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Linearized inversion of multiple scattering seismic energy

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Internal multiples deteriorate the quality of the migrated image obtained conventionally by imaging single scattering energy. So, imaging seismic data with the single-scattering assumption does not locate multiple bounces events in their actual subsurface positions. However, imaging internal multiples properly has the potential to enhance the migrated image because they illuminate zones in the subsurface that are poorly illuminated by single scattering energy such as nearly vertical faults.

Standard migration of these multiples provides subsurface reflectivity distributions with low spatial resolution and migration artifacts due to the limited recording aperture, coarse sources and receivers sampling, and the band-limited nature of the source wavelet. The resultant image obtained by the adjoint operator is a smoothed depiction of the true subsurface reflectivity model and is heavily masked by migration artifacts and the source wavelet fingerprint that needs to be properly deconvolved.

Hence, we proposed a linearized least-square inversion scheme to mitigate the effect of the migration artifacts, enhance the spatial resolution, and provide more accurate amplitude information when imaging internal multiples. The proposed algorithm uses the least-square image based on single-scattering assumption as a constraint to invert for the part of the image that is illuminated by internal scattering energy. Then, we posed the problem of imaging double-scattering energy as a least-square minimization problem that requires solving the normal equation of the following form:

$\mathbf{G}^T\mathbf{G}\mathbf{v} = \mathbf{G}^T\mathbf{d}$, **(1)**

where $\mathbf{G}$ is a linearized forward modeling operator that predicts double-scattered seismic data. Also, $\mathbf{G}^T$ is a linearized adjoint operator that image double-scattered seismic data. Gradient-based optimization algorithms solve this linear system. Hence, we used a quasi-Newton optimization technique to find the least-square minimizer. In this approach, an estimate of the Hessian matrix that contains curvature information is modified at every iteration by a low-rank update based on gradient changes at every step. At each iteration, the data residual is imaged using $\mathbf{G}^T$ to determine the model update.

Application of the linearized inversion to synthetic data to image a vertical fault plane demonstrate the effectiveness of this methodology to properly delineate the vertical fault plane and give better amplitude information than the standard migrated image using the adjoint operator that takes into account internal multiples. Thus, least-square imaging of multiple scattering enhances the spatial resolution of the events illuminated by internal scattering energy. It also deconvolves the source signature and helps remove the fingerprint of the acquisition geometry. The final image is obtained by the superposition of the least-square solution based on single scattering assumption and the least-square solution based on double scattering assumption.