Removing Readout effects from CEST images via general Bloch-Model-based Reconstruction

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INTRODUCTION:

In CEST MRI a general problem is that the prepared state decays during the acquisition of it. This decay is known to distort contrast information, leading to blurring or ringing in the often quickly acquired images. We recently developed a differentiable Bloch simulation[1] in PyTorch, which can describe arbitrary MRI sequences, thus also describe these decay-related artifacts. We propose herein to use this Bloch-Simulation for model-based reconstruction of the prepared magnetization state, allowing mitigation of e.g. blurring or other image artifact introduced by fast MRI readouts.

METHODS:

The conventional approach assumes that readout effects are removed by normalization

$$\mathrm{M}_{\mathrm{z,norm}} = \frac{S_z}{S_0}$$

Our overall approach is to reconstruct the prepared z-magnetization M_z, which is acquired by a centric FLASH sequence[2] leading to the signal S_z. Our Bloch simulation models the full Flash sequence dynamic and for any initial magnetization M_z and all tissue parameters T1, T2, T2*, PD, ADC, and B_0 and B_1 field inhomogeneities. This simulation forms directly the operator of our reconstruction model to reconstruct M_z from the FLASH signal S_z. The loss function is:

$$\mathrm{M}_{\mathrm{z,opt}} = argmin_{(\mathrm{M_z})}(\|\mathrm{Bloch}(\mathrm{FLASH}, \mathrm{M_z}) - S_z\|),$$

where $\mathrm{M}_{\mathrm{z,opt}}$ is the optimal initial magnetization generating the acquired image data (*S_z).* We optimize the initial magnetization M_z using the Adam optimizer over 100 epochs. We used M_z values with a PD contrast scaled by 0.5 and 0.25

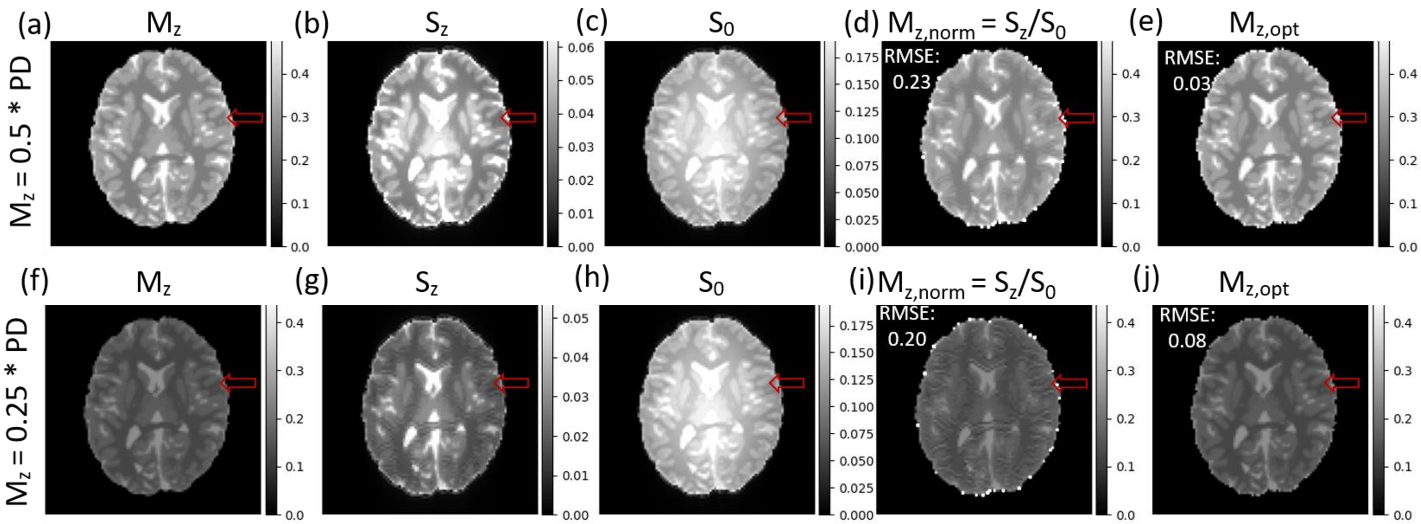

Figure 1: The prepared z- magnetization (a) is corrupted by the centric FLASH readout (b), showing B1 inhomogeneity and blurring. Conventional normalization resolves Tx/Rx inhomogeneities, but not blurring. Our approach closely recreates the original M_z.The proton density (PD) is the thermal magnetization, i.e. the initial magnetization without any preparation.

RESULTS: Figure 1a-d illustrates the issue: The prepared CEST contrast M_z is sharp and homogeneous (a), the FLASH image acquired after the preparation S_z, but also the normalization scan S_0, are corrupted by the centric FLASH readout showing B1 inhomogeneity and blurring (b,c). Normalization solves Rx/Tx inhomogeneities, but not the readout induced blurring (Fig. 1d, red arrow). The model-based reconstruction employing the full FLASH readout operator provides an improved estimate $M_{z,opt}$ of the prepared magnetization with visibly reduced blurring and lower RMSE compared to the conventional S_z/S_0 approach (Figure 1e). The improvement is even clearer for lower M_z (Figures f-j), where additional ringing artifacts occur in S_z (g) that are again resolved by the Bloch-model-based reconstruction (j).

DISCUSSION: The conventional method of estimating prepared magnetization in CEST-prepared sequences using a normalization can remove inhomogeneities, but not inherent imaging artifacts like blurring. Our proposed model-based reconstruction, which utilizes a differentiable Bloch simulation, significantly improves the M_z estimation. We showed results for a FLASH sequence, but our simulation works also for any other readouts like TSE or EPI. Our approach provides a robust and general solution for M_z reconstruction that may increase the reliability and diagnostic value especially of fast CEST sequences, where blurring is often accepted to decrease scan times.

CONCLUSION: Bloch-model-based reconstruction of the prepared z-magnetization removes readout-dependent artifacts.

REFERENCES: 1. Endres J, et al. MRM 2023 2. Haase A, et al. JMR 1969. 258-266