Navigator based FUS Transducer Tracking without the micro-RF coil setup

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Introduction: The ability to track the location of the ultrasound transducer is of utmost significance in various new Magnetic Resonance guided Focused Ultrasound (MRgFUS) applications such as in pain palliation of bone metastases and prostate tumor treatment. The ultrasound transducer is generally monitored using a micro-RF coil setup shown in Figure 1. The tracking of micro RF-coils was first introduced in [1] and in the MRgFUS applications they are embedded on the transducer and their positions are estimated to track the location of the transducer. The success of these applications is highly dependent upon the quality of the micro-RF coil position measurements, which could be erroneous if the signal from the surrounding anatomy is not properly suppressed. In this work, a kspace based novel technique is described to demonstrate the feasibility of transducer tracking without the micro-RF coil setup, which would be amenable for the new MRgFUS applications.

Theory: It is known that transducer shifts corrupt the phase of the measured MRI signal. To apply the technique for tracking the transducer in three dimensions, three lines in 3D kspace along k_x, k_y and k_z directions are acquired prior to each imaging acquisition. The k-space phase difference between each of these three lines is computed which yields the phase difference solely due to the shifts of the transducer in the three directions. An exponential is applied to the phase difference and an inverse Fourier transform is then performed. Using the following elementary property of the Fourier Transform,

$$F^{-1}\{e^{-j\omega\Delta}\} = \delta(x-\Delta) \qquad (1)$$

where F^{-1} denotes the inverse Fourier Transform and $\delta(x-\Delta)$ is an impulse function located at $x=\Delta$, a peak is detected at the location of the transducer shift, as shown in Figure 2.

Methods: All simulations and processing were performed using MATLAB. To validate the proposed algorithm, a synthetic 2D phantom was created with the transducer and other small background objects. Artificial shifts were applied to the transducer in the synthetic phantom to generate the shifted data. In order to evaluate the accuracy of the estimation of the shift parameters, a shift of 5 pixels each along x and y directions was imparted to the transducer. Two lines along k_x and k_y were collected through the center of the synthetic phantom. Each successive set of these two lines is compared with the first set to estimate the shifts of the transducer. A novel tracking pulse sequence, shown in Figure 3 is also developed on a GE Signa 1.5T MRI Scanner (GE Medical Systems, Milwaukee, WI, USA), which acquires the transducer data from the imaging surface coil rather than the micro-RF coils. A non-selective RF pulse (Θ = 10°) is followed by gradient echo projection readouts in three orthogonal directions, which yield the projections in the three directions through the center of the kspace. This tracking pulse sequence is then interleaved within each phase of the main thermal imaging pulse sequence (EPI pulse sequence) in a multiphase acquisition mode.

Results: Figure 4 shows the results of applying synthetic shifts on the transducer in the simulated data (A) which results in a transducer shifted output (B). The shifts of the transducer obtained using the proposed algorithm in the two planes are reported in Table 1, showing an excellent agreement with the applied and the obtained shifts. Figure 5 shows the axial cross-section of a GE phantom acquired from the imaging surface coil using the thermal imaging pulse sequence interleaved with the new tracking pulse sequence.

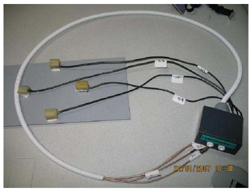

Fig 1. Micro-RF coil setup

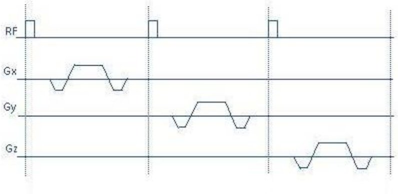

Fig 3. Novel Transducer Tracking Pulse Sequence

Direction	Imparted Transducer shift (pixels)	Obtained Transducer shift (pixels)
X	5	5
Y	5	5

Table 1. Comparison of transducer shifts estimated using the proposed algorithm

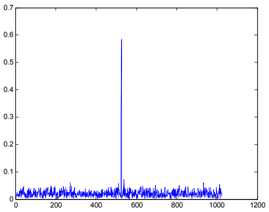

Fig 2. Peak at the location of transducer shift

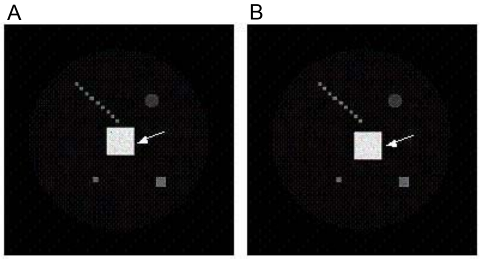

Fig 4. Synthetic Phantom Image (A), Transducer shifted Phantom Image (B). The arrow points to the simulated transducer

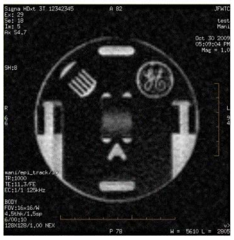

Fig 5. Axial cross section of the GE phantom acquired with the combined pulse sequence

Conclusions: A novel navigator based algorithm is presented to explore the feasibility of locating the ultrasound transducer in MRgFUS applications. The algorithm is shown to be capable of detecting the shift of the transducer accurately. This algorithm also obviates the need of a micro-RF coil setup. Computing the phase difference at a particular time instant would nullify the phase changes due to thermometry and hence this method is sensitive to phase changes only due to the shift of the transducer. Further work needs to be carried out to test the accuracy of this method on real MRgFUS data acquired with the new tracking pulse sequence.

References: 1. Ackerman J et al., Proc 5th ISMRM 1986:1131-32