Prospective Motion Compensation with Floating Navigators

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Introduction

Patient motion is a major source of image degradation and contributes to reduced throughput in clinical magnetic resonance imaging (MRI) exams. While translational motion can be compensated retrospectively by applying a k-space phase correction, rotational motion could become difficult to correct after the scan is completed. A sudden rotation during a scan can cause a "pie-slice" of k-space to be un-acquired, which in general cannot be corrected retrospectively if the rotation angle is large, and the resulting artifacts could be severe. Therefore it may be necessary to prospectively compensate for rotational motion.

A method of floating navigators (FNAV) was originally proposed to correct for in-plane translational motion [1]. The method enables the detection of motion along both x- and y-axes with a single navigator readout. In this work, a prospective motion correction technique based on detecting the positions of two markers using floating navigators is proposed. In addition, improvements to the prior floating navigator method are also proposed to enhance the robustness of the technique. In this preliminary investigation, in-plane rotational and translational motion correction is performed in a phantom experiment, demonstrating the feasibility of the proposed method.

Methods

Unlike the traditional navigator technique which involves acquiring signal along the k_y=0 line, FNAV samples along $k_y = k_f \neq 0$, where k_f is typically small to ensure a sufficient SNR. For an in-plane translation of (Δx,Δy), the phase of the FNAV signal changes by $\Delta\phi=2\pi(k_x\Delta x+k_f\Delta y)$ [Eq. 1]. A linear fit along k_x yields Δx from the slope and Δy from the y-motion-induced phase offset $\phi_y=2\pi k_f\Delta y$ (intercept). To resolve the phase-wrapping issue, we propose to acquire two FNAV signals at different phase-encoding frequencies (e.g. k_{f1}=2/FOV and k_{f2}=16/FOV). The first FNAV signal, with a small k_f value, permits the detection of a large range of motion without phase wrapping, while the second FNAV signal, with a larger k_f value, allows the detection of a more precise Δy value.

To allow detection of rotational motion from the FNAV readouts, two small circular pipettes (5mm width) filled with Gadolinium-doped water were attached perpendicular to the imaging slice (FOV 13x13 cm^2, 256x256 matrix size) and offset on both sides of the imaging object along the read-out (x) direction. Since the motion-induced point spread function (PSF) is spatially limited along the x-axis [2], signals from each marker can be separated from the main imaging object by taking the Fourier transform (FT). Following the isolation of each marker, inverse FT is taken to compute the FNAV signal. After deriving the positions for both markers from the Eq. 1, both in-plane rotation and translation can be computed [2,3]. The marker size was selected based on the following two considerations: First, the marker SNR in x-k_y hybrid space and k-space are approximately proportional to pipette radius r and r^2 respectively; therefore a larger marker size would boost the SNR and therefore reduce the measurement errors. Second, the size has to be small enough so that substantial phase dispersion does not occur for either of the FNAV lines. Based on these two criteria, a marker radius of 3-5 pixels can be used for k_{f2}=16/FOV.

Prospective FNAV were incorporated into an existing 2D spin-echo sequence (**Fig. 1**). For each TR (500ms), a FNAV block (~20ms) is first played out, followed by a 10 ms real-time processing time to compute both in-plane rotation and translation. The rotation angle is then used to modify the axes of gradients in the subsequent main imaging block. Although phase adjustments for translational motion could also be made in real time, the same corrections can be applied following the completion of the scan. The latter method was used in this preliminary study. Since the acquired FNAV signals are gradient-echo readouts, background gradient may introduce an additional phase term that is linearly dependent on the echo time. To remove this additional phase, a reference readout at k_y=0 was also acquired at time TE_{ref} (~5ms in this study), while the two FNAV readouts were acquired at 2*TE_{ref} and 3*TE_{ref}. When the marker position changes, the phase change detected at the first readout is used to compensate the background-induced phase in the FNAV signals. To avoid interfering with the steady-state of the main imaging volume, the FNAV data were acquired approximately 10 mm away from the imaging slice.

Results and Discussion

A phantom imaging experiment was conducted to demonstrate the feasibility of the proposed technique (**Fig. 2**). Sudden and gradual shifts and rotations were manually applied during the scans. In the first scan, no prospective correction was performed, and the resulting artifacts were severe (**Fig. 2b**). In the second scan, object rotation was compensated in real time using the FNAV signals and translations corrected during reconstruction, nearly eliminating all motion-related artifacts in the final image (**Fig. 2c**). Some residual artifacts remain that may be due to intra-view motion, which is not addressed by the proposed technique. Processing of the FNAV data revealed the range of motion was approximately 15^0 for rotation and 20 pixels for translations (**Fig. 2d**). Examination in portion of trajectory where no motion was applied showed that measurement errors associated with rotation and translation detection were less than 0.2^0 and 0.2 pixels, respectively. The proposed technique requires that the markers be offset from the main imaging object along the read-out direction, in order to avoid overlap of the marker with the main object in the FNAV projection. This constraint, however, can be relaxed if the markers were filled with chemically-shifted fluid. Extension to 3D rotation/translation correction is straightforward if two sets of FNAV signals were acquired on two parallel slices separated by a distance.

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References

[1] Kadah YM, et al. *Magn. Reson. Med.* 2004; 51: 403-407.
[2] Lin W, et al. *IEEE Trans Med. Imag.* 2005; 24: 1170-1176
[3] Korin HW, et al. *Magn. Reson. Med.* 1995; 33: 663–669.

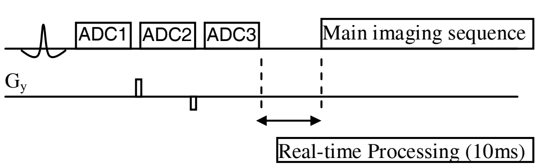

Fig. 1 The sequence diagram. During each TR, the FNAV block is first played out, followed by a 10 ms real-time processing period and the main imaging sequence. The three FNAV readouts are along k_y = 0, 16/FOV and 2/FOV lines.

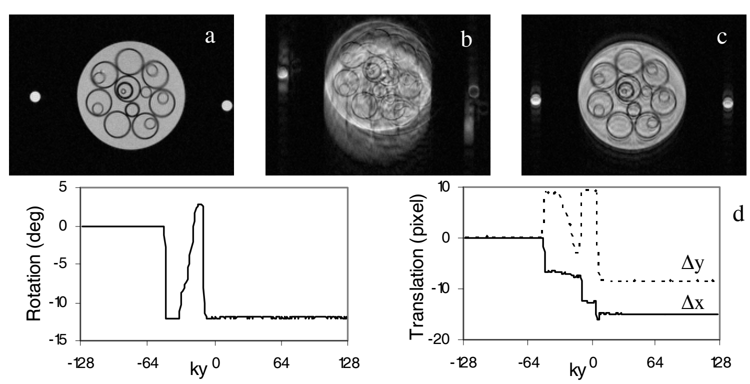

Fig. 2 Results from a phantom experiment. (a) Motion-free scan. (b) Motion-corrupted scan without real-time correction. (c) Motion-compensated using prospective FNAV. (d) Motion trajectories recovered from the FNAV data in (c).