Artificial Intelligence (AI) Driven Seismic Inversion Specifically with Limited Wells

Exploring deepwater and frontier basins with sparse well control (three or fewer wells) is one of the toughest challenges in oil and gas exploration. Traditional seismic inversion and Low-Frequency Model (LFM) building frequently break down under these conditions, introducing compounded errors into final impedance volumes.

To solve this sparse-data bottleneck, our latest R&D efforts have developed a **Dual-Stage AI Framework (1D CNN + 3D PINN)** for Post-Stack Inversion that completely bypasses the requirement of an accurate LFM. An ultra-smooth LFM based on just two to three wells over a 70–100 sq. km area is all that is needed.

The streamlined, non-redundant architecture operates through the following stages:

Stage 1: Smart Synthetic Data Generation
Instead of relying on unstable spatial gridding or unreliable variogram analysis, the workflow operates strictly in the vertical sequence domain. Using Markov chains, depth-wise non-parametric PDFs, and Monte Carlo simulations, the engine transforms 3 real wells into 500+ physically bounded pseudo-logs complete with realistic fluid substitutions (oil/water scenarios) and corresponding seismic pseudo-traces.

Stage 2: 1D CNN Pre-Training & Local Fine-Tuning
Vertical Pre-Training: Feeding data through a 6-channel input data matrix (integrating seismic amplitudes, CWT frequency vectors, structural dip, and smooth LFM baselines), a lean 1D Convolutional Neural Network built with 4 to 5 hidden layers trains on the synthetic library. This master network resolves the complex, non-linear transfer function mapping seismic reflection waveforms to absolute rock properties (acoustic impedance / wave-demodulation).

Basin Calibration: The pre-trained model undergoes a quick fine-tuning pass using the 3 real wells, perfectly aligning the network with the basin's actual phase, noise profile, and amplitude scaling.

Stage 3: 3D PINN Production Deployment
The calibrated 1D weights are mapped directly into a 3D architecture using a specialized **3D-to-1D Slicing Matrix Routine** via optimized tensor transformations. Real 3D seismic volume blocks are sliced into 1D parallel batches for rapid processing. The architecture—based on the similar 6 inputs (as in Stage 2) and featuring 4 to 5 hidden convolutional layers—predicts initial absolute acoustic impedance by evaluating neighboring inlines and crosslines concurrently before reassembling the output tensor back into a 3D spatial block. This vital step restores the true spatial 3D context of the subsurface, ensuring that structural dips and macro-geometries are properly maintained across the volume.

At this stage, the Physics-Informed Neural Network (PINN) loss loop activates, enforcing real-world compaction laws and spatial regularization on predicted impedance, such as adjacent trace averaging (3x3 patches). It enforces that neighboring pixels don't jitter wildly. It uses the **Structural Dip Vector (input channel)** to ensure this smoothing only happens along the natural bedding planes, preventing sharp stratigraphic boundaries from getting blurred. Guided by the **Ultra Low-Frequency Model (input channel)** acting as a mathematical gravity anchor, the PINN engine iteratively minimizes the error between synthetic traces computed from the predicted impedance and real seismic traces. This process permanently eliminates striping, continuously updating network weights to deliver the final, geologically realistic 3D impedance volume across the 70–100 sq. km area.

Project Status Update: AI-Driven Seismic & Petrophysical Inversion

- **Current Progress:** Literature search, extensive analysis, and core workflow formulation for **Part-I (Seismic Inversion)** are complete, with Python implementation planning underway.
- **Parallel R&D (Part-II):** Simultaneously, we are actively developing our R&D and workflow formulation for **AI-Driven Petrophysical Inversion**, where the high-resolution acoustic impedance volume from Part-I will serve as the direct foundation.
- **Partnership & Collaboration:** We look forward to opening formal discussions for sponsorship and strategic industry collaboration once our comprehensive, end-to-end technical write-up for Part-II is fully finalized.

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