Retrospective Correction of Motion Artifact in k-Space Using Optical Tracking

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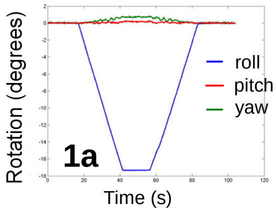
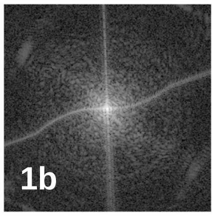
Introduction

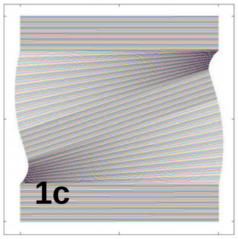
Conventional rectilinear k-space readouts, assuming a static object, collect samples on an evenly spaced Cartesian grid. For a moving object, according to the shift and rotation theorems of the Fourier Transform, distortions are introduced in k-space by the incorrect assumption that the data lie on the same Cartesian grid. Subsequent motion artifacts are introduced in MR images on Fourier Transformation of these k-space data. To demonstrate correction of this problem, 2D imaging was performed on a moving phantom while motion was tracked using an optical tracking system. The motion data were then used to correct for the actual k-space trajectories and phase prior to image reconstruction, thus dramatically improving image quality.

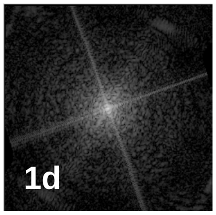
Materials and Methods

A optical tracking system (Polaris, Northern Digital, Inc.), modified for MRI-compatibility, was used to track the 3D position and orientation of a tracking tool (Traxtal, Inc., Toronto, Ontario) over six degrees of freedom (x, y, z, roll, pitch, and yaw) with spatial resolution of less than 100 microns in displacement, and nominally less than 0.1 degrees in rotation. Prior to motion tracking, a calibration procedure[1] localized the position of seven marker holes (labeled with aqueous MR contrast agent) on the tracking tool in both the tracking system and MR coordinates. The 3D coordinates of the set of points in the Polaris and MRI coordinate systems were used to recover the registration transformation between the two coordinate systems using Horn's closed-form solution[2]. An acrylic phantom was constructed, and filled with an agar gel doped with Gd-DTPA contrast agent (Magnevist, Burlex). A selection of plastic nuts, bolts, and washers was inserted into the gel to provide edge details and image contrast. The phantom was rotated by an MR-compatible stepper motor (MTL Microtech Laboratory Inc. Japan) mounted at the end of the patient bed, and controlled from a console hosting LabVIEW 6 (National Instruments, Austin, TX). A customized shaft linkage system coupled the motor-phantom motion. The phantom was positioned centrally in a head-coil for MR imaging, where the attached tracking tool was in an optimal region of visibility for position tracking. Acquisition of the position tracking data was triggered to the MR system's imaging sequence. The MRI system was a whole-body scanner (Signa, General Electric Medical Systems, Waukesha, WI; CV/i hardware; LX8.5 software) at 1.5 T magnetic field strength with a standard quadrature transmit/receive birdcage head-coil. T1-weighted spoiled gradient-echo sequences (slice thickness=4.0 mm; matrix=256x256; 1 slice; TE/TR/θ=6.9 ms/400 ms/35°; FOV=20 cm) were used to collect k-space data of the moving phantom.









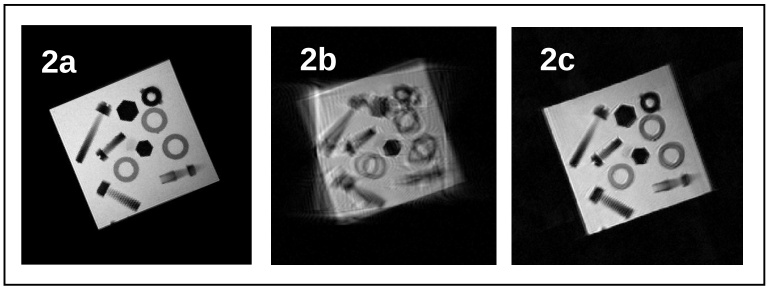
Selected Results

In the present experiment, roll rotation was imparted to the phantom back and forth about the longitudinal axis of the magnet by 17.34 degrees, beginning in the clockwise direction, for one cycle during k-space data acquisition. Motion data (FIG. 1a) were collected at a sampling rate of 4.5 Hz, transformed to MRI coordinates, and interpolated to determine the position of the phantom for each time point associated with the 256x256 k-space samples. Based on the Fourier rotation theorem, each trajectory point was rotated about the centre of k-space by the same amount as the measured rotation of the phantom at that instant. The raw corrupted k-space data (FIG. 1b), along with the corrected trajectories (FIG. 1c), were then passed through a reconstruction server for 2D gridding[3]. Inhomogeneous sampling densities in k-space were corrected by gridding a unity matrix with the corrupted trajectories. Dividing the corrected k-space information by the computed density map produced the rotation-corrected k-space (FIG. 1d).

The reconstructed reference image of the static phantom is shown in FIG. 2a. FIG. 2b shows the corrupted reconstructed image obtained with the phantom rotating during data acquisition. Motion artifacts are clearly observed. The motion-corrected image (FIG. 2c) shows negligible motion artifact on visual inspection. Although minor spatial blurring is observable due to apodization during the gridding process, the corrected MR image is an excellent representation of the reference.

Discussion

The present motion correction algorithm exhibited large improvements in the quality of anatomical MRI data corrupted by motion. This retrospective procedure may be applied to any set of k-space trajectories in the case of rigid-body motion, and provides framework for developing an analogous 3D motion correction algorithm. An extended comparison of retrospective and prospective motion correction schemes based on tracking system data is warranted and will be the subject of future work.



References

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