Impact of Coil Sensitivity Estimation on MRI reconstruction methods Combining Compressed Sensing and Parallel MRI

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INTRODUCTION: Parallel MRI has been used widely to accelerate image acquisition [1,2]. Recently, application of compressed sensing (CS) to MRI has been proposed and showed great promise [3]. It is reported that combining parallel MRI and CS can enable further acceleration in MRI acquisition [4,5]. SparseSENSE directly applies CS to SENSE by using a random under-sampling pattern and a regularization term in the objective function [4]. DCS-SENSE serially concatenates distributed CS and SENSE, exploiting the inter-coil dependencies for the CS reconstruction [5]. In this study, we will investigate the performances of the two aforementioned methods and examine the impact of coil sensitivity estimation in each reconstruction technique.

THEORY: The acquired k-space data in the l^{th} coil is given by $\mathbf{y}_l = \mathbf{F}_\Omega \mathbf{S}_l \mathbf{u} + \mathbf{n}_l$, where $\mathbf{u}$ is the desired image, $\mathbf{S}_l$ is the sensitivity of the l^{th} coil, $\mathbf{F}_\Omega$ is the partial Fourier matrix, and $\mathbf{n}_l$ is the observation noise. SparseSENSE minimizes the L_1 norm of the reconstruction image in a sparsifying domain: min $\|\mathbf{Wu}\|_1$ s.t. $\mathbf{y}_l = \mathbf{F}_\Omega \mathbf{S}_l \mathbf{u}$ for all $1 \le l \le L$ (1), where $\mathbf{W}$ is the sparsifying transform operator. Thus it produces a single output image using measurements from all L coils. DCS-SENSE first solves the CS problem for multiple coils producing L output images with reduced FOV, and uses these intermediate images as inputs to the SENSE reconstruction. The signal model for DCS-SENSE can be represented as $\mathbf{y}_l = \mathbf{F}_\Omega \cdot \mathbf{u}_l^A + \mathbf{n}_l$, where $\mathbf{u}_l^A$ is the aliased image of l^{th} coil modulated by the coil sensitivity with reduced FOV. All aliased images are simultaneously reconstructed by: min $\|C_1\|_2 + \|C_2\|_2 + \ldots + |C_N\|_2$, s.t. $\mathbf{y}_l = \mathbf{F}_\Omega \cdot \mathbf{u}_l^A$ for all $1 \le l \le L$ (2), where C_n is the n^{th} row of $[\mathbf{Wu}_1^A, \mathbf{Wu}_2^A, \cdots, \mathbf{Wu}_L^A]$. This assumes that the reconstructed aliased images are sparse in the transform domain and their nonzero coefficients are in the same coordinates. The final image is obtained by conventional SENSE reconstruction from aliased images $\mathbf{u}_l^A$'s and the coil sensitivity information. The coil sensitivity information is not utilized in the CS reconstruction of DCS-SENSE and only used in the SENSE reconstruction step.

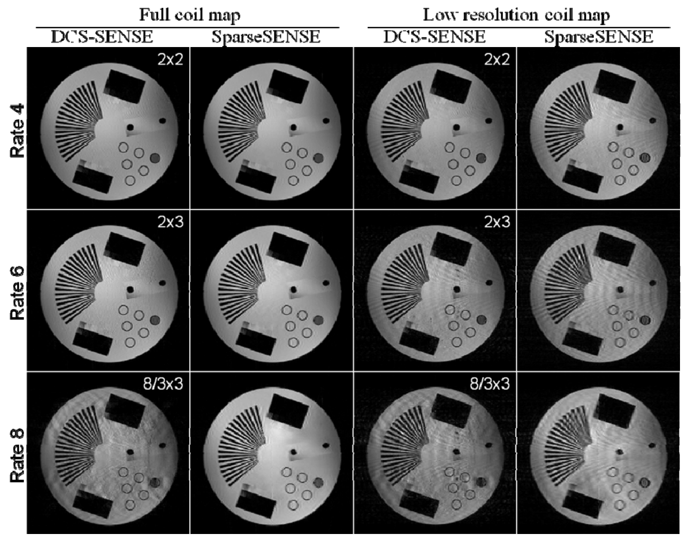

Figure 1: *Phantom image reconstructed using DCS-SENSE and SparseSENSE with full coil map and low resolution coil map.*

