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 radically 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 cardiac, body, pediatric, and neuro MRI, or anyone challenged by motion problems in MR.

Outcome/Objectives: To be able to optimize MRI techniques and protocols to minimize the effects of motion on image quality, for a variety of imaging subjects and applications.

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 restraint and/or sedation. 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: Most approaches for dealing with motion in MRI combine two features – motion tracking and motion correction. Tracking is achieved either by external sensors, by separate interleaved MR data collection (MR "navigators"), or by the MR imaging data themselves (commonly referred to as "self-navigation"). Motion correction is then accomplished by techniques that fall into one of three categories: 1) motion insensitive sequences such as real-time or single-shot, 2) prospective motion correction, or 3) retrospective motion correction.

External sensors include ECG and plethysmograph systems for gating to the cardiac cycle, and respiratory bellows for the breathing cycle, all of which have their drawbacks – For example ECG systems can pick up spurious signals from gradient pulses and from the magnetohydrodynamic effect. More advanced systems are under investigation by various institutions for use with MRI including acoustic triggering systems for cardiac gating, small accelerometers to track breathing, and 3D optical cameras to monitor head motion.

MR navigation techniques range from the original use of MR pencil selection to track diaphragm motion to newer methods including orbital, butterfly, and multi-plane spiral navigators. Self-navigation has been applied using a number of sequences including one that rotates a Cartesian "propeller" in *k* space – used primarily for head imaging - or another that spins through spiral interleaves (for coronary artery imaging). Another data-driven method uses entropy maximization to produce the smoothest image consistent with the data, when motion has caused different k-space data subsets to experience rotation and/or phase shifts relative to one another. Data-driven methods have also been used in fetal MRI to retrospectively realign slices acquired at sometimes radically different head positions into a 3D reconstruction using intersection-based motion correction.

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.