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Pre-Stack Wavefield Interpolation for 3-D Acquisitions

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Abstract

Interpolation of pre-stack data is a key processing tool for the reduction of the acquisition costs and it is generally required when the wavefield sampling needs to be densified along shot and/or receiver; higher wavefield sampling is required for noise suppression algorithms (e.g., ground-roll or multiples elimination). Irregular and sparse sampling of the wavefield in 3D surveys generates spatial aliasing: wavefield interpolation by wave-equation based techniques can yield densely sampled data when they operate in a suitable domain where sampling is more regular and it can be easily densified.

The shot continuation operator (3D SCO) is a pre-stack operator to interpolate 3D acquisitions when the data are sorted in common shot. The testing has been carried out on synthetic 3D data belonging to the SEG-EAGE Overthrust 3D Model: the two different examples discussed here simulate land and OBC acquisition. For regularly sampled wavefield the interpolation accuracy of 3D SCO is comparable with other methods (e.g., predictive technique), most of the advantages arise when the sampling geometry is not regular as the 3D SCO follows a Kirchhoff-type implementation. In any case, 3D SCO interpolation shows negligible residuals even in presence of complex tectonics.

INTRODUCTION

Interpolation of seismic data can be a useful method to reduce costs of seismic acquisitions, while improving the performances of those processing algorithms that cannot cope with coarsely sampled or aliased data. Nowadays, 3D seismic surveys usually yield irregularly sampled data that need regularization. Then, different approaches must be used to plan cost-effective acquisition in different environments (e.g., land surveys versus Ocean Bottom Cable acquisitions). The interpolation method investigated here, based on wave equation, allows to interpolate irregularly sampled seismic data by estimating a common shot gather from neighboring common shot gathers. This task is carried out according to a known velocity model.

THE 3D SHOT CONTINUATION OPERATOR

The 3D SCO is a pre-stack operator developed to estimate a common shot gather (CSG) from neighboring CSGs for 3D acquisition geometries; the estimation is performed according to a specified velocity model (Spagnolini and Opreni, 1996). 3D SCO can be specialized in any domain (e.g., offset and azimuth) and it can be viewed as a generalization of the well-known DMO (or continuation to zero offset). The 3D shot continuation operator can be basically described as the chain of two steps: the migration of one common shot gather, say S_1, and then the demigration to a displaced common shot gather S_2. It is important to stress that the Kirchhoff-type integral implementation permits to handle irregular sampling, usually encountered in real data (Bagaini and Spagnolini, 1996). The 3D SCO is space and time varying. However, its aperture is smaller than calculating explicitly the two steps of migration and demigration: 3D SCO is computationally cheaper.

Similarly to DMO, the kinematics of 3D SCO can be (logically and practically) divided into two parts:

1. NMO correction of the Common Shot Gathers (CSG) with a known velocity model;
2. Structural shot continuation (also referred to as SMO – Shot Moveout), that depends only on geometrical parameters and it is independent on velocity.

The 3D SMO is space-variant but time-invariant operator, this latter property greatly reduces the computational cost of the operator when applied to large dataset. In addition, the equivalence 3D SCO = NMO+3D SMO allows to handle variable velocity model similarly as for DMO.

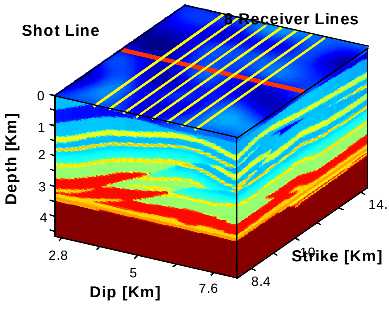


Figure 1. The velocity model of the SEG/EAGE Overthrust model for the selected area.

OVERTHRUST 3D MODEL: A4 “PATCH” ACQUISITION

Extensive testing has been carried out on synthetic data belonging to the Overthrust 3D Model. This SEG-EAGE model represents a useful benchmarking tool for 3D processing algorithms. The selected dataset, called “A-4 Patch”, simulates a 3D acquisition, with a single line of shooting laid down over the faults (called "Dip line"). The spacing of shots is 50 m. 8 receiver lines (line spacing is 300 m) are orthogonal to the shot line: distance between receivers is 50 m, and the distance between lines is 300 m (Figure 1). The choice of this 3D dataset permits the validation of the continuation algorithm with 3D data that show a complete azimuthal range, and the comparison of interpolation results obtained with a completely different approach. Examples reported next are selected from the faulty zone (detailed view of the velocity model is in Figure 1) of the Overthrust Model. The presence of strong dipping events (i.e. aliased data) and complex tectonics propose this model as a severe task for interpolation techniques.

