Field-Corrected MP-SWIRLS for 3D Isotropic High-Resolution T1-weighted Brain Imaging

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Introduction: SWIRLS is a 3D non-Cartesian trajectory that samples on a series of concentric spherical shells with continuous, pole-to-pole, helical-spiral interleaves. It has been shown that the SWIRLS trajectory can be combined with the magnetization-preparation (MP) technique to provide fast, volumetric, high-resolution brain imaging with excellent contrast between gray matter (GM) and white matter (WM) [1]. Due to its relatively long readout time, SWIRLS is susceptible to off-resonance artifacts caused by B_0 field inhomogeneity, as are many other non-Cartesian trajectories. The purpose of this study is to investigate the feasibility of applying standard off-resonance correction (ORC) methods to MP-SWIRLS to reduce image blurring.

Methods: *MP-SWIRLS*: The MP-SWIRLS trajectory was implemented on a GE 3T Discovery scanner (running 20.1IB2 software), which was equipped with 50 mT/m and 200 mT/m/ms gradients. An 8-channel receive-only head coil was used. To achieve 1 mm^3 isotropic resolutions with 24 cm FOV, 120 shells and 1mm shell intervals were used. To satisfy the Nyquist criterion, a total of 17300 interleaves were used. The pole-to-pole continuous helical spiral interleaves followed the three-stage design described in [2]. The magnetization preparation stage was implemented with an adiabatic 180° RF pulse followed by 900 ms wait time. During the acquisition stage, one group of 173 interleaves was played. Each interleave repetition takes 7.5 ms and includes 512 readout data points. The order of the shell interleaves was designed to synchronize the interleaves on central shells with the 900 ms TI time. Consequently, each acquisition segment starts with the outer shells with larger k-space radius and progresses to the k-space center and gradually returns to the periphery of k-space. After the acquisition is of a group is completed, a delay time of 660ms allows longitudinal recovery. The three stages of preparation, acquisition and recovery result in a TR of approximately 2300 ms. In total, 100 TRs were played, for a total acquisition time of 3 minutes and 50 seconds. Other imaging parameters include: flip angle =10° and readout bandwidth (BW) ±64 kHz.

Data Acquisition: We performed volunteer experiments under an IRB-approved protocol. Auto-shimming was intentionally disabled to exaggerate the field inhomogeneity. After MP-SWIRLS data were acquired, 3D B_0 map data were acquired for off-resonance correction. The field map estimation was based on two gradient echoes shifted by a user-designated time, which was 2.3 ms so fat and water were in phase at 3T. The corresponding gradient echo imaging protocol is listed here: TE1 = 3.9 ms, TR = 19ms, imaging matrix = 256x128x60, BW = ±16 kHz, FOV = 24cm, Δz = 4 mm, flip angle = 10°, total scan time = 2:44. A generalization of Funai's [3] regularized estimation strategy was used to form a single B_0 map from the multi-coil, multi-echo data set.

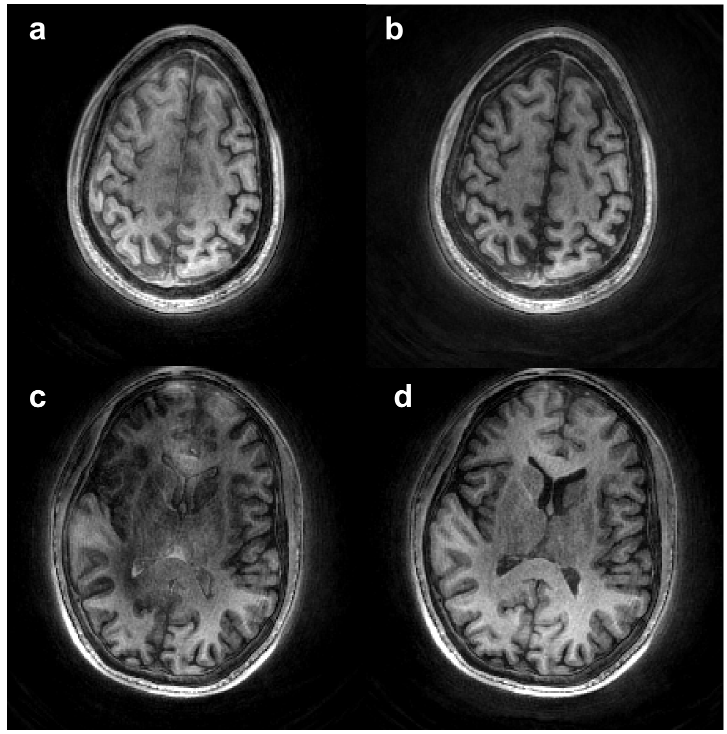

Figure 1: MP-SWIRLS results. Two slices of axial reformatted head images of a healthy subject with substantial dental work are shown. (a) and (c) were standard gridding reconstruction results. Off-resonance correction was applied to (b) and (d). The image blurring and intensity variation observed in (a) and (c) are largely removed in (b) and (d). All images are windowed and leveled the same.

Reconstruction and ORC: Both our gridding and ORC reconstructions are based on a 1.25x oversampled adjoint non-uniform fast Fourier transform [4, 5]. Time-segmented conjugate phase off-resonance correction [6] is performed using L=8 time segments and uniformly-spaced Hann windows. All reconstructions are performed on a coil-by-coil basis, with the results combined via sum-of-squares.

Results: On a dual 6-core Intel x5670 machine with 24 GB DDR3 1333 MHz memory, our standard gridding reconstruction takes ~12 seconds, and our ORC reconstruction takes ~116s (this included the ~40s needed for field map estimation). Figure 1 shows the comparison of two axial reformatted head images before and after the ORC. The improvement of the image quality is noticeable after the ORC. Excellent T1-weighted contrast between the GM and WM and clear delineation of the anatomy can be observed in the corrected MP-SWIRLS images.

Summary: In this work, we have demonstrated that off-resonance correction can help mitigate image blurring that arises from the long readout of the MP-SWIRLS technique. In vivo experiments show significant image quality improvement. Future work includes exploring iterative ORC methods (e.g., [7]) that may provide improved reconstruction performance in rapidly-varying field areas, such as near the auditory canals. Fat suppression is expected to be helpful to further remove the residual artifacts.

References:

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