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Adjoint State Method for Multiparameter Isotropic Elastic Full Waveform Inversion Gradient Computation

Deresse Ahmed Adem (Federal University of Rio Grande do Norte), Mesay Geletu Gebre (Federal University of Rio Grande do Norte), Paulo D. S. de. Lima (Federal University of Rio Grande do Norte), Claudionor G. Bezerra (Federal University of Rio Grande do Norte), João Medeiros Araújo (Universidade Federal do Rio Grande do Norte)

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Introduction

Full Waveform Inversion (FWI) is now a widely adopted powerful seismic inversion technique that uses the entire content of seismic traces to obtain physical data about the medium sampled by seismic waves. FWI can pinpoint the residuals between recorded data and a predicted seismic response by combining data from many seismic sources and receivers, regardless of the type of seismic wave involved. This pixel-by-pixel adjustment leads to a local optimization approach, which is essentially a linearized method based on the Newton equation. The most widely used methods for calculating the gradient of the objective function in isotropic elastic media in the time domain, based on second-order elastic wave equations, are Green's function-based methods and the Lagrange multiplier approach. The adjoint state method is a computationally efficient framework for calculating gradients that only requires two numerical simulations: (1) a forward simulation where the source is at the actual source location to generate predicted data, and (2) an adjoint simulation where the data residuals are virtual sources at the receiver locations to propagate the residuals back through the system. According to some litrature review, employing the adjoint state technique for gradient calculation improves computational efficiency.

In this work, we present a novel formulation for constructing a symmetric operator to compute the adjoint wavefield from the first-order velocity-stress adjoint wave equations. We then efficiently compute the gradients for P-wave velocity (V_p), S-wave velocity (V_s), and density (ρ)

Method and/or Theory

This study employs the first-order velocity-stress formulation of the isotropic elastic wave equations, in the time domain for gradient computation using the adjoint-state method. In this study, we construct a self-adjoint (symmetric) operator by introducing auxiliary variables. This self-adjointness ensures that the forward and adjoint wavefields can be computed using the same equation with finite-difference numerical techniques. We adopt the L2-norm misfit function for gradient computation of the Earth's seismic parameters of P-wave velocity (V_p), S-wave velocity (V_s), and density (ρ).

Results and Conclusions

Elastic Full Waveform Inversion (EFWI) is a powerful seismic imaging technique that reconstructs high-resolution subsurface property models by minimizing the misfit between observed and synthetic seismic data. This study employs the computationally efficient adjoint-state method, which requires only two simulations—a forward simulation and an adjoint simulation to compute the gradient. The gradients for P-wave velocity (V_p), S-wave velocity (V_s), and density (ρ) are obtained by cross-correlating the forward and adjoint wavefields. At the conference, we will present the theoretical formulation of the adjoint-state method and the results obtained.