QC of a marine seismic trace reconstruction technique

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Summary

We present a methodology for QC-ing regularization programs on real data. The regularization under consideration is a 2D CRS-based technique for seismic trace reconstruction. The technique is based on estimation and interpolation of local kinematic attributes of reflection wavefronts. The QC shows that the technique is successful in regularizing datasets.

Introduction

3D marine or land recorded seismic traces are never located where the user would like them to be. This fact of life may be due to many causes and has always unpleasant consequences. From an acquisition point of view, gaps in the data due to obstacles on land and/or severe marine currents impact heavily on the economics of the survey. From a processing point of view, modern anti-multiple techniques require a density of sources that is simply too costly to achieve, at least with today acquisition prices and techniques. One can easily understand the consequences of large gaps in the data. But even when the data do not present gaps, the simple fact that traces are positioned randomly rather than in a regular way, can have unpleasant consequences when the processing algorithms require a regular sampling (the Kirchhoff integral is a typical example). In time lapse seismic there is an obvious relationship between the position of shots and/or receivers and 4D repeatability.

Interpolation of seismic data has been a subject of research for many years. The usual problems are related to the underlying assumptions, amplitudes, occurrence of spatial aliasing or the capacity to deal with crossing events. Without being exhaustive, it is of some interest to review some of the familiar techniques. Use of a linear prediction error filtering interpolation (Spitz, 1991) assumes that the data is recorded on a regular grid. Fourier reconstruction methods, perhaps the best understood, are independent of a particular model, but require in general some extrapolation technique of the lower, non aliased, part of the spectrum (Sacchi and Ulrych, 1996). Radon type techniques have in general problems with the amplitudes of the interpolated (or extrapolated) events and require an a priori velocity model (Trad, 2003). Techniques based on spatial predictability can interpolate beyond aliasing and are robust with respect to crossing events; however they cannot move traces from their random positions onto a regular grid. In general, the size of the gaps that can be filled by a particular technique and its relationship with the particular geological setting is unclear. A sure bet is to exclude from the interpolation “large” gaps. As a consequence, all the techniques described are not fully 3D, since considering the azimuth between source and receiver leads to input gathers with too large gaps.

The subject of this paper is the geophysical benchmarking of a particular interpolation method. The method is able to reconstruct traces on a regular grid. The method is defined in the CRS framework and is model free, in the sense that the kinematical parameters needed are computed directly from the data; the amplitudes of the reconstructed traces are simply interpolated. The dataset we start with is one overpopulated swath acquired during the monitor of an actual marine 4D survey. Two datasets are extracted, and then reconstructed on the same grid. Ideally, since the two data sets have been acquired during the same survey, the interpolation should lead to identical traces on the grid. Since testing in a direct way a regularization technique on real data is not straightforward, we believe that transforming a benchmarking problem into a repeatability study is a valid and original idea.

CRS trace interpolation

The interpolation idea consists of using a local second-order approximation for describing one wave front of the reflection events. In this way the local dips as well as the local curvatures of the reflection events are taken into account. For one sample \( t_c \) of an interpolated trace located in this data cube, we describe a local iso-phase surface by a second-order approximation:

\[
 t(\Delta x, \Delta h) = t_c + b \Delta x + h \Delta h + a_0 \Delta x^2 + a_1 \Delta x \Delta h + a_2 \Delta h^2 \tag{1}
\]

where \( \Delta x = x - x_c \) and \( \Delta h = h - h_c \) are the midpoint/shot and the offset relative coordinate, respectively. The parameters \( b_0 \) and \( b_1 \) represent the local dips in midpoint/shot gather and offset direction, respectively. The second-order derivatives, \( a_{00}, a_{01} \) and \( a_{11} \) determine together with the dips \( b_0 \) and \( b_1 \) the local curvatures of a reflection event. These parameters can be related to the wavefront curvatures (Zhang et al., 2001).
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Since simultaneous search of five parameters is difficult and costly, we use (Hoecht et al., 2003) a scheme that splits the search into three steps: two parameters search in offset direction, two parameters search in CMP direction and one parameter search in full prestack data set. To interpolate a trace at an arbitrary position, we firstly interpolate the kinematics from the parameters on the search grid. Using the interpolated parameters we construct a time surface using equation (1) and then compute the output trace by stacking the data along the surface. Figure 1 illustrates the proposed interpolation procedure.

The real data example

The survey from which the data is extracted has been acquired off shore in 2001. The acquisition geometry consists of “flip-flop” shooting and eight streamers 50 m apart, leading to a bin size of 6.25 x 12.5 m. The swath itself, of roughly 6 km long and 800 m wide, is made of 5 primary and 2 infill sail lines. The overpopulation is due to the presence of the two infill lines and of a general feathering of the order of 8 degrees.

After binning, the traces in the swath have been partitioned into two data sets according to the following rule:
1. if only one trace appears in one bin and in one offset class, that trace is copied in the two data sets,
2. if several traces are present in one bin and in one offset class, that trace with the closest azimuth to the previous (1999) base survey is copied in one data set, and that trace with the farthest azimuth is added to the other data set.

For clarity sake, we shall call one data set NA (near azimuth) and the other FA (far azimuth).

After resorting in shot domain, both NA and FA datasets have been processed using the regularization process described above. All the traces pertaining to a dataset and acquired with the same source and on the same cable have been reconstructed in the centre of the bin, the CDP line being located half way between the source and the streamer. After some trials performed in the CMP – offset domain, we have chosen the shot – offset domain as the best suited to the application of our technique.