EXAMPLE: SHOT DENSIFICATION FOR LAND SURVEY

The most effective way to reduce costs in land acquisitions is by reducing the number of shots. So 3D SCO will be first used to double the shot number. Shot spacing of the original dataset is 50 m: every other shot has been taken out, then the removed shots have been interpolated so the results can be compared with the original ones. A crossline view of one cross-spread of the decimated dataset and its *f-k* spectrum (Figure 2) shows some aliasing problems. Therefore, the interpolation will have to dealias the dataset. 3D SCO processing is shot oriented, here we have chosen to estimate each missing common shot gather starting from the two nearest common shot gathers, as this choice leads to a lower sensitivity to the knowledge of the velocity model. Result of 3D SCO interpolation can be hardly distinguished from the original removed CSG (that is our reference): the best way to understand 3D SCO potentialities is to show (displayed with the same amplitude scale), the interpolated result along with interpolation error (e.g.: Original CGS minus Interpolated CSG). The low amplitude of the residual (Figure 3) illustrate how the interpolation task has been correctly achieved (result is almost correct both cinematically and dynamically). The position of the selected shot (4800 m) is directly over the most complex faulty zone of the model, in presence of strong dipping events.

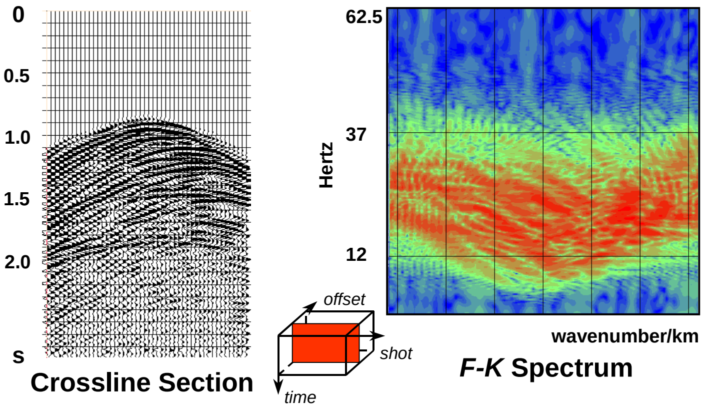
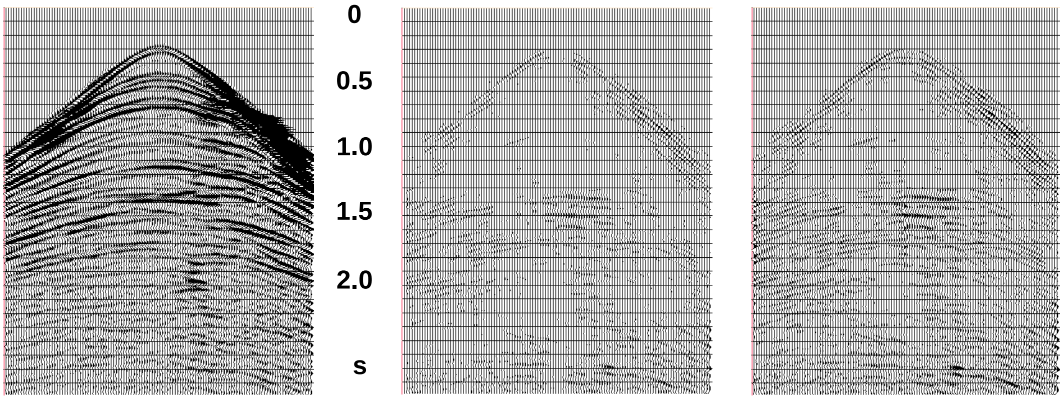


Figure 2. The decimated (• S=100 m) dataset. **Left:** one section of a selected cross-spread. **Right:** the aliased *F-K* spectrum.

