Rapid Real-Time Prospective Rigid Body Motion Correction During Imaging Using Clover-Leaf Navigators

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Introduction

The quality of high resolution structural scans used to quantify geometric measures of anatomical structures in the brain is frequently compromised by movement of the subject during the scan, especially in older subjects, children and patients with movement disorders. Long scans with 3D encoding are particularly sensitive to subject movement since every acquired line of k-space affects all spatial locations in the reconstructed volume. We have developed a method for measuring and correcting the rigid body motion of the subject's head in the scanner in real-time by means of a pulse sequence with embedded clover-leaf navigators, and implemented a prototype on 1.5T and 3T Siemens (Erlangen, Germany) platforms.

Background

Solutions to the problem of off-line motion correction for between-volume correction are well established [1,2], but correction for motion during the acquisition of a single volume still requires an effective solution. Straight-line navigators have been used to detect linear abdominal motion [3] and for phase correction in EPI. Orbital navigators are used to deal with the problem of rotation within a plane, and a combination of orbital navigators [4] or spherical navigators [5] can be used to deal with arbitrary rotation in any plane. Real-time motion correction using registered EPI volumes has also been implemented [6]. We present an improved k-space trajectory [7] and associated mapping procedure that allows rapid correction of rotations and translations with minimal additional acquisition time.

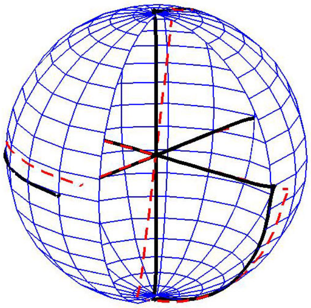

Figure 1: K-space trajectory for a short clover-leaf navigator (one of the rotated paths used for mapping is shown in red).

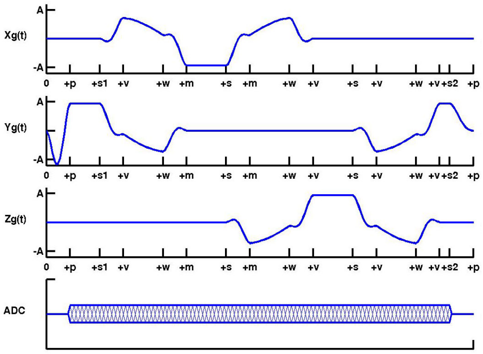

Figure 2: Navigator gradients required to realize a clover-leaf trajectory.

Methods

Figure 1 shows the k-space trajectory for a clover-leaf navigator and Figure 2 shows the gradients required to realize this trajectory. In the most recent instantiation, the clover-leaf navigator and associated prephasing and refocusing gradients occupy 2.2 ms of each TR of a conventional spoiled gradient echo sequence and share the existing RF excitation pulse. The trajectory includes straight-line segments that intersect the center of k-space. Translations of the subject result in an additional linear phase component in the measured signal on the straight-line segment of the corresponding axis. Rotations of the subject correspond to rotations in k-space. Because rotations may be out of the plane of the arc segments of the navigator, a map of k-space in the vicinity of the navigator is acquired in a short preliminary mapping sequence. The map consists of blocks of the imaging sequence containing navigators acquired with the gradients artificially rotated in each of 9 angles about 42 axes equally distributed in three dimensions to simulate real rotations of the subject. This procedure is completed in 15 s, including 3 s to reach steady-state.

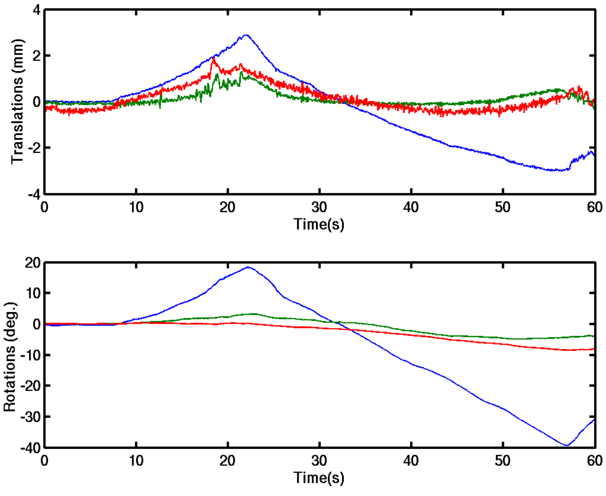

Figure 3: Motion of subject during 60 s FLASH scan measured using clover-leaf navigators with real-time rotation correction. Translations: sup-inf (red), ant-pos (green), left-right (blue). Rotation axes: left-right (red); ant-pos (green), sup-inf (blue).

A linear mapping that relates the acquired navigator to the rotations in the map is calculated from the map in 3 s. Once this relationship is established, the angle of rotation can be rapidly determined with a single matrix multiplication. A fraction of the rotation is fed back to the gradients and a correction is made every TR. The correction lags the corresponding navigator acquisition by two TR intervals. The linear approach allows rapid estimates of the rotation and degrades gracefully in the presence of noise.

Results and Conclusion

Figure 4 shows the rotations and translations of a subject detected during a one minute 3D FLASH with embedded clover-leaf navigators (TR=30 ms, 2^3 mm voxels). Figure 3 (top row) shows the corresponding image collected without real-time feedback and without correction with noticeable artifacts in the image. Figure 3 (bottom row) shows the corrected image collected in a separate run during which the subject replicated the motions of the first run. Translation-induced phase errors were corrected off-line. The system tracks rotations and improves image quality in the presence of large movements.

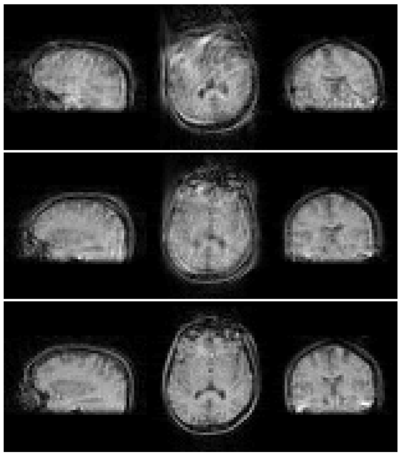

Figure 4: Comparison of 3 planes through a gradient image volume. Top: no feedback correction; Middle: real-time rotation correction, Bottom: real-time rotation and off-line translation correction.

Acknowledgement

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