Parallel Reconstruction of Projection MRI

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Introduction: In Cartesian parallel imaging, sub-sampling of phase encoding lines induces aliasing in the phase encoding direction of the reconstructed image. Conveniently, this aliasing exists in only the phase encoding dimension, and provided adequate sensitivity information of receiver coils, the SENSE parallel imaging technique removes this aliasing through multiplication by an unfolding matrix[1]. For non-Cartesian acquisitions, such as projection acquisitions, there is no simple implementation of the SENSE algorithm because the aliased energy is dispersed throughout the image. Presented here is a non-iterative parallel imaging method for undersampled projection acquisitions.

Methods: This method seeks to express undersampled projection acquisition data in a domain where the sub-sampling is reflected as one-dimensional aliasing such that a similar unfolding to that used of SENSE reconstruction can be applied. Consider data matrix P consisting of undersampled projections in the Fourier domain as would be acquired in MRI, this transformation can be accomplished with the following steps:

1. Re-grid P from size $N \times n_p$, to P_r with size $N \times (n_p \cdot R)$, where N is the length of the projection, n_p is the number of projections, and R is the reconstruction acceleration factor.
2. Perform a 1-dimensional Fourier transformation along the projection dimension of P_r, where the result is X_r.

Owing to the linearity of the Fourier transform, a SENSE-like reconstruction is applicable for the transformed data, including derivation of the coil sensitivities in the transformed domain. Ignoring receiver noise correlation, the data can be un-aliased in the transform domain by multiplication by the Moore-Penrose pseudoinverse of the coil sensitivities:

$$y = \left(C^H C\right)^{-1} C^H x$$

where C is a $N_c \times R$ matrix of the coil sensitivity values from each coil (N_c is the number of coils) at the aliased locations in the transform domain and x is a vector of length N_c that contain aliased pixel values from all receiver channels.

When calculated across all pixels in the aliased transform domain data (X_r), the result (Y_r) is an unaliased image in the transform domain. Following inverse 1-dimensional Fourier transformation of Y_r along the projection dimension, the result is frequency domain data with the number of projections increased by factor R. The image can then be reconstructed using conventional techniques such as backprojection or gridding.

As a demonstration, True-FISP images were acquired on a Siemens Tim Trio scanner equipped with a 12-channel receive-only head coil sampled with 256 readout points across 256 projections. The number of projections was downsampled to 8 and 64 to create sum-of-squares images and to obtain coil sensitivity information for the proposed method.

Results and Discussion: Figure 1 shows the True-FISP images of 256 × 256 resolution obtained using gridding reconstruction. To improve the phase consistency of the acquired data, the magnitude of the data in sinogram space was used prior to application of the proposed method. The sum-of-squares reconstruction of 8 undersampled projections is shown on the left, the image reconstructed with the proposed method with 8 undersampled projections with R=8 for 64 net projections is shown in the middle, and the sum of squares image of 64 projections is shown on the right. The image reconstructed using the proposed method with 1/8th the amount of data (and imaging time) compares favorably in SNR with the sum-of-squares image of 64 projections. The undersampled projection image reconstructed with the method described herein represents a total data acceleration factor of 32 compared to conventional Cartesian sampling for a 256 × 256 image.

Figure 1.

Sum-of-squares reconstruction of 8 projection image

Parallel reconstruction of 8 projection image using the proposed method (64 net projections) (SNR=16.5)

Sum-of-squares reconstruction of 64 projection image (SNR=21.1)
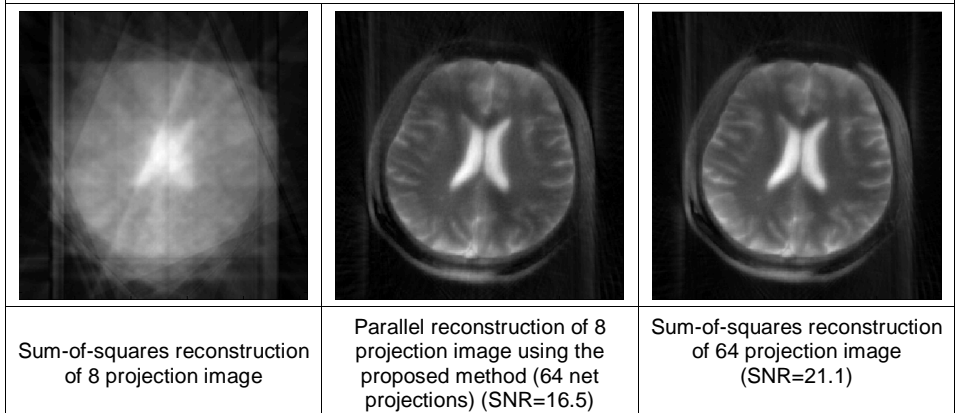
In contrast to Cartesian acquisitions of parallel imaging, the number of lines required to measure the coil sensitivity is equal to the number of final projections multiplied by the desired acceleration factor, which is advantageous in undersampled acquisitions. It is expected that this method will be best suited to dynamic imaging where the sensitivity information can be measured through interleaved acquisitions (e.g., ref. 2) or through a calibration scan prior to the dynamic run.

Conclusion: A new method for parallel reconstruction of projection acquisition data has been described. This method holds potential for the acceleration of dynamic MRI that combines the parallel imaging with undersampled projection acquisitions.

References: 1. Pruessmann et al., MRM, 1999;42:952-962. 2. Kellman et al., MRM, 2001;45:846-852.