Effect of Motion-Induced Altered Coil Sensitivity on Parallel Imaging Performance

M. Aksoy[1], and R. Bammer[1]

[1]Department of Radiology, Stanford University, Stanford, CA, United States

INTRODUCTION – Correction of involuntary patient motion remains to be one of the most important topics in MRI. In the case of rigid body motion (i.e., rotation and translation), motion correction can be accomplished by correcting for rotation by counter-rotating the k-space trajectories and correcting for translation by applying a linear phase to k-space data [1]. For a multi-coil acquisition, however, patient motion also causes a relative change in the position of the anatomy relative to the receiver coil elements. In this case, for better accuracy, the coil sensitivities should also be modified accordingly to reflect the positional change of the scanner (i.e. coil) frame of reference with respect to the patient frame of reference. In this study, we investigate the effect of the motion-induced coil sensitivity alteration on parallel imaging reconstruction performance.

MATERIALS and METHODS – For a multi-shot scan, if rigid body motion is present between the shots, the acquired k-space data can be given by the following expression in scanner frame of reference:

$$d_{\gamma,\xi}(\kappa) = \sum_{\rho} m\left(\mathbf{R}_{\xi}\mathbf{r}_{\rho} + \Delta\mathbf{r}_{\xi}\right) s_{\gamma}\left(\mathbf{r}_{\rho}\right) e^{-j\mathbf{k}_{\xi,\kappa}\cdot\mathbf{r}_{\rho}}$$

Here, *d* is the acquired k-space data, *m* is the image data to be found, and *s* is the complex coil sensitivity. γ is the coil index, κ is the k-space point index, ξ is the interleaf index and ρ is the image-space point index. The motion is represented by **R** and **Δr** where the matrix **R** is the 3x3 rotation matrix and the vector **Δr** is the translation from patient frame of reference to scanner frame of reference. By applying the change of variable $\mathbf{r}_{\rho}' = \mathbf{R}_{\xi}\mathbf{r}_{\rho} + \Delta\mathbf{r}_{\xi}$, this equation can be written in the patient frame of reference as follows:

$$d_{\gamma,\xi}(\kappa) = e^{j\mathbf{R}_{\xi}\mathbf{k}_{\xi,\kappa}\cdot\Delta\mathbf{r}_{\xi}} \sum_{\rho} m\left(\mathbf{r}_{\rho}\right) s_{\gamma}\left(\mathbf{R}_{\xi}^{T}\left(\mathbf{r}_{\rho} - \Delta\mathbf{r}_{\xi}\right)\right) e^{-j\mathbf{R}_{\xi}\mathbf{k}_{\xi,\kappa}\cdot\mathbf{r}_{\rho}}$$

The first exponential term represents the linear phase term that has to be applied to the k-space data to correct for translational motion and $\mathbf{R}_{\xi}\mathbf{k}_{\kappa}$ shows the counter-rotation of k-space trajectories to correct for rotational motion. The change of coil sensitivity with motion is apparent in the expression for the coil sensitivity in this equation. In this study, we evaluated the effect of the change of coil sensitivity on parallel imaging.

Computer simulations were carried out using a T2w axial brain image and an interleaved spiral sequence with 32 interleaves and matrix size =8x8. Acquired coil sensitivities from an 8 channel head coil were used to simulate parallel imaging. Rotational and translational motions with varying ranges were simulated, while keeping the coil sensitivity field static. The amount of rotational and translational motion was uniformly distributed and changed from shot-to-shot. Using the full simulated data, k-space data for reduction factors of R=2,3 and 4 were also obtained. The resulting k-space data were reconstructed using our Augmented Generalized SENSE reconstruction algorithm [1]. For each data set, the reconstruction was carried out with and without counter-rotation and counter-translation of coil sensitivities. The resulting images were compared with the original, unperturbed image by computing the correlation coefficient between both images.

