

Dynamic Image and Fieldmap Joint Estimation Methods for MRI Using Single-Shot Trajectories

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In susceptibility-weighted MRI, ignoring the magnetic field inhomogeneity can lead to severe reconstruction artifacts. Correcting for the effects of magnetic field inhomogeneity requires accurate fieldmaps. Especially in functional MRI, dynamic updates are desirable, since the fieldmap may change in time. Also, susceptibility effects that induce field inhomogeneity often have non-zero through-plane gradients, which, if uncorrected, can cause signal loss in the reconstructed images. Most image reconstruction methods that compensate for field inhomogeneity, even using dynamic fieldmap updates, ignore through-plane fieldmap gradients. Another major consideration in MR image reconstruction is the trajectory selection, since the quality of the obtained results can greatly depend on the chosen trajectory. Therefore, optimizing the trajectory used for the problem at hand may greatly improve the reconstruction quality. Furthermore, the echo-planar (EPI) trajectories used for fast acquisitions are susceptible to misalignments due to scanner imperfections that lead to ghosting artifacts in the reconstructed images. Finally, standard optimization methods, like CG-based algorithms, may be slow to converge and recently proposed algorithms based on the Augmented Lagrangian (AL) framework have shown the potential to lead to more efficient optimization algorithms, especially in MRI reconstruction problems with non-quadratic regularization.

In this work, we propose a computationally efficient, model-based iterative method for joint reconstruction of dynamic images and fieldmaps in single coil and parallel MRI, using single-shot trajectories. We first exploit the fieldmap smoothness to perform joint estimation using less than two full data sets and then we exploit the sensitivity encoding from parallel imaging to reduce the acquisition length and perform joint reconstruction using just one full k-space dataset. Subsequently, we extend the proposed method to account for the through-plane gradients of the field inhomogeneity. To improve the efficiency of the reconstruction algorithm we use a linearization technique for fieldmap estimation, which allows the use of the conjugate gradient algorithm. The resulting method allows for efficient reconstruction by applying fast approximations that allow the use of the conjugate gradient algorithm along with FFTs. Our proposed method can be computationally efficient for quadratic regularizers, but the CG-based algorithm is not directly applicable to non-quadratic regularization. To improve the efficiency of our method for non-quadratic regularization we propose an algorithm based on the AL framework with variable splitting. This new algorithm can also be used for the non-linear optimization problem of fieldmap estimation without the need for the linearization approximation.

In this work, we also explore the use of modified trajectories (both EPI and spiral) that provide full coverage of k-space and also contain enough inherent time differences to permit accurate fieldmap estimation. The need for modified trajectories is justified by performing variance predictions, based on the Cramer-Rao bound analysis, on the joint estimation using standard and modified EPI trajectories. Furthermore, to suppress the ghosting artifacts of the EPI-based reconstructions we developed a model-based iterative ghost correction method. The proposed method jointly estimates the correction factors and the reconstructed image and can be incorporated in our joint image and fieldmap reconstruction, instead of applying ghost correction as a post-processing step.

Finally, we investigate the effect of through plane dephasing in parameter estimation. We derive the Cramer-Rao bound for estimator variance and by its minimization we try to find optimal echo-times for parameter estimation including image and fieldmap. The goal is to theoretically explain what trajectories would be optimal for parameter estimation and then verify the theoretical expectations with simulation results. We develop a simple theoretical method that optimizes the choice of echo-time given the model parameters that we wish to estimate. Even though echo-time is just one trajectory parameter, it is possibly the most important one since image contrast and reconstruction quality can be greatly affected by the choice of echo time. In our method we derive the Cramer-Rao bound for the estimated parameters and minimize this lower bound on variance with respect to the echo-time.