Rapid prospective motion correction using principal axes computations

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Introduction: Patient motion is a significant problem in many MRI applications. Welch et al [1] and Ramanna et al [2] have proposed algorithms for correcting in-plane rigid-body motion in radial spin-echo and fast spin-echo (FSE) data respectively. Bajaj et al [3] have proposed an algorithm based on principal axes computation using spatial moments to effect prospective correction of rigid-body motion for self-navigated 2D radial and 3D imaging. In this work, we extend the algorithm proposed in [3] to radial FSE data and use a Projection Onto Convex Sets (POCS) algorithm to correct rigid-body motion in partial Fourier 2D radial-FSE data, which can significantly reduce T_2 blurring. We also propose a new, efficient method for prospective real-time motion correction in 3D MRI.

Theory: POCS has been effectively used to reconstruct images from partial Fourier 2D k-space data. However, for estimating motion using moments of spatial projections, this algorithm cannot be used as the reconstructed image will suffer from motion artifacts. Instead, in the present work, 1D POCS is first used to reconstruct full k-space radial projections from truncated radial projections. These reconstructed projections are used to compute the zeroth, first and second moments, which yield information about the centroid and orientation of the object. In FSE, the views obtained at different TEs have different amplitudes that result in an inconsistency in the second moments. Hence the normalization of the second moments is carried out similar to that of [2]. The moment of inertia matrix is obtained from these normalized second moments of the 0°, 45° and 90° projections, which is then diagonalised to yield the principal axes. Translation errors can be corrected by aligning the centroids of the projections to the center of the FOV following which rotation correction can be effected by computing the angle between successive principal axes measurements.

For the 3D case, the magnitude of the projections after inverse Fourier transforming the six radial lines in 3D k-space (no. 1-6) oriented at azimuthal and elevation angles ($\theta = 0°, \xi = 0°; \theta = 90°, \xi = 90°; \theta = 0°, \xi = 90°; \theta = 0°, \xi = 45°; \theta = 45°, \xi = 90°; \theta = 90°, \xi = 45°$) are used to compute the moments of the 3D object as in [3]. In this work, we make use of the following property to compute the second moments of the projections more efficiently.

$$\int x^2 f(x)dx = -F''(0)/4\pi^2 = (2F(0) - F(1) - F(-1))/4\pi^2 \qquad (1)$$

where F(w) is the Fourier Transform of f(x). This implies that, numerically, three samples about origin in k-space are sufficient to compute the second moments of the projections. The moment of inertia matrix is obtained from these second moments, that is then diagonalized to get the principal axes. The rotation matrix needed to align the principal axes is directly obtained using least-squares fitting of two 3-D point sets as given in [4]. The phase of the two samples about the origin of the radial lines 1-3 is used to compute the center of mass of the 3D object and the translation can be found out by calculating the difference between their centers of mass.

Methods: Radial-FSE datasets were collected on a GE Signa 3.0T MRI scanner (GE Medical Systems, Milwaukee, WI, USA) with actively shielded gradients capable of 40 mT/m with a projection angle view order as shown in Fig 2. Full k-space datasets (384 views, 256 xres, TR = 3s, echo sp. = 17ms, ETL = 8, 8 5mm slices) were collected from a healthy volunteer making multiple random movements (rotations and translations) during the scan. Half Fourier k-space datasets were created using 144 points (i.e. 16 extra points beyond origin). 1D POCS was used to reconstruct the full radial lines from the partial dataset by using phase and data consistency constraints. Translations were corrected by phase shifting while rotations were corrected by binning the projections to the correct view angles, which were determined from the principal axes. The images were reconstructed from both full as well as partial Fourier k-space dataset using filtered backprojection after applying the estimated translation and the rotation corrections and compared. For the 3D case, a translation of three pixels each in x, y, z and rotations of 6°, 4° and 3° in axial, sagittal and coronal planes were imparted halfway through the acquisition on synthetic 3D k-space data. Motion correction was performed on the 3D phantom using our proposed efficient algorithm as well as using the moments computed from spatial projections as in [3].

