Robustness of Compressed Sensing Parallel MRI in the Presence of Inaccurate Sensitivity Estimates

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Introduction: Recently, several combinations between parallel MRI techniques and Compressed Sensing (CS) have been proposed [1-6]. Following CS theory [7], these techniques exploit an irregular sampling pattern coupled with constrained L1-norm minimization of the image in a certain transform domain to enhance reconstruction by reducing noise and aliasing artefacts. In this work, the application of CS to reduce artefacts due to sensitivity estimate errors is investigated.

Theory: For irregular sampling trajectories, such as radial or Cartesian with variable density (V.D.), errors in SENSE reconstructions [8] due to faulty coil sensitivity estimates are very similar to the incoherent aliasing that has been shown to be effectively suppressed by Sparse MRI [9]. This suggests that applying the CS framework to such cases may be an alternative to algorithms that tackle sensitivity errors by solving a nonlinear joint estimation problem [10, 11].

Methods: Cartesian and radial data were simulated by using a Shepp-Logan phantom image with a resolution of 256x256 and sensitivity profiles of a coil array with 6 elements placed equidistantly on the circumference of a circular field of view. Inaccurate estimates of the sensitivity were generated by applying a rotation and a low-pass filter. In-vivo brain data were obtained with a gradient-echo sequence on a 1.5T scanner (Achieva, Philips Healthcare) with an eight-element head coil (FOV: 220 mm, slice thickness: 4 mm, matrix: 256x256, flip angle: 80°, TR: 250 ms) following a Cartesian (TE: 4.4 ms) and radial trajectory (TE: 4.6 ms). Low resolution coil sensitivities were measured separately, asking the volunteer to rotate his head slightly. Simulated and in-vivo data sets were undersampled at a net factor of 3.66. For the Cartesian data, regular undersampling of factor 4 with 6 autocalibrating (ACS) lines and V.D. random undersampling in one and two directions were used; for the radial data, regular undersampling of the profiles was applied. Reconstructions were performed by applying L1-regularized variants of generalized SENSE [8] and JSENSE [10] with a 6 degree polynomial. The transforms used for L1-norm minimization were spatial finite differences (simulated data) and Daubechies 4 wavelets (in-vivo data).

Fig. 1 NMRSE for the L1-regularized reconstruction of the simulated data undersampled at a net factor of 3.66 with different sensitivity errors and trajectories.

Fig. 2 Reconstructions of the in-vivo data undersampled at a net factor of 3.66 and reconstructed by applying L1-regularized generalized SENSE for regular Cartesian (a) and radial (c) trajectories and L1-regularized JSENSE for the same regular Cartesian trajectory (b).

Results: The normalised RMS error (NRMSE) of the reconstructed simulated data is shown in Fig.1 as a function of the rotation degree applied to the sensitivities. Application of the joint estimation scheme substantially improved the reconstruction results for the regular and one-dimensional V.D. random trajectories, but had less effect with the radial or two-dimensional V.D. random trajectories. CS in combination with irregular trajectories outperformed the joint scheme applied to regular Cartesian trajectories. The images for the in-vivo data are shown in Fig.2. Heavy aliasing was present in the generalized SENSE reconstruction with regular Cartesian undersampling and L1-norm regularization. Application of the joint scheme greatly reduced artefacts due to the sensitivity error. Reconstruction of the radial data with L1-norm regularization, but without the joint scheme, hardly presented any aliasing artefacts.

Conclusions: The obtained results seem to indicate that combining L1-norm minimization with an irregular undersampling trajectory may increase the robustness of image reconstructions to errors in coil sensitivities in a comparable way to nonlinear joint estimation schemes, which require the adjustment of more parameters (polynomial degree, number of ACS lines) and a polynomial fitting step that lengthens reconstruction time.

References: [1] King et al. ISMRM'08 [2] Bing et al. ISMRM'08 [3] Zhao et al. ISMRM'08 [4] Marinelli et al. ISMRM'08 [5] Uecker et al. ISMRM'08 [6] Liu et al. ISMRM'08 [7] Candès and Tao, ITIT; 52:5406-5425 (2006). [8] Pruessmann et al, MRM; 46:638–651 (2001) [9] Lustig et al, MRM; 58:1182-1195 (2007). [10] Ying and Sheng, MRM; 57:1196-120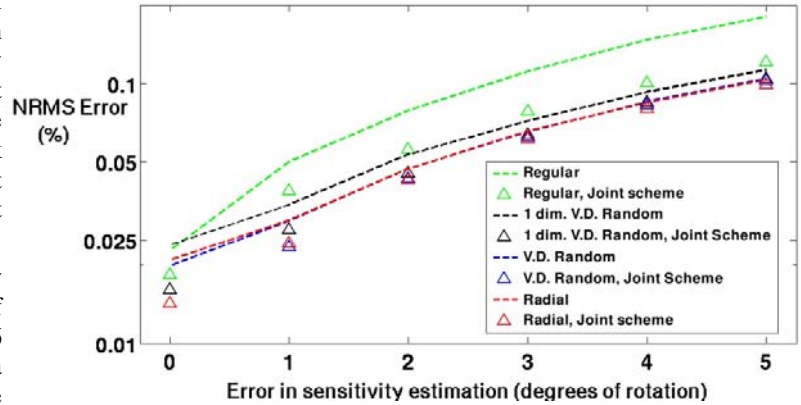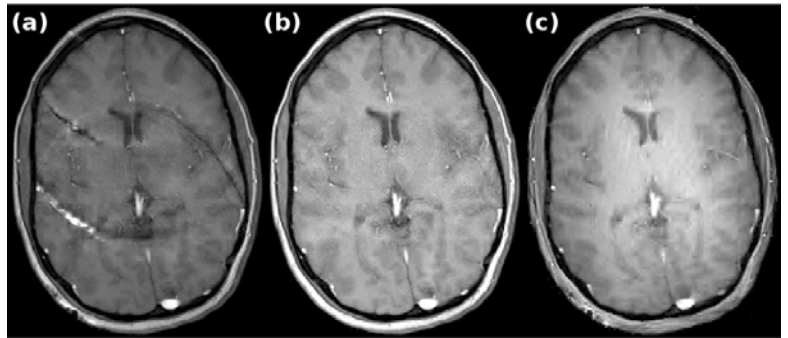2 (2007). [11] Uecker et al, MRM; 60:674–682 (2008).