Fast 3-D Kirchhoff poststack time migration with velocity analysis

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ABSTRACT

A fast and efficient algorithm is presented for 3-D Kirchhoff poststack time migration. The method forms migration gathers for each migrated trace before any time shifting, scaling, or filtering is required. Each migration gather contains all traces within the migration aperture, sorted and summed into bins based on the migration offset. The migration gathers are suitable for migration velocity analysis similar to conventional CMP gathers. The migration for each trace is completed by filtering, scaling, time shifting (NMO), and stacking the migration gather.

INTRODUCTION

3-D Kirchhoff post stack migration is not the usual method of choice because of associated long run times. It does however, provide a unique use by allowing subsets, such as 2-D lines, to be migrated efficiently from the entire 3-D volume of input data. These subsets produce preliminary results to evaluate migration velocities. Even smaller subsets of a few traces with a small time window, referred to as portholes, may be efficiently migrated. When the entire volume is migrated, other algorithms, such as downward continuation, are preferred because their overall runtimes are shorter.

The method of this paper radically improves the speed of Kirchhoff poststack migration while preserving the above advantages. It also offers an additional advantage of efficiently evaluating migration velocities.

3-D Kirchhoff time migration

Kirchhoff time migration sums energy from input traces within the migration aperture. The times on these input traces are computed using an equation identical to that used for NMO removal, i.e.,

$$T^2 = T_0^2 + \frac{4x^2}{V^2} \tag{1}$$

where T_0 is the time of the migrated sample, T the time on an input trace, x is the distance along the surface from the migrated trace to the input trace, and V is the migration velocity at T_0. In a 3-D volume of stacked data, T forms a hyperboloid, and is analogous to the hyperbolic diffraction of 2-D migration.

A major part of the time required in Kirchhoff migration is the computations required for evaluating T from equation (1), filtering, scaling and time shifting the input data. The first filter required is a phase correcting filter that should be applied to all the input data. These filters are the square root differential or 45 degree filter for 2-D data and the differential or 90 degree filter for 3-D data, as described by Gazdag 1984. They are often applied after migration (Silva 1992), however, applying them before migration may aid in migration velocity analysis by providing improved semblance focusing.

An additional antialiasing filter must also be applied locally around the time T in each input trace to prevent aliasing (Lumley 1994). The cutoff frequency of the filter at time T is a function of migration time T_0 and offset x, and must be repeated many times for the same input sample.

After local filtering, the magnitude of the sample at T must also be interpolated from the local discrete values and then scaled. The scaling of input data may be simplified to be $(T_0 /T)^2$ with additional scaling applied after the formation of the migrated trace (see Silva 1992).

The above process is applied to each input trace for one migrated sample. A 3-D data set has a circular migration aperture, and for example, if the migration aperture had a radius of 100 traces, samples from 10,000π traces will be required for each migrated sample. When the migration offset x is small, the antialiasing filter may be omitted, however the number of these input traces is few relative to the larger offsets whose number increases with increasing offset x. The computer time required for these processes is usually reduced by approximations or may be totally ignored producing inferior results.

A FAST KIRCHHOFF ALGORITHM

The time required for evaluating T, filtering, and scaling, may be significantly reduced by defining two steps in the migration process: *first*, forming a migration gather by gathering and summing all the traces which have the same migration offset x, and *second*, processing the migration gather by scaling, filtering, and time shifting the sum of these traces.

