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High Resolution 3D parabolic Radon filtering

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Summary

2D parabolic Radon filtering is a widely used method for multiple attenuation. However, for dense and wide-azimuth gathers that exhibit azimuthal variation effects, this approach can fail. Because of the variation of the curvature of the events with the azimuth, the bin gathers cannot be processed in one go but must rather be split into sub-collections where the azimuth either has little variation or varies smoothly. We instead propose herein to take into account the azimuthal effects by incorporating an elliptical model for the variations of the curvature with the azimuth, and hence define a 3D parabolic Radon filtering. This is a more natural way of processing dense wide-azimuth gathers, by honoring their actual 3D geometry, which results in more consistent decompositions and in a better filtering.
Introduction

Parabolic Radon filtering is, since a long time, one of the most used multiple attenuation processing solution. It belongs to the family of algorithms based on velocity discrimination between the primaries and multiples. The CMP gathers after NMO are modeled by a superposition of constant amplitude parabolas, and the most curved parabolas, assumed to be the multiples (slower than the primaries), are retained and subtracted from the data.

Thorson and Clearbout (1985) introduced the hyperbolic Radon inversion, including high resolution (HR) features that dramatically improve the capability of the method to process spatially aliased data and to preserve the primaries. Hampson (1986) introduced the parabolic Radon, and took advantage of the time-invariance property of the parabolas to propose a fast (but not HR) implementation. Fast HR implementations were finally achieved by Sacchi and Porsani (1999) and Herrmann et al. (2000).

The existing 2D implementations, time-offset, are perfectly suited to 2D or 3D narrow azimuth (NAZ) data, or to any geometry where the azimuth varies smoothly with offset. However, problems arise with the more recent dense and wide-azimuth (WAZ) geometries, where some traces can have similar offsets but very different azimuths. If there is any azimuthal variation of the curvature (whatever the reason), then the arrival times vary randomly from trace to trace when sorted by offset and the effectiveness of the algorithm is degraded. Practical solutions typically consist in applying the 2D parabolic Radon filtering on azimuth sectors or on suitable pseudo-2D sub-collections, but this is still often not fully satisfactory. Modern WAZ marine and land acquisition geometries motivate the need for the development of one pass, 3D, HR, de-aliased parabolic Radon filtering solutions.

3D parabolic Radon

In a WAZ gather, we consider the offset vector \((x,y)\) instead of the scalar offset \((x^2+y^2)^{1/2}\). The azimuthal variations of the curvature are handled with an elliptical model. The CMP gathers are now modeled by the superposition of constant amplitude, squeezed and rotated paraboloids:

\[
t = \tau + q_x x^2 + q_y y^2
\]

\[
= \tau + q \text{ell}^2 + y^2 + r \text{ell}^2 - y^2 + s \text{ell} \cdot x \cdot y
\]

with:

\[
q = \frac{q_x + q_y}{2}
\]

\[
r = \frac{q_x - q_y}{2} \cos \theta
\]

\[
s = \frac{q_x - q_y}{2} \sin \theta
\]

Note that while with the 2D case we go from a 2D data space \((t,x)\) to a 2D model space \((\tau,q)\), with the 3D case we go from a 3D data space \((t,x,y)\) to a 4D model space \((\tau,q,r,s)\) with one extra dimension. This can result in dramatically increased runtimes (to scan the whole model space) and in strongly ill-conditioned problems (many more model parameters than data samples). The reasonable hypothesis that the variations of the curvatures are limited helps to reduce the scan ranges in the model space, and hence the runtime. Enforcing stronger HR constraints in the model space (compared to the 2D version) helps to deal with the higher ill-conditioning.

