Tracking Discrete Off-resonance markers with Three Spokes (trackDOTS) – a new motion tracking methodology

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Purpose: High resolution imaging at high fields (~ 0.4-0.7mm isotropic) is typically acquired in over 10 mins, over which period of time, even the most cooperative subject is expected to have moved on the order of 1 or 2 mm. Various motion tracking methodologies have been presented: image and k-space based navigators[1], motion tracking with external optical devices[2], 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. Furthermore, MR-based methods tend to affect the host sequence timings and/or image contrast. In this abstract we present an MR setup that allows motion tracking with both minimal impact on the sequence timing and contrast.

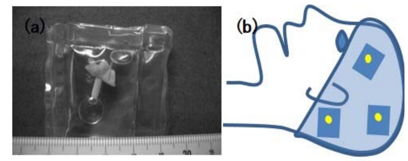

Figure 1: (a) picture of the marker setup: glass ball filled with TMS inside a water bag; (b) 6 markers were held in place using a

Theory: Tetramethylsilane (TMS) is the conventional proton NMR spectroscopy calibration substance in respect to which frequency others are reported (water and fat are at 4.7 and 1.2 ppm, respectively). 6 small glass NMR spheres (d-9mm) filled with TMS were placed in small plastic water containers (see Fig. 1a) and tightly fitted around a subjects head using a silicon cap (see Fig. 1b). TrackDOTS uses frequency selective RF pulses to excite the TMS protons in leaving water protons untouched. Given the small number and the spatial sparsity of the TMS, Track DOTS uses a novel method for combining the signals from the separate RF channels to be able to locate the position of the various probes using only 3 projections.

Experimental and Processing Protocol: Two subjects were scanned on a Siemens 7T MR equipped with a 32-Ch RF coil (Nova Medical Inc.). In this proof of concept implementation, 2 whole brain (FOV=224x224x224mm, res=1.75x1.75x1.75mm) acquisitions were interleaved: (i) non selective excitation 3DGRE: TR/TE=6/2.7ms FA=5°, iPAT=2x2, T_{acq}=30s; (ii) TMS frequency selective 3DGRE: TR/TE=12/4.5ms, FA=4° RF_{dur}=5ms TimeBW=2.7, T_{acq}=3min30s; The two protocols were repeated for 5 different head positions.

Water images were coregistered using flirt (www.fmrib.ox.ac.uk) 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 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 highest fit of a simulated sphere projection. The sets of 6 coordinates (POS_{CM} and POS_{NAV}) were fitted to the respective reference position. If, after fitting, one marker was over 1mm away from its reference position, the marker with largest distance was discarded and the fitting was repeated.

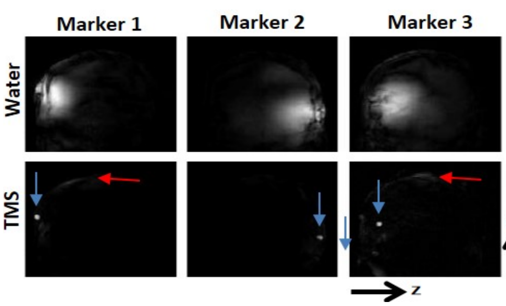

Fig. 2 Projection images along the anterior posterior direction of the water image (top row) and TMS image bottom row using three different coil modes generated to focus the receive field on Marker 1, 2 and 3 respectively. Blue arrows highlight the markers and the red arrows show

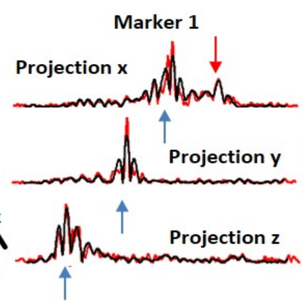

Fig. 3 Projection along x, y and z obtained from the navigator data from three orthogonal center k-space lines (red line), sphere projection fitting (black line). Blue arrows show the position of marker 1 (see Fig. 2) and red arrow the fat residual

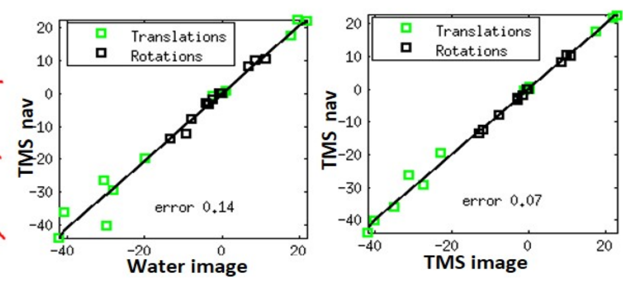

Fig.4 Plots showing the correlation between movement parameters (translation along x,y,z in mm and rotations along x,y,z in degrees) obtained by different methodologies: (a) co-registration of the TMS POS_{NAV} of the 6 markers vs co-registration of water images; co-registration of the POS_{NAV} vs co-registration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

Results: Figure 2 shows projection images of 3 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 (despite the proximity of markers 1 and 3), the rf pulse is able selectively excite the TMS markers and only some residual off resonance fat signal remains. Figure 3 shows representative projections along x,y,z from where the POS_{NAV} was calculated can be seen with its position in good agreement with of 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 coregisteration (Fig.4a) and center of mass estimation (Fig. 4b). High correlation was also found for the phase of S_{AV} (for a specific coil mode) and the phase of the coefficients used to fit the projection which suggests the probes could be used also for dynamic shimming purposes.

Discussion and conclusion: The current setup has some limitations that impact on the accuracy of motion tracking and dynamic shimming that can be overcome: the long T_1 of TMS impacts on the available SNR; the chosen off resonance marker is not too far from the surrounding fat frequency; air bubbles inside the probes (see Fig. 1a) induce dephasing of the probe signal and its movement might introduce systematic errors on the coordinate estimation (and explain the better agreement between TMS based motion parameters in respect to the water parameters). Nevertheless, the results shown demonstrate the potential of trackDOTS for rigid body motion tracking when multiple receive coils are available, with minimum impact on the subjects 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).

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 **Acknowledgement:** This work was supported by CIBM of the UNIL, UNIGE, HUG, CHUV, EPFL and the Leenaards and Jeantet Foundations.