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SSA filtering applied to NMR signal for petrophysical characterization of samples

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SSA Filtering Applied to NMR Signal for Petrophysical Characterization of Rock Samples

Introduction

Nuclear Magnetic Resonance (NMR) has become a key non-invasive technique for petrophysical evaluation of reservoir rocks, allowing estimation of porosity, pore-size distribution, and fluid behavior through relaxation time analysis. However, NMR signals—particularly the CPMG (Carr-Purcell-Meiboom-Gill) sequences acquired in low-field settings—are often contaminated by noise, which may degrade the stability and resolution of T_2 distributions obtained via Laplace inversion.

Method and/or Theory

In this study, we apply Singular Spectrum Analysis (SSA) as a non-parametric filtering method to enhance signal quality before inversion. SSA is based on singular value decomposition of the trajectory matrix of the time series and allows separation of meaningful components from noise without assuming a prior signal model. The SSA method consists of two main steps: decomposition and reconstruction. In the decomposition stage, the real component of the CPMG signal is embedded into a multidimensional trajectory matrix using a sliding window. This matrix decomposes into orthogonal components through singular value decomposition (SVD). The dominant singular values—associated with structured signal components such as exponential decays—are retained, while the smaller ones (primarily noise) are discarded. The signal is then reconstructed by diagonal averaging of the filtered components. When necessary, the SSA-reconstructed signal is automatically corrected for phase inversion to preserve physical consistency with the original NMR decay. The filtered signal is then submitted to Laplace inversion for T_2 distribution analysis. The SSA-filtered signal showed substantial improvement in signal-to-noise ratio while maintaining the expected exponential decay profile. Scree plots were used to select the optimal number of singular components for reconstruction, typically between three and four. The filtered signal exhibited a smoother decay, free of high-frequency oscillations and end-of-sequence growth artifacts. The resulting T_2 distributions obtained from Laplace inversion were more stable and better resolved, particularly in samples with low amplitude or moderate acquisition noise.

Results and Conclusions

The proposed approach demonstrates that SSA is an effective filtering tool for NMR petrophysical applications and provides a robust alternative to traditional signal processing methods, especially under challenging experimental conditions.