Validation of a Convex Relaxation Approach for Field Map Estimation

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Target Audience: This work targets researchers in Dixon-based water/fat separation in all anatomies.

Introduction: MRI techniques for separating fat and water signals have gained significant importance in recent years for their unique contribution to the clinical diagnosis of fat-related diseases. Dixon techniques [1] explore the chemical-shift property between fat and water to produce two separate images for water and fat, respectively. However, B0 magnetic field inhomogeneities represent the main obstacle preventing successful fat/water separation. An incorrect estimation of B0 inhomogeneities can severely impede the clinical diagnosis by swapping the fat and water components in their respective images – so called fat/water swaps. Therefore, estimating those inhomogeneities – so called field map estimation – has become the key for a successful fat/water separation. A commonly used technique is the region-growing method [2]. It is based on the well-known IDEAL method [3], which is currently used in clinical practice. Recently, we proposed a labeling approach [4-5] for field map estimation that outperforms the IDEAL-based region-growing method in cases where abrupt changes of magnetic field exist. In this work, we validate this technique based on the online available data from the ISMRM challenge [6] in which many clinical cases acquired at both 1.5 and 3.0 Tesla, containing severe inhomogeneities from a variety of anatomies, are presented.

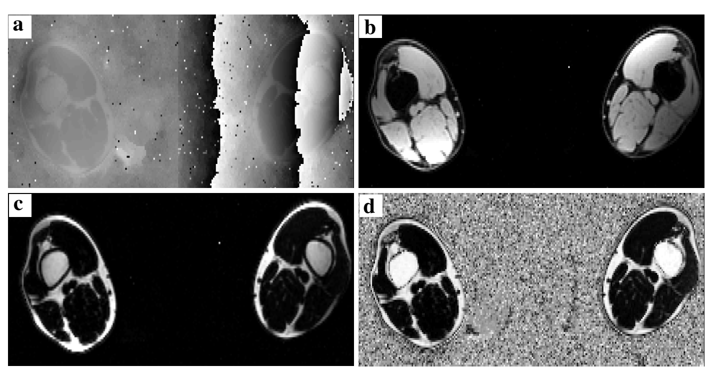
Materials and Methods: Our approach consists of two stages. A convex relaxation method [7-8] is used in the first stage. Its output is a coarse estimation of field map, in which the acquired image is 'labeled' into several regions, where each is assigned an approximate frequency offset – the so called labeling stage. The second stage employs the output of the first stage into the IDEAL iterative process to simultaneously estimate the field map, fat and water components.

Nine datasets at 1.5 and 3.0 Tesla with equally-spaced TEs, representing different anatomies, are provided by the ISMRM challenge [6]. All data were processed with multi-peak fat spectrum and T_2^* decay was integrated in the signal equation. The predefined background masks were not used in the reconstruction; however, it is used online for scoring the results. The scores were calculated online as follows: $Score = \frac{\sum(|FF - FF_{ref}| < 0.1)\,.mask}{\sum mask}$, where FF is the fat fraction map [fat/(water+fat)] produced by our method while FF_{ref} is the reference fat fraction obtained from data with additional TEs. Dataset #3 was omitted as it was acquired with non-equally-spaced TEs.

Results: The average scoring from the nine cases was 98.78 %. The average processing time was 78 sec per 2D slice. The whole two-stage approach was implemented on MATLAB. A reconstruction from case #5 is shown below, where high-rate of change of B0 inhomogeneities can be noticed; the scoring of this case is 99.27% from all slices.

Discussion: The main advantage of our approach is that it breaks down the field map estimation problem into two steps. The labeling step avoids fat/water swaps by using a convex relaxation approach that guarantees a global optimum solution for the proposed problem, while the second step converges to the exact values of frequency offsets, simultaneously producing the field map, fat and water components. In some cases, it was necessary to consider the T_2^* decay in the cost function to avoid fat/water swaps. Adjustment of parameters is recommended in some cases in order to get the optimal reconstruction, particularly in the datasets where high-order synthetic field maps are imposed (cases #8 and #9), where only moderate smoothness prior should be enforced. A possible solution of auto-tuning might be by detecting the rate of change of inhomogeneities throughout the field of view and correspondingly updating the necessary smoothness parameters. The presented approach can be easily accelerated 4-5x over modern GPU.

Conclusion: The convex relaxation –based labeling approach was validated in this work over a wide variety of anatomies from the online available data of ISMRM challenge, and was shown to be an efficient technique for accurate fat/water separation.



Slice#5 of dataset #5: (a) field map, (b) water, (c) fat, (d) fat fraction

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