

Susceptibility mapping: computation of the field map using water-fat separation at 7T

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Introduction. Quantitative susceptibility mapping (QSM) is gaining popularity for its ability to quantify biomarkers in human and animal imaging [1]. QSM solves the inverse problem from field inhomogeneity map to the susceptibility source map. Because the inverse problem is ill-posed, it is crucial to use high-quality field measurements. High-field (7T) MRI provides good SNR and sensitivity for animal imaging. However, the artifacts, such as chemical shift and background field inhomogeneity, have stronger presence, too. As there are fatty tissues present in the animal body, water-fat separation must be used to correctly estimate the field. In this abstract, we propose a method for water-fat separation that is suitable for strongly inhomogeneous fields occurring at 7T. Using our method, it is possible to obtain an accurate estimate of the field map that is suitable for QSM inversion.

Theory. The MR signal $S(t)$ that is generated by a voxel with (unknown) water and fat quantities of ρ_{water} and ρ_{fat} , respectively, is given by

$$s(t) = (\rho_{water} + \rho_{fat} e^{j2\pi\Delta f t}) e^{j2\pi f_B t}$$
, where f_B is the inhomogeneity map of interest, and Δf is the fat-water shift. Using the VARPRO formulation, it is possible to reduce the optimization to a one-dimensional global search [2]. In typical water-fat imaging applications, f_B is treated as an auxiliary variable; e.g., spatial smoothing is performed to obtain robust water and fat masks. On the contrary, with the goal of applying QSM, f_B must be exact. After having found the candidate minima for f_B in each voxel, we select the appropriate values by extending to 3D the spatial Markov-chain-based algorithm previously used for phase unwrapping [3]. Additionally, we use linear prediction to fill in the phase values in the areas where the presence of air, contrast or chemical shift artifact voids the signal.

Materials and methods. We prove the consistency of our algorithm by comparing the field, the water and the fat masks to those obtained by IDEAL in a clinical 3T

knee scan. We show the feasibility of QSM in a phantom made of agarous gel (media), ferumoxide nanopowder (contrast) and vegetable oil (fat) scanned at a 7T Bruker scanner. Finally, we show the field map and the QSM reconstruction of the tumor implanted in the mouse flank measured at 7T.

Results. All computations were performed using Matlab on a Intel Macintosh MacBook Pro. For the knee scan, we show the field, water and fat images from one coil out of 8. The field map obtained by our method is almost identical to the map from IDEAL; we are able to get correct water and fat images. The QSM map reconstructed from 8 coils is shown on the right. For the phantom, the algorithm correctly detects the water and the fat areas. After the removal of the background drift, a clear dipole pattern is seen. Consequently, we are able to map the susceptibility source.

In mouse models, the tumor is often implanted in the flank, where it is surrounded by subcutaneous fat. Our method allows the computation of the field map, taking the fat frequency offset into account.

Discussion and conclusion. High field MRI provides great opportunities in terms of sensitivity to biomarkers. However, water-fat separation becomes challenging due to unavoidable drift in the B_0 field along the bore. It turns out that the IDEAL method, while being the current standard for medical datasets, is sensitive to the initial values of the estimates and fails at 7T. In this abstract, we present a method that, by combining the ideas from the phase unwrapping techniques with water-fat separation, computes the exact field inhomogeneity in each voxel. We expect our method to be of high utility in animal body imaging, particularly for quantifying contrast-carrying biomarkers targeted to specific disease sites.

References.

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