Application of TurboSENSE for Non-Cartesian Trajectories

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Introduction: TurboSENSE (1) is part of a family of solutions (2,3) combining the idea of SENSE mixed with magnitude-only reconstruction. Specifically, with phase-constrained techniques, there is lower g-factor noise enchancement because of better conditioning of the sensitivity matrices. However, there is high sensitivity to phase errors, which are expressed as aliasing artifacts in the reconstruction. TurboSENSE's particular solution is to improve the phase estimation through an iterative process with the SENSE reconstruction (fig. 1). Initial results had previously shown the application of turboSENSE to Cartesian trajectories. Here, turboSENSE is applied to generalized trajectories. The process parallels similar to previous published methods of iterative SENSE reconstructions. (4,5)

Conventional SENSE reconstruction for non-Cartesian trajectories is expressed by Eq [1] $\mathbf{E^H E v = E^H m}$, where **E** is the encoding matrix, **v** is the reconstructed image, and **m** is the collected k-space data, and solved by conjugate gradient iteration. For magnitude-only reconstruction, the equation is similar, except now **E** incorporates a phase estimate and separated into real and imaginary parts, **v** is the reconstructed magnitude image, and **m** is the collected k-space data separated into real and imaginary parts. Figure 2 shows the block diagram of how to modify conventional SENSE into magnitude-only SENSE reconstruction. The phase refinement step is likewise expressed similarly as a least squares problem (1), and is also conveniently solved by conjugate gradient iteration.

1) Perform magnitude-only reconstruction (eq. 1) using an initial phase estimate provided by the coil calibration measurements.
2) Perform phase refinement
3) Add this new phase onto the phase estimate
4) Repeat steps 1-3 until convergence

Figure 1. Steps for performing turboSENSE

Methods: Data was acquired with the SNAILS diffusion-weighted sequence (5) from a GE Signa 1.5T scanner and 8-channel head coil. 20 interleaves were acquired off a variable-density spiral trajectory. Interleaves were removed to simulate the undersampling. Coil sensitivities were obtained from the central fully-sampled portion of the interleaves. The reconstruction was visually inspected at every iteration for convergence. The SNAILS motion correction algorithm was used for the diffusion-encoded images.

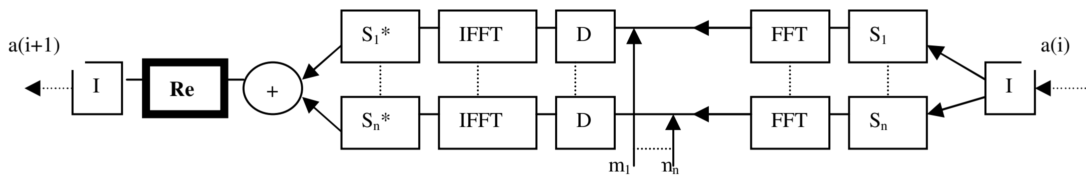

Figure 2. Segment of the iterative reconstruction. Magnitude-only reconstruction is performed by adding the real operator. I: intensity correction, D: density and gridding, S: coil sensitivities, m: k-space data, a: residuum

Results: Figure 3 shows the truth images for the T2-weighted image and one diffusion-encoding gradient direction. Figure 4 shows the T2 images for SENSE and turboSENSE at reduction factors of 3, 4, and 5. SENSE has lower SNR than the turboSENSE counterparts, especially at R=5. The lateral ventricles visually shows this difference. TurboSENSE does not eliminate all the spiral artifacts from incomplete phase estimation and has difficulty at certain air-tissue nulls. Figure 5 shows the SENSE and turboSENSE images for the diffusion-encoded gradient direction at R=3. There is also visual improvement of turboSENSE over SENSE.

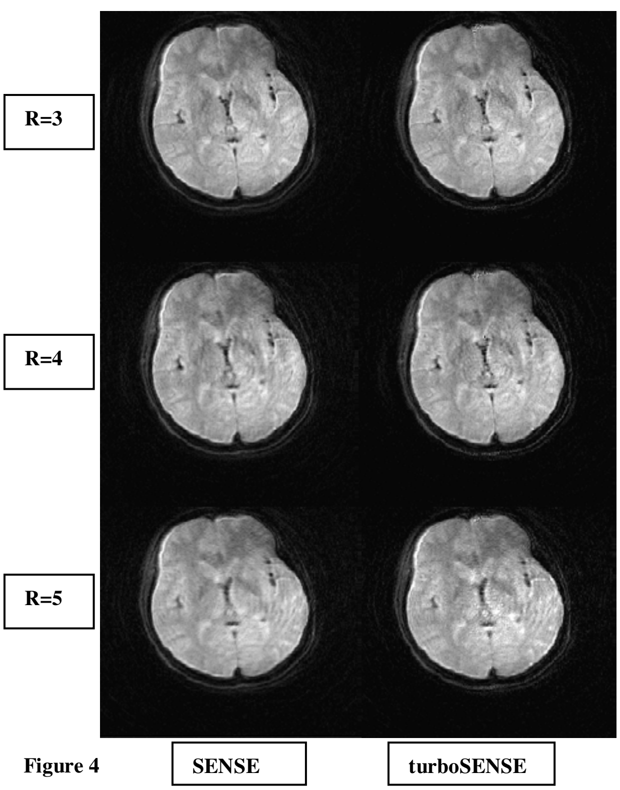

Figure 4

Discussion: The challenge of applying turboSENSE to non-Cartesian trajectories lies in obtaining a favorable phase estimate. This abstract provides an approach similar to that used for Cartesian trajectories that refines the phase by solving a least-squares equation. The initial reconstructions show that this approach is plausible and performs some improvement in SNR over conventional SENSE reconstruction. There may be inherent problems due to the greediness of the conjugate gradient algorithm, which may lead to incorrect local minima and incorrect phases. Further efforts would include the effects of using different initial reconstructions to refine the phase.

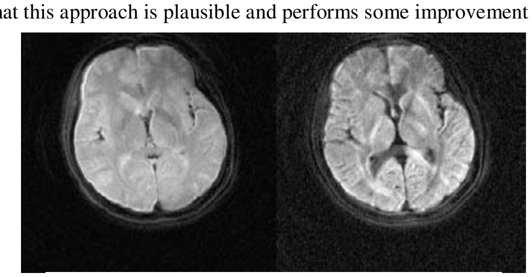

Figure 3. Reference T2 and diffusion image

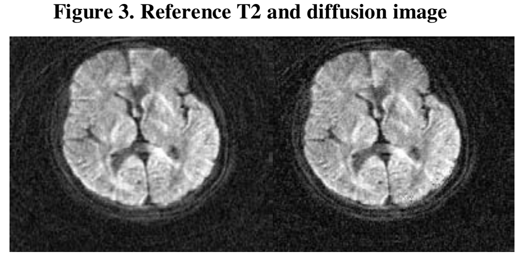

Figure 5. R=3 SENSE and turboSENSE diffusion images

References: 1. Lew, C., et al, 2443, ISMRM 2005. 2. Willig-Onwuachi, J.D., et al., 19, ISMRM 2003. 3. Bydder, M, Robson MD, 53:1393-1401, 2005. MRM, 4. Pruessman, K.P., et al. MRM, 42:952-962, 1999. 5. Liu, C., et al, 509, ISMRM 2005.

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