High resolution T1 mapping within seconds: model-based reconstruction without regularization

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Target Audience: MR-Researchers with interest in model-based reconstruction, relaxometry, and parameter mapping techniques; Clinicians with interest in quantitative MR techniques

Purpose: Look-Locker type MR sequences [1] allow a fast determination of T1 values [2]. These techniques can further be accelerated by parallel imaging and radial encoding on the data acquisition side using high undersampling factors. Additionally, a model-based image reconstruction technique can compensate the lack of fully sampled data by exploiting the compressibility in the parameter domain [3-5]. We developed a model-based reconstruction algorithm for the reconstruction of high resolution T1 maps from a radially sampled single-shot Inversion Recovery FLASH experiment in the context of parallel imaging. In order to avoid falsification of quantitative values we did not utilize any kind of spatial regularization techniques such as total variation.

Methods: We used a radial FLASH sequence (resolution 0.75 x 0.75 x 6 mm^3, TR = 3.29 ms, 2500 projections, T_{ACQ} = 8.2 s) with pure RF spoiling in combination with a prior inversion pulse (global, adiabatic). All experiments were performed at a 3 T clinical scanner (MAGNETOM Prisma, Siemens Healthcare, Erlangen, Germany) using a 64 channel head coil. The radial sampling trajectory was optimized for the use with our spoiler-gradient free sequence and utilized a heuristically optimized angular displacement from one projection to the next of about 19,9°.

The reconstruction problem was formulated as a non-linear optimization problem

$$x^* = \arg\min \sum_{t,j} \left\| \left(W + P_t^k\right) F C_j M_t(x) - y_t \right\|_2^2 \qquad \text{(eq. 1)}$$

with y_t the measured raw data at time point t, $M_t(x) = a + be^{-ct}$ the underlying inversion recovery model with the unknown vector $x = (a, b, c)$ consisting of three unknown parameter maps, C_j the j-th coil sensitivity profile, F the Fourier transform, P_t^k the (time dependent) sampling trajectory, W an operator penalizing frequencies in the four corners of k-space outside the sampling disk, and x^* the solution to the minimization problem.

This non-linear problem was solved by the Gauss-Newton method following the scheme below:

1. Grid raw data and sampling pattern onto Cartesian grid
2. Fit coil profiles to the gridding solution of composite data from trailing 450 projections
3. Get c map estimate using a single atom matching pursuit algorithm on a generic overcomplete dictionary [6]
4. Get a map estimate by SENSE-like reconstruction of projections from last 2 seconds of the recovery process, using coil profiles from (2)
5. Get b map estimate from a and c under constant flip angle assumption
6. Solve problem by Gauss-Newton method, use estimates as initial value
7. Calculate T1 map from solution x^* ($T_1 = (a - b)/ac$)

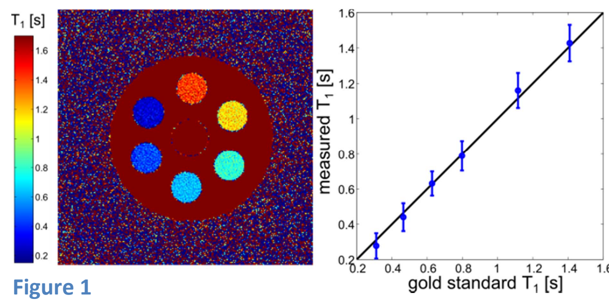

Figure 1

Results: Figure 1 shows the reconstructed T1 map from a phantom containing 6 compartments with different T1 values (Diagnostic Sonar LTD., Scotland, UK). For analysis we calculated the average and standard deviation per ROI and plotted this against the values obtained by a Cartesian Fast Spin Echo sequence with 16 different inversion times TI (gold standard). Figure 2 shows the brain T1 map (transversal) from a volunteer with no known illnesses using the very same parameter set as in the phantom study in both sequence and reconstruction part.

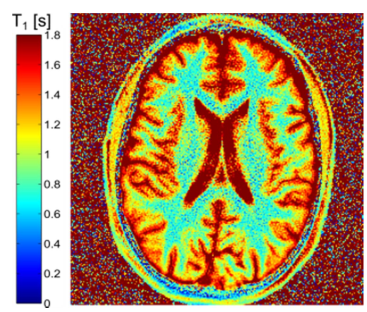

Figure 2

Discussion: The presented model-based reconstruction algorithm allows the calculation of T1 maps from highly undersampled data acquired within a few seconds. The mean values match with the gold standard. Common compressed sensing type problem formulations often use sparsifying domains such as Wavelet, Fourier or DCT. Here, the presented problem (eq. 1) is formulated in the parameter space which – by construction – is the sparsest possible domain along the time direction. In this domain, the problem is no longer ill-posed and no additional regularization terms are necessary.

Conclusion: The presented reconstruction algorithm provides a method to reconstruct high resolution T1 maps from radial undersampled data. The phantom study confirmed an excellent agreement of the mean values with the gold standard. Robustness of the proposed method is demonstrated by reconstructing *in vivo* maps without changing parameters. Future studies will focus on the reduction of noise in the maps.

References:

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