A Variational Approach for Coil-Sensitivity Estimation for Undersampled Phase-Sensitive Dynamic MRI Reconstruction

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INTRODUCTION: Coil sensitivity estimation for the phase-consistent array combination and SENSE like [1] reconstruction of undersampled dynamic MR data remains a challenge. This is a crucial point as the best possible quality for advanced reconstruction methods is bounded by the quality of the coil estimates. Furthermore, a growing number of MR applications require acceleration together with measurement of the signal phase and changes in phase. The widely used adaptive reconstruction method proposed by Walsh et al. [2] satisfies these requirements - although enhancing SNR - to a certain extend but leads to inconsistencies in phase and magnitude estimation. We propose a variational approach that iteratively takes already estimated phase contributions into account and introduces a-priory knowledge for the magnitude and phase of the coil sensitivities and also for the complex transverse magnetization.

Initialize

- Get coil weighted time-constant images v_j
- Get time weighted averaged data u_0
- Get absolute value of sensitivities (H1-regularization) $|\sigma_j|$
- Set phase of starting coil to zero $\phi(\sigma_0) = 0$

Iterate

- $u_+ = \arg\min_u \left(\nu \mathrm{TGV}(u) + \sum_k \|\sigma_k u - v_k\|_2^2 \right)$
- $\phi(\sigma_+) = \arg\min_p \left(\frac{\mu}{2} \|\nabla p\|_2^2 + \frac{1}{2} \|p|\sigma_+|u_+ - v_+\|_{w,2}^2 \right)$

Table 1 *Pseudo-code for proposed method*

METHODS: For the initialisation of the sensitivity estimation from dynamic data the time-constant coil-weighted images v_j and combined images u_0 are computed as in the TSENSE [3] approach, in order to yield a H1-regularized estimate of the absolute value of the sensitivities σ_j. As the absolute phases of the sensitivities cannot be determined, the initial coil-phase is normalised to zero. From there on we iterate between TGV [4] constrained estimation of the magnetisation u_+, where TGV implies piecewise smoothness for magnitude and phase, and estimation of the consecutive coil phase $\Phi(\sigma_+)$ in close overlap with the already gained confidence region. Again H1-regularization on the coil phase is employed to enforce smoothness. **Table 1** summarizes the described procedure. For simulation purposes we used fully sampled functional cardiac CINE data acquired in breath-hold, thus satisfying the assumption that the receiver coils are static in time. Frame-wise reconstruction was performed using the adaptive combine method to yield a reference with magnitude- and phase-information. This reference was modulated with simulated coil-sensitivity profiles according to Biot-Savarts law and Fourier-transformed to yield synthetic data. The synthetic coil geometry and number was chosen such that independence of the receiver-channels is similar to the original setting. The synthetic data was retrospectively undersampled on a randomized Cartesian grid for acceleration-factors from 4 to 10. Coil sensitivities were then re-estimated from the accelerated data, again with the adaptive combine method, and our approach. Evaluation was performed in two ways: First, by computing the root-mean-squared-error (RMSE) of the true sensitivity profiles to the estimated ones and second by computation of the RMSE of our dynamic MR reconstructions based on [5] with the true and with estimated sensitivities.

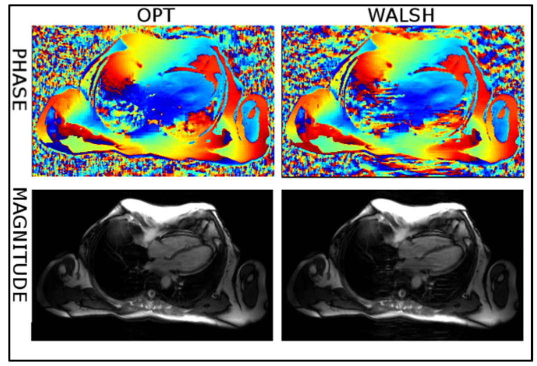

Fig 1 *Phase and magnitude for 6-fold accelerated dynamic MRI reconstruction with opt coil sensitivities (1st column) and adaptive combine (2nd column)*

RESULTS: Figure 2 depicts the estimated and true coil sensitivities in phase and magnitude. For our proposed variational approach (OPT) these are in good accordance with the true profiles and exhibit smoothness across the whole FOV. Iterative updating ensures that the phase information in the next coil estimate is consistent with already explored regions. Sensitivities gained from the adaptive combine approach (WALSH) suffer reliability in phase and magnitude, which is also apparent in the magnitude/phase reconstructions from undersampled data displayed in **Figure 1**. Finally, quantitative evaluation by means of RMSE emphasises the gain in quality in sensitivity estimation with substantial enhancement of reconstruction quality from 6-fold undersampled data (**Figure 3**).

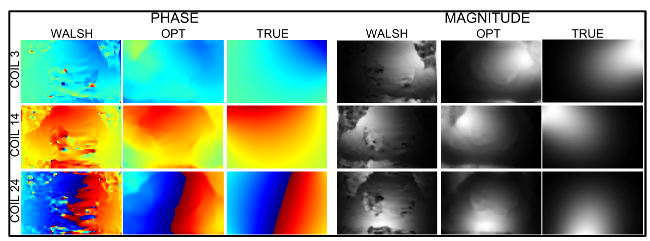

Fig 2 *Phase and magnitude for coil-sensitivities estimated from 6-fold undersampled cardiac data against true synthetic sensitivities*

DISCUSSION AND CONCLUSION:

The proposed method may serve for two purposes. First, for high quality determination of the complex coil sensitivities of a coil array from undersampled dynamic data, measured with the coil array. Thus superior reconstruction quality for the dynamic setting in magnitude and phase compared to conventional coil estimation methods can be achieved. Here, the time-averaged data needs to yield a complete k-space. Second, the proposed method allows in principle for the correct estimation of an in-vivo phase distribution from measurements of an array coil. Current procedures produce to some extent inconsistencies in the phase information, in particular at higher field strengths [6]. In both cases the proposed method poses a new approach opposing subspace methods as [2] or ESPIRIT [7]. First results in the context of dynamic MR image reconstruction suggest that a viable gain in reconstruction quality can be achieved. Future work will report on phased array combining with different noise-levels and auto-calibration for static MR image reconstruction.

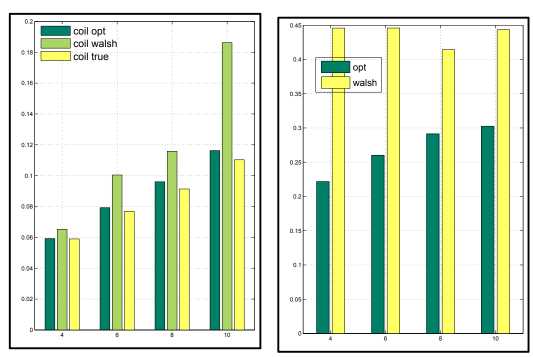

Fig 3 *Quantitative evaluation (RMSE) for reconstructions (left) and coil-sensitivities (right) for the described estimation methods for acceleration factors from 4 to 10*

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