Motion Correction for 3D Radial Encoded Spoiled Gradient Echo Imaging of the Head

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Introduction

Rigid body motion correction can be achieved in 3D radial encoded sequences by arranging the radial k-space lines so that subsets of contiguous samples result in a uniform sampling of k-space. Adjacent windows of k-space samples can then be reconstructed and registered with one another in image space to generate subvolumes and achieve tracking of a rigid body such as the head throughout the scan (1,2). A scheme for arranging the radial lines is presented in which their end-points are uniformly spaced on a sphere within a hierarchy of window lengths. The scheme is implemented in a spoiled gradient echo sequence, allowing greater flexibility with respect to the ordering scheme, together with a method for reconstructing the full motion compensated image volume from the hierarchically reconstructed k-space windows. This results in a volume with substantially reduced motion blurring and artifacts.

Methods

A standard set of radial directions is reordered to allow hierarchical image reconstruction. Figure 1 illustrates the time ordering of 16 radial spokes in three dimensions. Note that the spacing of points is uniform on the surface of the sphere at all levels n of partitioning into 2^n groups in time (two halves of the data, four quarters of the data, .., groups of four points, pairs of points). In practice many more k-space lines are collected. Therefore images can be reconstructed at all levels provided the sampling is sufficiently dense. Spoke ordering is determined using a multi-level sorting algorithm that maximizes the total spacing between points on the sphere at all levels. For human testing, a 3D radial encoded spoiled gradient echo sequence was implemented with 32768 radial lines sorted hierarchically. Protocol: TR 2.39 ms, single ultrashort echo with TE 50 µs, BW 1002 Hz/px, T_{acq} 1 min 18 s, flip angle 2°, FoV 256 mm, resolution 4^3 mm^3. System: 3 T Siemens (Erlangen, Germany) Tim Trio, 32 channel head coil.

At each level of reconstruction, starting with a large number of small groups, adjacent pairs of volumes are registered using FLIRT (3,4) with correlation ratio cost function to determine the translations and rotations required to align the second volume with the first, as shown in Figure 2. At the next level, the combined volume is reconstructed after regridding the rotated k-space lines to account for the rotations and correcting the phase of each sample to account for the translations. Following this procedure to the top level, a single volume is reconstructed from the full and consistent collection of k-space lines corrected for motion throughout the acquisition.

Results and Discussion

Figure 3 shows three fully reconstructed volumes from two scans using the protocol described above. During the first scan, the subject was instructed not to move and the volume shown on the left resulted. During the second scan, the subject was instructed to move the head approximately every 10 seconds. Without motion correction, the volume shown in the middle resulted. After motion correction, the same data produced the volume on the right. The procedure also generated a position estimate for every subinterval (every 4.9 s) shown in the motion plot accompanying Figure 3.

A protocol with ultrashort TE was used. Only motion correction is presented, but the purpose is to track motion during MR-PET imaging and obtain an attenuation correction map of the head including bone.

The hierarchical time ordering scheme is achieved with a hierarchical sorting algorithm. The initial set of spokes is not prescribed and in this work it was generated by wrapping a single spiral along the spherical surface. Interleaved spirals have been used to achieve a sliding window reconstruction for motion correction (2). In such schemes, spokes are denser along the length of the spiral than between spiral windings. A smooth progression of spoke orientations is essential to avoid artifacts in TrueFISP sequences (2). With spoiled sequences, the spoke orientations can be random and the hierarchical scheme becomes possible. The hierarchical scheme has the advantage that the spokes are equally dense everywhere on the spherical surface at all levels of subdivision that are powers of two. The hierarchical image reconstruction approach ensures that the maximum amount of information is used to drive the registration at each level of data reconstruction i.e. registration accuracy is not dictated by the SNR of the images at the smallest window size. In principle, subvolumes that are so corrupted by motion that they cannot be registered could be omitted. This was not necessary in this example.

Acknowledgments

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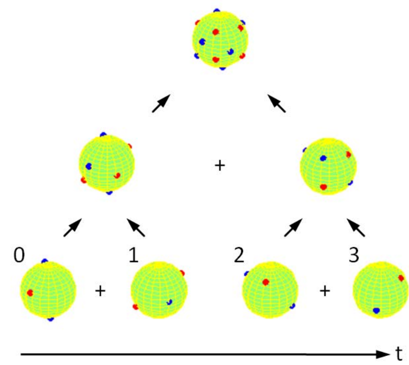

Figure 1: Time ordering of 16 radial spokes in three dimensions (top row: complete set, second row: first and second half, third row: four consecutive time intervals of 4 spokes each). Red and blue dots represent spokes in first and second subinterval of each interval.

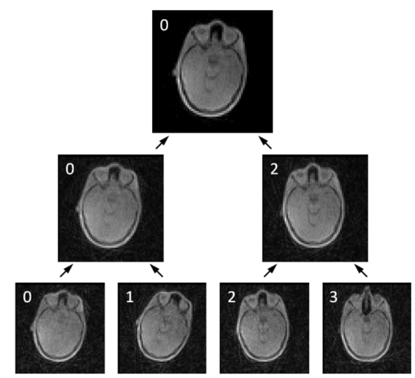

Figure 2: Representative axial slice for each of a set of hierarchically reconstructed volumes. Each pair of volumes from a subinterval are registered to the first volume in the pair from the deepest level to the top level and the k-space lines are resampled and phase corrected to form a consistent k-space volume for the entire scan.

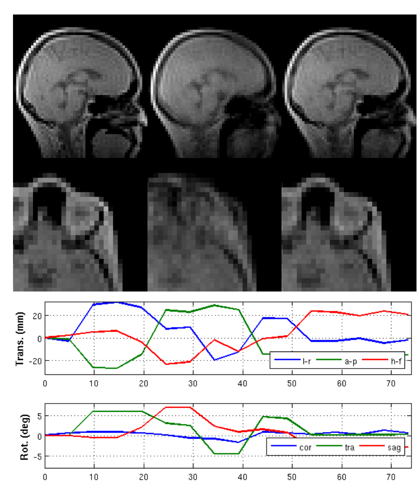

Figure 3: Sagittal and zoomed axial slices from volumes: (left) without motion, (middle) with motion, without correction, (right) same with motion and correction. (Bottom) Translations and rotations.