Nonlinear Inverse Reconstruction for Real-time MRI of the Human Heart Using Undersampled Radial FLASH

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Introduction:

Nonlinear algorithms are able to improve the reconstruction quality in autocalibrated parallel imaging [1,2]. As shown in [1], the nonlinear inversion algorithm not only estimates image content and coil sensitivities at the same time, but also requires only very few data in the center of k-space. It is therefore ideally suited for dynamic imaging of moving objects with the use of undersampled radial trajectories. This work describes (i) the extension of the original algorithm to non-Cartesian trajectories, (ii) a simple but efficient implementation on a graphical processing unit (GPU), and (iii) its application to real-time MRI of the human heart with radial FLASH [3].

Theory:

In MRI, the image relates to the measured signal by a multiplication with the coil sensitivities, a Fourier transformation, and a projection to the k-space trajectory. Using the Iteratively Regularized Gauss Newton Method (IRGNM) with suitable regularization terms, the signal equation can be simultaneously solved for the image and coil sensitivities [1]. An extension to non-Cartesian trajectories can be accomplished by adding an interpolation step into the forward operator [4] and a convolution-based approach as proposed for iterative SENSE [5]. The latter requires a larger matrix size during reconstruction, but only involves scalar products, point-wise operations, and FFT applications during iteration. Because the initial interpolation to the Cartesian grid is not time-critical and can be executed on the CPU as a pre-processing step, the implementation of the convolution-based algorithm on a GPU emerges as a simple task.

Methods and Results:

Real-time movies of the human heart were obtained using RF-spoiled radial FLASH (TR/TE = 2.0/1.3 ms, flip angle 8º) at 3 T. Short-axis views ($2 \times 2 \times 8$ mm^3, 128×128 matrix) were acquired with 45 to 125 spokes (90 to 250 ms acquisition times). Before reconstruction, the data were whitened, compressed to 12 virtual channels using a principal components analysis, and interpolated to a 384×384 matrix. Offline computations were done on a computer with two GTX285 GPUs (Nvidia, California, USA). In addition to the standard algorithm, a faster version was developed for real-time MRI by reducing the number of virtual channels to 6 and the oversampling to 256×256. For further acceleration, the algorithm was initialized with the image and sensitivities of the previous frame and the number of Newton steps was set to one. These modifications allow reconstruction times as low as 90 ms per frame on a single GPU. Although the quality of the real-time version and its ability to adapt to sudden changes in the coil sensitivities is slightly reduced, both nonlinear versions are superior to gridding reconstructions, which present with streaking artifacts for a low number of spokes.

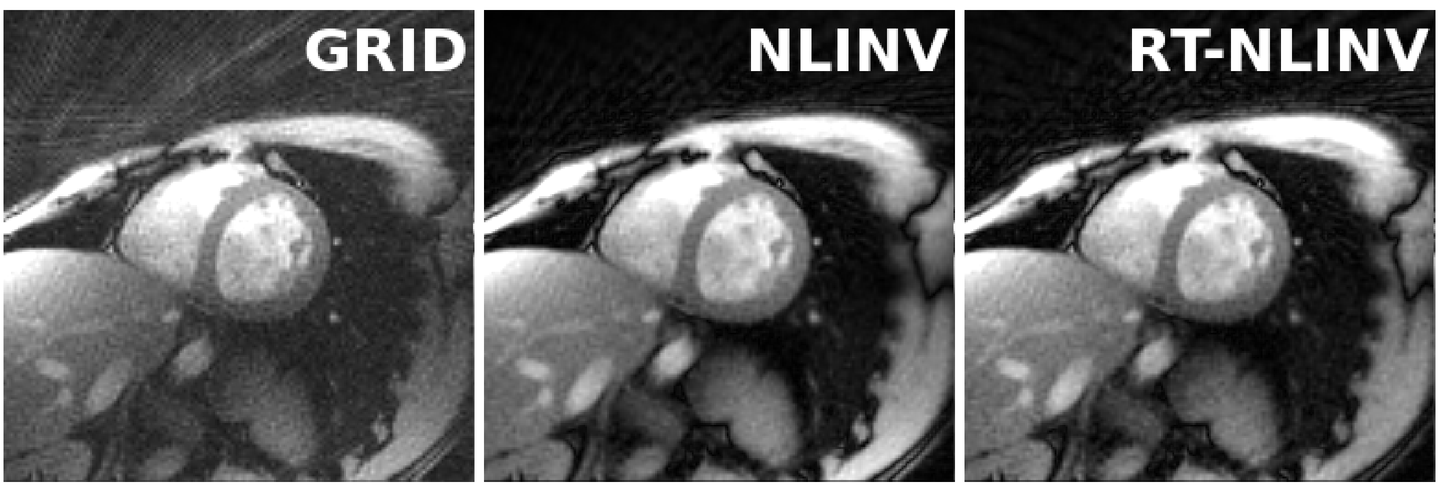

Figure: A single frame from a real-time MRI movie of the human heart acquired with 65 spokes (130 ms) and reconstructed using gridding (GRID), nonlinear inversion (NLINV), and nonlinear inversion modified to achieve real-time reconstruction speed (RT-NLINV).

Discussion and Conclusions:

Because of its ability to accurately estimate coil sensitivities and image content from a single acquisition with only a very small fully sampled area in central k-space, the nonlinear inverse reconstruction for autocalibrated parallel imaging [1] emerges as an ideal choice for real-time MRI with radial trajectories. The adaptation of the algorithm to non-Cartesian data by a convolution with the point spread function separates the interpolation from the iterative reconstruction, which allows for an acceleration of the remaining algorithm by a GPU with very little programming effort. The method was validated for real-time MRI of the human heart based on RF-spoiled radial FLASH. Real-time reconstruction speed could be achieved with only minor compromises in image quality.

References:

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