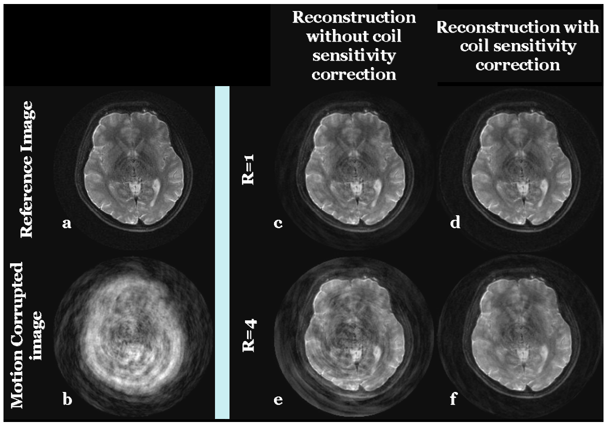

Figure 1 - The images reconstructed in the case of large motion and with and without motion correction, for reduction factors of R=1 and 4. When no motion correction was applied, severe motion artifacts were observed (b). With the application of motion correction without coil sensitivity correction, these artifacts were mostly removed (c,e), however, some residual artifacts still remained due to the unaccounted change in coil sensitivities (see image background) from shot-to-shot, which was more apparent for the R=4 case.

RESULTS – Fig 1 shows the reconstruction results with and without coil sensitivity correction in the case of reduction factors of R=1 and 4. The image reconstructed with no motion correction showed significant motion artifacts (Fig1b). After motion correction with SENSE reconstruction was applied, these artifacts are significantly removed (Fig1 c-f). If the coil sensitivities were not corrected to reflect the actual coil sensitivity exposure, some artifacts still remained, which were more apparent at the reduction factor of 4 (Fig 1e). Motion correction with consideration of changing coil sensitivities gave results comparable to the reference image (Fig 1d,f). Figure 2 shows the correlation coefficients in the case of small (θ~Uniform[-5º,5º], Δr~ Uniform[-2,2 (in mm)]), medium (θ~Uniform[-10º,10º], Δr~ Uniform[-4,4 (in mm)]) and large (θ~Uniform[-20º,20º], Δr~Uniform[-6,6 (in mm)]) simulated motion. It can be seen that the effect of altered coil sensitivity exposure becomes more apparent at high reduction factors and at high degrees of motion. For the cases of small and medium motion simulated in this study, the final image quality was mostly affected from the changing coil sensitivity for the reduction factor 4, whereas for lower reduction factors this effect was relatively small. For the case of largest simulated motion, the effect was more severe, where; artifacts resulting from the change in coil sensitivities were visible even for lower reduction factors. There are two reasons for this: First, the change in coil sensitivity exposure goes up with motion; and second, the counter-rotation of k-space trajectories for motion correction causes undersampling in k-space and this results in a higher “effective” reduction factor.

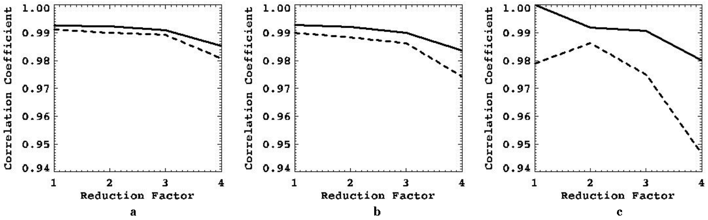

Figure 2 - Reduction factors vs. Correlation Coefficient for three degrees of simulated motion. Results with (solid line) and without (dashed line) coil sensitivity correction are shown. The effect of changing coil sensitivity with motion was not apparent for low degrees of motion and low reduction factors (a,b). At high degrees of motion, this effect was more pronounced (c). For the case of highest simulated motion, R=2 had higher correlation coefficient compared to R=1 when no coil sensitivity correction was applied (c, dashed line). This was due to the fact the removal of interleaves while going from R=1 to R=2 eliminated some of the interleaves that had high motion and higher inaccuracy in the coil sensitivities.

DISCUSSION – The effect of motion-induced altered coil sensitivity on parallel imaging performance was evaluated in this study. It was observed that for accurate parallel imaging reconstruction, it is necessary to correct for coil sensitivities in the case of large motion and high reduction factors. It is obvious that the effect of changing coil sensitivities on PI performance will be more serious in the case of smaller coil elements, in which case, the amount of subject motion causes a more dramatic change in the area which is “seen” by each coil. The imperfections in the estimation of coil sensitivities from low or high resolution data are also expected to affect the results in the case of in-vivo studies.

References [1] Bammer et al, MRM, **Acknowledgements** This work was supported in part by the NIH (2R01EB002711, 1R21EB006860), the Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation and Oak Foundation.