A novel compressed sensing (CS) method for B1+ mapping in 7T

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Introduction

B1+ inhomogeneity is severe at high field and produces a variety of artifacts [1]. Measured B1+ maps for parallel transmission (pTx) systems make it possible to design excitation pulses to mitigate the B1+ inhomogeneity [2,3] or design spatially tailored excitations. B1+ maps cannot be measured by a single image, but are typically acquired with several and requisite processing to separate the transmit profile (B1+), the density profile (spin density, T1), and the receive profile (B1-). Several mapping methods (e.g. DAM [4], AFI [5], Fautz [6]) estimate the flip angle of the excitation by calculating the ratio of the two images. Others collect multiple images for fits of flip angle data by sine [7] or block-simulated [8] curves.

A notable feature of B1+ maps is the spatial smoothness of these maps, which can be translates into a sparse representation and potentially be exploited to accelerate the acquisition of such data with sparse sampling and compressed-sensing (CS) reconstruction. In several cases, especially in-vivo, the B1+ or flip-angle maps is in fact sparser than the acquired image used to estimate the B1+ because the acquired image contains not only the transmit profile, but also factors due to the spin density, relaxation, and the receive profile.

We propose a CS reconstruction method for B1+ mapping that imposes sparsity on the flip angle image acquired with sparse sampling. In this implementation, the CS reconstruction method requires only one fully-sampled image to capture the complexity of the receive profile and the density profile, but all other images that enter the B1+ estimation are sparsely sampled. We have applied the CS reconstruction method to a B1+ mapping approach by Fautz [6] that uses a ratio of two images, acquired with and without saturation to estimate the cosine of the saturation flip angle.

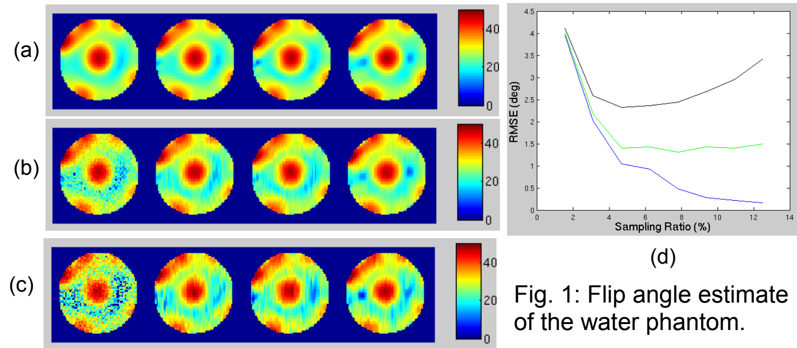

Fig. 1: Flip angle estimate of the water phantom.

(a-c) Flip angle image with sampling ratio of 100% (64 lines), 16% (10 lines), 12.5% (8 lines), 9% (6 lines) from left to right: (a) SNR = infinite, (b) SNR = 65, (c) SNR = 32, (d) Root mean square error of the CS estimation: blue (SNR = infinite), green (SNR = 65), black (SNR = 32)

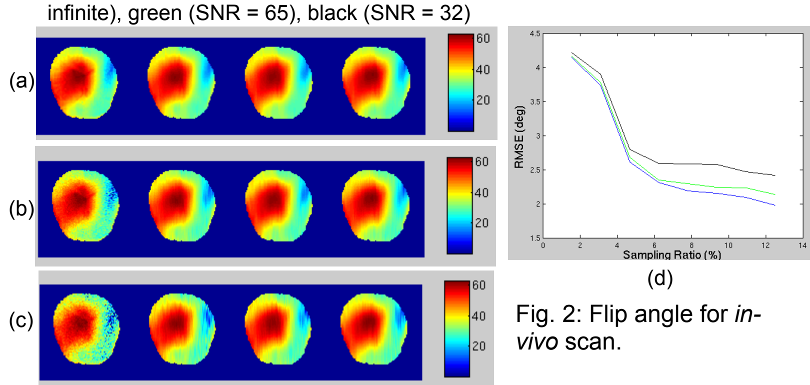

Fig. 2: Flip angle for *in-vivo* scan.

(a-c) Flip angle image with sampling ratio of 100% (128 lines), 8%(10 lines), 6% (8 lines), 4.5% (6 lines) from left to right : (a) SNR = infinite, (b) SNR = 65 , (c) SNR = 32, (d) Root mean square error of the CS estimation: blue (SNR = infinite), green (SNR = 65), black (SNR = 32)

Methods

The reference image, I_{ref}, is fully-sampled, but the saturation image, I_{sat}, is under-sampled. We denote the Fourier transform of the sparse sampling as F_u, and the raw data for the saturation image as $\underline{d_u}$. We estimate the saturation flip angle, θ_s, by minimizing the following CS criterion: $\left\| F_u\{I_{ref}\cos\theta_s\} - d_u \right\|_2^2 + \lambda \left\|\theta_s\right\|_{TV,ROI}$.

We impose the total-variation (TV) norm criterion only inside the region of interest (ROI). As an initialization, we under-sample the reference image with the same sampling pattern applied in the saturation image and the ratio of the two under-sampled images determines a low-resolution estimate of the saturation flip angle. Then, we smooth the initial estimate and iterate the minimization process by the steepest-descent algorithm.

Results

The scans on the water phantom and *in-vivo* are performed on the Birdcage mode of parallel transmit system in 7T Siemens scanner. We collect reference and five saturation images using turbo-flash sequence with 64 or128 PE lines. We estimate the flip angle image and receive profile from the fully-sampled data by cosine fitting. Then, to measure the performance of the CS reconstruction method, we create simulation data with one reference image and one saturation image. Fig. 1 shows the flip angle image estimate of the water phantom and the performance with the several under-sampling ratios and levels of noise. For under-sampled data, we reconstruct by the CS method. As a demonstration purpose, for fully-sampled data, we estimate the flip angle as a ratio of the two noisy images. Fig. 2 shows the performance of the CS estimate for *in-vivo* brain scan at 7T. The CS reconstruction for *in-vivo* brain performs well even with the 6 PE lines and SNR of 32.

Discussion and Conclusions

We have developed and demonstrated a novel CS algorithm for B1+ mapping that yield excellent agreement with fully sampled data for mapping of 3:1 inhomogeneity of B1+ at 7T in human brain. The CS reconstruction was applied to one of several available B1+ mapping methods [3], that uses one reference and one saturation image, but it can be readily modified and applied to other B1+ mapping methods.

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References: [1] Wald, Springer Verlag, 2006, [2] Grissom, MRM 2006, [3] Setsompop, MRM 2008, [4] Cunningham, MRM 2006, [5] Yarnykh, MRM 2007 [6]Fautz, p1247, ISMRM 2008, [7] Kerr, p2561, ISMRM 2006, [8] Brunner, p353, ISMRM 2007.