Autocalibrated Approach for the Combination of Compressed Sensing and SENSE

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INTRODUCTION: Following the introduction of SparseMRI [1], the combination of Compressed Sensing (CS) and parallel imaging has been of great interest to further accelerate MRI acquisitions [2-10]. With the exception of the autocalibrated GRAPPA-like approach [10], all these methods require accurate coil sensitivity estimations to achieve good quality reconstructions. Common approaches for this estimation are based on reference scans or fully sampled acquisition of the *k*-space center. However, the quality of the coil sensitivity maps can be affected by motion between the pre-acquired reference scans and the undersampled acquisition, whereas the acquisition of the central *k*-space (typically between 20% and 30%) can limit the maximum achievable undersampling factor. To overcome these problems, we propose an autocalibrated approach for the combination of CS and SENSE (SparseSENSE and its equivalents [2-5]) which does not require extra central *k*-space acquisition. This approach is based on the sequential estimation of the coil sensitivity maps and SparseSENSE reconstruction, from the same data set.

This abstract describes the new approach and its application to 2D black-blood atrial wall images. The results show that undersampling factors up to *3,* using the sparsity in the image domain, and up to *5* by sparsifying using wavelet transforms, can be achieved. The proposed autocalibrated method was compared against the conventional SparseSENSE (using coil sensitivity maps from a reference scan) and against the single coil approach SparseMRI.

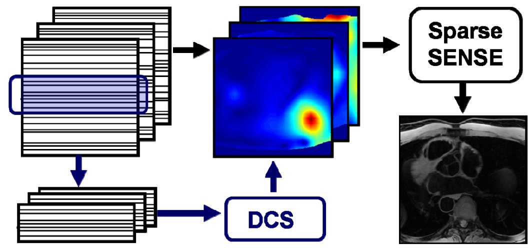

Fig1: Coil maps are estimated from the undersampled k-space center using DCS. Afterwards SparseSENSE is applied to obtain the reconstructed image.

METHODS: A sequential estimation of the coil maps using distributed CS (DCS) [10] and the reconstructed image using SparseSENSE are performed, as shown in Fig. 1.

a) Coil estimation using DCS: Low resolution images are reconstructed for each coil using DCS to estimate the coil sensitivity maps. Since only the measurements corresponding to center of the *k*-space need to be estimated and high resolution reconstruction is not required, a small number of coefficients in the sparsity domain is necessary. DCS is used to take advantage of the correlation between the individual coil images. Let $\boldsymbol{mc}_i$ be the reconstructed low-resolution image and $\boldsymbol{Bc}_i$ be the acquired central *k*-space data for the corresponding coil *i.* Letting $\boldsymbol{F}_u$ be the undersampled Fourier operator and Ψ_C a sparse transform for the coil estimation (here wavelet), the simultaneous reconstruction of the single-coil images is given by: $Min \ \|\Psi_C \boldsymbol{mc}\|_{1,2}$, s.t. $\boldsymbol{F}_u[\boldsymbol{mc}_1\ \boldsymbol{mc}_i \ldots \boldsymbol{mc}_N] = [\boldsymbol{Bc}_1\ \boldsymbol{Bc}_i \ldots \boldsymbol{Bc}_N]$, where $\boldsymbol{mc}_i$ is the *i*-th row of $\boldsymbol{mc}$.

b) SparseSENSE Reconstruction: The reconstructed image $\boldsymbol{m}$ is obtained from the acquired data $\boldsymbol{B}_i$ by solving: $Min \ \|\Psi \boldsymbol{m}\|_1$, s.t. $[\boldsymbol{F}_u\boldsymbol{C}_1\ \boldsymbol{F}_u\boldsymbol{C}_i \ldots \boldsymbol{F}_u\boldsymbol{C}_N]\ \boldsymbol{m} = [\boldsymbol{B}_1\ \boldsymbol{B}_i \ldots \boldsymbol{B}_N]$, where $\boldsymbol{C}_i$ corresponds to the sensitivity map of coil *i* estimated from $\boldsymbol{Bc}_i$ in the previous step, and Ψ a sparse transform for the image estimation.

