Processing orthogonal geometry – what is missing?

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Summary

The differences in properties between parallel geometry and orthogonal geometry call for different approaches to various prestack processing steps. Indeed, a number of authors have published results of prestack processing of orthogonal geometry data on basis of geometry-oriented approaches, such as 3Dfk-filtering of cross-spreads. Yet, this treatment of orthogonal geometry is far from being standard in the industry.

This paper discusses the potential of using both cross-spread oriented and offset-vector oriented prestack processing operations. In cross-spread oriented processing the spatial continuity inherently present in cross-spreads is exploited as much as possible. In offset-vector oriented processing the data is gathered according to small ranges in the components of the offset vector rather than in absolute-offset ranges as being used predominantly in the industry. In this way, the typical wide-azimuth nature of orthogonal geometry is better taken care of.

Introduction

The two major types of 3D acquisition geometry being used in the industry are parallel geometry and orthogonal geometry. Parallel geometry data are acquired with marine streamer configurations, whereas orthogonal geometry data are acquired on land and in OBC work.

The properties of these two types of geometry are different. Parallel geometry is intrinsically narrow-azimuth geometry, whereas orthogonal geometry is suitable to acquire wide-azimuth data. For parallel geometry data it is possible to create low-fold regular coverage by selecting a small range of absolute offsets, whereas in orthogonal geometry such a selection would provide highly irregular fold-of-coverage.

Yet, the surprising observation can be made that current processing techniques hardly make a difference between the data acquired with the different geometries. Many processing steps are either shot oriented or midpoint oriented, which might be applied to both types of acquisition geometry. Other processing steps are absolute-offset oriented which do not make sense for orthogonal geometry, yet they are being applied to such data quite frequently.

Orthogonal geometry data processing would benefit from cross-spread oriented and offset-vector oriented processing steps. Only a few companies seem to have discovered the need for processing steps that are specific to orthogonal (or other crossed-array) geometries. Examples are CGG who has published several papers showing the benefit of 3Dfk filtering (Girard et al, 2002; Galibert et al, 2002; Karagül et al, 2004) and WesternGeco who demonstrated cross-spread oriented noise-removal techniques (Quigley, 2004; Shabrawi et al, 2005). Yet, these applications seem to be incidents rather than a systematic answer to the question: what can we do to optimally process the data acquired with orthogonal geometry?

This paper makes an inventory of processing steps that could be improved by taking into account the properties of orthogonal geometry. This inventory is a partial extension of ideas published earlier in Vermeer (2002). First, cross-spread oriented processing steps are reviewed followed by offset-vector oriented processing steps.

Cross-spread oriented processing

The data acquired with orthogonal geometry can be considered as a collection of cross-spreads (Vermeer, 2002). Each intersection of a source line and a receiver line forms the center of a cross-spread. The dense sampling of the sources along the source line and of the receivers along the receiver line creates a dense single-fold areal coverage.

The midpoints of traces with the same absolute offset are located on a circle with diameter equal to that offset. Therefore, the first arrivals of the ground roll are lying on the surface of a circular cone. Hence, the ground roll in a cross-spread behaves as a truly three-dimensional event and can best be removed by a 3Dfk-filter. Karagül et al. (2004) demonstrated that this 3D filter performs considerably better than the cascaded application of two 2D filters. (It should be noted that their result actually pertains to slanted geometry rather than orthogonal geometry. Obviously, in slanted geometry, a 3Dfk filter can also be used successfully, but "slanted cross-spreads" are much more difficult to deal with.)

The spatial continuity of the midpoint area of a cross-spread offers great potential for prestack processing steps that may exploit similarity between neighboring traces. Next to 3Dfk-filtering, other examples are:

- ambient noise removal,
- interpolation of missing shots or receivers,
- time-shift measurements for first-break and residual statics picking,
- redatuming,
- migration operator derivation.

Ambient noise may be entirely random or it may be coherent in the common shot domain and random in the common receiver domain. Existing noise removal techniques such as *fxy*-filtering and even median filtering can be applied optimally in the cross-spread domain. Quigley (2004) shows an example of noise removal in the cross-spread.

Interpolation. A missing shot constitutes a missing cross-section in all cross-spreads that would have listened to that shot. However, in the common-receiver gathers of those cross-spreads the missing shot only constitutes a single trace that can easily be interpolated (although a real shot is always better than an interpolated shot, of course). Irregular sampling may also be regularized in the cross-spread, provided there are no spatial discontinuities in the sampling of shot and receiver lines.

Time-shift measurements. Perhaps one of the most promising applications of cross-spread oriented processing is the measurement of time shifts between traces for first-break measurements and for residual statics computations. Eight near neighbors surround each inside trace in a cross-spread. All those neighboring traces are very similar to the central trace, hence accurate time shifts can be measured with each of those eight neighbors. The time shifts of each of those neighbors can be measured in turn with their nearest neighbors. Carrying out the time-shift measurements in this way leads to a highly redundant interlocking mesh of time shifts. The sum of all time shifts along any closed loop of traces should be equal to zero. The areal redundancy in time-shift measurements offers a great way of identifying loop skips or any other mispicks. This means that the collection of time shifts to be fed into the statics computation procedure will be cleaner and more accurate than the time shifts measured with conventional techniques.

