The 2D-GRAPPA-Operator for 3D MRI

M. Blaimer[1], F. Breuer[1], M. Mueller[1], R. M. Heidemann[1], M. A. Griswold[1], P. M. Jakob[1]
[1]Department of Experimental Physics 5, University of Würzburg, Würzburg, Germany

Introduction: In 3D MRI, a greater scan time reduction and improved reconstruction quality of parallel imaging methods can be achieved by undersampling the data set along two spatial dimensions [1]. In this work it is shown, that the k-space reconstruction process can be broken up into two separate reconstruction processes by using the GRAPPA-Operator formalism. In this way, the k-space reconstruction can be simplified and the number of required reference lines can be reduced.

Theory: It has been shown that the GRAPPA-reconstruction can be reformulated as a matrix operation [2], which allows one to shift signal in k-space. For a shift from an arbitrary position k in k-space to position $k+\Delta k$, an appropriate set of coil weights $\hat{G}$ has to be applied to the signal:

$$S(k+\Delta k) = \hat{G}\cdot S(k) \quad (1)$$

Other shifts to positions $k+m\Delta k$ can be realized by applying the matrix $\hat{G}$, which is referred to as the GRAPPA-Operator, m times:

$$S(k+m\Delta k) = \hat{G}^m\cdot S(k) \quad (2)$$

In standard 2D imaging, this shift is performed along one particular direction, (phase-encoding (PE) direction). However, in 3D imaging it is beneficial to subsample the k-space along both PE and 3D direction [1]. Using the GRAPPA-Operator formalism, the reconstruction can be broken up into two separate processes. In a first step $\hat{G}_y$ is applied m times to the signal to perform a reconstruction in k_y-direction and in the second step $\hat{G}_z$ is applied n times to reconstruct the missing data along the k_z direction (see Figure 1).

$$S(k_y+m\Delta k_y,k_z+n\Delta k_z) = \hat{G}_z^{\,n}\cdot\hat{G}_y^{\,m}\cdot S(k_y,k_z) \quad (3)$$

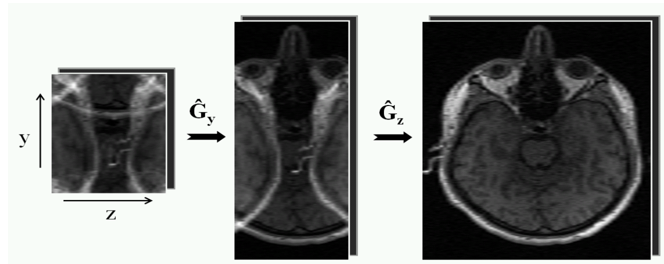

Figure 1: Using the 2D-GRAPPA-Operator, the reconstruction of 2D undersampled data (left side) can be split into two separate processes.

Methods: Several *in-vivo* experiments were performed on 1.5T and 3T whole body scanners (Siemens, Erlangen, Germany) using 8-channel head coils (MRI Devices, Waukesha, WI). 3D gradient echo sequences were used for head imaging. The experiments were accelerated in both the PE direction by a factor of R_{PE} and the 3D direction by a factor of R_{3D} resulting in total acceleration factors of $R = R_{PE} \times R_{3D}$. Fully sampled low-resolution reference data (matrix 24 x 64 x 24) was used to calculate the GRAPPA-Operators for shifts in PE and 3D-direction. The missing data were reconstructed using equation (3).

Results: In Figure 2, images from an $R = 6$ accelerated 3D gradient experiment are shown. The reconstructions show good quality and demonstrate the successful implementation of the 2D-GRAPPA-Operator. Figure 3 shows images of an $R = 4$ accelerated experiment, reconstructed with a reduced amount of reference data. In this example, 5x(24+24) reference lines were used to calculate the reconstruction parameters. This is less than half of the 24x24 lines that would typically be required for a conventional 2D-GRAPPA- reconstruction.

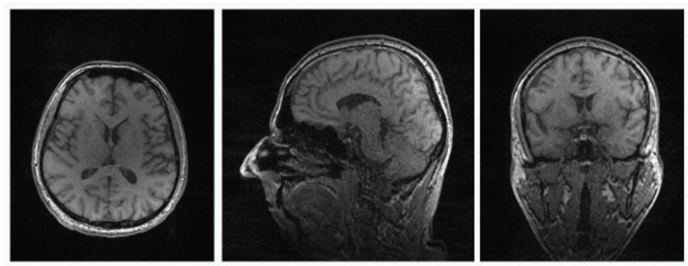

Figure 2: Transverse (left), sagittal (middle) and coronal (right) view of an $R = 6$ accelerated 3D experiment with an isotropic resolution of 1.1 mm using the 3T system (FOV 280 x 280 x 230 mm³, matrix 256 x 256 x 208, TE / TR = 5.3 / 20 ms, flip angle 25°).

Discussion: In this work, it has been shown that the 2D-GRAPPA-Operator can be used to simplify the k-space reconstruction process of data sets undersampled along two dimensions. With this method, no modifications of the reconstruction algorithms are necessary; algorithms for 1D reconstruction can simply be applied twice. Additionally, a significant reduction in the required number of reference lines can be achieved. In general, N reference lines are used to accurately calculate the coil weights for a 1D GRAPPA reconstruction. For a 2D-GRAPPA reconstruction, a block of N^2 reference lines would be required to obtain accurate results. However, by splitting the reconstruction into two parts, one can reduce the amount of required reference data to the order of $N+N$ k-space lines, resulting in essential time savings.

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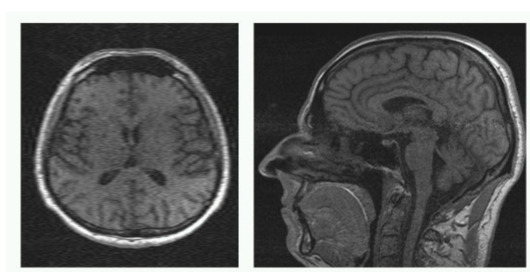

Figure 3: Results from an $R = 4$ accelerated 3D experiment using the 1.5 T system (FOV 240 x 240 x 192 mm³, matrix 256 x 256 x 64, TE / TR = 4.8 / 20 ms, flip angle 25°). In total, 5x(24+24) = 240 reference lines were used to calculate the reconstruction parameters.

References:
[1] Weiger M et al. MAGMA. 2002;14:10.
[2] Griswold MA et al. Proc ISMRM 2003 (Toronto), #2348.