Image Acquisition & Reconstruction

Dealing with Motion: Gating, Triggering, and Sampling

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Highlights

- Acoustic, optical, and accelerometric sensors are under investigation for use with MRI, and have the potential to significantly improve motion robustness in some applications.
- Advanced navigator methods can enable the rapid tracking and correction of motion in two or three dimensions.
- Self-navigation methods can be applied in some cases to correct for motion from the imaging data themselves, without separate motion-tracking sequences.

Target audience: Primarily practitioners of body, cardiac, pediatric, and neuro MRI, or anyone challenged by motion problems in MR.

Outcome/Objectives: Upon completion of this course, participants should be able to:

- describe the effects of various types of motion on MR images;
- implement simple measures to mitigate motion artifacts;
- compare strengths and weaknesses of retrospective and prospective motion correction;
- describe new motion-correction techniques for different body regions/subspecialities.

Purpose: MRI's biggest weakness is arguably its long scan times, which result in increased susceptibility to motion artifacts, producing more complex patient workflow, degraded image quality, and the need in some cases for patient sedation, restraint, or rescanning. A number of technologies have been developed or are under investigation to ameliorate this problem, with a view towards unlocking the full potential of MRI.

Methods & Results: While advanced motion correction techniques are a major area of research in MRI, many other, more conventional, methods are currently available for implementation on most commercial scanners. These include signal averaging to cancel ghosting, use of saturation bands to suppress regions of moving anatomy, exclusion of signals from RF coil elements near moving anatomy, gradient-moment nulling to avoid artifacts from pulsatile or complex flow, swapping of phase and frequency directions to move ghost artifacts away from anatomy of interest, and use of real-time or single-shot pulse sequences to freeze motion. Other conventional methods incorporate motion tracking of some kind. These include use of signals from ECG, finger-plethysmographic, or respiratory-belt sensors to trigger or gate MR image acquisition to cardiac or respiratory motion. View ordering can be arranged to push motion-induced ghosts outside the anatomy of interest. And respiratory navigator sequences can be interleaved with image acquisition to track motion of the diaphragm for respiratory gating or triggering.

There are also a number of advanced approaches under development that can potentially provide significantly improved motion tracking and correction. New kinds of external sensors may ameliorate some of the problems experienced with current-generation sensors. These include acoustic triggering systems[1] for cardiac gating, which can avoid common ECG-gating problems such as spurious signals from gradient pulses and from the magnetohydrodynamic effect. Some groups are also investigating small accelerometers to track breathing[2], and optical cameras to monitor head motion[3-4].

New kinds of navigator sequences are being explored, including orbital[5], spherical[6], cloverleaf[7], and three-plane[8]. These all expand the range of available motion data beyond the 1D data collected from classic navigator pencils[9], and thus enable potentially better tracking of body or head motion. A number of self-navigated techniques[10-14] have also been developed which allow motion tracking from the imaging data themselves, without the need to interleave separate tracking sequences. These sequences include one that rotates a Cartesian "propeller" in *k* space[10] – used primarily for head imaging - or another that spins through spiral interleaves[11] - for coronary artery imaging.

Various groups have been developing data-driven methods to retrospectively correct for motion after data collection is complete. In fetal MRI, for instance, intersection-based motion correction has been used to retrospectively realign slices acquired at sometimes very different head positions into a 3D reconstruction[15]. Another retrospective "auto-focusing" method iteratively searches for the motion trajectory that yields the sharpest image as measured by the entropy of spatial gradients[16]. For non-rigid-body motion, a motion model can be incorporated into the image reconstruction based on prior knowledge from external sensors – The motion model and the image are refined together in each stage of an iterative reconstruction[17].

Discussion & Conclusions: There are a number of complicating issues that motion correction techniques sometimes must contend with, including spin history; non-uniform RF, B_0, and gradient fields; through-plane motion; and directional encoding (e.g., in the case of phase-contrast or diffusion imaging). Those investigational techniques that can navigate these issues while proving robust and easy to use should be most successful in moving into routine clinical practice. In addition, any new tracking/triggering/gating devices will need to have a small footprint and minimal impact on patient setup and workflow. The successful application of new motion correction techniques will allow MRI to expand into new areas and provide even more clinical impact.

References:

1.) T Frauenrath, et al. Acoustic cardiac triggering: a practical solution for synchronization and gating of cardiovascular magnetic resonance at 7 Tesla. J Cardiovasc Magn Reson 2010;12:67-80.
2.) L Rousselet, et al. Association of several motion sensors for free breathing reconstruction method. Proc 19th ISMRM; Montreal, 2011. p. 4609.
3.) M Zaitsev, et al. MRI of freely moving objects: Prospective real-time motion correction using an external optical motion tracking system. NeuroImage 2006;31:1038-1050.
4.) L Qin, et al. Prospective head-movement correction for high-resolution MRI using an in-bore optical tracking system. Magn Reson Med 2009;62:924-934.
5.) ZW Fu, et al. Orbital navigator echoes for motion measurements in magnetic resonance imaging. Magn Reson Med 1995;34:746-753.
6.) EB Welch, et al. Spherical navigator echoes for full 3D rigid body motion measurement in MRI. Magn Reson Med 2002;47:32-41.
7.) AIW van der Kouwe, et al. Real-time rigid body motion correction and shimming using cloverleaf navigators. Magn Reson Med 2006;56:1019-1032.
8.) N White, et al. PROMO: Real-time prospective motion correction in MRI using image-based tracking. Magn Reson Med 2010;63:91-105.
9.) RL Ehman and JP Felmlee. Adaptive technique for high-definition MR imaging of moving structures. Radiology 1989;173:255-263.
10.) JG Pipe. Motion correction with PROPELLER MRI: Application to head motion and free-breathing cardiac imaging. Magn Reson Med 1999;42:963-969.
11.) CJ Hardy, et al. Coronary angiography: Respiratory motion correction with BACSPIN. J Magn Reson Imaging 2003;17:170-176.
12.) ACS Brau and JS Brittain. Generalized self-navigated motion detection technique: Preliminary investigation in abdominal imaging. Magn Reson Med 2006;55:263-270.
13.) S Skare, et al. An auto-calibrated, angularly continuous, two-dimensional GRAPPA kernel for propeller trajectories. Magn Reson Med 2008;60:1457-1465.

14.) J Mendes, et al. Rigid-body motion correction with self-navigation MRI. Magn Reson Med 2009;61:739-747.
15.) K Kim, et al. Intersection based motion correction of multislice MRI for 3-D in utero fetal brain image formation. IEEE Trans Med Imaging 2010;29:146-158.
16.) A Loktyushin, et al. Blind retrospective motion correction of MR images. Magn Reson Med 2013;70:1608-1618.
17.) P Vuissoz, et al. Free-breathing imaging of the heart using 2D cine-GRICS (Generalized Reconstruction by Inversion of Coupled Systems) with assessment of ventricular volumes and function. J Magn Reson Imaging 2012;35:340-351.