Usually time shifts between traces are measured in a one-dimensional way, in common shot gathers for first-break picking or in bin gathers for residual statics. Cross-spread picking provides an areal way of time-shift measurement in which only traces are compared with each other that are very similar. A perceived disadvantage of cross-spread oriented picking might be that the measured time shifts are not only caused by statics but also by residual moveout and by structure. However, the properties of these effects are different and allow separation of the different contributions. The velocity and structure effects should behave in a smooth way across the cross-spread, whereas shot and receiver statics will cause the time-shift surface to be jittery. A first estimate of the shot and receiver statics can be found by removing the jitter from that surface.

Often good quality time picks cannot be picked for all offsets. Small offsets may be noisy due to ground roll; long offsets may suffer from muting. This means that the picking procedure can only use a limited range of absolute offsets. In each cross-spread, a ring of midpoints forms a limited range of offsets. The inside diameter of the ring is equal to the smallest useful offset; the outside diameter is equal to the largest useful offset. This ring of data still provides a connected time-shift surface from which loop skips and jitter can be removed.

The number of cross-spreads to which each shot and receiver contributes is equal to the crossline fold and the inline fold, respectively. Therefore, after removal of time-shift jitter from all cross-spreads, there will still be differences in the shot and receiver statics found for the different cross-spreads to which they contribute. A global fitting of all statics has to round off the statics computation procedure.

The procedure described thus far may not yet provide sufficient coupling of statics throughout the survey area. Additional coupling can be achieved by also measuring time-shifts between traces of neighboring cross-spreads. *I know no published examples of this technique.*

Redatuming. A complex near surface may severely affect the interpretability of the deeper subsurface. Redatuming to a level below the complex near surface may be the answer to that problem. Kelamis et al. (2002) describe an elegant procedure for 2D data based on common focal point analysis. The extension of their method to 3D data is much more cumbersome. Van de Rijzen et al. (2004) deal with operator derivation in “sparse” (less than full 3D) data. Those operators are applied in the Kirchhoff redatuming procedure discussed by Tegtmeier et al. (2004). Both approaches struggle with the sparseness of conventional 3D data that do not provide 3D shots or 3D receivers.

However, both the operator derivation and the actual redatuming procedure can benefit from exploiting the fact that cross-spreads are minimal data sets (Padhi and Holley, 1997). Minimal data sets are suitable for application of DMO and prestack migration; therefore, they can be exploited in the derivation of the operators needed in those operations. Minimal data sets can also be exploited in the derivation of the near-surface operators needed in Kirchhoff redatuming, whereas that process itself can be applied in minimal data sets as well.

The aim of redatuming is to generate a new 3D data set that does not suffer from near-surface effects. This can be achieved by sinking each shot and each receiver vertically down onto a new datum level. Each sample in each trace in the new data set can be computed by integrating all traces of the original data set that have potentially illuminated the ellipsoid defined by the new shot and receiver and the time of the new sample (Figure 1). For a sufficiently large minimal data set there is always a shot receiver pair that has illuminated any given point on the ellipsoid. Therefore, integration along all points of the ellipsoid is ensured for the computation of the sample.

Migration operator derivation. Just as near-surface operators can be derived from cross-spread images in redatuming, migration operator derivation can be based on cross-spread images as well. Al-Ali and Blacquière (2005; pers. com.) have submitted first research results on this subject for presentation at the 2005 SEG conference.

Offset-vector oriented processing

Often the offset vector is described in terms of absolute offset and azimuth, but in orthogonal geometry it is also convenient to describe all offset vectors occurring in the geometry by their inline and crossline components. The midpoint area of each cross-spread can be divided in small offset-vector tiles (OVT), each with the size of a unit cell (area between two adjacent receiver lines and two adjacent shot lines). The number of such tiles is equal to the total fold of the geometry, and each tile is characterized by its average absolute offset and average azimuth (Figure 2a; Vermeer, 2002).

Selecting the same OVT from each cross-spread in a regular orthogonal geometry produces a single-fold OVT gather. This is the nearest you can get in orthogonal geometry to a common offset-vector gather (COV gather) or a common offset common azimuth gather. A COV gather is a minimal data set with the unique property that it extends across the whole survey area because it is not offset-limited like other minimal data sets such as cross-spread and 3D shot gather. Therefore, the OVT gather may be called a pseudominimal data set. Gesbert (2002) calls it a quasi-minimal data set. Cary (1999) calls OVT gathers also COV gathers.

Another useful subdivision of cross-spreads is in areas with the size of a quarter unit cell. Taking from each cross-spread all quarter-unit-cell-sized areas with the same average absolute offset provides either a single-fold data set or a two-fold data set with the smallest possible variation in absolute offset that is possible in orthogonal geometry (Figure 2b).

