spacing (i.e., spacing along shot lines) is four times coarser than the receiver spacing, giving rise to a highly elongated natural cmp bin (specifically, 39 x 156 m); (ii) several shot and receiver lines have been truncated in the field because of access limitations associated with the rugged topography. In light of the relative algorithmic pros and cons discussed above, one reasonable approach is to use DSINTERP to decrease the shot spacing (and thereby upsample the crossline midpoint coordinate) in order to cast the data onto square bins (i.e., of size 39 x 39 m), and 5D interpolation to extend certain missing segments of source and receiver lines. Figure 1 shows a single inline from a structure stack of the original (i.e., "uninterpolated") data set cast onto the 39 x 39 m grid together with the associated surface map (inline is indicated by thick blue line in inset). Shots and receivers are shown by green and red dots, respectively (note the disparity in shot and receiver spacings). Areas of low fold are apparent on the section. Figure 2 shows the corresponding image after inserting an additional 3 shot stations in between existing ones (i.e., the shot spacing has been reduced by a factor of four) using DSINTERP, thereby reducing the natural cmp bin size from 39 x 156 m to 39 x 39 m. While DSINTERP has greatly improved image quality, it cannot infill a large chunk of missing shot line coverage (missing segment shown in black box in figure inset, and by black arrow in main pane), and low fold persists across many traces in the vicinity of the missing shot line. Figure 3 shows the result of cascading DSINTERP followed by 5D interpolation. For illustrative purposes, we parameterized the 5D interpolation algorithm in such a way that it manufactured new data along the single missing shot line segment only (thick green line in inset), and nowhere else--various alternative output data configurations and cascading strategies will be explored in the oral presentation. The additional uplift in image quality is modest but nonetheless visible, and is due to the fact that 5D interpolation has succeeded in synthesizing the missing segment of shot line.

There are many ways to combine the two methods to make full use of the power of interpolation. For example, one can further improve the image quality by inserting shot lines and receiver lines to increase the fold of CMPs and to improve the offset and azimuth sampling. Another idea is to switch the order of interpolation – use 5D interpolation first to regularize the data on the original grid and then use DSINTERP to upsample the data onto the finder grid. We are comparing different processing flows to find an optimal solution to the land data interpolation problem.

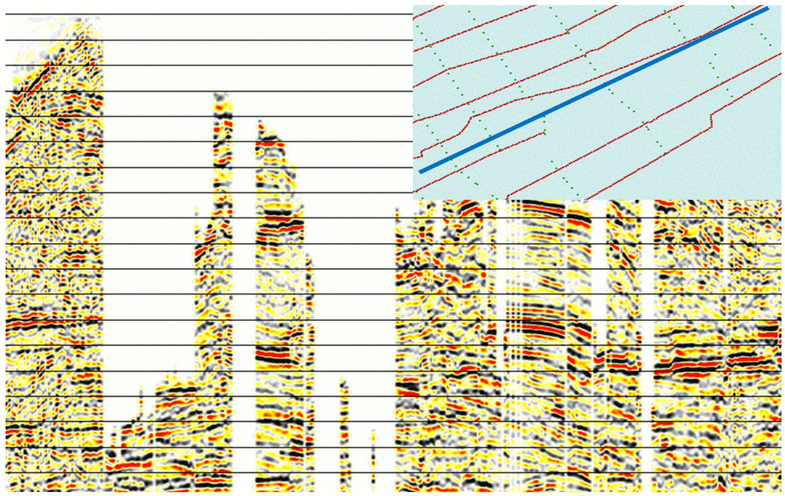

Figure 1: Structure stack of raw data (main) together with surface geometry map

(inset).

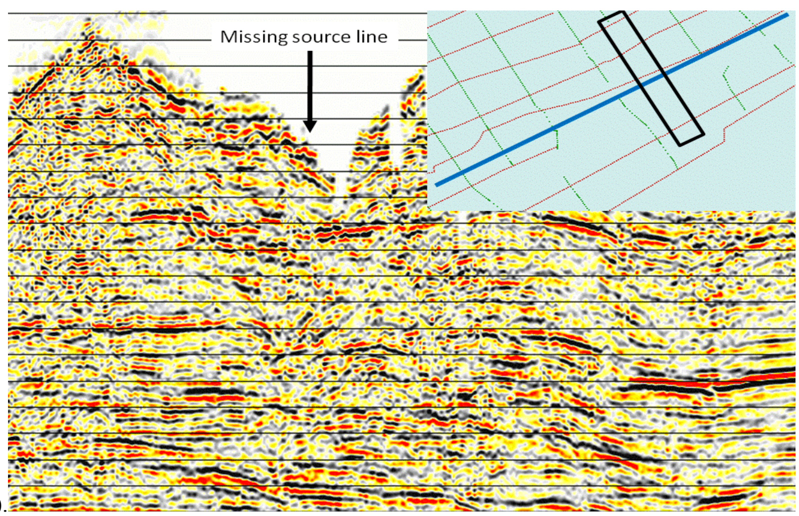

Figure 2: Structure stack of data after DSINTERP (main) together with modified surface geometry map showing inclusion of new shots along existing shot lines (inset).

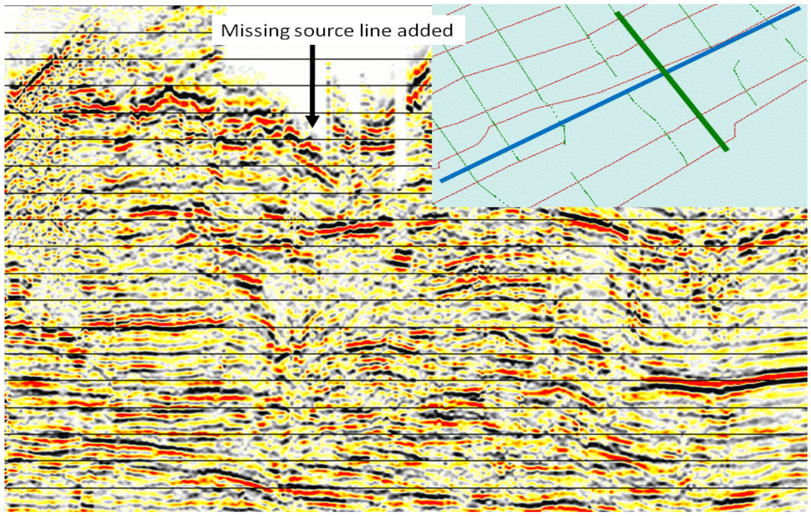

Figure 3: Structure stack of data after DSINTERP followed by 5D interpolation. Inset shows modified surface geometry map after inclusion of new shots along existing shot lines (via DSINTERP) together with inclusion of a previously missing segment of shot line (via 5D interpolation).

Conclusions

Both 5D interpolation and DSINTERP carry relative algorithmic advantages and limitations. We have found that judicious cascading of the two algorithms has given good results on a highly structured and sparsely acquired 3D land data set.

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