Reconstruction of multiband MRI data using Regularized Nonlinear Inversion

Sebastian Rosenzweig[1] and Martin Uecker[1,2]

[1] Department of Diagnostic and Interventional Radiology, University Medical Center Göttingen, Göttingen, Germany,
[2] German Centre for Cardiovascular Research (DZHK), University Medical Center Göttingen, Göttingen, Göttingen, Germany

Synopsis

Multiband MRI can be used to acquire several slices at the same time. Here, we propose a new method of multiband MRI based on Regularized Nonlinear Inversion (NLINV). This method does not require a priori knowledge about the coil sensitivities. Simultaneous estimation of images and coil sensitivities of two slices is demonstrated from six-fold undersampled data for a simulated multi-band acquisition.

Introduction and Purpose

Reducing image acquisition time is of utmost importance in in-vivo MRI. Lately, multiband MRI has attracted increased interest among researchers since it allows the simultaneous acquisition of several slices of an object. In multiband MRI, the spatial encoding information inherent in a multi-coil receiver system can be used to dis-entangle the information of multiple slices, while only the time of a single slice measurement is needed to acquire the data. In the common reconstruction approach a linear equation is solved by making use of previously estimated coil sensitivities. Here, we propose a new method of multiband MRI based on Regularized Nonlinear Inversion (NLINV).[1] This method does not require a priori knowledge about the coil sensitivities and is attractive especially for real-time imaging where coil sensitivities may change due to motion or interactive changes to the slice position.

Method

Phantom: All measurements are performed on a phantom of 6 bottles arranged in a triangle. To create two distinguishable transverse slices, the peripheral bottles are completely filled with water whereas the centered ones are only half-full, see Fig. (1).

Simulation of multiband MRI data: To mimic the simultaneous and undersampled acquisition of two slices (multiband MRI) we first measure the full k-spaces of each slice (B_0 = 3T, 2D FLASH, 20-channel head coil). We then add or subtract the k-spaces of the two slices (Hadamard encoding) and apply k-space masks P_A or P_B respectively to simulate undersampling for all channels. We obtain: $Y_A = P_A (k_0+k_1)$, $Y_B = P_B (k_0-k_1)$. A visualization of this process can be found in Fig. (1). Both k-space masks contain the center of k-space. In this work, only k-space Y_A contains samples outside the center where it is further undersampled by a factor of three. This corresponds to a total acceleration factor of six (ignoring center lines).

Reconstruction of multiband MRI data with Regularized Nonlinear Inversion: With the definitions $\mathbf{X}=(X_0,X_1)$ and $\mathbf{Y}=(Y_A,Y_B)$, we can set up the nonlinear equation $F(\mathbf{X})=\mathbf{Y}$, that need to be solved. Here $X_i=(r_i,\mathbf{c_i})$ with $r_i(x)$ the object function (spin density) of slice i and $\mathbf{c_i}(x)$ an N-dimensional vector containing the coil sensitivities of the N=20 coils for slice i. F is the non-linear encoding function. As in NLINV, the system is jointly solved for image and coil sensitivities using the Iteratively Regularized Gauss-Newton Method: Using an initial estimate $\mathbf{X_n}$ we obtain $\mathbf{X_{n+1}}=\mathbf{X_n}+d\mathbf{X}$ by solving the linearized equation $DF(\mathbf{X_n})d\mathbf{X}+F(\mathbf{X_n})=\mathbf{Y}$ with suitable regularization terms. The solution to this linear system is then computed using the method of Conjugate Gradients.

Results and Discussion

Fig. (2) shows the reconstructed object function of the lower slice (a) and upper slice (b) after n=7 Newton steps. Both slices can be reproduced without significant artifacts. As a reference, we perform a coil-wise inverse Fast Fourier Transform of the full k-spaces for each slice and use the Sum-of-Squares method to reconstruct the image from the multiple channels. The result is shown in Fig. (2c), which shows aliasing artifacts at the position of the peripheral bottles. In Fig. (3), we show the reconstructed complex coil sensitivities of the first three coils for (a) the lower and (b) the upper slice. As our phantom does not cover the entire field of view, we obtain black spaces where no information can be extracted.

Conclusion and Outlook

In this work, we extended the method of Regularized Nonlinear Inversion to multiband MRI. We successfully reconstructed two slices from six-fold undersampled simulated multiband data without prior knowledge of the coil sensitivities. One possible next step is the application of the proposed method for real-time MRI, which would allow the simultaneous acquisition of multiple slices without significantly longer acquisition times.

Acknowledgements

No acknowledgement found.

References

1. Uecker M, Hohage T, Block KT, Frahm J. Image reconstruction by regularized nonlinear inversion--joint estimation of coil sensitivities and image content. Magn Reson Med. 2008 Sep;60(3):674-82.

Figures

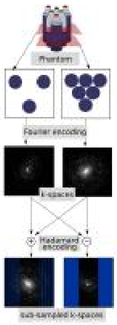

Fig. (1) Schematic of the simulation of multiband MRI data.

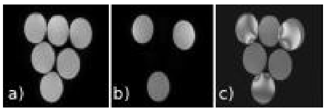

Fig. (2) Reconstructed images. **(a,b):** Reconstruction of simulated multiband data using NLINV. (a) lower slice, (b) upper slice. **(c):** Reconstruction of coil-wise added full k-spaces using the inverse Fast Fourier Transform and the method of Sum-of-Squares.

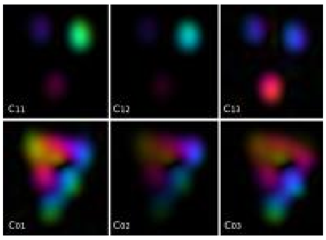

Fig. (3) Reconstructed complex coil sensitivities C_{ik} of simulated multiband data using NLINV. (i=0: lower slice, i=1: upper slice. k: coil)