Joint Image Reconstruction and Sensitivity Estimation in Spiral SENSE

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INTRODUCTION

Spiral MRI has received increasing attention due to its reduced T_2-decay and robustness against bulk physiologic motion (1). In parallel imaging, spiral trajectories are especially of great interest due to their inherent self-calibration capabilities, which is especially useful for dynamic imaging applications such as fMRI and cardiac imaging (2,3). The existing self-calibration techniques for spiral use the *k*-space center data that are sampled densely in the accelerated acquisition for coil sensitivity estimation (3). There exists a tradeoff in choosing the radius of the center data: it must be sufficiently large to contain all major spatial frequencies of coil sensitivity, but not too large to cause significant aliasing artifacts due to undersampling below Nyquist rate as the trajectory moves away from the center *k*-space. To address this tradeoff, we generalize the JSENSE approach (4), which has demonstrated success in Cartesian case, to spiral trajectory. Specifically, the method jointly estimates the coil sensitivities and reconstructs the desired image through cross validations so that the sensitivities are estimated from the full data recovered by SENSE instead of the center k-space data only, thereby increasing high frequency information without introducing aliasing artifacts. The improved sensitivities lead to a more accurate SENSE reconstruction.

THEORY

Similar to the self-calibrated spiral SENSE (3), we use the *k*-space center data that are sampled densely in the accelerated acquisition for coil sensitivity estimation so that no additional scans or encodings steps are necessary. We then generalize JSENSE (4) to spiral case. Specifically, we model the coil sensitivities as a polynomial function with the coefficients assumed to be unknown. Taking into account the data noise which is usually Gaussian, we can jointly estimate these coefficients for coil sensitivities $\mathbf{a}$ and the desired image $\mathbf{f}$ by minimizing a cost function $\mathrm{U}(\mathbf{a},\mathbf{f})$. The procedure is represented as $\{\mathbf{a},\mathbf{f}\} = \arg\min_{\mathbf{a},\mathbf{f}} \mathrm{U}(\mathbf{a},\mathbf{f}) = \arg\min_{\mathbf{a},\mathbf{f}} \left[\frac{1}{2}\left\|\mathbf{d}-\mathrm{M}(\mathbf{a},\mathbf{f})\right\|^2\right]$ [1], where $\mathrm{M}(\mathbf{a},\mathbf{f})$ is the encoding function which takes the Fourier transform of the product of the desired image and the sensitivities modeled by a polynomial, and $\mathbf{d}$ is a vector formed by the k-space data acquired on a spiral trajectory. The joint optimization problem in Eq. [1] is solved by a greedy iterative algorithm which alternates between updating the image and the polynomial coefficients of the coil sensitivities, both employing the conjugate gradient algorithm. The first iteration of JSENSE is exactly the same as the conventional non-Cartesian SENSE (5) with the initial set of sensitivities estimated by the self-calibrated technique (i.e. use center k-space data within a radius to generate low-resolution images). Theoretically, as long as the dimension of data $\mathbf{d}$ exceeds the total dimension of the unknowns $\mathbf{a}$ and $\mathbf{f}$, the above least-squares problem is overdetermined and thus has a unique solution.

METHOD AND RESULTS

The proposed approach has been tested on a number of real data sets. Here we show a set of representative results from a watermelon acquired with spiral trajectory. The data were collected in a GE 3T Signa scanner (Waukesha, WI) with an eight channel head coil and spin echo sequence (TE = 3.2ms, TR = 2sec, FOV = 24cm, matrix = 256*256, slice thickness = 5mm). The fully sampled data were acquired with 24 interleaves with 2332 points in each interleaf. We simulate the downsampled data with a reduction factor of 2 by keeping every other interleave. For initial sensitivity estimation, we choose a radius of 4/FOV for center k-space data (need to be greater than 3.8/FOV according to Ref. 3). The order of the polynomial for coil sensitivities was chosen to be 11. For comparison, we also show the reconstructions using SENSE, where the sensitivities were estimated using the center k-space data with the optimal radius (3). All the algorithms were implemented in the MATLAB environment (MathWorks, Natick, MA). The performance of the proposed algorithm can be evaluated visually in Fig. 1. It is seen that the proposed method greatly reduces the image artifacts. The normalized mean-squared-errors are compared in Fig. 2.

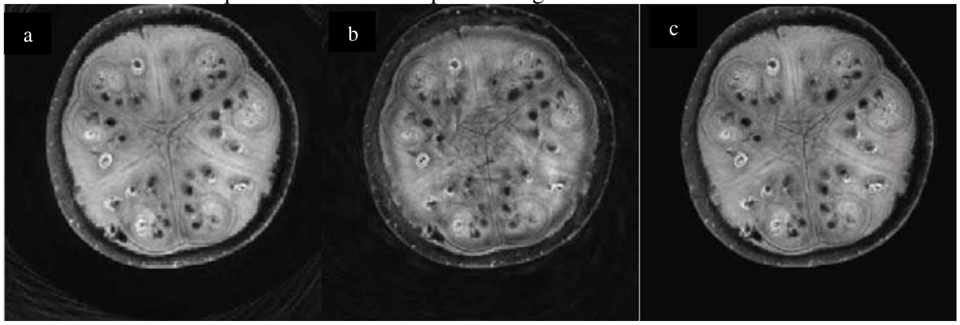

Fig. 1 Spiral reconstruction from (a) full samples, (b) self-calibrated SENSE, and (c) proposed JSENSE.

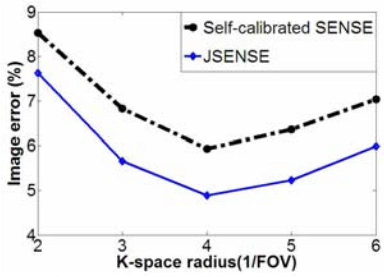

Fig.2 Error comparison

DISCUSSION AND CONCLUSION

The efficient SENSE reconstruction algorithm developed in (6) can replace the conjugate gradient method in JSENSE to reduce the computation time. The proposed method has the potential to increase the acceleration factors in dynamic spiral imaging where self-calibration is needed. The maximum achievable factor depends on the actual spiral trajectories used and will be studied further.

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