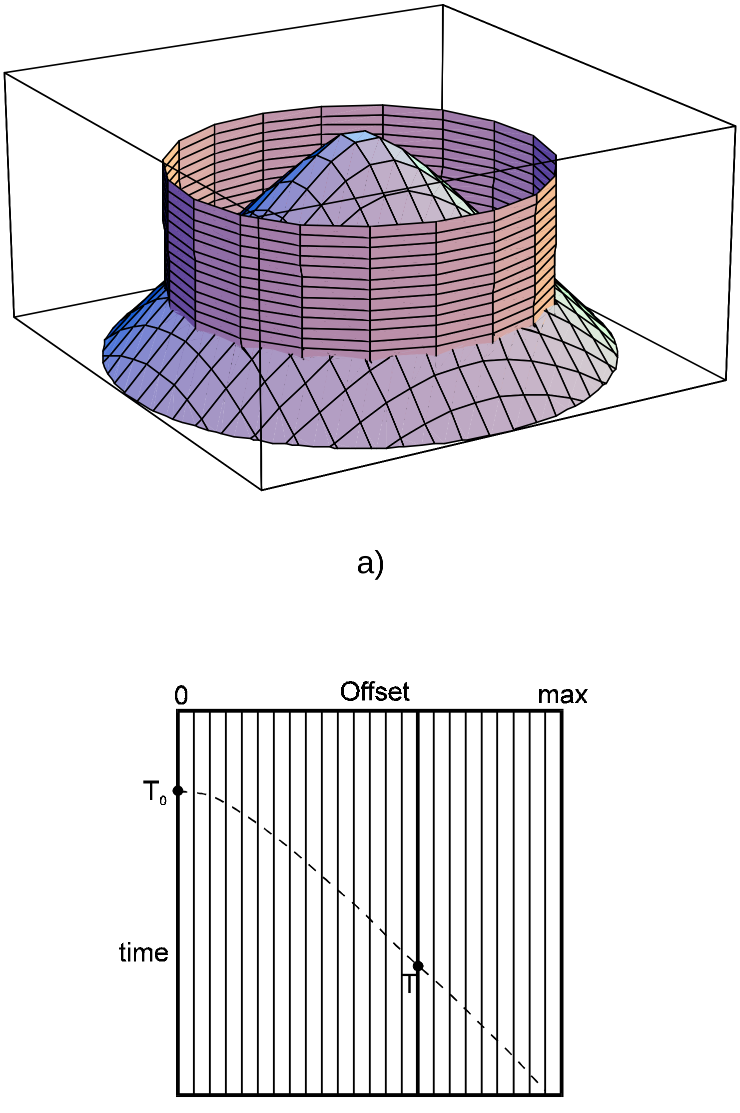
Forming the migration gather

Consider all the input traces required to migrate one output trace. The evaluation of T, the antialiasing filter, and scale factor are all dependent on the offset x. These operations are linear and could be postponed till after all input traces with the same offset x are gathered, as illustrated in Figure 1. All the input traces at offset x are identified by the cylinder around the hyperboloid in (a), which are then summed into offset x of the migration gather (b). The migration gather in (b) has offset bins that span the range of the migration aperture to allow input traces to be summed into the appropriate bin. This gather is referred to as a *migration gather*.

The number of input traces mentioned above (10,000π) which contribute energy to a single migrated trace is effectively reduced to the number of traces in the migration gather (say 100). This relative number of traces are schematically illustrated in

Figure 1 by showing the number of traces in the cylinder of (a) that sum to one trace on the migration gather of (b).

Diffracted energy that was dispersed over the hyperboloid is now aligned along a hyperbola of the migration gather of (b), and may be analyzed by conventional methods to evaluate the migration velocity.



a)

b)

Fig. 1 3-D post stack migration, (a) the migration ellipsoid illustrating a circle of traces with that same migration offset, and b) the migration stack of the concentric traces showing the summed ring of traces and the summed sample from the hyperboloid on the hyperbola.

Processing the migration gather

After the formation of the migration gathers, the evaluation of T, filtering, and scaling, is now performed on the traces in the migration gather. The reduction in computing time proportional to the ratio of original input traces to the number of traces in the migration gather. The migration gather is similar in form to a CMP gather where the time shifting from T to T_0 is identical to NMO removal. The migration gather now has a larger maximum offset that requires antialiasing filters. It should be noted that conventional NMO has already been applied to the input data, and that moveout on the migration gather is for migration.

The summing of traces that fall in the small range of offsets in each offset bin provides a benefit to the process. The moveout of the diffraction energy acts as a natural antialiasing filter, reducing the energy of aliased high frequencies. Additional antialiasing filters may still be required, however due to the significant reduction in the number of times the antialiasing filters are applied, the quality of these filters may be of a higher standard than those used directly on the input traces. The better quality filters would have better pass band characteristics, and higher attenuation of aliased energy.

Migration moveout may be applied with conventional NMO routines, however care should must be taken when using a stretch factor to preserve the desired dips. After migration moveout, stacking the migration gathers completes the migration process. Care must also be taken when using conventional stacking routines to preserve the amplitudes expected by the migration process.

Migration velocity analysis

The migration gather has an additional property that increases its value to the processor, migration velocity analysis. Horizontal data (after conventional NMO) will reconstruct on the migration gather also as horizontal data and provide no benefit. However, diffraction information that lies on the hyperboloid is now mapped to a hyperbola allowing conventional velocity analysis tools to evaluate the migration velocity.

Real time migration

The formation of the migration gathers allows rapid migration of selected portions of the 3-D volume. Small windows of data, or *portholes*, may be selected and the appropriate gathers formed. After pre-scaling and filtering the gathers, the data in the portholes may be rapidly migrated in real time to evaluate an optimum migration velocity (or other parameter such as dip limits).

CONCLUSIONS

A fast method of poststack Kirchhoff time migration allows the formation of migration gathers. Time computations, filtering,. scaling, and stacking, complete the migration process and are applied after the migration gathers have been formed. The gathers are suitable for migration velocity analysis in areas with diffraction energy. The method is efficient for migrating the entire 3-D, and allows real time porthole migration to evaluate migration parameters such as velocity or dip range.

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