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A Velocity Model Inference from the Inversion of 3D Zero-Offest Seismic Traces in the Space-Frequency Domain

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The goal of this work is to infer a reliable velocity model from zero-offset seismic traces by minimizing the difference between input and simulated data in the space-frequency domain. Typical applications of this inverse problem include subsoil imaging for hydrocarbon prospecting, near surface geophysics, environmental monitoring, archaeological investigation and risk assessment analysis.

In geophysical surveys, data are collected from multi-shot acquisitions covering wide areas. For each shot gather, the seismic traces are recorded by an array of receivers; the total amount of stored information can reach the order of terabytes. Seismic data are then averaged in such a way to simulate zero-offset traces resulting from a virtual experiment where sources and receivers are coincident. The resulting compressed datasets are at most of the order of gigabytes. Transforming these data in the time frequency domain yields a further compression, making full 3D inversions feasible.

In the standard industrial approach, a rough velocity estimate results from a simplified processing on the complete set of shot gathers, coupled to a long interpretation phase. The proposed automatic procedure is innovative in the sense that it requires finding the medium velocities that minimizes the L2 norm of the misfit between *zero-offset* and simulated data. The resulting formulation gives rise to non-analytic and non-linear problem with about 10^8 unknowns. The direct problem consists in the simulation of zero-offset data by propagating *upward* the acoustic wave-field using the one-way wave equation. The reflectivity of the medium, computed along zero-offset ray trajectories, is used as a source term for the upward propagation. The estimate of the reflectivity is possible by a simple edge detection filtering of the velocity field.

To control the velocity model updating, we have adopted a Lagrange minimization approach in which the enlarged objective function includes an additional field multiplying the one-way equation. From the first variation of the objective function, one obtains the equation propagating the Lagrange multiplier. As a matter of fact, this field is downward propagated by the adjoint of the one-way operator including a source term equal to the residual between simulated and zero-offset data. Because of the nature of the direct operator, it is natural to approximate the adjoint operator by its conjugate.

Finally, this formulation provides the gradient of the objective function with respect to the velocity field as the integral over all frequencies of the wavefield times the velocity derivative of the direct operator applied to the Lagrange field. The gradient evaluation loop is concurrent over the frequencies and the only communication phase is just the sum over all frequencies of each partial contribution.

A *projected conjugate gradient* algorithm for the velocity updating solves the minimization problem simultaneously for all frequencies. At each step, once computed the conjugate direction, a Brent's method bracketing performs the minimum line search. Numerical results on synthetic and almost real datasets will be provided to demonstrate the accuracy and the robustness of the overall procedure.