# Iterative reconstruction for SMART imaging

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## Introduction

SMART (Simultaneous Multi-slice Acquisition using Rosette Trajectories) [1] is a unique fast 2D volume imaging method that uses the spectral selectivity of rosette trajectories. In [1], three separate slices were excited simultaneously, and small amplitude gradient ($G_{sm}$) in slice-select direction was applied during the readout to impose different resonance frequencies on each slice (Figure 1). The reconstruction was done by simply demodulating the received data at the resonance frequency of each slice and applying the conventional conjugate phase reconstruction [2]. However, those reconstructed images suffered from the *spectral residuals* from the off-resonance slices, which limited the method to functional imaging and could degrade motion correction accuracy. Here, we propose a new iterative reconstruction method that reduces most of the spectral residuals to provide image quality almost as good as that of conventional single slice imaging. A simulation study and a scanner experiment at 3T demonstrate significantly improved image quality using the proposed reconstruction method.

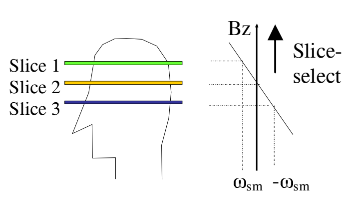

Figure 1. SMART acquisition

## Methods

**Theory :** The MR signal model for SMART acquisitions is simply the sum of signals from the three simultaneously excited slices. The signal is demodulated at the resonance frequency of the middle slice and the corresponding discrete signal model is

$$Y = E_z E A_1 X_1 + E_z A_2 X_2 + E_z E^* A_3 X_3 , \qquad (1)$$

where $Y$ is the measured SMART signal, $E_z$ is a diagonal matrix representing the through-slice de-phasing due to $G_{sm}$, which can be modeled as a sinc function, i.e., $E_z(t_j) = (2\Delta z \sin(\gamma(G_{sm}t_j - G_{sm}T_{acq}/2)/2)/(\gamma(G_{sm}t_j - G_{sm}T_{acq}/2))$ for a perfect rect slice profile, and E is a diagonal matrix representing the off-resonance modulation due to $G_{sm}$, $E(t_j) = e^{-i2\pi\omega_{sm}t_j}$, and $[A_i]_{pq} = e^{-i2\pi(k_x(t_p)x_q + k_y(t_p)y_q)} e^{-i\omega_i(x_q,y_q)t_p}$ denotes the MR system matrix for each slice $X_i$. The proposed reconstruction is done by solving the inverse problem of eqn (1) iteratively using fast implementation of MR system matrix [3] with spatial regularization for each slice, i.e., minimizing the following cost function

$$\phi = \left\| Y - (E_z E A_1 X_1 + E_z A_2 X_2 + E_z E^* A_3 X_3) \right\|^2 + \beta \sum_{i=1}^{3} \left\| C X_i \right\|^2 , \qquad (2)$$

where $C$ is spatially differencing matrix, and β is spatial regularization parameter.

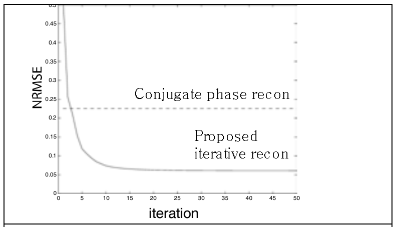

Figure 2. Reconstruction error of the proposed method in simulation

**Simulation :** For comparison, we applied the conventional conjugate phase reconstruction and the proposed iterative reconstruction to synthesized SMART data. The Normalized Root Mean Squared Error (NRMSE) was measured with respect to the reference images in the region of interest, which was defined as inside of the imaging object. The reference images were 64 x 64, the SMART off resonance $\omega_{sm}/2\pi$ was 165Hz. The single-shot rosette trajectory had 96 petals, where the radial frequency and the angular frequency were 1041.7Hz and 108.5Hz respectively.

**Scanner experiment :** A human subject was scanned using GE EXCITE II 3T scanner (GE Healthcare, WI). We used the same rosette trajectory as in the simulation study, and TE = 30ms, TR=2s, $G_{sm}$=0.012G/cm ($\omega_{sm}/2\pi$ =165Hz), readout $T_{acq}$ was 46.3ms. The field map was measured using 8 shot rosette acquisition and the accuracy was enhanced using spatio-temporally regularized reconstruction [4]. The conjugate phase and iterative reconstructions used the measured field maps and $E_z$,. For the reference, we also acquired conventional single slice images using the same scan parameters as SMART but with $G_{sm}$=0 and reduced coverage in slice-select direction due to tripled scan time.

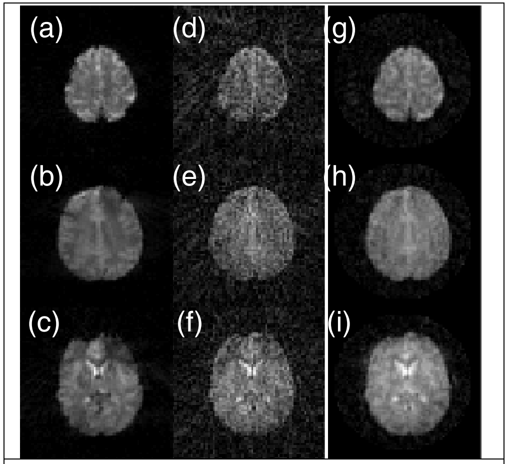

Figure 3. (a~c) single slice acquisition, (d~f) conjugate phase reconstruction of SMART acquisition (g~i) proposed iterative reconstruction of SMART acquisition

## Results and Discussion

The iterative reconstruction significantly reduced the reconstruction error (conjugate phase 0.23 NRMSE, proposed method 0.07 NRMSE for simulation data) (Figure 2) and the most of the residual off-resonance artifacts (Figure 3) both in simulation and scanner experiments. However, due to the sparse sampling of the 3D k-t space, the spatial resolution was slightly reduced compared with conventional single slice imaging (full width half max of the point spread function was 1.5 pixels for the proposed method, where it was 1.2 pixels for the standard single slice reconstruction). Using more petals in rosette trajectory would increase spatial resolution for the price of increased scan time and off-resonance sensitivity. The proposed method was very sensitive to field map errors; therefore the enhancement of the field map using spatio-temporally regularized reconstruction was essential in the proposed method.

## References:

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4. Lee et. al., ISMRM, p2515, 2006

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