Real-time shim compensation in the human breast

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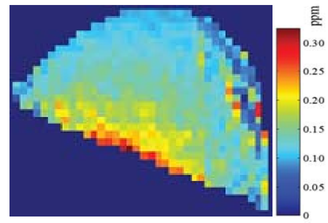
Introduction

Large dynamic B0 fluctuations are observed in the human body during MR scanning, compromising image quality and detection sensitivity in several MR imaging and spectroscopy sequences. Partially, these dynamic B0 fluctuations are due to physiological motion such as breathing, but also other sources of temporal B0 field fluctuations are present in the MR system (e.g. field drift, eddy currents). Especially at ultra-high field the increased susceptibility effects lead to large B0 field variations over time. In the human breast severe dynamic field disturbances can be observed using fast gradient echo imaging (fig 1). Direct measurement and correction of these temporal B0 field variations will lead to a significant reduction of artifacts and improved measurement stability/reproducibility for a range of MR sequences. For direct measurement of the temporally changing B0 field caused by physiological motion, several simple and small 19F field probes were developed, that can be placed close to the body around any organ of interest. In this work it is shown how such a field probe system can be used to monitor both temporal and spatial B0 field variations in the human body. Especially when integrated in the MRI console, fast acquisitions are demonstrated that allow for real-time field corrections.



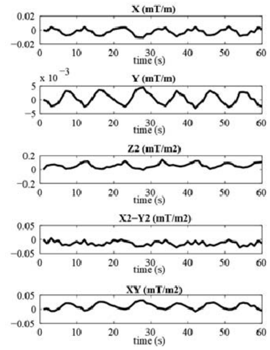
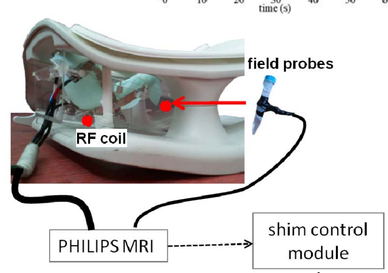


Figure 1: Dynamic B0 maps (left) obtained from the human breast demonstrating significant linear and 2nd order shim terms (right).

Methods

To assess the real-time B0 field correction capability, the individual parts of the correction system were analyzed. Simple field probes were designed for fast and high SNR measurements of the local magnetic field. The design consisted of a Helmholtz coil pair wound on a thin tube filled with 2,2,2 trifluoroethanol (TFE). The coil was tuned to the 19F frequency at 7T and interfaced to the spectrometer (fig 2). A linear fit to the phase in the time domain was used to estimate the frequency. An RS232 communication protocol was established between the spectrometer and a dynamic shim control unit (DSU, Resonance Reasearch Inc., Billerica, MA, USA) which was interfaced to the shim coils in the MR system. The shim control module was equipped with pre-emphasis compensation on all 0th through 3rd order shim channels. Single voxel MRS measurements (STEAM, TE=7ms, TR=2s, 16 averages) with Z0 field updating were performed in the human breast to demonstrate the ability to update the B0 field in real-time.



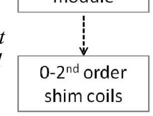


Figure 2: Setup of the breast coil including the integrated field probe consisting of a TFE tube and a small coil.

Results

All parts of the real-time B0 field correction chain were analyzed. The 19F field probes generated a high local B1+ field, and therefore allowed for very short RF pulse durations (<0.1 ms). A reliable frequency estimation was already possible with 4 ms data acquisition (fig 3). Data handling and calculations on the spectrometer and the concurrent communication with the shim control unit were performed within 17 ms (fig 4). Updating of the shim fields was feasible within 2.5 ms (fig 5). Real-time measurement and updating of the Z0 field in the human breast shows to reduce the frequency variation during a single voxel MRS and restores a good line shape for the water signal (fig 6).

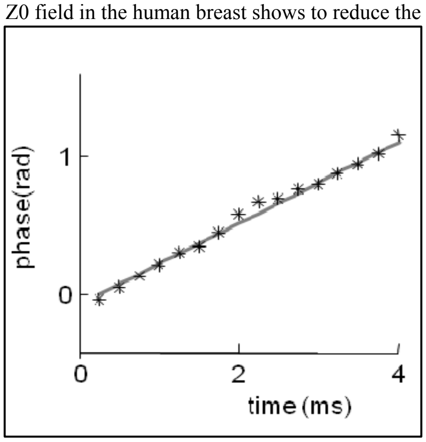


Figure 3: Phase difference data obtained from the field probe, used to calculate the offset frequency at the location of the probe.

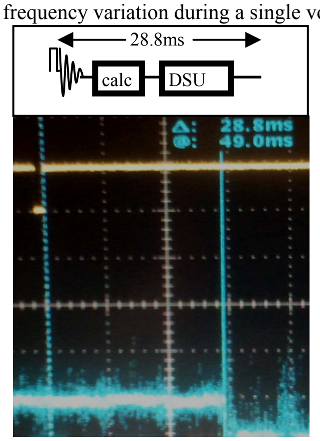


Figure 4: Timing between the excitation of the field probe until the updated current from the DSU based on calculation of the field.

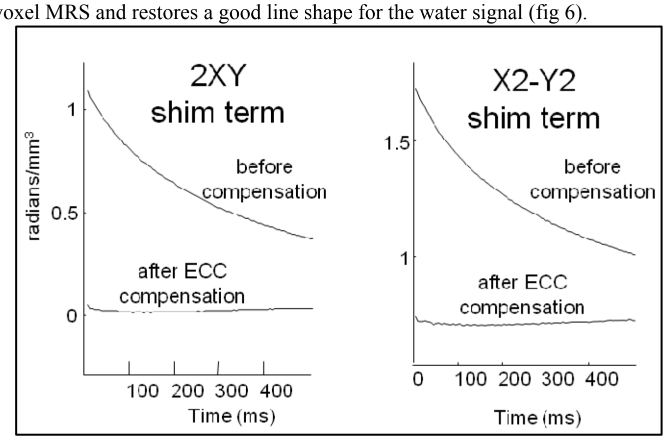
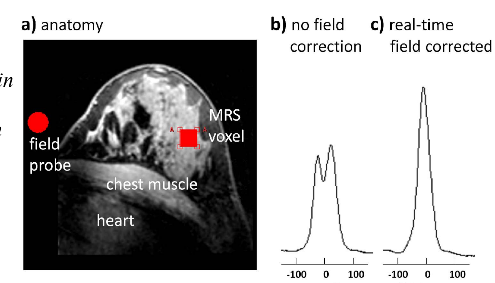


Figure 5: Impulse response of higher order shim terms that have relatively long eddy currents. Note that calibrated eddy current compensation within the DSU can bring the response time back to less than 2.5 ms.

Conclusion and discussion

Real-time measurement and updating of the shim fields is possible within 30 ms. Simple 19F field probes allow for fast and accurate frequency measurement on specific points in the magnet bore. Integration of the data processing and serial communication into the spectrometer then allows for real-time control of the shim fields to correct for breathing in the human breast, but potentially also for heartbeat, non-voluntary motion etc.

Figure 6: Single voxel MRS of water localized in glandular tissue (a) in the human breast while breathing either without (b) or with real time correction (c).



References

[1] van de Bank et al. ISMRM 2011