Retrospective Registration-Based Motion Correction with Interleaved Radial Trajectories

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Introduction: Depending on the k-space acquisition trajectory, patient motion can cause blurring, ghosting, or other artifacts that reduce diagnostic value of MR images [1], often requiring repeat scans. This is especially problematic in 3D imaging due to long acquisitions, and when imaging very young, uncooperative, or impaired patients. Bulk patient motion, e.g. adjusting for comfort or twitching, usually occurs in a discontinuous manner. Many successful retrospective motion correction techniques [2,3] rely on this assumption to estimate motion from low resolution data acquired in interleaves, additionally assuming that each interleaf is motion-free. Here, we propose a novel technique that makes no assumptions about when motion-free periods occur. The proposed technique decouples the motion detection scheme from the motion estimation process, thereby improving scan efficiency and potentially increasing correction accuracy, enabling robust correction of 3D rigid body motion.

Theory: The approach relies on a radial k-space acquisition with a pseudo-randomly interleaved sampling scheme. These data are divided into consistent subsets using a motion detection algorithm based on correlations of center of mass (COM) vectors for all receiver coils. With a single coil with near-uniform spatial sensitivity, COM plots can be used both to detect and correct rigid body translation by shifting projections to align their COMs [4]. In the multi-coil case, each coil records the object modulated by its own sensitivity profile. When the object moves, the coils stay in place, eliminating the linear dependence between the translational motion vector and COM values, as well as the ability of COM analysis to estimate motion directly. However, we found that since each coil records a different amount of motion, COM values become even more sensitive to motion, detecting not only translations but also rotations, since in the multi-coil case rotational motion will affect COM values for at least one coil. Images obtained from each motion-free subset are co-registered to estimate motion parameters. A single final image is reconstructed by applying the proper corrections to the raw data. The timescale for motion correction is determined by the number of projections used to calculate COM. Since each subset is delineated by the actual object motion, this technique may utilize larger consistent subsets than fixed-width techniques, resulting in more accurate motion correction.

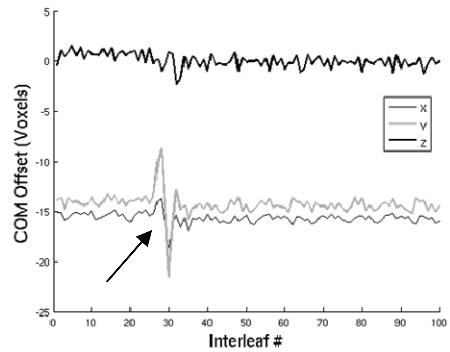

Figure 1. Multi-channel COM analysis results (single channel shown) for a volunteer cranial exam with one instance of motion (arrow)

Methods: The proposed approach was validated in three volunteer studies. After obtaining informed consent, data were acquired using an interleaved 3D radial sequence (VIPR) with modified gradients to compensate for trajectory deviations caused by gradient delays [5]. This sequence was implemented on a clinical 3.0 T scanner (Discovery ™ MR750, GE Healthcare, Waukesha, WI). Scan parameters for the spoiled gradient echo acquisition included: TE/TR = 2.9/7.0 ms, BW = 62.50 kHz, flip angle = 17°, voxel size = 0.94 mm isotropic, FOV = 240x240x240 mm^3, 8 channel phased array head coil, 100,000 projections. Subjects were asked to adjust head position several times during exam. Motion-corrupted and motion-free datasets were acquired back-to-back to assess motion correction quality. Motion-free subsets of data were determined from COM vectors calculated on a per-channel basis for each interleaf. Low resolution footprint images were reconstructed from the identified motion-free subsets and individually co-registered to the initial footprint using FLIRT, a registration tool provided in the FMRIB Software Library (FSL) [6], based on the correlation ratio cost function. The resulting registration parameters were used to realign k-space data, from which the final motion-corrected image was reconstructed with density compensated gridding.

Mean SNR	6.67	10	12.5	16.67	25
Translation, pixels	1.75	1.25	0.75	0.75	0.5
Rotation, degrees	2	1	0.67	0.5	0.25

Table 1. Smallest amounts of detectable motion by the proposed algorithm with sensitivity of at least 0.90

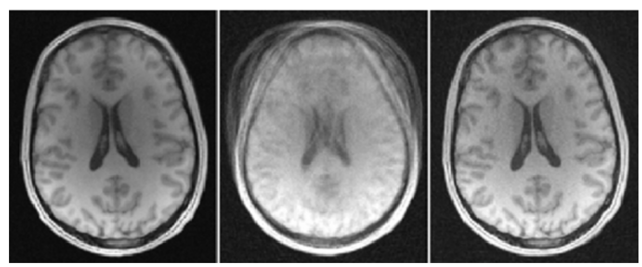

Figure 2. In-vivo brain images with no motion (left), with motion corruption (center), and with motion corrected by the proposed technique (right)

Results: Figure 1 shows the calculated COM for a single channel of a multi-coil cranial exam with a single instance of motion. The image COM was calculated for each interleaf (50 projections), corresponding to a frame duration of 350 ms per interleaf. Standard deviations of COM estimates for a corresponding motion-free exam were 0.36, 0.45, and 0.55 pixels, for X, Y, and Z coordinates, which sets the sensitivity of motion detection per receiver channel. Separate simulations studies (Table 1) revealed sub-pixel sensitivity of the motion detection method for realistic SNR values (>12) with four coils. Figure 2 shows representative results from a separate volunteer study. Total 6000 out of 100,000 projections were additionally rejected due to motion corruption in the example.

Discussion and Conclusions: We developed a novel technique that enables robust correction of motion artifacts in any 2D or 3D radial acquisition without additional navigators or external motion monitoring. The ability to recover resolution from motion corrupted data was demonstrated through representative volunteer cranial acquisitions, for which the proposed method is well suited since expected patient motion in cranial exams conforms to our assumptions. Our studies demonstrated successful correction of sub-voxel motion with a timescale of 350 ms. We found that previously described method to determine translational motion parameters by COM analysis in single channel receiver systems [4] no longer is applicable to multicoil phased arrays. However, it remains sensitive to translational motion and additionally gains capability to detect rotational motion. Hence, in our method we utilize COM for motion detection, while motion parameters are estimated by co-registration. Interestingly, the observed variations of COM during motion are much larger than what may be expected from baseline COM values of the resting positions (Figure 1). This may be due to additional effects caused by motion such as motion-induced steady state signal changes, and may improve motion detection sensitivity in both single- and multi-coil acquisitions even in presence of uncompensated k-space trajectory deviations, which introduce error in COM analysis. Resolution is apparently restored (Figure 2), but we observed some SNR loss in the corrected images, likely due to residual gaps in k-space resulting from rotation corrections and discarded interleaves. An optimized reconstruction with parallel imaging such as that proposed by Bammer *et al* [7] may reduce streaks caused by the missing data and improve apparent SNR. Further work is planned to investigate applications of this technique in other areas such as phase contrast imaging and body imaging.

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