Redefining MRI:
From Image to Insight

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Zoomed MRI with Deep Learning

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Background & Motivation

High-resolution structural brain MRI with volumetric coverage is essential for delineating fine anatomical boundaries and detecting subtle tissue abnormalities. Gradient and spin-echo (GRASE) sequences employing inner-volume excitation have been established as an effective way of achieving high spatial resolution by restricting the field-of-view (FOV) to a targeted anatomical region, thereby reducing the phase-encoding burden without sacrificing in-plane resolution.

Problem Statement

To extend spatial coverage, accelerated 3D GRASE acquisitions that omit phase encodings along both the in-plane and slice-encoding directions have been proposed, necessitating a concomitant increase in echo train length (ETL). This strategy, however, introduces two physically distinct but interrelated degradations. First, two-dimensional undersampling in the phase-encoding plane leaves substantial k-space regions unmeasured, rendering direct Fourier reconstruction ill-conditioned. Second, the extended ETL imposes a T2-dependent amplitude modulation across k-space. Specifically, the acquired k-space signal is weighted by T2 and T2* relaxations. Spin relaxation acts as an anisotropic low-pass filter in k-space, broadening the effective point spread function (PSF) and manifesting as spatial blurring across the phase encoding directions in the reconstructed image.

Proposed Method — Deep Super GRASE

In this work, we propose Deep Super GRASE, a dual-module reconstruction framework designed to resolve both aliasing and blurring from an image processing perspective grounded in the physical signal model. To address the missing k-space problem, a deep learning (DL)-based network is trained to synthesize absent phase-encoding lines from undersampled measurements, learning a robust mapping that surpasses conventional compressed sensing (CS) by exploiting data-driven priors rather than hand-crafted sparsity constraints. To resolve the physics-induced blurring, a super-resolution (SR) module is formulated as a learned image restoration problem. The SR network is trained to invert this physically defined degradation operator, recovering suppressed high-spatial-frequency content without the SNR penalty inherent to the variable flip angle (VFA) strategy, which modulates the refocusing pulse train to partially reshape the PSF at a substantial cost in signal intensity.

The proposed framework was validated on 3D brain CEST MRI acquired at 3T, demonstrating significant improvements in spatial sharpness, and structural fidelity relative to both CS-based reconstruction and VFA-based blur mitigation, while preserving SNR comparable to standard GRASE acquisitions.

Keywords: Zoomed MRI, Variable flip angle, Deep learning, Super-resolution