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Machine-Learning-Driven Seismic Super-Resolution: A Multi-Stage Framework Using Well-Log Guidance

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Abstract

Enhancing seismic resolution remains a critical challenge in reservoir characterization, particularly in mature fields and clastic settings where well coverage is limited and legacy seismic data lack interpretability. This abstract introduces a three-stage machine-learning workflow that integrates well-log information with seismic responses to generate high-resolution seismic volumes while maintaining geological sanity and operational utility.

The workflow begins with the generation of reflectivity-constrained pseudo-logs that introduce well-derived rock properties into the seismic bandwidth. This first stage ensures that the inferred reflectivity traces remain consistent with measured logs and properly corrected for phase rotation and time-depth alignment. The second stage constructs supervised learning pairs by applying controlled low-pass filters to model both low-resolution and high-resolution seismic traces, enabling a ML/DL model to learn a stable and geologically meaningful high-frequency mapping. In the final stage, the trained model is applied across the full seismic volume to produce enhanced traces with improved bandwidth, sharper reflector continuity, and reduced high-frequency artifacts.

Applications to the Enfield and Volve datasets demonstrate that this methodology achieves significantly higher correlation with ground-truth high-frequency data (up to 0.96) compared with existing ML approaches, while also preserving phase and minimizing artificial events. The enhanced seismic volumes reveal clearer compartment boundaries, stronger reservoir continuity, and improved imaging of subtle structural and stratigraphic features.

This ML-driven super-resolution workflow provides a practical, field-ready solution that can be integrated into existing interpretation environments, enabling faster reservoir evaluation, reduced acquisition costs, and maximized value from legacy datasets across diverse geological settings