Compressed Sensing for Motion Artifact Reduction

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Introduction: Navigators can effectively track rigid-body motion of limited amplitude, such as respiratory motion [1,2,3]. In a Cartesian scan, data is corrected by applying to each k-space line the phase modulation corresponding to the amount of detected motion. However, lines associated with significant motion (e.g., swallowing in larynx imaging) are uncorrectable and therefore need to be discarded. If those lines are close to the center of k-space, the resulting artifacts can be severe. Different ordering schemes (spiral, elliptical [4, 5]) have been investigated to increase the robustness of MR acquisition against motion. They aim at acquiring the most important data – namely the center of k-space – first, since the patient is less prone to sporadic motion during that time. Compressed sensing states that images with a sparse representation in a given domain can be accurately reconstructed from undersampled datasets by using a nonlinear reconstruction. This method has been recently introduced in MRI to reconstruct randomly acquired undersampled datasets [6]. We propose to use a pseudo-random trajectory and compressed sensing to reconstruct datasets where data corrupted by motion has been detected by navigators and rejected. When the phase and slice encodes of a 3D Cartesian trajectory are randomly acquired, motion taking place over several TRs results in corrupted lines randomly distributed and the center of k-space is less likely to be severely damaged. Discarding the corrupted lines provides a randomly undersampled dataset that can be accurately reconstructed with compressed sensing methods.

Methods: To evaluate the impact of spurious motion on compressed sensing reconstruction and random acquisition, we performed simulations on in vivo data and conducted phantom experiments.

Simulations We simulated data rejection due to gross motion with a sequential trajectory and with a random trajectory by discarding 30% of the phase (ky) and slice (kz) encodes in both cases. ky lines for the sequential trajectory and (ky,kz) points for the random trajectory were randomly set to zero. For the sequential trajectory, it corresponds to a segmented acquisition with a short TR (~80ms) and a small number of clustered slices (~32). For the sequential trajectory, we reconstructed the data using 3DFT. For the random trajectory, we estimated the phase and reconstructed the data with an L1-penalized non-linear conjugate-gradient method, which enforces data consistency and uses finite-differences as the sparsifying transform [6].

Experiments We designed a random trajectory in (ky,kz) space. We first acquire the center 25% of k-space, then the remaining 75%. For each of those two sets, the next encode to acquire is randomly chosen but cannot fall within the periphery (radius R) of a previously acquired one. When all other encodes have been acquired, R is decreased. This trajectory was incorporated into a 3D Fast Large Angle Spin Echo (FLASE) sequence [7]. Cartesian navigators were acquired along the three axes. We scanned a resolution phantom using the following parameters: TR/TE 40/15 ms, FOV 20 cm, slice thickness 5 mm, matrix size 512x256x16, BW ±32 kHz. 64 points were acquired for the navigators. At mid-scan the phantom was manually moved along z by sliding the table, and brought back to its original position.

Results and Discussion: Figure 1 shows the results of the simulation. Each readout line (phase-encode position) is represented by one point in the (kz, ky) plane. Discarded phase-encode positions are in black. The coherent aliasing artifacts are removed when compressed sensing is used. Figure 2 shows the phantom scan results. The navigator data indicate that the amount of motion was comparable between the scans: 245/257 encodes had to be discarded with the sequential/random trajectory (Figs. 2b and 2d). Here, even a 3DFT reconstruction provides accurate results when data is randomly acquired (Fig 2e).

The simulations and experiments indicate that our approach will be useful for in vivo imaging. We will use a variable-density random trajectory. Indeed, aliasing interferences are larger and more structured when a uniform-density undersampled trajectory is used [6]. In addition, we will weigh the probability distribution such that data towards the center of k-space are more likely to be acquired first.

Conclusion: A new approach to increase the robustness of MR against spurious motion has been proposed. It uses a pseudo-random trajectory and reconstructs the data by L1-minimization. Results from simulations and phantom experiments demonstrated its potential to reduce motion artifacts.

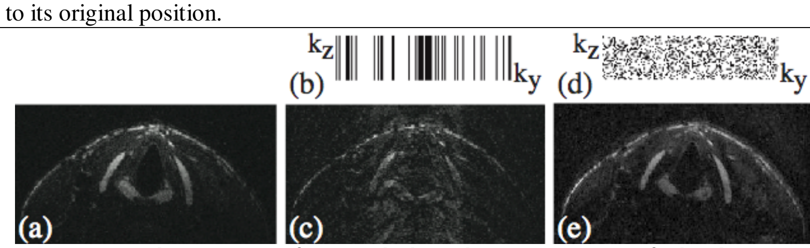

Figure 1. *Simulation. Data from a high-resolution 3D scan of the larynx with 312μmx391μmx1mm resolution. An axial slice is shown. (a) Original Image. (b) Classical Trajectory Affected by Motion. (c) 3DFT Reconstruction. (d) Random Trajectory Affected by Motion. (e) Compressed Sensing Reconstruction.*

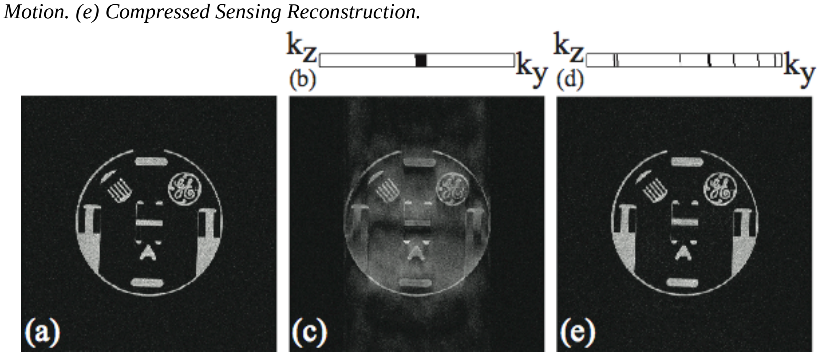

Figure 2. *Phantom Experiments. (a) Classical Trajectory – No Motion. (b-c) Classical Trajectory – Motion at Mid-scan. (d-e) Pseudo-random Trajectory – Motion at Mid-scan.*

References:

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