Results: Figure 1 shows comparison of motion corrupted 2D radial FSE data from a normal volunteer (A) and images corrected using our algorithm on full k-space (B) and partial k-space data (C). The difference between (B) and (C) is shown in (D) showing minimal error using POCS in conjunction with our algorithm. Figure 3 shows axial, coronal and sagittal slices of a 3D synthetic data set corrupted with motion (col. 1). The corresponding slices after our fast correction method is shown in col. 2. The error images for our new method and the method using moments of spatial projections is shown in columns 3 and 4.

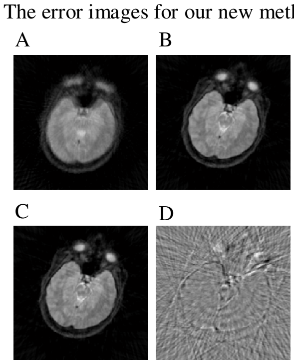

Fig 1. (A) Motion corrupted image (B) Motion corrected image from full k-space dataset; scale [0-1] (C) Motion corrected image from partial k-space dataset; scale [0-1] (D) Difference image of (B) and (C) scale [-0.15- 0.15].

References: 1. Welch et al. Magn Reson Med 52:337-345(2004)
2.Ramanna et al. Proc ISMRM 14 (2006), 2980
3. Bajaj et al. Proc ISMRM 14 (2006), 3199
4. Arun K.S. et al. IEEE Trans PAMI 9:698-700 (1987)

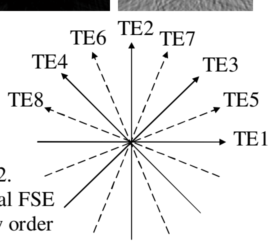

Fig 2. Radial FSE View order

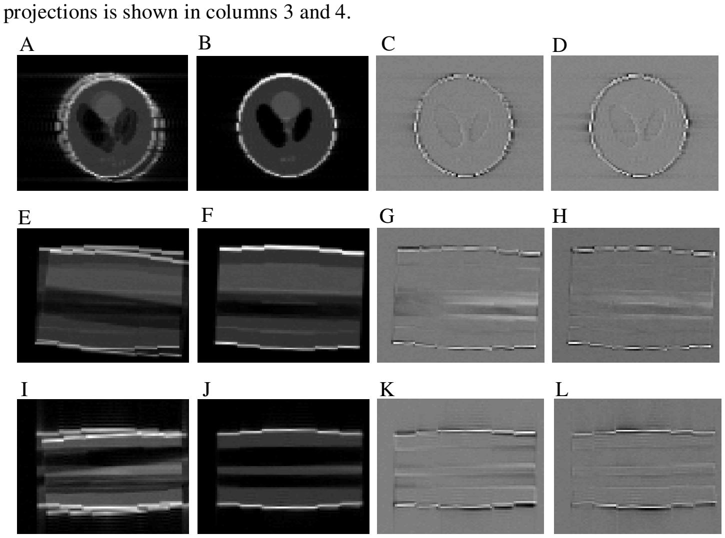

Fig 3. Cross-sections of 3D phantom corrupted by motion (A, E, I) and after correction using our algorithm (B, F, J) Error Images using our fast algorithm (C, G, K) and using algorithm proposed in [3] (D, H, L) scale [-0.25, 0.25]

Conclusions: We have extended the method of principal axes to retrospectively correct rigid-body motion in partially acquired radial-FSE datasets. For the 3D case, our proposed fast algorithm is found to be comparable with the algorithm proposed in [3]. With the proposed changes to 3D motion correction algorithm, three samples about origin in k-space, each along six directions, are sufficient to calculate the translation as well as the rotation matrix, which can speed up the algorithm dramatically for real-time prospective 3D motion correction.