Dynamic off-resonance magnetic field monitoring and correction using proton field probes

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TARGET AUDIENCE Scientists interested in dynamic magnetic field fluctuation monitoring and calibration.

PURPOSE Physiological fluctuations, such as breathing and heartbeats, can cause magnetic field drifting and image quality degradation and can cause significant noise in high field fMRI experiments[1]. Stationary field inhomogeneity can be partially estimated and corrected by field mapping. Navigator echoes provide dynamic estimates of the field drifting with limited spatial information[2]. Magnetic field probes can dynamically detect spatial distributions of magnetic field disturbances[3]. However, field probes using proton as the signal source have serious coupling to the NMR signal from the subject. This challenge can be mitigated by using RF shielded field probe transceivers[4] or using non-proton sample (such as ^{19}F) as the field probe signal source[5, 6].

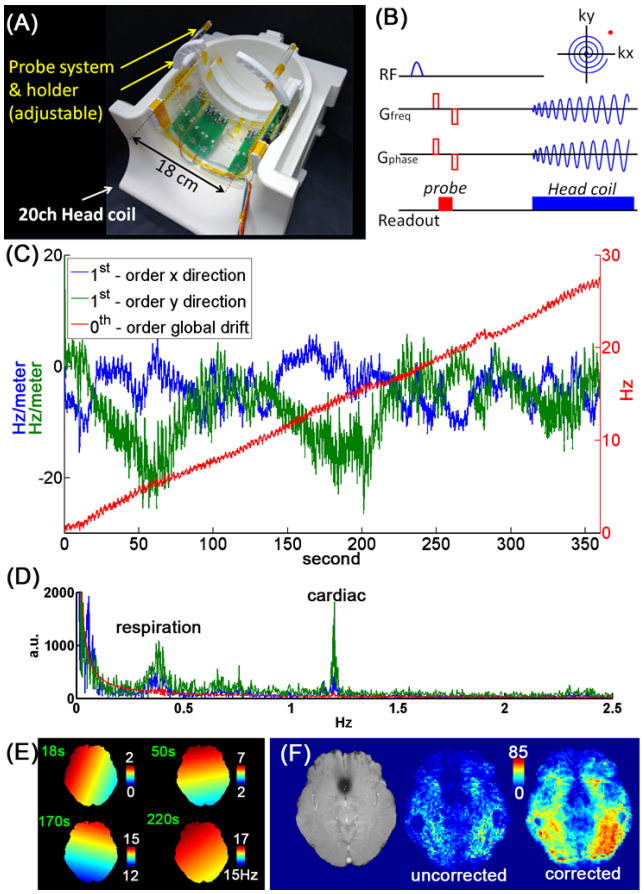
Here we develop a 10-channel field probe system using ^{1}H as the NMR signal source to monitor the magnetic field. The field probe is decoupled from the subject by interleaving the field probe measurement and subject imaging. Specifically, field probe NMR signal was measured at high spatial frequency *k*-space point in order to minimize the NMR signal from the subject. Empirical data showed successful monitoring of respiratory and cardiac cycles. We can track 2D field drifting with 0.1 s temporal resolution and use this information to improve the time-domain SNR (tSNR) of dynamic spiral imaging by 137 %.

METHODS A 10-channel field probe array (Figure A) was designed to be integrated with a 20-channel head coil array (Siemens). Probes were arranged on the circumference of a ring structure (PC-ISO, Fortus 400mc, Stratasys, MN, USA) with 18 cm diameter. Probes used a water droplet (1 mm diameter) as the signal source and were susceptibility matched using FC40 (3M, MN, USA). Low noise pre-ampfilers were connected to by probe and matched to 50 Ω (LNC, Siemens). All probes were tuned to 123.25 MHz and detuned by PIN diode during RF transmission.

A spiral pulse sequence (TR = 100ms, $\alpha = 30^{o}$, TE = 30ms, and resolution = 2mm x 2mm x 5mm; 110 T/m/s slew rate) was used to measure the resting state fMRI for 6 minutes. To monitor field disturbances, probes measured a 9 ms FID right after strong pre-phasing gradients (Gradient moment: 59 mTms/m) after RF excitation (red trace in Figure B). Re-phasing gradients were added before spiral readouts to acquire the NMR signal from the subject (blue trace in Figure B).

Field probe FIDs were used to calculate the magnetic field by fitting both the 0th and 1st order spatial distributions at every TR. We calculated the spectra of magnetic field fluctuation and the associated off-resonance fields. The spiral trajectory was also calibrated by a 25-channel grid probe array. The performance of dynamic field tracking was further quantified by the tSNR using measurements with and without the dynamic field maps estimated from field probes. All measurements were performed on a 3T system (Skyra, Siemens).

RESULTS Our field probe system dynamically measured the 0th order field and the 1st order field gradients in x and y directions (Figure (C)) in the presence of a subject. The spectra show clear respiratory and cardiac cycles (Figure (D)). We found there was more than 20 Hz off-resonance over 4 minutes. The spatial distributions of off-resonance field strength also changed over 4 minutes. (Figure (E)). Figure (F) shows that tSNR after correcting field drift was improved by 137% compared to the uncorrected one.



DISCUSSION Our probe system and the pulse sequence can dynamically detect the distributions of magnetic field drift caused by physiology and system instability. We can only measure off-resonance field disturbance varying no faster than TR (time between two excitation). Importantly, we found the spatial distribution of the off-resonance magnetic field is not uniform. Thus it cannot be corrected effectively by navigators[2]. Significantly improved tSNR in dynamic spiral scan, which is particularly susceptible to field inhomogeneity, suggested the usefulness of our approach in tracking magnetic field disturbances.

CONCLUSION Our probe array has a simpler construction (no RF shield, no transceiver, same NMR active nuclei for both probes and subject imaging). Paired with a customized sequence, off-resonance field can be mapped dynamically at 10 Hz. Significantly improved tSNR in dynamic spiral imaging supports the validity of our field monitoring system. We expect that this system can be particularly useful for single-shot 3D imaging[7].

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