METHOD: In order to compare the performances of the two methods and examine the impact of coil sensitivity estimation, we tested under-sampling rates of 4, 6, and 8, and relative coil sensitivities estimated by conventional sum of square method from (a) fully sampled k-space data (full coil map), and (b) 30 fully sampled central phase-encode lines without any further post-processing (low resolution coil map). The reconstruction methods were implemented in Matlab using SPGL1 package [6]. For DCS-SENSE, the phase-encode lines were regularly under-sampled for SENSE reconstruction by reduction factor of R_2 first and then the remaining phase-encode lines were randomly under-sampled for further acceleration by reduction factor of R_1. Thus, the overall reduction factor is $R=R_1 \times R_2$. For SparseSENSE, the phase-encode lines were randomly under-sampled by reduction factor R. Fully sampled k-space data were acquired with 5 coils in a resolution phantom and retrospectively under-sampled. Images were reconstructed using both methods with either a full or low resolution coil map. Thoracic 3D contrast-enhanced MRA images from a pig study were also used for *in vivo* validation.

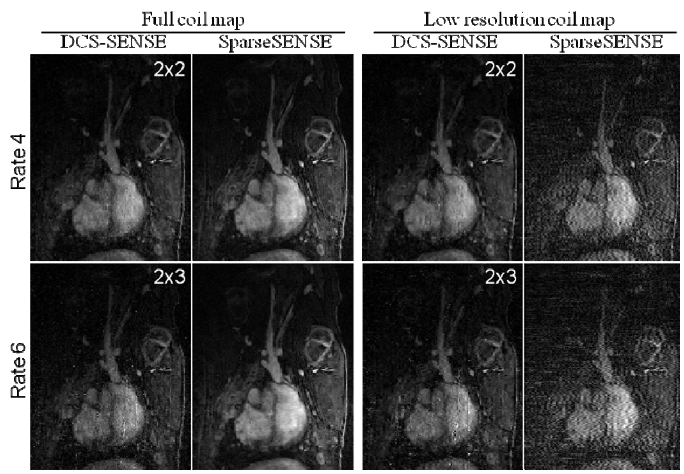

Figure 2: *Example 2D images of contrast enhanced thoracic angiogram reconstructed using DCS-SENSE and SparseSENSE with full coil map and low resolution coil map.*

RESULT AND DISCUSSION: Figure 1 shows the reconstruction of a phantom image with reduction rate of 4, 6 and 8. For R=4 and 6, both methods successfully reconstructed the image with full coil map, but the reconstruction of SparseSENSE with low resolution coil map is degraded more severely. For R=8, DCS-SENSE shows visible artifacts inside the phantom object with both coil maps, whereas SparseSENSE successfully reconstructs the image with full coil map, but produces blurry images with low resolution coil map. The degradation of image quality is more severe than DCS-SENSE. Figure 2 shows the reconstruction results of the *in vivo* data with R=4 and 6. For R=4 with full coil map, SparseSENSE shows slightly better result than DCS-SENSE, but it produces visible artifacts and noise with low resolution coil map. The degradation of reconstruction quality by using low resolution coil map becomes more severe at a higher acceleration rate (R=6). Results indicate that SpareSENSE is more sensitive to the coil sensitivity estimation procedure since the coil sensitivity is used throughout the reconstruction, while DCS-SENSE does not utilize the coil sensitivity in its CS reconstruction and only uses it for the SENSE reconstruction step.

CONCLUSION: The effect of coil sensitivity estimation procedures for two reconstruction methods of combining CS and parallel MRI were examined at different acceleration rates. SparseSENSE is shown to provide better reconstruction quality for high reduction factors with full coil map while DCS-SENSE is shown to be less sensitive to the spatial resolution of coil sensitivity maps.

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