Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction (PROPELLER) MRI; Application to Motion Correction

James G. Pipe
Wayne State University, Detroit, MI

Introduction

Motion during the encoding process corrupts MR images through both displacement-related blurring and motion-related phase artifacts. Many investigators have used Navigator pulses (1) for reduction of in-plane motion and rotation, phase changes due to motion, and through-plane motion (2).

Theory

PROPELLER MRI collects the MR data in such a way that all of the above (in-plane motion, phase inconsistencies, and through-plane motion) can be mitigated. This approach can be blended with many techniques, and has been successfully implemented with gradient echo and turbo spin echo sequences.

(1) Data are collected in k-space in N strips, each consisting of L parallel lines, corresponding to the L lowest phase encoded lines in any Cartesian-based data collection method.

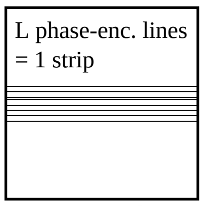

Fig. 1. Single strip in k-space.

(2) Each strip is rotated in k-space by an angle $\alpha = \pi / N$, so that the total data set spans a circle in k-space. If a matrix diameter of M is desired, then Land N are chosen so that
$$\mathbf{L\ N = M\ \pi / 2}.$$

(3) The central circle in k-space with diameter L is collected for each of the N strips; these are used to form N low-resolution images, which are compared to each other to remove in-plane displacement and phase errors that are slowly varying spatially. These factors are corrected for each strip.

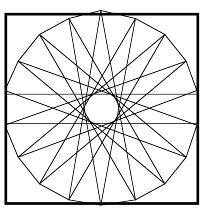

Fig. 2. Rotated, overlapping strips in k-space.

(4) Cross-correlation measures between the low-resolution images (similar to those used by Hardy (3)) are used to determine which strips were collected with significant through-plane displacement. As the data are combined in k-space, the data from strips with the least amount of through-plane motion are preferentially used in regions of strip overlap, thus reducing artifacts from through-plane motion.

Application to Turbo-Spin Echo T2-Weighted Imaging

This method was implemented on a Siemens Vision scanner. A T2-weighted turbo spin echo sequence with an echo train length (ETL) of 17, was modified so that one echo train encoded the L=17 lines for a single strip. Every TR, the frequency and phase encoded direction were rotated, so that in 24 TR's, 24 strips covered a 256 diameter imaging matrix in k-space. The data were collected with no motion, and then separately with significant motion (spanning several centimeters in all directions).

Application to Cardiac Motion

The goal of this application is removal of respiratory motion from ECG gated cardiac MRI, allowing breathold-quality images without breatholding. A double inversion dark blood gradient echo sequence (4) was modified to collect 24 lines over a 102 msec period each cardiac cycle, comprising one strip. A TR of three heartbeats, and 17 strips required 51 heartbeats to complete a 256 diameter matrix (over a 400 mm FOV). Data were collected twice; first with normal breathing, and then with small shallow breaths in-between breatholds and an end-exhalation diaphragm position for each TR (pseudo-breathold). Motion correction was performed using only a limited FOV around the heart in the low-resolution images.

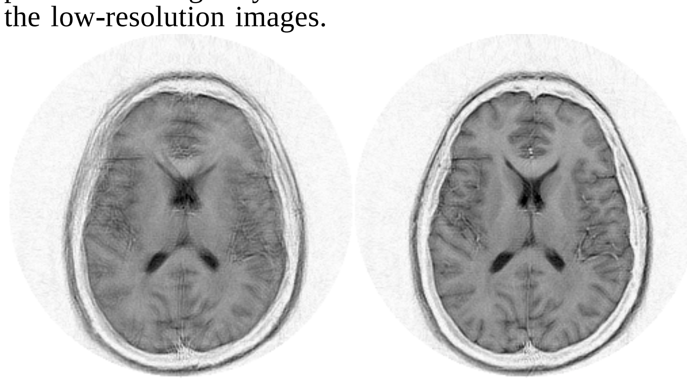

Fig. 3. Axial images of head showing images without correction (left) and after motion correction (right).

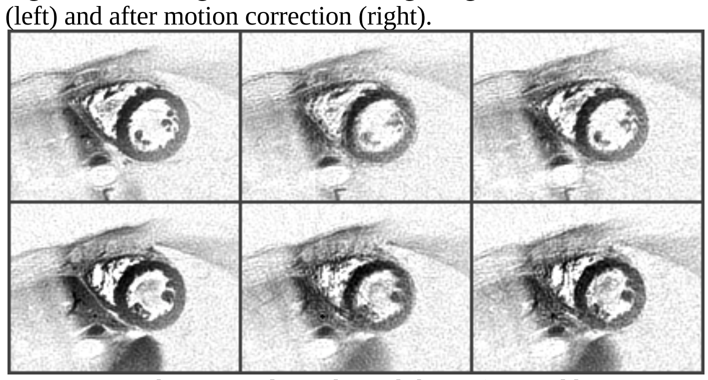

Fig. 4. Two short-axis slices through heart (top and bottom row are different slices), showing 'breathold' (left), uncorrected nonbreathold (middle), and corrected nonbreathold (right). Oversampling at the k-space origin reduces motion artifacts by itself, and image quality is improved with applied correction.

Discussion

PROPELLER MRI is an efficient, self-navigated data collection method that allows for correction of many types of motion (including through-plane), as well as inconsistent phase due to motion. The penalty, with respect to conventional Cartesian methods, is a 57% increase in overall imaging time (due to strip overlap) and a loss of information at the corners of k-space. Some SNR benefits are obtained by data averaging in the center of k-space. In this study in-plane motion correction included only bulk translation and rotation; warping and shearing corrections may be helpful in body applications.

References

1. R. Ehman, J. Felmlee, Adaptive technique for high-definition MR imaging of moving structures. *Radiology*, **173**, 255-63 (1989).
2. T. Sachs, et al., The diminishing variance algorithm for real-time reduction of motion artifacts in MRI. *Magn Reson Med*, **34**, 412-22 (1995).
3. C. J. Hardy, R. W. Curwen, R. D. Darrow, Robust Coronary MRI by Spiral Fluoroscopy with Adaptive Averaging, Proceedings of the International Society for Magnetic Resonance in Medicine Sixth Scientific Meeting and Exhibition Sydney, 1998, vol. 1, pp. 22.
4. R. R. Edelman, D. Chien, D. Kim, Fast Selective Black Blood Imaging. *Radiology*, **181**, 655-660 (1991).