Accurate Localization of Active Devices using Multi-scale analysis for Interventional MR Imaging

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Objective: During MR-interventions, precise localization and robust tracking is performed by utilizing locally sensitive small RF coils mounted at known positions along the device. The localization of the coils is achieved in a few milliseconds by, first, acquiring one dimensional projections along all three spatial directions (X, Y, and Z) and then, either by finding the maxima in the power spectra, whose frequency is indicative of the coil position in actual space [1], or by finding the highest similarity between the projections and a theoretical waveform model [2] known as cross-correlation method. While it has been previously shown that the cross-correlation method helps to accurately determine coil position as compared to maxima method, it relies on hardware characteristics of the coil, is noise sensitive, and the parameter estimation doesn't include the degree of reliability, confidence interval or likelihood. The problem is accentuated in a tracking module-imaging slice interleaved acquisition when the imaging slice intersects the tracking coil thereby causing signal saturation and low SNR projection signals.

In order to overcome these drawbacks, a multi-scale tracking method is proposed by considering the signal of interest as a singularity smoothed by a diffusion process. The parameter estimation is then done by performing edge detection at different scales [3] and characterizing them to find suitable patterns for a given projection signal. The resulting patterns from different scales are combined to obtain the likelihood estimation at every position.

Materials and Methods: The typical tracking projection signal is shown in Fig. 1. The variations or edges seen in the signal are important features which can be detected with a pattern detection algorithm. The benefits of using edge patterns for our estimation are, that edges are noise-robust features. In a noisy environment, it should still be possible to detect them as opposed to the cross-correlation method [2] which relies on a specific solenoid coil model. The flow chart of the multi-scale tracking method shown in Fig. 1 executes the following steps: (1) Perform a multi-scale decomposition, i.e., transforming the signal into different bases using wavelet transform (2) Use this multi-scale decomposition to calculate modulus maximum at each scale (3) Calculate edge detection and characterization and find patterns matching the smoothed singularity at each scale (4) Estimate the parameter likelihood by combining matching patterns and finally (5) Extract the maximum likelihood to obtain the final estimation.

The projection measurements were done on a 3T scanner (Siemens MAGNETOM Trio a Tim System, Erlangen, Germany). A custom-built micro-coil mounted catheter was used (MRI Interventions, Irvine, USA). The micro-coil was placed at a known position which served as a ground truth. The low SNR projection signal was obtained by placing interleaved the imaging slice so that it overlapped the micro-coil. Position detection was performed using both cross-correlation analysis and multi-scale tracking method.

Results and Discussion: Fig. 2 shows the modulus maxima at various scales computed using the wavelet transform with detected patterns matching the smoothed singularity (as pink intervals) for two different signals. Note that the matching intervals are shifted according to the scale and converge towards the coil position when the scale decreases; it needs to be compensated when estimating the coil position. The vertical dotted line indicates the ground truth. The left panel shows the several false-positive detections for low SNR signal. In spite of this it is possible to determine the coil position, by finding regularity through different scales. Although the position detection accuracy of multi-scale tracking method is similar to cross-correlation [2] (data not shown), the multi-scale method offers an added advantage of robustness against low SNR signal. Furthermore, it is possible to construct an estimate of the likelihood function based on detected patterns. An example of likelihood function for 2 different signals is shown in Fig. 3. This added information can be utilized during interventions for real-time decision on signal quality. It can further be used for post-processing algorithms, such as filtering or optimization methods.

Conclusion: In conclusion a multi-scale tracking method is proposed to accurately estimate the coil positions. The benefits over previous proposed methods are increased robustness, less sensitivity to noise, and the ability to estimate the likelihood information at every position over the field of view. It is then possible to use this information in further steps for optimal filtering techniques or simply to display this information so that proper actions can be taken to restore the signal SNR.

References: [1] Dumoulin CL et al. MRM 29(3):411-15, 1993.[2] Barbot et al. ISMRM11, p. 1747, 2011. [3] Mallat et al. IEEE Tran 14(7):710-32, 1992.

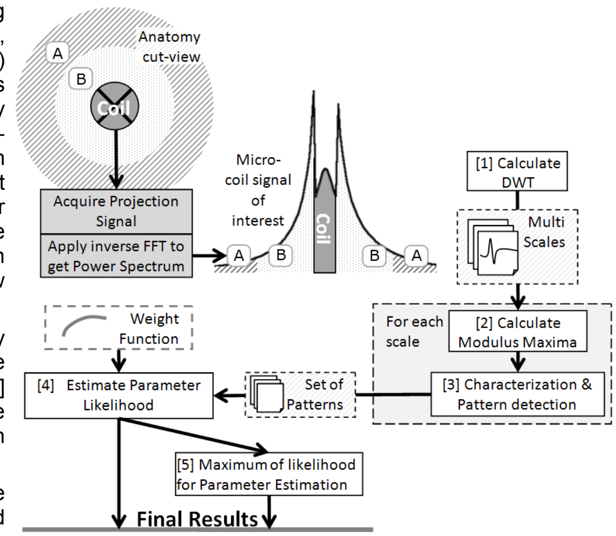

Figure 1 *Multi-scale tracking algorithm flow chart, including signal pattern of a projection signal with respect to surrounding anatomy.*

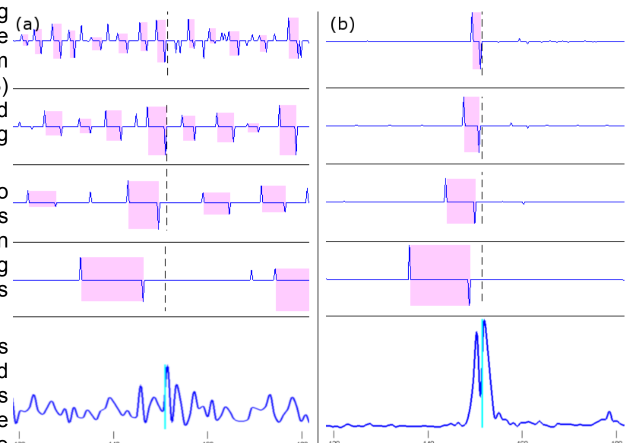

Figure 2 *Modulus maxima at multiple scales (in blue), with pattern detection overlaid (as pink intervals) and corresponding projection signals (bottom), for: (a) Low SNR signal; (b).High SNR signal. The ground truth is shown as vertical lines (dotted and light blue).*

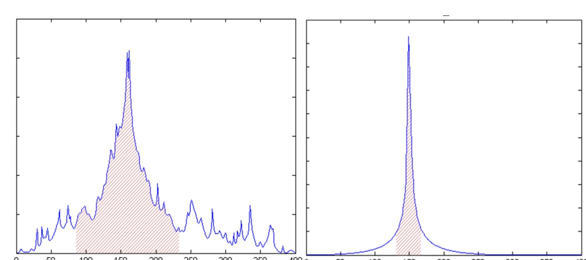

Figure 3 *Resulting estimated likelihood function, with a 90% confidence interval shown in red, for: (a) Low SNR signal; (b).High SNR signal.*