In-Plane Bulk Motion Correction in 2D Radial Fast Spin Echo MRI

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Introduction: In this work an algorithm for correcting in-plane motion artifacts in radial fast spin-echo (radial-FSE) sequences is described. The technique makes use of the consistency properties of the moments of projections, which has been applied previously to radial spin-echo data [1]. In radial-FSE, however, each radial line acquired within an echo train has a different T_2 weighting, and the consistency properties cannot be directly applied. The extent of the differences depends on the inherent T_2 relaxation times within the object, the number of views collected within an echo train and the receiver bandwidth. In this work, specific view ordering and data normalization are employed that enable consistency properties to be implemented in radial-FSE to correct for rigid body motion. Results from simulation as well as in imaging of phantoms and volunteers are presented.

Method: The Fourier transformation of an individual radial line of k-space data (view) yields a projection of the object at an orientation coincident with the view angle. The moments of these individual projections follow certain consistency conditions that can be used to correct for translations and rotations [1]. In FSE, however, views obtained at different TEs, show a consistency behavior that is different in amplitude and phase from the behavior of the moments of projections obtained at other TEs. However, the phase change in the 2^{nd} moment curves are not noticeable for objects like the simulated datasets shown in Fig.1 as well as for the experimental datasets shown in Fig.2. In order to estimate the consistency behavior for each TE, the views collected at each TE have to be spread evenly throughout the full 2π radians of k-space. Moment curve from views collected at identical TEs can be used to correct for scaling between moment curves calculated at different TEs. Views obtained within a particular echo train can then be used to correct for translational and rotational motion occurring between TR periods.

Translation Correction: The Center of Mass (CoM) of each view is calculated as the ratio of the 1^{st} moment to the 0^{th} moment of the projection. The CoM of all the objects in the field of view is brought to the center of the image space by aligning the CoM of all the projections. This requires each radial complex dataset in k-space to be multiplied by a linear phase term that depends on the CoM of its projection. In radial-FSE, variations in the calculated CoM can be present even from stationary objects due to views being collected at different TEs and objects having different T_2 relaxation. To account for this, the CoM of the object is calculated from views obtained with the first two echoes of each echo train (TE_1 and TE_2 views) that are collected to be nearly orthogonal and for which little change in signal intensity is observed. Estimated CoM is then applied to the remaining views collected within the TR.

Rotation Correction: The 2^{nd} moment of the projections from views collected at identical TEs (from different TRs) follow a sinusoidal consistency relationship. Within each echo position, the periodicity of the sinusoidal curves is maintained but the amplitude of the moment curves are reduced (Fig. 1b). To use the consistency of these moments, curves from individual TEs are normalized in magnitude allowing views collected in different TR periods to be used to estimate rotational motion. From the normalized points, sinusoidal curves are estimated for each TR. When the object moves, there is a considerable deviation from the consistency behavior of the 2^{nd} moment curves, especially in the phase of the estimated 2^{nd} moment curve for each TR. Measuring the phase difference in the estimated curves for each TR gives a good approximation of the amount of rotation that occurred in that TR. These estimated rotation angles are then compensated for while reconstructing images using filtered back-projection (FBP) or regridding.

Results: Datasets were collected on a GE Signa 3T MRI scanners (GE Medical Systems, Milwaukee, WI, USA) with actively shielded gradients capable of 40 mT/m. Datasets were taken of a healthy volunteer making a single step motion (in the middle of the scan) and multiple random step rotations during the scan (Fig. 2a,d). After translation correction of the motion-affected data set, the pivot of rotation is brought to the center of the image (indicated by the arrows in Fig.2b, e). For a head moving in the scanner (making a left to right movement with the head rested on a pillow) as shown in Fig. 2a and Fig.2d, the assumption is that motion is occurring in between the TRs; and that views collected in a single TR are stationary with respect to each other since data acquisition is fast in a TR. Thus a single rotation correction is given for all the views collected in one TR. Finally, images are reconstructed using FBP (Fig. 2c,f) after applying both the estimated rotation and translation corrections. It can be seen clearly that motion artifacts have significantly reduced in the reconstructed images after both corrections have been applied.

Conclusion: While previous methods have been described to correct in-plane motion in radial-SE datasets, the variation in TE in FSE datasets precluded the use of this method with radial-FSE. Here, view ordering and second moment normalization has been applied that allows the technique to estimate motion correction parameters over the full echo train. This post processing technique may be retrospectively applied to reduce bulk motion artifacts in radial-FSE datasets.

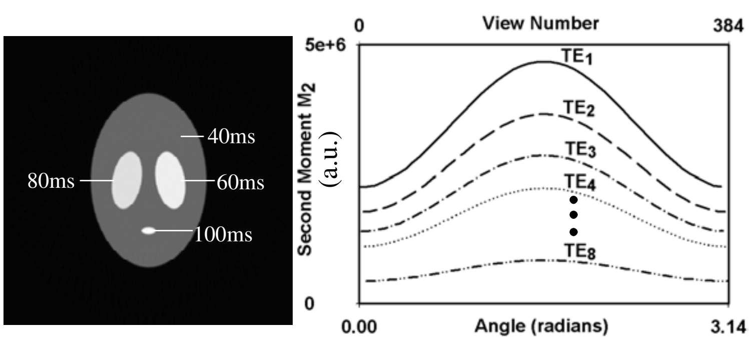

Fig.1. a) Simulated dataset with T2 relaxation time = [40,60,80,100] ms. b) 2^{nd} moment curve generated from simulated data with ETL=8, echo spacing= 10ms.

References [1]. Welch EB, et al., M.R.M., 52, 337-345, 2004

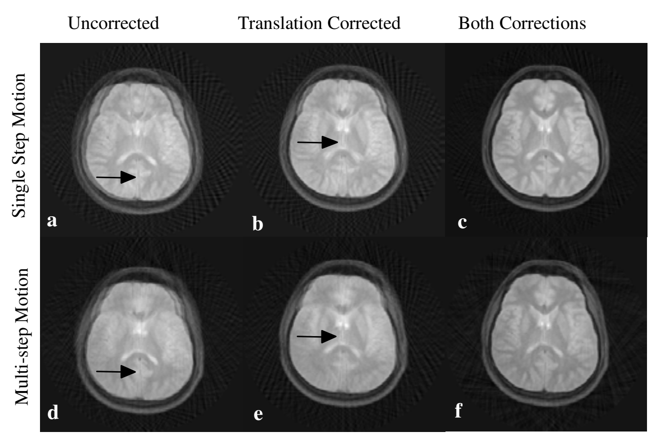

Fig.2. T2 weighted Image reconstructed using FBP collected using 384 views with 256 points along each view, NEX=1. TR = 3s, Echo Spacing =17ms, Receiver Bandwidth = 62.5kHz, ETL=8, Fat Sat On, Slice thickness = 5mm. Arrows indicate shift in CoM location.