D031 SEISMIC DATA INTERPOLATION USING LOCAL WAVE FIELD CHARACTERISTICS

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Introduction

Data interpolation in a classical sense means to generate unrecorded data from measured data that are, in general, irregular distributed in a data space. This problem has been widely investigated and solved for different applications. For seismic reflection data an additional difficulty occurs. Not all recorded samples pertain to actual reflection events where an interpolation makes sense. Additionally, the recorded wave field consists of different events, each of them is distributed along its own iso-phase surfaces. Each of these surfaces has to be treated separately in the interpolation. Different strategies are used to overcome this problem: for instance the use of a linear prediction error filtering interpolation (Spitz, 1991) or an interpolation derived using the Cauchy criterion to obtain a high resolution sparse discrete Fourier transform (Sacchi and Ulrych, 1996). The latter method estimates an operator that acts locally but is constructed by a global minimization.

The parabolic and hyperbolic Radon transforms have been widely used as a tool for data interpolation. The quality of the results depends on how well the data satisfy the assumption of hyperbolic moveouts. The idea of a hyperbolic Radon transform with the apex location as an extra parameter was proposed recently by Trad (2003).

Here, we present an interpolation method for 2D seismic reflection data that is based on the common-reflection surface method for finite offset (Zhang et al., 2001). From a 2D acquisition we get a 3D (*x-h-t*) data cube, where, in general, the prestack data are either arranged in common-shot (CS) or common-midpoint (CMP) gathers. In the following, x denotes either the midpoint or the shot position, h the offset and t the time. Our interpolation operator is estimated and acts locally in prestack (*x-h-t*) domain. The basic idea is to fit locally a second order surface to the seismic events for each sample of a trace that has to be interpolated. A subsequent weighted stack along this surface achieves the interpolation. The presented method is supposed to be more accurate and stable than the methods based on a single local dip estimation.

Theory

For a sample $\hat{t}$ of an interpolated trace located at $(\hat{x}, \hat{h})$ in this data cube, we describe an iso-phase surface in the prestack data locally by a second-order approximation as follows:

$$t(\Delta x, \Delta h) = \hat{t} + b_0\,\Delta x + b_1\,\Delta h + a_{00}\,\Delta x^2 + a_{01}\,\Delta x\,\Delta h + a_{11}\,\Delta h^2\,. \qquad (1)$$

Here, $\Delta x = x - \hat{x}$ is the midpoint (or shot) coordinate and $\Delta h = h - \hat{h}$ the offset coordinate relative to the interpolated trace. The parameters b_0 and b_1 represent the local dips in midpoint (or shot) and offset direction, respectively. They are related to the wavefront (ray) direction at the shot and receiver positions of the interpolated trace by the near surface velocity. 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. They can also be related to the wavefront curvatures of different observation configurations (common-shot, common-receiver or a hypothetical common-midpoint experiment) (Zhang et al., 2001).

Practical application

In practice, we consider each sample $\hat{t}$ of an interpolated trace as part of a potential reflection event. This means that an iso-phase surface has to be fit to each sample regardless of whether an actual reflection event passes through the point or not. For the fit, we calculate the coherence (semblance) along surfaces constructed for different parameter sets (b_0, b_1, a_{00}, a_{11}, a_{01}) and choose the one with the highest coherence. This implementation requires the determination of the five unknown parameters which is both nontrivial and costly. Instead of a five-parameter global search optimization we choose to split the search into several steps and to perform a full search of the parameters at each step. To explain these different steps let us consider an arbitrary chosen constant offset $\hat{h}$.

Step 1. The first step consists in using formula (1) in each (CS or CMP) gather of the prestack data. For one gather formula (1) reduces to

$$t(\Delta h) = \hat{t} + b_1\,\Delta h + a_{11}\,\Delta h^2\,. \tag{2}$$

The two unknown parameters b_1 and a_{11} can be estimated either by two one-parametric searches or a single two-parameter search using one gather. Performing the search for all gathers (i.e. for all CS or CMP positions) along the profile, we estimate the parameters b_1 and a_{11} for each sample of the traces pertaining to the offset $\hat{h}$. A subsequent local stack along the curves given by eq. (2) in each gather provides a common-offset section for the offset $\hat{h}$.

Step 2. At the second step we use this simulated common-offset section as input data for the search of b_0 and a_{00} by using formula (1) for one offset:

$$t(\Delta x) = \hat{t} + b_0\,\Delta x + a_{00}\,\Delta x^2\,. \tag{3}$$

Again, we can use either two one-parameter searches or a single two-parameter search for a sample $\hat{t}$. In general, two one-parameter searches are sufficient at this stage because the input common-offset section is provided by a local stack, hence, with better signal-to-noise ratio than the prestack data.

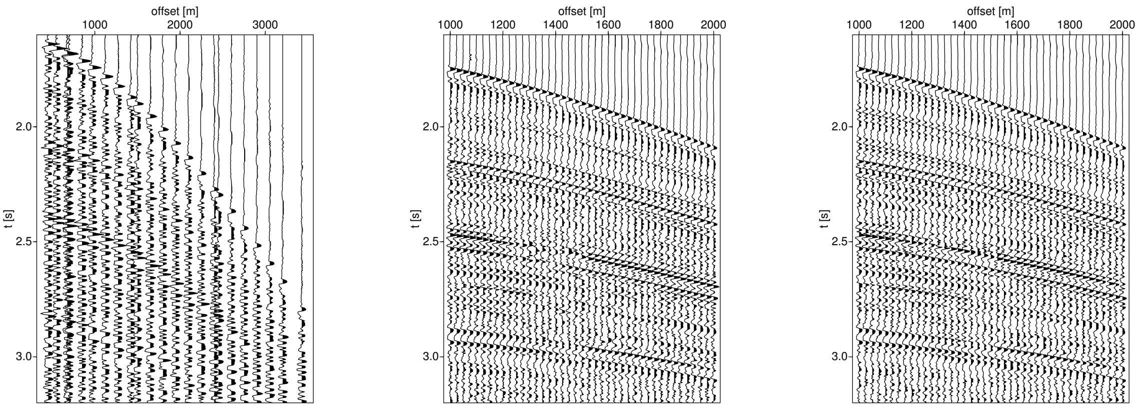
Step 3. The third step consists in determining the remaining unknown parameter a_{01} for each sample $\hat{t}$ of every trace for the chosen offset $\hat{h}$. Therefore, we use formula (1) in the prestack data with the known parameters b_0, a_{00}, b_1 and a_{11} from the first and second step in order to derive the mixed derivative a_{01} by a one-parameter search.

