Magnetic Field Mapping in Real Time with a Single RF Pulse

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ABSTRACT: Echo planar images are sensitive to magnetic field inhomogeneities because of the long readout times used. Acquiring magnetic field maps allows geometric corrections to be performed that can correct image warping. Maps acquired with different scan techniques, or at different times can suffer from registration problems with the anatomical data. A new technique is described that allows magnetic field maps to be calculated using the same data that is used to generate the images. These field maps are registered with the anatomical images, and can be used to perform geometric corrections.

INTRODUCTION: Echo planar acquisition uses long readout times (on the order of tens to hundreds of milliseconds), making it prone to image warping in the phase encoding direction, from magnetic field inhomogeneities. This imposes stringent requirements on magnetic field uniformity to reduce image distortions. However, magnetic field corrections are not perfect and residual field perturbations can exist, even after shimming.

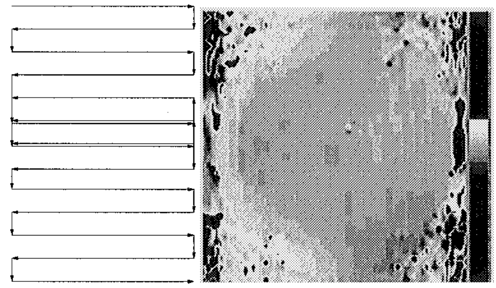
Information from a magnetic field map can be used to correct geometric distortion in images. Previous correction techniques acquired magnetic field maps at different times, or used separate scans. In these cases, registration issues between the magnetic field map and the anatomical data become relevant. A method was developed that allows simultaneous collection of echo-planar anatomical images and magnetic field maps, which can be used to correct the geometric distortions. This is accomplished by scanning the center of k-space twice and using the phase evolution in the MR signal to reconstruct a magnetic field map.

METHODS: Experiments were performed on a Bruker Biospec 30/60 3T MR scanner, using a torque-balanced local head-gradient coil and an end-capped birdcage RF coil. Images were collected from a 165 mm diameter phantom with an internal grid and filled with a 0.005/0.0938 M $CuSO_4$/NaCl solution. The following acquisition parameters were used: TR = 6000 ms, TE = 32.3 ms, image matrix = 64 × 64, BW = 125 kHz, number of slices = 5, slice thickness = 3 mm, slice separation = 9 mm, and 16 lines double-scanned.

To collect magnetic field map data, the center of k-space is scanned twice with the modified echo-planar trajectory in Fig. 1(a). The initial jump in k-space allows the line acquisition to be reordered so there is a temporal delay between successive acquisitions of the same line. This delay allows phase evolution from which a magnetic field map can be computed. This map has a lower resolution in the phase-encoding direction. However, the field map is smoothed by fitting to a 7 × 7 polynomial before being used for geometric corrections, so acquiring a higher resolution field map does not improve correction.

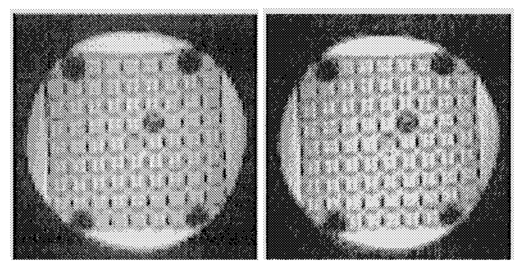
RESULTS: Figure 1(b) shows an example of the magnetic field map acquired using this technique. Figure 2 shows distorted lines in the phantom being straightened using the magnetic field map to perform geometric corrections.

DISCUSSION: This is an extension of the technique initially proposed by Jesmanowicz *et al.* (1), and more recently by Nayak and Nishimura (2) and Durand *et al.* (3), in which doubly-acquired data at the center of k-space provides the means to correct timing errors and temporal and spatial magnetic field perturbations.



(a) (b)

Figure 1: (a) K-space trajectory used for real-time magnetic field mapping, and (b) resulting field map (full scale is -4.2 ppm to +4.2 ppm)



(a) (b)

Figure 2: Echo-planar images (a) without and (b) with geometric corrections from acquired magnetic field map.

The magnetic field maps and magnitude data are perfectly registered since they are both reconstructed from the same raw data. With simultaneous collection of magnetic field and anatomical data, it is possible to monitor magnetic field changes, perform geometric corrections and eventually hardware corrections in real time.

Since magnetic field map resolution is lower than the magnitude image in the phase encode direction, magnetic field map resolution can be balanced with desired temporal resolution. However, (as Fig. 2 demonstrates) even at one-quarter of the image resolution, magnetic field maps provide sufficient information for geometric correction.

REFERENCES:

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