Interpolation of shots (from ΔS=100 m to ΔS=50 m) has been carried out using also a completely different technique, that exploits the spatial predictability of the wavefield as parameterized by one (or more) plane events (Spitz, 1991). In fact, the algorithm is based on prediction error filtering (PEF): it’s model independent (while the NMO correction of 3D SCO depends on a velocity model), but it has a simple form only when traces are located on a regular grid (in this case, interpolation problem can be solved without any attempt of explicitly calculating true dips of seismic events, solving two linear systems). It can be seen as a two step algorithm: first, the prediction error filter is computed from known data; then, interpolated traces are computed from known traces and prediction error filter. The algorithm has been efficiently implemented in the *f-xy* domain. This algorithm is expected to interpolate spatially aliased events correctly. As the residual traces (in Figure 4) state, even with this technique interpolation achieved its goal that is the correct dealias the dataset. Comparision between the two results show that 3D SCO interpolation error energy is lower than PEF interpolation error energy. However, the two different techniques have a similar computational cost (CPU_{SCO}~$3CPU_{PEF}$). This is indeed interesting, because one technique is based on wave equation (3D SCO), while the other (PEF) is not (Mazzucchelli et al, 1998).



Original CSG **3D SCO Interp. error** **PEF Interp. error**

Figure 3. The CSG (S_{DIP}=4800 m) is shown. **Left:** reference CSG (missing in the decimated dataset). **Middle:** the resulting interpolation error of 3D SCO interpolation. **Right:** the interpolation error of PEF *f-xy* method.

Another way to appreciate the quality of 3D SCO interpolation is to show time slices for the same cross-spread at different times: the residuals (negligibly small for practical purposes with both methods) demonstrate how wavefield reconstruction is almost correct both for shallow and deeper times (Figure 4).

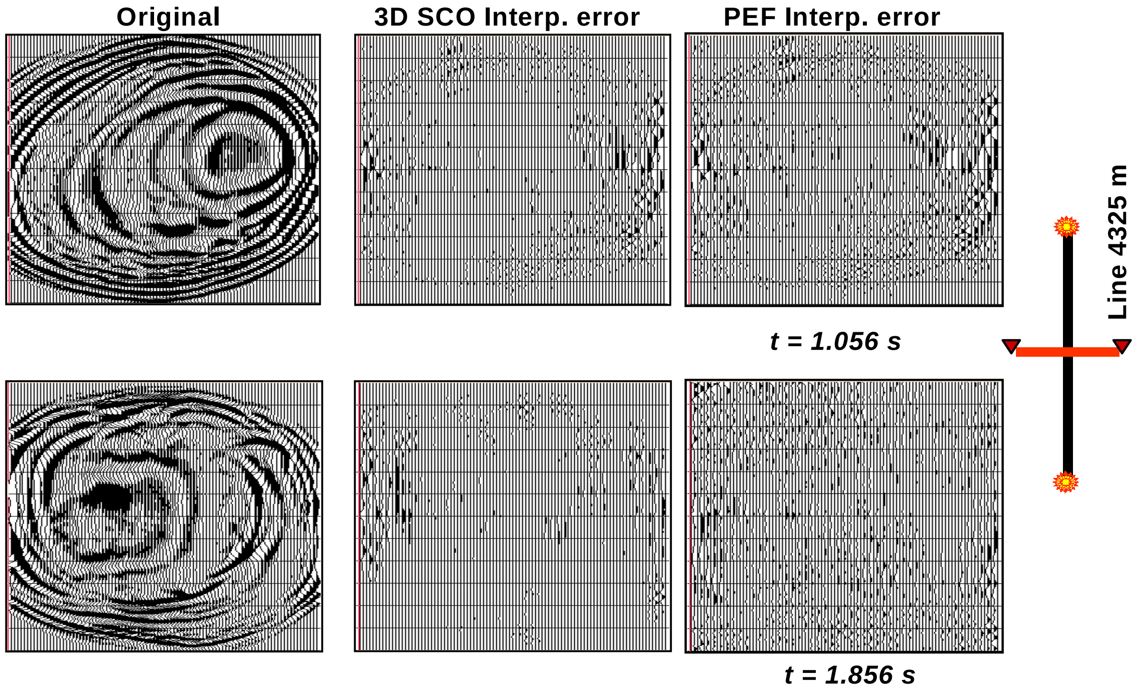


Figure 4. Time slices of one selected cross-spread are shown: interpolation is good even for deep events directly under the faults, for both the methods.

