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Restoring GPR Continuity Under High Data Loss Using Adaptive Nonstationary Filtering

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Introduction

Ground Penetrating Radar (GPR) surveys in coastal and sedimentary environments often face challenges such as irregular sampling, high noise levels, and complex stratigraphy. Traditional interpolation techniques like splines, kriging, and cokriging frequently fail to reconstruct data reliably under these conditions. To address these limitations, this study evaluates the use of Regularized Nonstationary Autoregression (RNA), which employs adaptive prediction-error filters (APEF) to interpolate missing GPR traces in highly variable and undersampled scenarios.

Method and Theory

The RNA-based interpolation estimates prediction filter coefficients through an inverse modeling approach, followed by regularization to ensure smooth adaptation to local data variations. This process helps preserve the continuity of subsurface reflectors while minimizing artifacts. Missing traces are reconstructed using an iterative least-squares procedure that leverages the stability of the regularized system, showing reliable performance even under high levels of decimation and global nonstationarity.

Two datasets were used for validation. A synthetic dataset was derived from a 3D sedimentary model with reflectors of varying dips and was progressively decimated from 20% to 90% to test the robustness of the interpolation. The real dataset was acquired in a coastal region of Pará, Brazil, where stratigraphic complexity and GPS-based trace misalignment led to significant data gaps.

Results and Discussion

The RNA-APEF interpolation demonstrated robust performance in synthetic tests even under severe data decimation. When 70% of the traces were randomly removed, the method achieved reconstruction fidelity above 93%, successfully preserving the continuity of reflectors without introducing artifacts or excessive smoothing.

The real GPR dataset, acquired in a coastal area of Pará (Brazil), contained approximately 40% missing traces, mainly due to operational issues and GPS-based reordering. Given that the synthetic benchmark confirmed reliable interpolation performance up to 70% decimation, we had strong confidence in applying the method to the real dataset. The results confirmed our expectations: the RNA-APEF filter effectively reconstructed missing segments of up to 41 consecutive traces, restoring reflector coherence, high-frequency content, and phase continuity even in stratigraphically complex zones.

These results reinforce the capability of the RNA method to handle severe sampling irregularities, both in controlled simulations and real-world scenarios. Its adaptability and accuracy suggest strong potential for broader geophysical applications, particularly in challenging environments where data integrity is frequently compromised.