k-Space trajectory mapping for ultra-short, single-shot, non-Cartesian imaging

F. Wiesinger¹, P. T. Sipliæ,¹ Y-F. Yen¹, D. Mayer¹, E. Fiveland¹, S. A. Greding², D. M. Spielman¹, A. Pfefferbaum³, and R. F. Schulte¹

¹Imaging Technologies, GE Global Research, Munich, Germany, ²Institute for Physics of Electrotechnology, Technical University Munich, Munich, Germany, ³Global Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States, ⁴Department of Radiology, Stanford University School of Medicine, Stanford, CA, United States, ⁵MRI Laboratory, GE Global Research, Niskayuna, NY, United States

INTRODUCTION

In-vivo MR image encoding speed is physiologically limited by gradient-induced peripheral nerve stimulations [1]. Due to the linear nature of the magnetic gradient field, the acceptable gradient slew rate increases with decreasing subject dimensions. This makes high performance gradient insert coils an attractive choice for performing small-animal MR imaging and microscopy studies in a whole-body, clinical MR scanner [2]. Such enhanced performance also amplifies gradient imperfections due to Eddy currents, coupling effects, mechanical vibrations, etc. On the other hand, the smaller dimensions and higher gradient amplitude often result in only suboptimal gradient calibration results using standard service tools [3].

Recently, magnetic field sensors in the form of small NMR probes have been described as a highly accurate tool for spatiotemporal magnetic field mapping [4, 5]. In this work such magnetic field sensors were used in combination with a high-performance gradient insert coil for ultra-fast, single-shot, high-resolution, non-Cartesian imaging.

MATERIALS and METHODS

Spatiotemporal magnetic field mapping was achieved using susceptibility-matched, transmit-receive NMR probes as described in Ref. [5]. The probes consist of a ~1μl small H₂O signal droplet, closely surrounded by a solenoid coil for high SNR signal detection. Signal lifetimes on the order of 100ms could be achieved by applying susceptibility-matching methods in order to minimize static ΔB₀ variations across the water droplet. Using a distributed array of such NMR probes, the spatially-constant, B₀ phase variation φ₀(t), and the k-space trajectory k(t) can be extracted based on the Larmor relation. The measured k-space encoding information is then used in the following image reconstruction, according to:

\[ \phi_{\text{probe}}(t) \cdot \Delta \omega_{\text{probe}} = t = \phi_{0}(t) + (t) + k(t) \cdot r_{n} \cdot \Delta \omega_{\text{probe}} \] with: \( \phi_{0}(t) = \gamma \Delta \omega_{0}(t) \Delta f'k(t) = \gamma G(t) \Delta f'k(t) = \text{image}(t) = \int \text{data}(t) \text{dcf}(t \cdot e^{i \phi(t)}) dk \)

with \( r_{n} \) and \( \Delta \omega_{\text{probe}} \) denoting the n-th probe spatial position and off-resonance, respectively. Both can be obtained from a single FID-type calibration measurement. The NMR probes were analyzed and found to be sensitive enough (\( \Delta B_{0} = 500 \text{ mT/m}, \Delta \phi = 1750 \text{ T/m/s} \)) for circular EPI, and \( \Delta f'k = 13.7 \text{ ms}, G_{\text{max}} = 92 \text{ mT/m}, S_{\text{max}} = 1750 \text{ T/m/s} \) for circular EPI, and \( \Delta B_{0} = 1800 \text{ T/m/s} \) for the spiral, respectively (cf. figure).

RESULTS

The left column of the figure shows k-space trajectory mapping and imaging results for the single-shot, circular-EPI acquisition. Performing image reconstruction based on the calibrated k-space trajectory resulted in significantly reduced ghosting artifacts compared to the reference image obtained using the nominal prescribed gradient waveforms. The right column shows the same comparison for the single-shot spiral acquisition. MFI deblurring was applied based on separately acquired off-resonance maps. Also in this case the image was significantly improved using the measured k-space trajectory. The reproducibility of the gradient insert system was tested by multiple repetitions of the k-space trajectory measurement, with the gradient insert removed in between. The obtained k-space trajectories resulted in no significant difference in the reconstructed images, verifying the assumption of time stability for the gradient insert system. An initial attempt to apply an advanced frequency-domain, linear-system gradient calibration approach failed, however, calling for further investigations.

DISCUSSION and CONCLUSIONS

In this work, ultra-fast, high-resolution, single-shot, non-Cartesian imaging was demonstrated using a high performance gradient insert coil. This was enabled using an NMR-probe based k-space trajectory calibration method. In comparison to alternative k-space trajectory methods [9, 10], susceptibility-matched, transmit-receive NMR probes provide important advantage over gradient-based, conjugate-gradient (CG) algorithms with optional multi-frequency interpolation (MFI) off-resonance correction [6, 7].

ACKNOWLEDGMENTS

The authors would like to thank Adam B Kerr (MRSL, Stanford University, CA, USA) and Atsushi Takahashi (ASL, GE Healthcare, Menlo Park, CA, USA) for support and insightful discussions. This work was supported by NIH grants AA05965, AA03521-INIA.

REFERENCES