Self-navigated motion correction using moments of spatial projections in radial MRI

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Abstract

MR acquisitions using a radial MR trajectory are known to have intrinsic advantages over 2DFT *k*-space trajectories when imaging a moving object. Many techniques have been proposed to further improve the robustness of projection reconstruction (PR) MRI against motion artifacts. However, it has not been realized previously that consistency properties of the 2nd moments of the spatial projections can directly detect in-plane rotation of the imaged object. Here we propose a correction algorithm with only one requirement beyond a standard PR acquisition: a specific view angle acquisition order. The approach is demonstrated on a resolution phantom with computer-controlled 2-D translational artifacts and rotation artifacts created by rotating the imaging gradients. In all cases, the corrected PR images are improved over the original PR and interleaved 2DFT images and nearly restore the quality of static images.

Theory

The 0th moment of each spatial domain projection of an ideal static object is constant and independent of the view angle θ. Higher order moments of the projections are functions of θ and are known to be bandlimited by $n\theta$ (1), with the 1st moments following a sinusoidal function of θ. In-plane rigid-body translation causes reversible inconsistencies in the projection data. If each projection is shifted to align its center of mass to a reference position, e.g. the center of the FOV, the artifacts caused by the translation are eliminated. In-plane rigid-body rotation causes a projection to be acquired at a view angle different from the desired angle and creates inconsistencies in both the 1st and 2nd moment trajectories. We have established that the 2nd moments of a static object follow a sinusoid of frequency 2θ (rather than being simply bandlimited by 2θ). This allows detection of rotational motions, after alignment of the first moment, from the remaining inconsistencies in the 2nd moments. A near-optimal acquisition order to detect such inconsistencies is to sample the 2nd moment trajectory with approximately 90˚ spacing, which implies a view angle acquisition order with approximately 45˚ spacing (e.g., 0˚, 45˚, 90˚, 135˚, 1˚, 46˚, etc.). An estimate of the object's rotational position time record can be fit in least-squares manner to the observed 2nd moment trajectory and used to improve the reconstruction of the projection data.

Methods

A standard 2DFT spin echo pulse sequence was modified to acquire projection angles in the order described above interleaved with the standard 2DFT acquisition. A computer-controlled phantom capable of performing precise 2-D translations was used to image a resolution phantom undergoing known translational motion without and with additional rotation corruption. The magnitude of the complex spatial domain sinogram data was used for all moment calculations and for image reconstruction. Each projection was shifted to align its center of mass with the center of the FOV. The 2nd moments of the aligned projections were calculated and used in a weighted least squares inversion to yield an estimate of the rotational motion over time. The nominal projection view angles were adjusted by the detected rotations and used in a sampling-density-corrected (2) reconstruction of the aligned projections.

Results

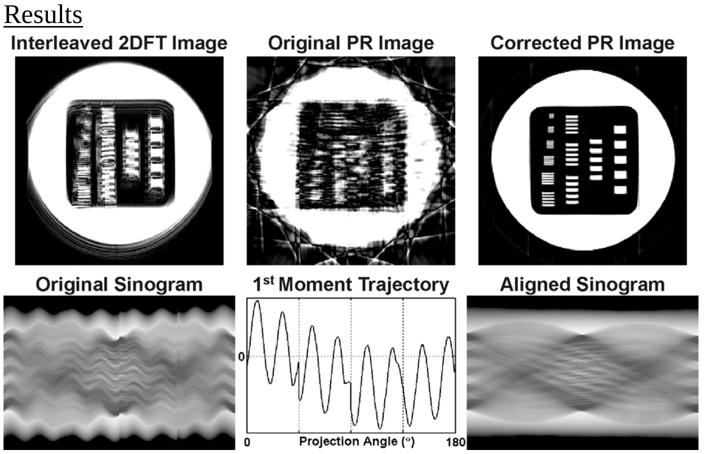

Fig. 1. Correction of in-plane translation. The boundaries of the original sinogram show the effect of translation, as does the 1st moment trajectory plot. After aligning the projections, the boundaries are smooth. The corrected PR image is superior to both the original PR image and the interleaved 2DFT image.

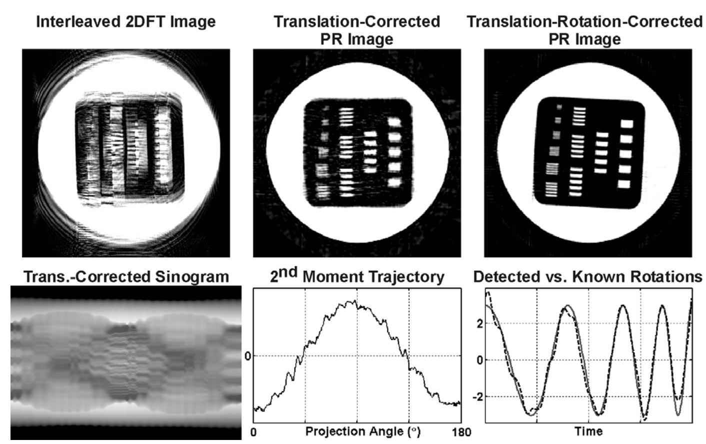

Fig. 2 Correction of translation followed by rotation detection. After translation correction, sinogram inconsistencies remain due to intentional perturbations of the imaging gradients. Detected rotations based on the 2nd moments are similar to the known rotation and improve the quality of the final PR image significantly over both the translation-corrected PR image and interleaved 2DFT image.

References

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