EXAMPLE: RECEIVER LINE DENSIFICATION FOR OBC ACQUISITION

The same A4 “Patch” dataset can be interpreted as part of an Ocean Bottom Cable (OBC) marine acquisition. In an OBC-type survey, the reduction of costs requires the reduction (and then the interpolation) of receiver lines laid down in deep water. Therefore, we performed the interpolation of A4 dataset receiver lines, halving their original space (from 300 m to 150 m). Due to large intervals between receiver lines, these data show a severe aliasing. No direct comparison with original data can be made for this example: the best way to evaluate the quality of the interpolation is to show CSG (figure 5) and time slices (figure 6) selected from three cross-spreads (e.g. the interpolated cross-spread, and the two neighboring ones at distance of 150 m). Visual inspection assures the correctness of 3D SCO interpolation for this example: results are encouraging even in presence of complex tectonics and of aliased events. Interpolation is still performed in Common Shot domain, so there’s no need of any (expensive) data sorting before applying the operator

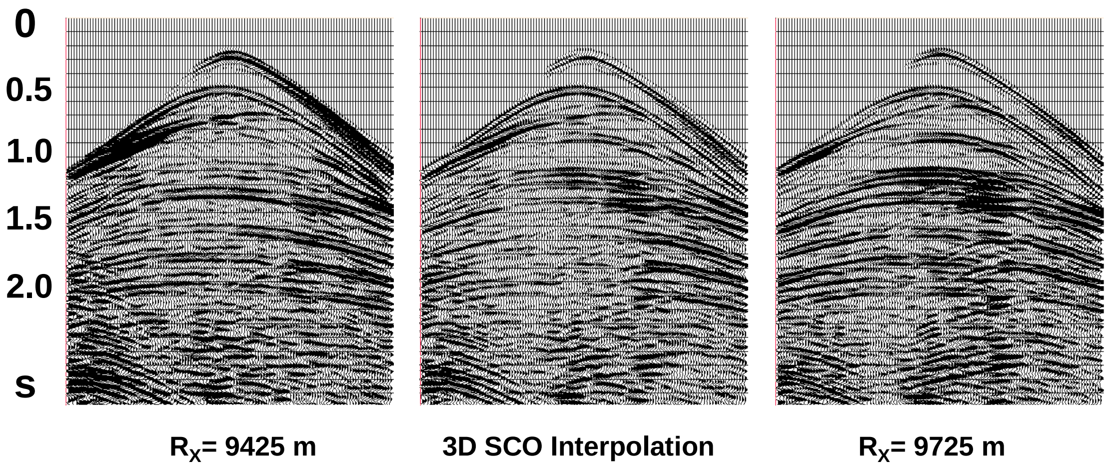


Figure 5. Three near receiver lines for the same selected shot: the interpolation quality of the middle receiver line needs to be achieved by the visual inspection of events continuity.

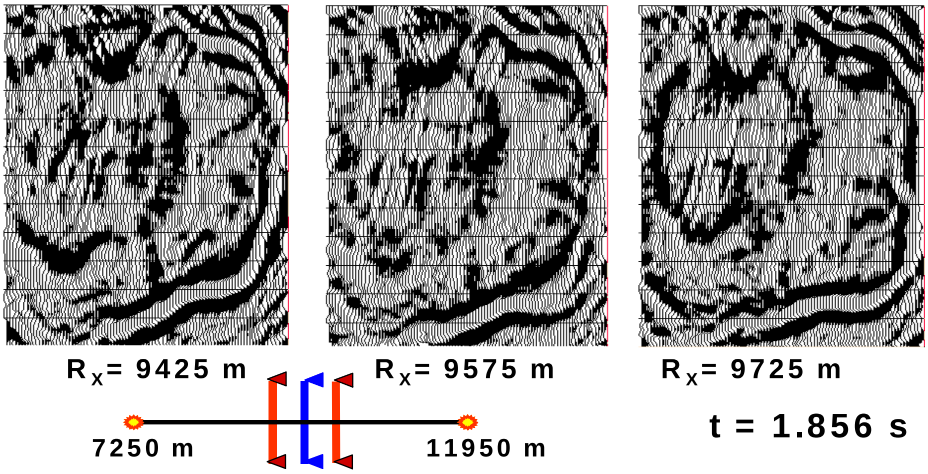


Figure 6. Three time slices from near receiver lines cross-spreads. Only deep time (t=1.856 s) is shown.

CONCLUSIONS

The examples shown here demonstrate the potentialities of 3D SCO as an interpolation technique: residuals show little energy, even if data are coarse sampled and show aliasing problems. Our testing demonstrated that 3D SCO interpolation is reasonable (i.e. interpolation error is below 10%) even if the error in the velocity model is approx. 5%-10%. Similarly to other methods (PEF) 3D SCO allows the densification of shots; however it is feasible even for OBC-like geometries, without any data reordering (3D SCO always operates in Common Shot domain). Thus, because of its ability to handle irregularly sampled data, 3D SCO demonstrates to be a very interesting tool to process 3D seismic data. Similarly to any interpolation method a careful pre-processing can improve interpolation results as coherent noise and statics can degrade their performances.

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