High Speed 3D b-SSFP at 6.5 mT

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Target audience: MR physicists and clinicians interested in performing fast 3D imaging at very-low magnetic field and on the design of high-performance purpose-built MRI systems.

Purpose

Without major innovation, high-field MRI instruments offer limited utility in field deployable and portable contexts. Our effort focuses on the high-risk and critical challenges that must be solved to enable deployment of transportable dedicated MRI systems. This includes the development of robust low-field scanner hardware methodologies, the development of state of the art high-speed imaging strategies and work on advanced adaptive reconstruction methods including navigators and sparse sampling. With the goal of demonstrating a proof-of-principle of a suite of techniques and technologies to advise future development of a field-deployable device with high diagnostic impact, the present work reports on the development of fast 3D imaging at very-low magnetic field (6.5 mT) using the intrinsic ^{1}H NMR signal and balanced steady state free precession (b-SSFP).

Methods

A very stable magnetic field is a critical element of the experiment as off-resonance effects can distort the image and cause severe banding artifacts [2]. A custom built, low-field MRI scanner with a bi-planar 6.5 mT electromagnet (B_0) and bi-planar gradients was used for all experiments and was previously described [1]. The system was upgraded and optimized for ^{1}H imaging resulting in improved B_0 stability, higher gradient slew rates, and lower overall noise. This effort included the use of an improved power supply (System 854T, Danfysik, Taastrup, Denmark) for the electromagnet with ±1 ppm stability over 20 minutes and ±2 ppm stability over 2 hours, and the addition of high-current shielded cables throughout the system. The scanner operates inside a double-screened enclosure (ETS-Lindgren, St. Louis, MO, USA) with a RF noise attenuation factor of 100 dB from 100 kHz to 1 GHz. The 3D imaging experiment was performed with Cartesian acquisition of k-space using b-SSFP. The sequence was set with TR/TE = 42/21 ms, acquisition matrix = 128×41×11, voxel size = 2.7×2.5×9 mm^3, number of averages (NA) = 40. The readout duration was 7.04 ms with 9091 Hz bandwidth and total acquisition time was 12.6 min for fully sampled k-space.

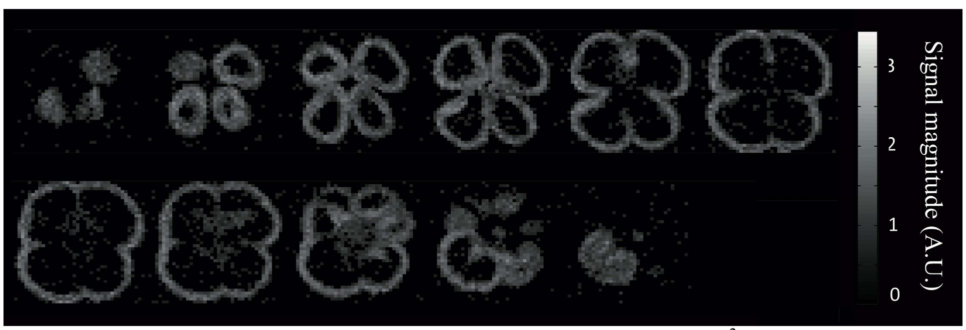

Figure 1: 11 slices of the imaged bell pepper at 6.5 mT with 2.7×2.5×9 mm^3 resolution in 12.6 min.

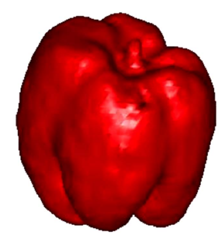

Figure 2: 3D rendered image of the bell pepper reconstructed from the acquired MRI dataset.

Results

Figure 1 shows the 11 slices of a bell pepper acquired using 3D b-SSFP with 2.7×2.5×9 mm^3 resolution. Figure 2 shows a 3D rendered image of the reconstructed object.

Conclusion

3D imaging across a 10 cm diameter bell pepper with 2.7×2.5×9 mm^3 voxel size was achieved within 13 min at 6.5 mT. This result is the first implementation of b-SSFP at very low magnetic field. The presented work overcomes the main limitations of working at low field, which typically results in poor SNR and prohibitively long acquisition times, by using a custom built optimized scanner with stable magnetic field B_0 and low overall noise that allows implementation of b-SSFP imaging. The use of undersampling strategies and compressed sensing reconstruction algorithms could further reduce the imaging time. We have recently shown that an undersampling rate of 70 % gives unperceivable reconstruction errors when compared with fully sampled data sets [3]. Thus, we expect the total acquisition time for the presented image to reach ~6 min and ~3 min with 50% and 70% undersampling respectively. The optimized bi-planar electromagnet combined with fast 3D imaging strategies and sparse sampling has potential to reach clinical standards for patient imaging and open new perspectives for a generation of low-cost, high-performance, and purpose-built imagers practical for operation in hospitals, battlefield medical facilities, or forward triage centers.

References: [1] Tsai LL *et al.* JMR 2008; 193: 174-85 ; [2] Scheffler K *et al.* Eur Radiol 2003;13:2409-18; [3] Sarracanie M *et al.* MRM 2012; submitted.

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