Prospective motion correction using principal axes computation from moments of spatial projections

N. Bajaj[1], M. Saranathan[1]

[1]Dept. of Electrical Engineering, Indian Institute of Science, Bangalore, Karnataka, India

Introduction: Patient motion is a significant problem in many MRI applications. Rigid body translation and periodic motion have been addressed using a variety of navigator echo based techniques, prospective and retrospective. Prospective techniques are attractive as there is no need for interpolation, which often leads to errors and blurring. However, prospective correction of 3D rotations and translations remains challenging. Orbital navigators (ONAV) and spherical navigators (SNAV) [1-2] have been proposed for prospective motion correction with two or more degrees of freedom. They are either inaccurate due to through-plane motion [1] or are computationally expensive [2]. In this work, we explored the use of a novel fast technique based on principal axes computation using spatial moments to effect prospective correction of rigid body motion (rotation and translation) for (a) 3D imaging (b) self-navigated radial 2D imaging.

Theory: It is well known that any rigid object is related to another rotationally by its principal axes and translationally by its center of mass. The zeroth, first and second moments provide all the information needed to obtain the centroid and orientation of the object. These moment calculations can be performed on k-space projection data invoking the projection-slice theorem. For the 2D case, the horizontal, vertical and diagonal projections contain sufficient information to compute these moments while for a 3D object, 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 these moments. The zeroth and the first moments of the 0° and 90° projections are computed to get the center of mass of the imaged object. The moment of inertia matrix is obtained from the 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. The same idea has been extended to 3D case where the center of mass of the 3D object is computed from the zeroth and first moments of radial lines 1-3. Unlike the 2D case, in 3D imaging, 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 [3] instead of explicit computation of angles.

Methods: All processing was performed using MATLAB on a single-processor 2GHz PC. 2D radial data was generated from a synthetic phantom or an MR brain image with a projection angle view order as follows: (0°, 45°, 90°, 135°; 23°, 68°, 113°, 158°; 1°, 46°, 91°, 136°…). A spacing of 23° between successive sets was used to account for large rotational motion. After acquiring each successive set of 4 projections in the above order, the center of mass and principal axes were computed to correct for in-plane translation and rotation. Translations were corrected by phase shifting. Since rotations result in acquisition of the wrong view angle, they were corrected by binning the projections to the correct view angle, which can be determined from the principal axes. To test the accuracy of the algorithm, two rotations of 3° and–4° (Fig. 2) and two translations of 4 pixels along x and y were applied to a 2D dataset during the acquisition. For the 3D case, a translation of 3 pixels each in x, y, z and axial, sagittal and coronal rotations of 6°, 4° and 3° were imparted halfway through the acquisition on synthetic 3D k-space data. Unlike the 2D case, 6 projections were computed after all the k_z encodes were acquired to check for motion. The total computation time of the algorithm was 50 ms in MATLAB, which would significantly decrease when using a dedicated processor in the MR system, making it attractive for real-time prospective 3D motion correction.

Results: The results of 2D and 3D motion correction algorithm are shown in Figures 1-3. The mean and SD of rotation angle errors are summarized in Table 1.

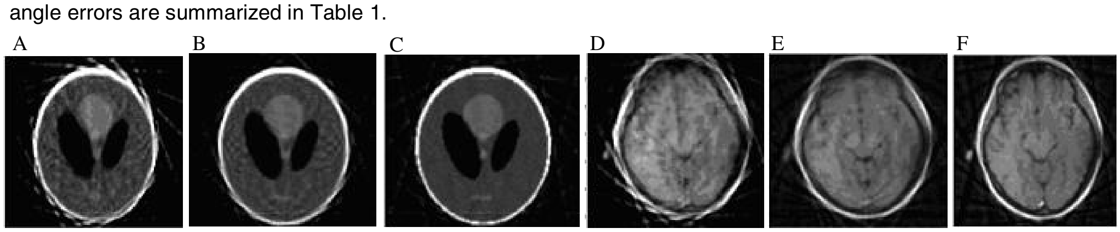

Fig. 1. Motion corrupted images (A, D), Translation Corrected Images (B, E), Translation and Rotation Corrected Images (C, F)

Table 1. Mean and SD of rot. angle errors for brain image

Rot. Ang (°)	Mean error (°)	SD error (°)
7	0.05	0.05
3	0.03	0.05
-4	0.05	0.03
-8	0.08	0.03

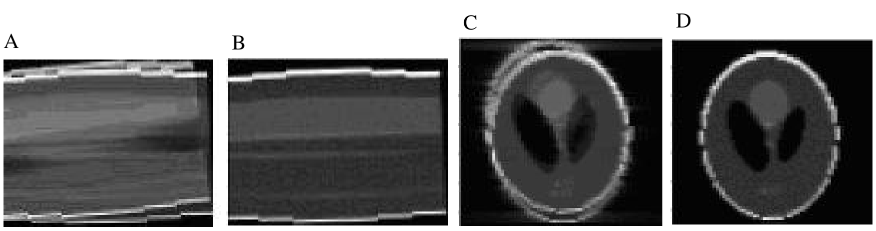

Fig 3. Sagittal and axial cross sections of 3D phantom corrupted by motion (A, C) and after correction using our algorithm (B, D)

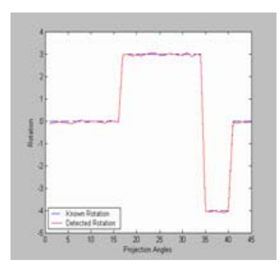

Fig 2. Detected rotation angle versus applied rotation for the MR brain data (step inputs of 3° and –4°)

Conclusions and Discussion: We have demonstrated a novel, fast algorithm for prospective correction of 3-D rigid-body motion. It can also be used to perform self-navigated radial 2D imaging with rotation and translation correction. Welch et al [4] have also used spatial moments to correct for rotations but using fitting in sinogram space instead of using the principal axes making our method more suitable for real-time applications and 3D imaging. While translational correction is very robust to noise, the rotational correction accuracy is affected by low SNR. Further work needs to be carried out to improve the robustness of this method on low SNR data.

References: 1. Ward et al. Magn Reson Med 43:459-469(2000) 2. Welch et al. Magn Reson Med 47:32-41(2002) 3. Arun K.S. et al. IEEE Trans PAMI 9:698-700 (1987) 4. Welch et al. Magn Reson Med 52:337-345(2004)