Repeating this procedure for different common offsets we obtain a grid that is chosen in offset direction and predetermined by the input CMP or CS gathers of the prestack data. Every sample of each trace on this grid point now carries the information of the local second-order approximation by means of the parameters. Note, that the grid spacing for the search should stay reasonable. One will not acquire new information by searching on a grid that is so fine that neighboring grid traces use the same data traces for the search. Therefore, we use a grid spacing in offset direction that has the same order of an average trace distance in a CS or CMP gather of the data. However, the obtained grid must not be the final one if the offset spacing is to sparse or an interpolation between CS or CMP gathers is desired. Let us consider the desired output grid which does not necessarily coincide with the search grid. Firstly, we interpolate the parameters estimated on the sparse search grid to the finer output grid. Finally, the parameters on the output grid are used to construct locally the surfaces along which we perform a weighted stack to interpolate the traces on the output grid. A weighted stack within a small aperture respects the local behavior of the prestack data and preserves the local information. Stacking along a larger aperture clearly increases the signal-to-noise ratio and can be used for signal enhancement. Information on local dips, curvatures and coherency, is available from the parameters and can be used for different applications.

Examples

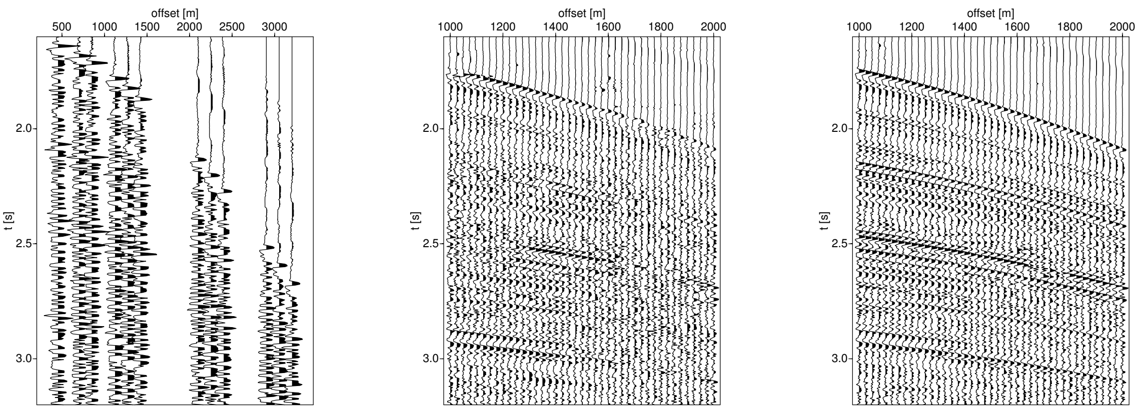
We illustrate two applications of the proposed interpolation method on real data and investigate the effect of using different parameter estimation strategies in the first step, namely, two one-parameter searches versus one two-parameter search. The parameter search grid spacing in offset direction was 100m, and the output trace spacing in offset direction was chosen 25m. The final local stack for interpolation uses only three neighboring traces in the data. For the illustration, we confine ourselves to the interpolation result for one CMP gather.

Figure 1a) shows a CMP gather of the prestack data. Figures 1b) and c) show the interpolation results using a separate and a simultaneous parameter search for the parameters b_1 and a_{11}, respectively. One can observe regions where the interpolation using a separate parameter search provides less good results compared to the simultaneous search. The reason is connected to an inaccurate dip estimation (parameter b_1). For sparse data, the advantage of simultaneous dip and curvature search is even more obvious. Figure 2a) illustrates a CMP gather with large gaps between the traces. Figures 2b) and c) show the results of the interpolation using a separate and a simultaneous search, respectively. A large search aperture is required in order to get enough input traces for the parameter search. However, the assumption of a linear behavior of the reflection events in such a large aperture is no longer valid. Therefore, a single dip estimation can not afford this situation.



a) b) c)

Figure 1: real data example: a) original CMP gather of the prestack data, b) interpolated CMP gather using a separate search of the parameters b_1 and a_{11} in the first step, c) interpolated CMP gather using a simultaneous search of the parameters b_1 and a_{11} in the first step.



a) b) c)

Figure 2: real data example with large gaps: a) original CMP gather of the prestack data, b) interpolated CMP gather using a separate search of the parameters b_1 and a_{11} in the first step, c) interpolated CMP gather using a simultaneous search of the parameters b_1 and a_{11} in the first step.

Conclusions

The proposed interpolation method is based on an accurate estimation of local properties of the prestack data. It is achieved by using a local second order approximation for seismic events. Therefore, we do not assume global hyperbolicity of coherent seismic events in CMP domain. A simultaneous two-parameter search of local dip and curvature in a single CMP or CS gather allows to increase the aperture for the search. This is computational more expensive, but provides more stable and reliable results on the estimated parameters. It is especially important for noisy and sparse data.

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