Figure 1: Interpolation scheme: parameter search along offset and CMP directions (red lines) to calculate the desired trace (green line)

Figure 2: Distributions of input traces in the common shot-offset domain for the sail line number 2, port source and one inner cable. The shots are on the horizontal axis, the offsets on the vertical axis. The NA (FA) distribution is shown in the upper (lower) panel.
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At this stage we want to stress that under normal conditions, the shot domain is also the domain that displays the smallest holes for a 2D process, as long as the azimuth of each trace is ignored. However, the rules applied to the creation of the NA and FA datasets lead to huge gaps in this domain. Figure 2 illustrates the input to the reconstruction in the common shot-offset domain for one source, one streamer and one particular sail line. While NA displays gaps at large offsets, the FA shows also large gaps, mainly at short and middle offsets. Thus the exercise is also well suited to the appraisal of the reconstruction technique in the presence of large gaps in the coverage.

Results of the reconstruction process and the comparison between the 2 reconstructed volumes (NA and FA) have been analyzed both in pre-stack and post-stack domains.

Pre-stack appraisal of the interpolation radius. The first question arising is: with a given reconstruction method and geological situation, how large can be a gap in the data that can be filled? Tests on the actual datasets show that if in the neighbourhood of 60 m radius centred on an output trace there are less than three live traces, then that reconstructed trace has a noisy aspect. We have performed the regularization of the datasets with this 60 m value as a threshold. Nevertheless, the proximity of large gaps still impacts the reconstruction, as illustrated in figure 3.

Post-stack appraisal of the reconstruction outputs. We also compared the independently regularized NA and FA datasets in the post-stack domain. This comparison is not obvious. Indeed, due to the very dissimilar distribution of gaps in the datasets, and because all the gaps could not be filled by the regularization process, the FA and NA output data can show a different fold at a given CMP location. For the appraisal we have stacked in each bin only those traces that have been reconstructed on both datasets with the same offset. We have chosen the NRMS (energy of the difference between the NA and FA, normalized by the energy of NA) as the value that characterizes the similarity between the two datasets. We have also chosen to focus on two particular time windows. One includes only the water bottom, in order to minimize the incidence of any possible azimuthal anisotropy. The other one includes strong reflectors.

The similarity between the regularized datasets is strongly dependent of the fold coverage. This general result is illustrated in figure 4. Moreover, due to the particular construction of the datasets, we also found that the quality of the reconstruction also depends on other parameters, such as on the possible mixing of streamers, or sail lines in the same CMP.

![Figure 3: On the left, a portion of a NA reconstructed shot gather. On the right, the difference between the NA and FA portions of the same shot gather, on the same amplitude scale. The largest differences are found at traces located near large gaps.](image)

![Figure 4: Post stack comparison of independently regularized NA and FA. Panel on the left: one stacked line of NA data. Above, the CMP fold coverage; the variation range is between 25 and 50. Panel on the right: difference between NA and FA stacked line on the same amplitude scale. Above, the NRMS attribute computed in the two time windows indicated by the arrows. The range of NRMS variation lies between 25%, on the left of the section, and 4%, on the right of the section.](image)
mostly data from a primary line, while the other dataset displays mostly traces pertaining to the infill acquisition. We have also tried to assess the impact of using a procedure that neglects the azimuth. For that we have looked at those CMPs that contain for one dataset (say NA) data from an inner streamer, while on the other dataset (FA) mostly traces recorded with an outer streamer. While reconstruction analysis in prestack domain shows some differences, the stacked traces show again that the similarity is mostly dependent on the stacking fold.

Discussion and conclusions

We have presented the results of benchmarking a particular regularization technique based on 2D common offset CRS. This reconstruction technique is velocity model independent and it uses local wavefield kinematic parameters estimated directly from seismic data. The regularization is performed in the common shot-offset domain.

The numerical results show that, starting with randomly located traces, the method is able to correctly reconstruct traces into a regular grid. The presence of large gaps in the coverage impacts strongly on the performance of the regularization. The proposed technique is not able to replace a large amount of infill acquisition. Nor do we anticipate it to be able to reconstruct the missing shots necessary to transform a standard 3D acquisition into the one needed for the application of advanced methods for the prediction of the multiple wavefield. However, when holes in the acquisition have to be filled, we expect this regularization technique to be useful as a pre-process to other techniques that require the data to be already regularly sampled, such as the PEF based interpolation (Huard and Spitz,1998).

Time lapse seismic offers an obvious application domain to regularization. Indeed, in areas with strong and unpredictable currents, even the most advanced acquisitions cannot guarantee the navigation repeatability. In areas of subtle 4D signal the impact of navigation can be important. The ability of the regularization technique to reconstruct traces acquired with various acquisitions on the same position looks promising, although its insensitivity to azimuth is a matter of concern.

Apart the relative inability to deal with large gaps, we think that the main limitation of the technique is its blindness to azimuth, which restricts its application to data acquired with polarized geometries and in geological areas that display only small angular anisotropy. The regularization of cross spread geometries, as well as the regularization of data in strongly inhomogeneous areas, will require more sophisticated 3D implementations together with acquisition geometries less sparse in azimuth.

Because we have experimented only with one data set, these conclusions are only preliminary. Some more work is needed in order to assess the usefulness of the proposed regularization.

References


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EDITED REFERENCES

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