trackDOTS - Tracking Discrete Off-resonance markers with Three Spokes

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Purpose: Various motion tracking methodologies have been presented such as image and k-space based navigators[1], motion tracking with external optical devices[2] and fluorine markers tracked using additional spectrometers[3]. While MR-based methodologies do not require external hardware and synchronization between different devices, their computational expense[4] makes them mostly suitable for retrospective image reconstruction and they often affect the host sequence timings and/or image contrast. In this abstract we present an MR setup that allows motion tracking (with additional potential for dynamic tracking of shim fluctuations) with both minimal impact on the sequence timing and contrast.

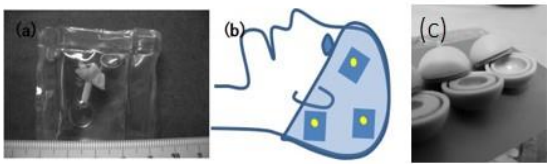

Figure 1: (a) picture of the marker setup: glass ball filled with TMS inside a water bag; (b) 6 markers were held in place using a silicon cap. (c) Alternative marker setup based on peek spheres.

Theory: Tetramethylsilane (TMS) is the proton NMR spectroscopy calibration substance in respect to which frequency others are reported (the spectral offsets from TMS of water and fat are 4.7 and 1.2 ppm, respectively). 6 glass spheres (d-9mm) filled with TMS were placed in small water containers (see Fig. 1a) and fitted around a subjects head (see Fig. 1b). TrackDOTS uses frequency selective RF pulses to excite the off resonance protons while leaving water protons untouched. Given the small number and the spatial sparsity of the markers, TrackDOTS uses a novel method for combining the signals from the separate RF channels to further suppress the small integrated residual signal from extraneous spins to a level allowing the localization of the various probes using only 3 projections.

Experimental and Processing Protocol: Two subjects were scanned on a 7T Siemens MR equipped with a 32-Ch RF coil. In this proof of concept implementation, 2 whole brain (FOV=224mm, res=1.75mm) acquisitions were interleaved: (i) non selective excitation 3DGRE: TR/TE=6/2.7ms iPAT=2x2, T_{acq}=30s; (ii) TMS frequency selective 3DGRE: TR/TE=12/4.5ms, RF_{dur}=5ms TimeBW=2.7, T_{acq}=3min30s; Protocols were repeated for 5 different head positions.
Water images were coregistered using FLIRT (www.fmrib.ox.ac.uk/fsl) and the resulting motion transforms used as motion tracking ground truth. From TMS images it was possible to: (a) extract 3 pseudo-navigators along x, y and the z direction; (b) segment the markers and calculate their centers of mass (POS_{CM}) and average signal ($S_{AV,CM}$).
Using the 32 coil images from the first water acquisition 6 coil combination modes were built with apparent sensitivities limited to a region surrounding each marker (magnitude least squares B_1^- shimming, similarly to what is done in parallel transmission pTX[5] see Fig. 2); The 6 coil-combination modes were used to combine the 32 channel dataset into 6 modes from which the coordinates, POS_{NAV}, were computed by finding the best fit of a simulated sphere projection. The sets of 6 coordinates (POS_{CM} and POS_{NAV}) were compared to the respective reference position.

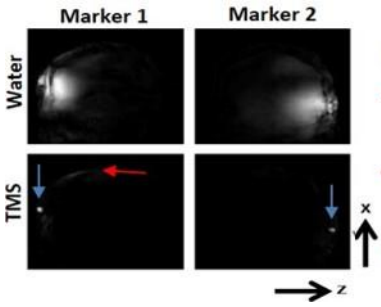

Fig. 2 Projection images along the anterior posterior direction of the water image (top row) and TMS image bottom row using three different coil modes generated to focus the receive field on Marker 1 and 3 respectively. Blue arrows highlight the markers and the red arrows show residual fat signal.

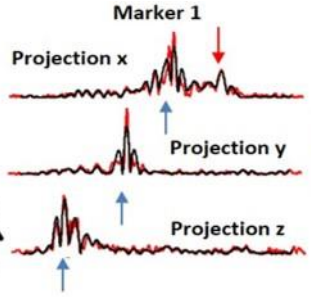

Fig. 3 Projection along x, y and z obtained from the navigator data from three orthogonal center k-space lines (red line), sphere projection fitting (black line). Blue arrows show the position of marker 1 (see Fig. 2) and red arrow the fat residual signal.

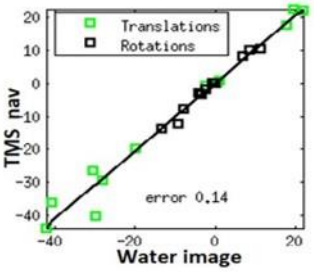

Fig.4 Plots showing the correlation between movement parameters (translation along x,y,z in mm and rotations along x,y,z in degrees) obtained by co-registration of the TMS POS_{NAV} of the 6 markers vs co-registration of water images;

Results: Fig. 2 shows projection images of 2 coil modes applied to one of the head positions. From the TMS images it is possible to appreciate that: the different markers are successfully separated, the RF pulse is able selectively excite the TMS markers and only some residual off resonance fat signal remains. Fig. 3 shows representative projections along x,y,z from where the POS_{NAV} was calculated, with its position in good agreement with Fig.2. The positions found for different head orientations were robust, as attested by the high correlation and low error found between both rotation and translation movement parameters both in respect to image coregistration (Fig.4) and center of mass estimation (data not shown).

Discussion and conclusion: The current setup (Fig1.a) has some limitations that impact the accuracy of motion tracking and dynamic shimming that can be overcome: **(1)** the long T_1 of TMS impacts on the available SNR; **(2)** the frequency of TMS is closer than would be desirable to endogenous fat; **(3)** air bubbles inside the probes (see Fig. 1a) induce dephasing of the probe signal (see Fig 5b) and its movement might introduce systematic errors on the coordinate estimation. Current work has been directed towards new probe holders based on acetic acid which has two proton peaks (-OH at 11.9ppm -see Fig. 5a and hence far from water and fat) and is dopable with Manganese. The use of more advanced markers (see Fig. 1c) devoid of air bubbles make the phase within the marker more reliable (see Fig. 5c) and the method potentially applicable to dynamic shimming.
The results shown demonstrate the potential of trackDOTS for rigid body motion tracking when multiple receive coils are available, with minimum impact on subject comfort. With trackDOTS the position of the subject requires a 10-30 ms acquisition that does not affect the host sequence image contrast and benefits from a very fast processing protocol (3x1D Fourier Transforms per marker and a peak detection routine).

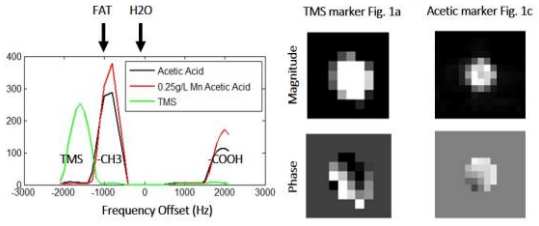

Fig. 5 (a) intensity profile of TMS and Acetic Acid markers as a function on the frequency offset of the frequency selective RF pulse, arrows at the top indicate expected water and fat resonances. (b) magnitude and (masked) phase images of a TMS marker using setup shown on Fig. 1a and (c) an acetic acid marker using setup Fig. 1c

References: [1] White et al, MRM (2010); [2] Maclaren et al, MRM (2013); [3]Haeberlin et al, proc. ISMRM 2013, p304; [4] Gallichan et al, proc. ISMRM 2013, p309; [5] Setsompop et al, MRM, 2008
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