EVALUATION OF TRACKDOTS POTENTIAL TO PERFORM MOTION TRACKING AND DYNAMIC SHIMMING

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Purpose: In this work we explore the potential of TrackDOTS (tracking Discrete Off-resonance markers with Three Spokes) [1] to give information regarding not only the head position, but also of the local respiration-induced frequency fluctuations in an acquisition time of 24ms.

Material and Methods: TrackDOTS uses off-resonance markers that can be selectively excited using frequency selective pulses. Using the standard receive arrays, a specific coil mode can be created to reduce the sensitive region to each single marker. It is then possible to achieve localization of any given marker using only three orthogonal k-space projections. To measure its frequency, two echo times should be used.

Twelve markers were positioned in an adapted EEG cap (see Fig 1.a). The markers were 3D milled spherical shapes of PEEK (see Fig. 1b) filled with acetic acid (CH3COOH) that has proton resonance peaks at 2.0 and 11.6 ppm (water is at 4.7ppm) doped with manganese chloride. To selectively excite OH protons, 2ms pulses with a BW 750Hz were used 2000 Hz off-resonance from the main water frequency. Such a broad frequency pulse has to be used due to the spread of frequency shifts that naturally occur around the head (see Fig. 1c).

Six subjects were scanned on a 7T MR scanner (Siemens) equipped with a 32-Ch RF coil (Nova Medical Inc.). To study the precision and accuracy of the apparatus to subjects head movement, the subject's head rested on an air pillow that was connected to a pump that inflated at a constant rate of 5ml/min over 12 minutes, inducing displacement up to 6mm and 1.7°. During this time 24 repetitions of the following protocol were performed:

A) Water 3D-GRE images TR/TE = 3.5/1.5ms α=5° iPAT=4, res= 3.5x3.5x1.75mm acq. time=6.7 secs
B) 3 orthogonal projections TR/TE1/TE2=8/2.4/5ms, BW=500Hz/px, were acquired using the frequency selective RF pulse α =30°, resolution along projection = 1.75mm; This was repeated with 96 different pre-phasing gradients [2]; acq. time = 3.8s
C) Marker-frequency selective 3D-GRE images TR/TE = 6.8/3.1ms, res=1.75mm isotropic, iPAT=8, acq. time=13s

In a follow-up acquisition the subjects were scanned with 150 repetitions of a modified protocol (b) containing only 20 different prephasers during 80s, while the respiration was monitored using the vendor-supplied physiological monitoring system.

Protocol C gives a quick image of the markers and was used as a validation of the possibility to use the markers positions to perform motion tracking. The water image was used to create the coil modes[1] that are only sensitive to the region in the neighborhood of one marker and as motion correction ground truth. The signal and position of each marker was assessed by finding the maximum along its coil mode projection, integrating the signal along its known extent (d-7.5mm) and finding the center of mass. Example of the data obtained from this 3 acquisitions is shown on Fig. 1d. The positions were used both for estimating the variations of head position and, together with its signal phase, used to estimate shim variations from shot to shot.

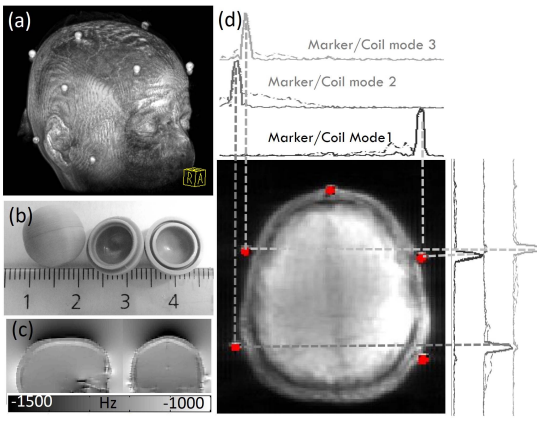

Figure 1: (a) Rendered 3D-GRE image of a subject with the 12 markers positioned around his head in an EEG like cap. (b) The 7.5 mm inner-diameter marker (c) Sagittal and coronal cut of the frequency shift (Hz) expected in and around the head. (d) Transverse slice of water image acquired with protocol A, overlaid with the marker specific image acquired with protocol C (in red) and the x and y projections acquired with protocol B using combination modes that generate 3 of the distinct markers. The projections with full and dashed lines correspond to with and without pre-phaser respectively.

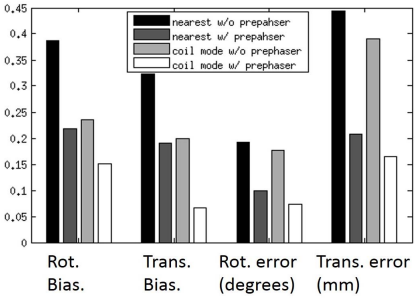

Figure 2: Comparison of estimated motion parameters using TrackDOTS vs the standard water images, comparing bias (left) and error (right).

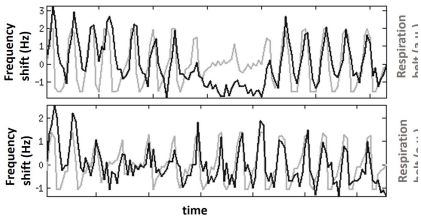

Figure 3: Timecourses over 80 secs of the estimated frequency shift (black line) in the brain and the respiration belt position for two different subjects.

Results: In this analysis only two gradient pre-phaser amplitudes were used, either zero (w/o) or at a strength sufficient to give a modulation of π radians across the size of the marker in the directions orthogonal to the projection (w/)[2]. Figure 2 demonstrates the importance of combining the use of coil modes (as opposed to using the nearest coil) and gradient pre-phasers. The bias between the estimated motion parameters using TrackDOTS and the ground truth (deviation from slope 1) was found to be 0.15 and 0.08 for the rotations and translations respectively, and get further reduced to 0.04 and 0.03 when using the marker images (of protocol c) as ground truth. In terms of accuracy (see Fig. 2b), the gradient prephasers have the strongest positive influence, allowing a final precision of 0.07 degrees and 0.16mm for the rotations and translations respectively (this was unchanged when using protocol C as ground truth). Figure 3 shows the plots, for two subjects, of the measured frequency shift over time. A clear agreement with the corresponding respiration belt information can be appreciated with both having similar amplitude fluctuations. The z-gradient could also be measured in some subjects, although with a lower SNR, the frequency range was nevertheless on the order of magnitude of what has been presented in literature in the past (7Hz from bottom to top of the brain)[3].

Discussion and conclusion: In this abstract we demonstrated the precision and accuracy of TrackDOTS to obtain both motion tracking information and relevant frequency shift information with an acquisition time of only 24ms that has no impact on the water signal of interest. The precision is expected to be limited by the SNR of the markers and contamination by water excitation (as suggested by the impact of the use of gradient pre-phasers). The optimization of the marker doping as well as the testing of alternative compounds to fill the markers will be important for future development.

References: [1] Marques et al, Proc. ISMRM (2014) 1597; [2] Sengupta et al, MRM (2013); [3] Van de Moortele PF et al, MRM (2002);