The Correction of Motion-Induced Coil Sensitivity Miscalibration in Parallel Imaging with Prospective Motion Correction

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INTRODUCTION: Patient motion during an MRI of the brain can result in non-diagnostic image quality. Parallel imaging (PI) can shorten scan time (1–2), however, scan time reduction alone is not adequate to mitigate all motion artifacts. Retrospective motion correction on non-uniform PI acquisition by using iterative NUFFT was proposed (3). Unlike the retrospective technique, prospective motion correction (Mo-Co) (4) can avoid spin history effects as well as k-space inconsistencies. However, in case of large motion during multi-coil acquisition, the coil sensitivities that change relative to the object are one of the most considerable residual artifact causes in prospective Mo-Co (5). Recently, prospective Mo-Co with regular Cartesian sampling (R=1) and accurate knowledge of coil sensitivities was shown (6). In this study, we investigate the effect of coil sensitivity variations on parallel prospective Mo-Co data (R>1) if only initial coil sensitivities are known. We also propose a correction technique to reduce aforementioned artifacts.

METHODS: By applying prospective Mo-Co, the receiver coils moves around the object virtually. The relationship between an MR signal from pose p, coil γ, and the unperturbed image v_0 can be written as a large system of linear equations [1]. $E_{\gamma,p}$ is the encoding matrix comprising the sampling pattern D with value one at measured points and zero elsewhere, a discrete Fourier transform F_p, the moving sensitivity profiles matrix $(\Omega^p_{inv} c^\gamma_p)$ - Ω^p_{inv} is an inversion of the pose matrix. This system is called here "Augmented Cartesian SENSE (ACS)" and solved by minimizing the residual sum of squares [2] using the conjugate gradient (CG) method. In this study, we assume that when motion occurred, the central k-space data were fully sampled to generate $\Omega^p_{inv} c^\gamma_p$, and the number of central lines along phase-encoding (PE) was 12. Low resolution sensitivities which are estimated from the central k-space data are usually subject to spatially varying noise and data truncation errors. For this reason, we introduced the regularization technique to reduce noise in the reconstructed image. The total variation (TV) regularization [3] was chosen for this work (λ: the regularized parameter). The iterative reweighted least square (IRLS) algorithm (7) was applied to solve Eq.3.

$$m_{\gamma,p} = E_{\gamma,p} v_0 \quad --[1], \quad \boldsymbol{E_{\gamma,p} = DF_p(\Omega^p_{inv} c^\gamma_p)} \qquad \min_{v_0}\{\|m - Ev_0\|_2^2\} \quad --[2] \qquad \min_{v_0}\{\|m - Ev_0\|_2^2 + \lambda\|v_0\|_{TV}\} \quad --[3]$$

Experiments were performed on a 7T Siemens scanner equipped with a 24-channel head coil. A volunteer was scanned using 3D MPRAGE at three constant poses. He was instructed to move his head after each full scan. The imaging gradients were updated to maintain the imaging volume by prospective Mo-Co. The imaging parameters were: TR/TE/TI=2250/2.11/1050 msec., 224x224x208 mm^3 (1 mm^3 voxel size). The tracking log file showed up to 3 mm translation and 16 degrees rotation. 1D iFT along readout direction (RO) was performed, and only one slice along RO was selected for demonstration. This slice is located close to isocenter in order to avoid gradient nonlinearity effects (3). Artificially corrupted data were created by mixing k-space data from the three poses and subsampling along PE by R=3 and 4 (1D SENSE). Note that the full central k-space data (12 PE lines) from each pose were truncated by using a cosine taper window before applying iFFT. These were normalized by dividing by their sum of square (SoS) image to obtain low resolution sensitivities $\Omega^p_{inv} c^\gamma_p$.

RESULTS: According to Fig.1, the prospective Mo-Co data with R=1, 3, and 4 were reconstructed by SoS (1^{st} column). The images in 2^{nd} and 3^{rd} columns were reconstructed by 10 ACS iterations. The 2^{nd} column shows that only the image from fully sampled data (R=1) is free of residual artefacts but the rest are perturbed by severe sensitivity artifacts when only coil sensitivities from pose1 were used. On the other hand, when the coil sensitivities relative to each motion pose are given the reconstructed images are greatly improved even at high R as shown in the 3^{rd} column. However, when R is greater, noise is increased (3^{rd} and 5^{th} columns) due to the inaccuracy of coil sensitivities. The 4^{th} column shows that this can be notably reduced after applying ACS with TV regularization (8 outer iterations and 6 inner iterations CG via IRLS). Note that the reference is the SoS image of the pose1 dataset.

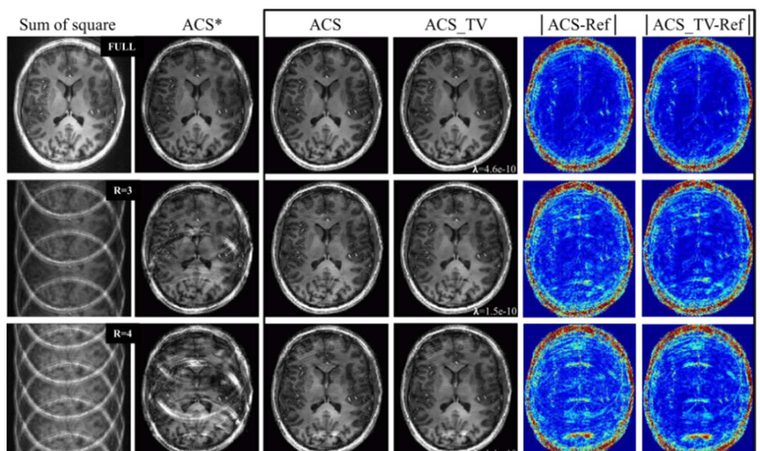

Fig. 1. The images in columns 1 - 4 were reconstructed by SoS, ACS*, ACS, and ACS with TV regularization, respectively. The absolute differences in 5^{th} and 6^{th} columns are identically windowed. *Only coil sensitivities from pose1 were used.

DISCUSSIONS: Prospective Mo-Co is an effective tool in preventing head motion artifacts in MRI. In the case of Cartesian full sampling (R=1), using SoS reconstruction still provides an acceptable image. However, without knowledge of coil sensitivities after motion, neither SoS nor ACS* is adequate to reconstruct parallel prospective Mo-Co data (R>1). This study shows that if a small number of central k-space which is sampled densely enough to satisfy the Nyquist rate can be acquired when motion occurred, these data are sufficient for estimating coil sensitivities. Nevertheless, the accuracy of coil sensitivities which are obtained from very low resolution images can be insufficient. This causes ill-conditioning of the reconstruction matrix (8) and leads to noise amplification at high R. The proposed regularization techniques may improve reconstruction in this case. In addition, gradient induced distortions also need to be considered for slices that are located further away from the scanner isocenter (6).

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