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Filtering High-Frequency GPR Data with Dip-Oriented Algorithms: Validation with Synthetic and Real Data

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Introduction

Ground Penetrating Radar (GPR) data often presents significant challenges in noise attenuation, particularly in shallow and heterogeneous subsurface environments. This study evaluates the applicability of structure-oriented filters implemented in the PySEISTR package — the Structure-Oriented Mean Filter (SOMF) and the Structure-Oriented Median Filter (SOMEAN) — to denoise synthetic and real GPR data. The methodology was validated using a 2D section extracted from the well-known 3D fluvio-glacial aquifer model of Herten, followed by application to real GPR data acquired in unconsolidated coastal dune sediments in Crispin, north-east Pará.

Processing Workflow

The methodology comprised four main steps. Synthetic GPR data were generated using realistic dielectric properties and electromagnetic simulation, resulting in matrices stored in `.ASC` format. Two types of noise were artificially introduced: (i) random Gaussian noise to simulate high-frequency ambient interference and (ii) vertical spike noise to mimic electronic and coupling artifacts. The noisy dataset was pre-smoothed and subjected to dip estimation via PySEISTR's `dip2dc` function, using a search window of [10, 20, 1] to produce local structural slopes.

The estimated dip field was then used to guide the application of the SOMEAN and SOMF filters. Both filters were configured with a radius of 2, smoothing parameter $\varepsilon = 0.01$, and filter order = 2. The outputs included filtered data, noise residuals, and slope images, which were analyzed quantitatively and visually. The same workflow was applied to real GPR data acquired with a GPS-referenced, fixed-offset system in coastal dunes, following preprocessing steps such as gain correction and amplitude normalization.

Results and Conclusions

The SOMEAN filter provided superior performance in attenuating erratic and spike noise, while preserving coherent reflectors and stratigraphic continuity. Compared to SOMF, it demonstrated better resolution of structural features and lower signal distortion. The dip estimation step proved crucial for aligning the filters along geological structures, and the algorithms in PySEISTR showed excellent compatibility with the high-frequency characteristics of GPR signals.

Application to the real dataset revealed subsurface layering and depositional features previously masked by noise, confirming the robustness of the approach beyond synthetic conditions. These results suggest that structure-guided filtering using PySEISTR is a practical and effective tool for enhancing GPR data quality. Future work will explore its extension to coherent-source noise and applications to 3D datasets..