MRI Motion Compensation by Ultrasound Navigators

B. M. Schwartz[1], and N. McDannold[2]
[1]Biophysics, Harvard University, Boston, MA, United States, [2]Radiology, Harvard Medical School, Boston, MA, United States

Introduction: There is a long history of motion compensation in MRI using navigator echoes, now a mature technique [1]. MR navigators work well, but their applications have been limited by several factors: the need to slow down imaging in order to make time for the navigator, interference with the steady state of the base sequence, and substantial engineering needed to implement and validate new navigated sequences. For this investigation, we have built a simple prototype ultrasound navigation system, analogous to MR navigation but using an ultrasound echo for position measurement. Previous efforts in this area have employed entire ultrasound imaging arrays, resulting in dramatically slower tracking and requiring considerably more expensive equipment [2].

Methods: The ultrasound transducer we employed was a 5 MHz broadband 5-element annular array 1.5 cm in diameter, driven as a single element. It produces an approximately collimated "pencil-like" beam. The target was a motion phantom, driven cyclically with a period of 7 seconds by a motor outside the scanner room, approximating breathing motion. The phantom was constrained to move in one dimension, parallel to the ultrasound beam. Part of the phantom was held in a water tank, due to the need for ultrasound conduction. Positions were derived from the ultrasound data by a simple FFT-accelerated cross-correlation [3].

Imaging was performed on a 1.5T scanner (GE Signa) with the body coil. The pulse sequence was SSFP (GE Fiesta), with the source code modified to update its slice position before every excitation based on input received through the RTHawk real-time control framework [4]. To minimize the amount of electrical noise introduced, the ultrasound pulse was triggered from the MRI scanner, ensuring that the ultrasound electronics were quiescent during MR readout. For prospective motion correction, this created a total system latency of approximately TR + TE. With our test sequence TR=10 ms, and TE=1.7ms. TR could be reduced as low as 5 ms, but is limited by ultrasound data processing speed on the acquisition computer (Pentium 4, 3 GHz). Nonetheless, the total latency (less than 12 ms) was sufficiently low that we employed no Kalman filtering or other extrapolation.

Results: The ultrasound motion compensation system was highly effective at canceling in-plane motion artifacts both prospectively (Figure 1) and retrospectively. Prospective correction of through-plane motion was also effective for slice following, maintaining the imaging plane relative to the phantom.

Discussion: Ultrasound navigation appears to be a promising technique for MRI motion compensation. The technique as employed here also applies naturally to motion at arbitrary obliquity to the imaging plane, and to volumetric images. The technique's low latency also creates the potential for application to interventions such as MR-guided focused ultrasound surgery, where fast and accurate positioning is critical for safety. As described here, the technique is limited to linear motion parallel to the ultrasound beam, which may hinder application to tracking breath-related motion in humans. Current investigation concerns extending the technique to motions not parallel to the ultrasound beam.

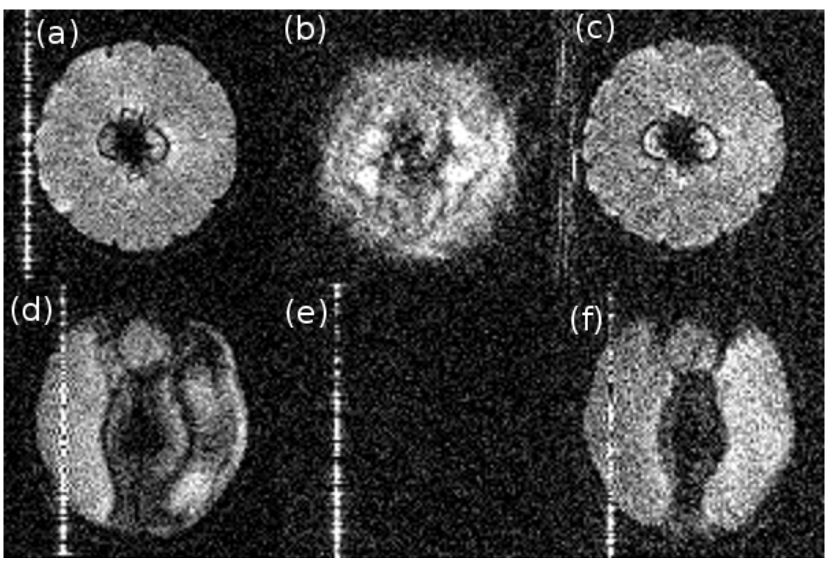

Figure 1: Images of a navel orange motion phantom (GE Signa 1.5T, SSFP/Fiesta). Images (a-c) show the effect of in-plane motion, and are respectively stationary, moving uncorrected, and moving with prospective correction. Images (d-f) similarly show through-plane motion. Image (e) is empty because without correction, the orange has moved entirely out of the imaging plane. Line artifacts and increased background noise are due to imaging with the scanner room door open, which was necessary to accommodate the motorized phantom.

References: [1] Ehman, R.L., and Felmlee, J. P. 1989. *Radiology* 173: 255-263
[2] Günther, M. and Feinberg, D. 2004. *Magn Reson Med* 52: 27-32
[3] Frigo, M. and Johnson, S.G. 2005. *Proc of the IEEE* 93 (2), 216–231
[4] Stang, P. et. al. 2008. ISMRM 16, 348.
Acknowledgement: This work was supported by NIH grants U41RR019703 and P01CA067165.