Simultaneous Off-Resonance and Phase Correction for Multi-Shot DWI

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INTRODUCTION

Self-navigated interleaved spirals (SNAILS) (1) have been used for high resolution diffusion weighted imaging (DWI). Although spiral trajectories have many advantages for fast image acquisition, they normally suffer from image blurring caused by off-resonant spins. Many techniques have been developed for off-resonance correction (2). However, few studies have been reported for off resonance correction for multi-shot DWI. One difficulty in this situation originates from the **k**-space data distortion caused by motion-induced phase errors. Here, we integrate multi-frequency off-resonance correction with SNAILS image reconstruction. Using the proposed technique, off-resonance correction and phase correction are achieved simultaneously for multi-shot DWI.

METHOD

Phase navigation is crucial for multi-shot DWI. In SNAILS, phase navigation is achieved by oversampling the center of **k**-space. For each interleaf of a variable-density (VD) spiral (3), a low resolution phase map is estimated and iteratively applied to correct for the phase error (2). To incorporate off-resonance correction, the phase correction iteration needs to be performed at different frequency bands.

Given one interleaf of VD spiral, we first grid the raw data onto Cartesian grids. For each **k**-space sampling points, the corresponding time delay from the beginning of the acquisition is calculated. A Cartesian time map is generated through gridding. The field map is measured at the beginning using two calibration scans. Following the multifrequency reconstruction algorithm (2), a finite set of frequencies are selected to cover the whole range of off-resonant frequencies. For each frequency level, the gridded k-space data is demodulated using the precomputed time map. Following the demodulation step, a phase map is estimated using the center **k**-space data. This low resolution phase map is then used to correct for the motion-induced phase error in the image domain. The resultant images are then masked using a mask that corresponds to each particular frequency level. Finally, images reconstructed at different frequecy levels are summed together to form the final image. This process can be iterated several times to achieve better phase correction. However, the demodulation steps can be neglected if the field map is not updated. The flow chart is shown in Figure 1.

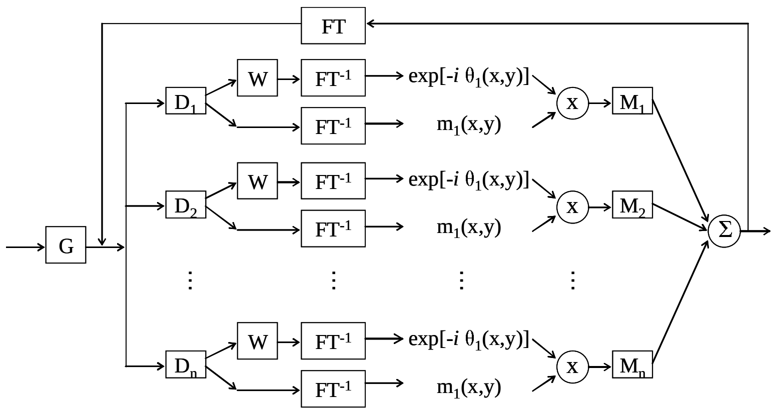

Fig 1 – Flow chart for simultaneous off-resonance and phase correction. This applies to each interleaf data separately. G: gridding; D_n: demodulation using *n*-th frequency level. W: Gaussian windowing; M_n: mask corresponding to the *n*-th frequency level in the image domain.

The combined off-resonance and phase correction algorithm was tested using both phantom and in vivo data. The data were acquired on a healthy volunteer with a GE Signa 1.5T whole-body system using the SNAILS sequence (TR = 2.5s and TE = 68ms). The field map was measured in two separate calibration scans at the beginning of the study.

RESULTS

Figure 2 compares phantom images reconstructed with and without off-resonance correction. Figure 3 shows in vivo results. Fig 3a and b shows the measured field map and the corresponding time map associated with **k**-space trajectory. Fig 3b and c shows in vivo images both with and without diffusion weighting. Fig 3b shows images without off-resonance correction. Fig 3c shows images after correction.

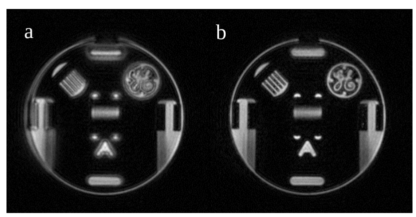

Fig 2 – Phantom images. (a) without off resonance correction ; (b) with correction.

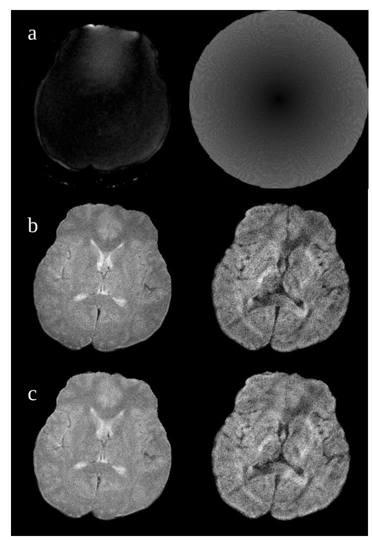

Fig 2 – In vivo results. (a) field map and time map; (b) without off resonance correction ; (b) with correction. Left images are non-diffusion weighted.

DISCUSSION

We have proposed an algorithm for simultaneous off-resonance and phase correction in high resolution DWI. Successful off resonance correction has been demonstrated on both phantom and in vivo images. With successful off-resonance correction, this algorithm allows a reduction of the number of interleaves required (4). Reducing the total number interleaves is important for fast acquisition of high resolution diffusion tensor data, where multiple averages are usually needed for sufficient signal to noise ratio (SNR).

Besides sharpening the image, off-resonance correction also enhances image intensity as shown in Fig 3b and c. In particular, great signal improvement appears in areas of strong off-resonance. This is because by demodulating the signal at the correct frequencies, signal cancellation is eliminated.

ACKNOWLEDGMENTS

NIH-1R01NS35959, NIH-1R01EB002771, Lucas Foundation, Center of Advanced MR Technology of Stanford (NCRR P41 RR 09784)

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