The rest of the implementation is similar to the 2D algorithm as described by Herrmann et al. (2000). The curvature cutoff is determined with respect to the average curvature of the paraboloids, and we end up with the decomposition of the input gathers into three terms: primaries, multiples, and “noise” (everything that is not fitted by the constant paraboloids model). Note that the correction of the azimuthal variations is beyond the scope of the paper: here we simply take these variations into account to achieve a better filtering of the multiples. The illustration on synthetic data will be found in Hugonnet et al. (2008).
Real data example: land WAZ

We show a pre-stack time migrated bin gather from a dense WAZ land acquisition (fig. 1). The nominal trace intervals within the bins are 400x400m. The inline and crossline offset components range from -2800 to +2800m, and from -2700 to +2900m. The nominal fold is 225. The traces are sorted first by offset classes (400m wide) and then, within the offset classes, by increasing azimuth. The undulations of the strong primary at the middle of the time window (figure 3) reveals azimuthal variation of the residual curvature. The inability of the PSTM to fully cope with lateral velocity variations likely explains these azimuthal variations (Jenner, 2008). Please note that this sorting is for display purpose only, and does not represent the way the data are internally processed.

In the following we compare the ‘primary’ and ‘noise’ terms, fig. 4, obtained with 2D Radon (without and with azimuthal sectoring) and the proposed 3D Radon decomposition. With the 2D Radon, without azimuthal sectoring, the primaries are poorly estimated: without taking into account the azimuthal variations, a large part of the primary energy leaks into the noise term. When applied independently on 22.5° sectors, the 2D Radon achieves a much better primary estimation. However, the ‘noise’ term looks much lower than expected, with vertically stripped amplitude variations. Because each sector has a low fold (around 28) compared to the number of Radon parameters (q), the actual noise tends to be mapped into the Radon domain. With the 3D Radon the primary term is significantly better in terms of event continuity (particularly on the large offsets), and the noise term is the most realistic, without primary energy leakage: the 3D Radon decomposition is here the most consistent one. Note that the large trace intervals are well handled by the 3D algorithm, at least much better than 400m intervals would be by a 2D algorithm.

Real data example: marine WATS

This WATS marine acquisition, in a deep water and salt geology context, is made of 7 tiles (fig. 2). The nominal trace intervals within the bins are 300x1200m. The inline and crossline offset components range from 200 to 8000m, and from -4000 to +4000m. The nominal fold is 189. The water bottom (not visible on the figures) is around 1400ms. The multiples are not so energetic on these data: we can see on a NMO corrected bin gather (sorted wrt the radial offset) the first water bottom bounce around 2800ms (fig. 5a): thanks to the WAZ coverage, this multiple is nicely attenuated on the stack (fig. 6a). However, the tails of the multiples on the large offsets get strong and aliased, resulting in a significant noise level deeper on the stack (wide open mute).

Different parabolic Radon filterings are applied: 2D, 2D sectored, and 3D (fig. 5 & 6). The 2D Radon does attenuate almost nothing, and even creates spurious coherent events in the bins (the azimuthal variations results in time-jitters in offset sorting, and the coherent multiples look more or less like noise). The application on azimuth sectors dramatically improves the attenuation, but still with a significant residual energy. Again, the best attenuation result so far is obtained with the 3D Radon. We have however to mention that the 3D Radon algorithm slightly more attenuates the primaries compared to the 2D sectored algorithm (fig.6e-f): with cross-line intervals of 1200m, we are probably at the limit of what the algorithm can handle in terms of aliasing.

Conclusions

The extension to 3D of the HR, de-aliased parabolic Radon filtering can handle azimuthal variation effects on WAZ gathers by using an elliptical model for the curvature variations. Azimuth sectoring by the user is no longer required; hence the algorithm can take advantage of the full fold to achieve more consistent decompositions and filtering. Relatively large trace intervals within the bins can be accepted.

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References


Figure 1: distribution map of the offset vectors for the gather displayed fig. 3

Figure 2: distribution map of the offset vectors for the gather displayed fig. 4-5

Figure 3: time-windowed bin gather. The traces are sorted by offset classes and then wrt the azimuth within each offset class.

Figure 4: (top) primary terms after Radon decomposition. (bottom) “noise” terms after Radon decomposition.
(a): 2D Radon. (b) sectored 2D Radon. (c) 3D Radon
Figure 5: (a) input bin gather. (b) 2D Radon. (c) sectored 2D Radon. (d) 3D Radon

Figure 6: (a) input stack; (b) 2D Radon stack; (c) sectored 2D Radon stack and (e) difference; (d) 3D Radon stack and (f) difference