Parellel Magnetic Resonance Imaging Reconstruction

J. Petr, J. Kybic, V. Hlaváč

petrj5@cmp.felk.cvut.cz

Department of Cybernetics, Faculty of Electrical Engineering, Czech Technical University in Prague, Karlovo nám. 13, 121 35 Prague 2, Czech Republic

Parallel MRI (pMRI) is a way to use data obtained simultaneously from several receiver coils to increase the speed of MRI acquisition. The receiver coils have distinct spatial sensitivities. Therefore, the measured data contains more information about the position of the radio-frequency signal than data obtained by a single coil. The idea is to speed up the acquisition by sampling the imaged object more sparsely and compensate the arising data loss by the use of additional information obtained by a higher number of receiver coils. The key contribution of our work is design of a new reconstruction algorithm working in image domain. We emphasize on the speed of the reconstruction process and minimization of the reconstruction error.

An image acquired by a coil with varying spatial sensitivity can be interpreted as a point-wise multiplication of the coil sensitivity and the ideal image retrieved by a coil with homogeneous sensitivity. This is linear transformation from the ideal image to the coil-image. MRI images are acquired in Fourier domain or as it is referred to in MRI books – k-space (that is caused by the character of the MRI image acquisition process). In pMRI, acquisition is accelerated by acquiring only every M-th line in k-space along one image axis. This speeds up the acquisition M times. However, it also causes aliasing along one image axis in the retrieved images. This aliasing is also linear transformation from the ideal image to the image with aliasing. Therefore, the composite transformation of the two mentioned transformations is also linear. Invertibility of this composite transformation is assumed. This is generally the case of a reasonable coil configuration (the coil sensitivities should be distinct from each other and the number of coils must be equal to or higher than the acceleration factor) and it is an implicit assumption of all reconstruction methods. The task of pMRI is to find a proper inverse linear transformation that reconstructs the ideal image from a set of images with aliasing that were acquired simultaneously using a set of coils with distinct spatial sensitivities. For the process of estimation of the reconstruction transformation a set of reference images without aliasing has to be known.

Standard pMRI methods working in image domain estimate the sensitivities of all coils first and then are trying to find the inverse transformation in each point independently. In our method (PROBER), we estimate the reconstruction transformation directly using the reference images without aliasing. These images contain both the ideal image and the images with aliasing (by introducing aliasing artificially). We search for a reconstruction transformation that minimizes the difference between the ideal image and the reconstructed image (reconstruction transformation applied on the images with aliasing).

The sensitivities of the receiver coils are smooth and slowly changing in space. We assume that the same applies for the reconstruction transformation. Therefore, the reconstruction coefficients are not minimized directly. Instead, we approximate the reconstruction coefficients using B-splines and the coefficients in B-spline basis are estimated in order to minimize the reconstruction error. B-splines are piecewise polynomial functions with compact support. They are widely used for its desirable properties in approximation of smooth functions.

We define the total reconstruction error as the sum of square differences of the reconstructed image and the ideal reference image. The reconstruction error is a function of the B-spline coefficients. We compute partial derivatives with respect to each B-spline coefficient and set them to zero in order to find the coefficients that minimize the reconstruction error. This yields a system of linear equations with the same number of equations as the number of parameters. This system is solved using a standard Gauss-Newton elimination method. With the known B-spline coefficients it is an easy task to find the reconstruction transformation and apply the transformation on the input images with aliasing in order to reconstruct the ideal image.

Since the sensitivity maps are changing slowly in space, it is not necessary to have full-resolution images for the estimation. Instead, we acquire low-resolution images without aliasing together with the accelerated images. For this purpose a variable-density (VD) images are retrieved. Variable density image is an image with a fully sampled center of k-space (i.e. low-resolution images without aliasing that serve as reference images for the estimation) and sub-sampled outer part of k-space (full-resolution image with aliasing). VD-images are used for both estimation and reconstruction and are acquired in not much longer time than the standard sub-sampled images.

We have tested three pMRI methods (GRAPPA, mSENSE and PROBER) on a set of 20 phantom and in-vivo images. We measured the error as a difference between the reconstructed images and a perfect image that was averaged over ten measurements without aliasing. We have measure the error only over the part of the image where was any object present. The results proved that all three methods have comparable quality of reconstructed images. In several datasets, our method has the lowest reconstruction error. It demonstrates that our new method should take place among the other mentioned methods in everyday practice of parallel MRI reconstruction.

Most of the methods that work in image domain estimate the reconstruction transformation independently in each point. This makes the reconstruction time to increase significantly with high image size. We have proposed an algorithm that uses a smooth model instead of computing the reconstruction coefficient independently and pixel-wise. This regularizes the reconstruction transformation and makes the method more robust to noise in the reference data. Our method offers approximately the same reconstruction quality as GRAPPA and mSENSE for most coil configurations. There are coil configurations where our method offers higher reconstruction quality than both of the mentioned methods. This makes our method a good alternative for pMRI reconstruction.

References:

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