The various offset-vector oriented subdivisions of orthogonal geometry may be exploited in offset-vector oriented processing to get better prestack processing results. Examples of such applications are:

- offset-vector oriented muting,
- generating clean common image gathers (CIGs),
- robust AVO and AVD(irection) analysis.

Muting. The subdivision of orthogonal geometry into single-fold or two-fold data sets using quarter-unit-cell-sized OVTs splits the data into groups with a small range of absolute offset. Allocating the same mute time to all traces in such a subdivision and repeating this allocation for all possible subdivisions leads to constant fold at all time levels. This type of muting removes the variation in fold

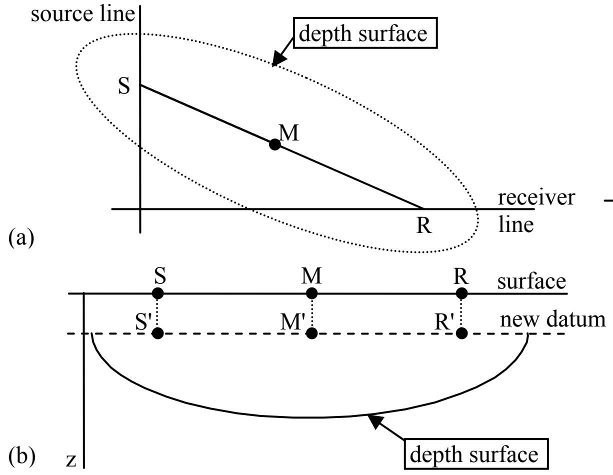

Fig. 1. Redatuming procedure in cross-spread. (a) Plan view, (b) cross-section. The trace corresponding to shot receiver pair SR with midpoint M has to be redatumed. The depth surface (ellipsoid) defined by the new shot receiver pair S'R' at datum level will be illuminated by a range of midpoints around M.

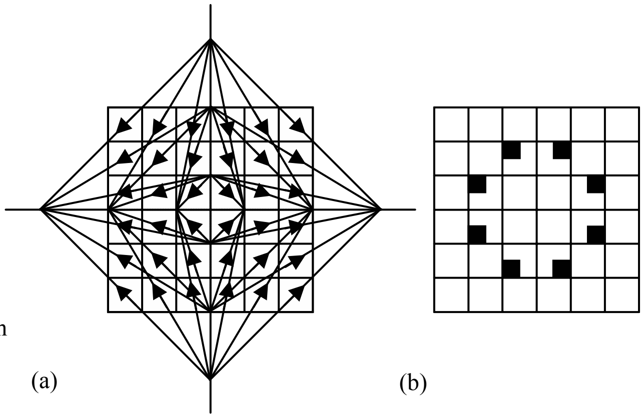

Fig. 2. (a) Midpoint area of cross-spread split into 36 unit-cell sized OVTs (fold-of-coverage of corresponding geometry is 36). Average absolute offset and azimuth are indicated for each tile. (b) Same midpoint area as in (a). The eight quarter-unit-cell sized black tiles have the same average absolute offset. Collecting the traces in these eight little tiles from all cross-spreads in the geometry would generate a two-fold data set covering most of the survey area.

that would otherwise exist at all time levels where total fold has not been reached yet. This should reduce the acquisition footprint at those time levels.

Common image gathers. The conventional way of generating CIGs by subdividing the data set into small ranges of absolute offset produces serious migration artifacts in each image trace because of the abundance of spatial discontinuities in absolute-offset gathers. Using synthetic data, Vermeer (2002) and Gesbert (2002) have discussed the benefit of creating CIGs from OVT gathers. Cary (1999) argues as well that OVT gathers are most suitable for CIG analysis. Although this method is exploited by at least one processing contractor (Cary, 2005, personal communication), examples of the benefit of this technique as applied to real data have not been published yet.

AVO and AVD. The relatively small range of offsets in OVT gathers makes them suitable for amplitude smoothing and noise removal prior to any amplitude measurements. This pre-AVO processing might best be carried out in horizon slices sorted in OVT-gather arrangement. Another step in pre-AVO (and -AVD) processing might also be prestack migration of OVT gathers. Although offset is not constant in such gathers, measured amplitudes might be allocated to the average offset (and average azimuth for AVD) of the gathers. Further refinements can be obtained by using partially overlapping OVTs as the basis for generating OVT gathers, thus generating amplitude measurements for a finer sampling of offset.

Conclusions

Cross-spread oriented processing methods and offset-vector oriented processing methods offer the means of exploiting the specific properties of orthogonal geometry. Such methods would lead to better quality of the final product. Unfortunately, software that allows this optimal processing of orthogonal geometry data is nowhere near widely available. A notable exception is the use of 3Dfk-filtering to suppress shot-generated noise in cross-spreads.

An important benefit of the techniques described in this paper is the cost saving that can be achieved in data acquisition because lower folds will be sufficient for the same quality. However, optimal benefit of those techniques can only be obtained if 3D survey design already concentrates on the generation of regular orthogonal geometry with proper sampling of shot and receiver lines.

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