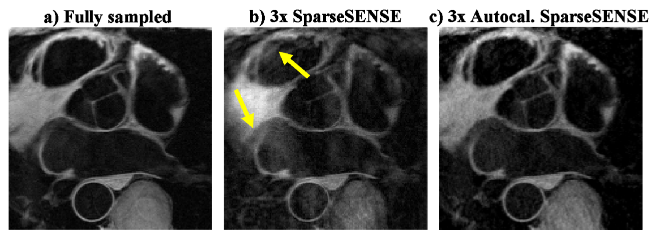

Fig2:3x Undersampled reconstruction using sparsity in the image domain: a) Fully sampled image, b) Conventional SparseSENSE (using coil maps estimated from pre-reference scans), c) Autocalibrated SparseSENSE.

The proposed approach was tested on 2D black-blood atrial wall images (*FFE, 220mm^2 FOV*, *0.75 mm^2* resolution, *TR/TE=3/1.46 ms*) acquired on a 3T Philips scanner using a 6-channel coil. Retrospective random undersampling in the phase-encoding direction was performed for undersampling factors up to *5*. To observe the influence of motion between the pre-acquired coil-sensitivity reference and the actual scan, an additional reference scan was performed *5* min before the black-blood acquisition. For the coil sensitivity reference scan, two low-resolution images (body and array coil) without cardiac triggering and without respiratory gating were obtained.

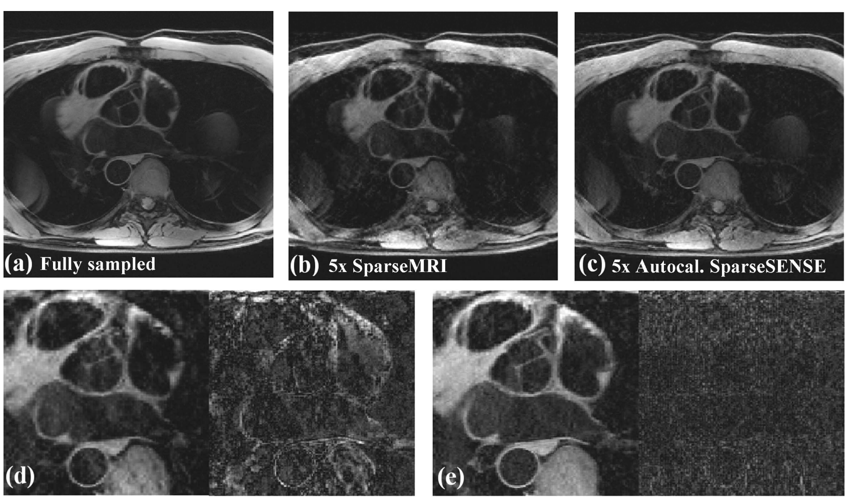

Fig3:5x Undersampled reconstruction using sparsity in wavelet domain: a) Fully sampled image, b) SparseMRI, c) Autocalibrated SparseSENSE. ROI and difference images with respect to the fully sampled for d) SparseMRI and e) Autocalibrated SparseSENSE.

RESULTS: Reconstruction results for an undersampling factor of *3* (sparsity in the image domain) and *5* (sparsity in wavelet domain) are shown in Fig. 2 and Fig. 3. The comparison between conventional SparseSENSE (using the coil maps estimated from pre-reference scans) and the proposed autocalibrated approach is shown in Fig. 2 for a region of interest, showing reduction of artifacts with the proposed approach. The comparison between SparseMRI (coil by coil followed by sum of squares) and the proposed autocalibrated SparseSENSE is shown in Fig. 3, showing the superior reconstruction of the proposed method.

CONCLUSIONS: We have proposed an autocalibrated approach for the combination of Compressed Sensing and SENSE. The method was tested with undersampling factors up to *5*, showing good image quality. This method does not require extra reference scans and avoids the acquisition of the fully sampled *k*-space center, which could limit the maximum achievable undersampling factor.

REFERENCES: [1] Lustig et al, MRM 2007, [2] Liu et al, ISMRM 2008, [3] Zhao et al, ISMRM 2008, [4] Wu et al, ISMRM 2008, [5] King et al, ISMRM 2008, [6] Liang et al, MRM 2009, [7] Otazo et al, ISMRM 2009, [8] Beatty et al, ISMRM 2009, [9] Usman et al, ESMRMB 2009, [10] Lustig et al, ISMRM 2009, [10] Duarte et al, IPSN 2006.