GRAPPA-UNFOLD: Application to the Temperature Measurement

J-Y. Guo[1,2], E. G. Kholmovski[2], D. L. Parker[1,2], L. Zhang[2,3], R. B. Roemer[2,4]

[1]physics, University of Utah, Salt lake city, UTAH, United States, [2]UCAIR, Radiology, University of Utah, Salt lake city, UTAH, United States, [3]Electrical Engineering, University of Utah, Salt lake city, UTAH, United States, [4]Mechnical Engineering, University of Utah, Salt lake city, UTAH, United States

Introduction

Magnetic Resonance Imaging Thermometry (MRIT) has been successfully used to measure temperature changes during thermal therapies in vivo. To improve the accuracy of temperature measurements and guarantee reliable feedback (control), high resolution multi-slice or 3D datasets must be acquired with the highest possible temporal resolution. Improved temporal resolution in dynamic MRI applications such as thermometry or perfusion studies can be achieved by utilizing parallel imaging techniques like GRAPPA [1] or locally dynamic techniques such as UNFOLD [2]. Recently, the combination of SENSE with UNFOLD [3] had been developed to achieve improved image quality in cardiac imaging with high speedup factors. In this study, we have proposed a combined GRAPPA-UNFOLD method and have studied its applicability to MRIT.

Methods

The data sampling strategy implemented for GRAPPA-UNFOLD with reduction factor of four is illustrated in Fig. 1. Image reconstruction by GRAPPA-UNFOLD method can be described by:

$$I(x,y,z,t) = U\{G\{K(k_x,k_y,k_z,t)\}\}$$

where $K(k_x,k_y,k_z,t)$ is the k-space dataset consisting of the k-space data acquired by all coil elements, *G{}* is a GRAPPA operator, and *U{}* is a UNFOLD operator. First, the k-space data of each time frame is proceed by GRAPPA. In contrast with the conventional GRAPPA processing, where all missing k-space lines are reconstructed, only a fraction of the missing k-space lines are recovered during the GRAPPA step of GRAPPA-UNFOLD. Assuming that imaging FOV is only a half of the prescribed FOV, the resulting dataset has the structure typical for UNFOLD acquisition with an acceleration factor of two: only even k-space lines are acquired for the odd time frames and vice versa. The final images are reconstructed from the dataset by UNFOLD.

To test the utility of the GRAPPA-UNFOLD technique for MRIT with high speedup factors, imaging experiments were performed on a 3 Tesla MR scanner (Trio, Siemens Medical Solutions, Erlangen, Germany) equipped with an 8-channel head coil. The temperature of the phantom filled by hot water was monitored for about 10 minutes using a 2D GRE pulse sequence (TR/TE=100/10 ms, FOV=100×100 mm, imaging matrix=128×128, and 36 time frames).

When the GRAPPA-UNFOLD method is used in the imaging studies where real-time control is not essential (e.g. cardiac imaging), the UNFOLD step of the method can be delayed until a substantial number of time frames are acquired. In such cases, UNFOLD with the conventional low-pass filter (Fig. 2a) can be successfully used to remove high temporal-frequency components and to reconstruct the images without any obvious aliasing artifacts. However, when real-time control is required (e.g. MRIT during thermal therapy), the UNFOLD step of the method should be applied as soon as each new frame is sampled and the number of time frames included in the processing should be limited to speedup the reconstruction. If UNFOLD with a conventional low-pass filter is used in such a situation the resulting images for the first several and the last several time frames would be artifactual due to Gibbs artifact and the periodicity of the discrete Fourier transform. The resulting images could not be used to quantify the temperature changes. However, temperature measurement from the last time point is crucial for real-time temperature monitoring. To resolve the problem, the optimal low-pass filter in Fig. 2b should be used and the series of time frames to be proceed by UNFOLD should be expanded appropriately.

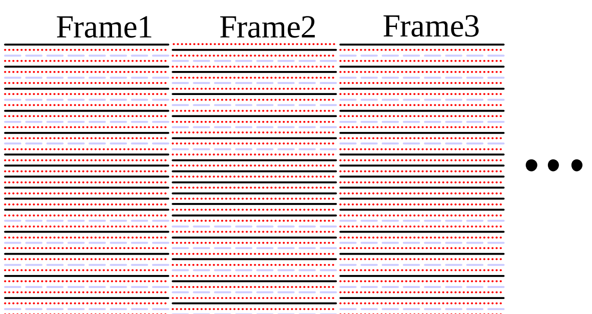

Figure 1. The sampling pattern for GRAPPA-UNFOLD with the reduction factor of 4. The solid lines correspond to the acquired k-space data. The dashed lines represent the missing k-space lines to be recovered by GRAPPA. The dotted lines correspond to the missing k-space lines for the UNFOLD acquisition with acceleration factor of 2.

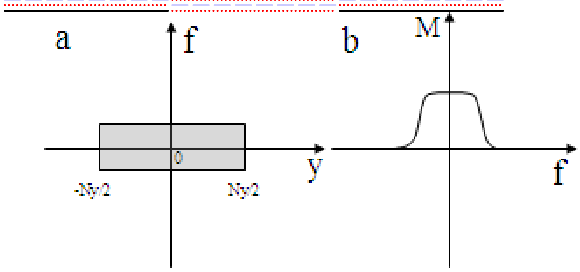

Figure 2. Low-pass filter for the UNFOLD method. **a.** The conventional low-pass filter. **b.** The modified low-pass filter. y is the phase encoding direction. f is the frequency direction. M is the magnitude of filter.

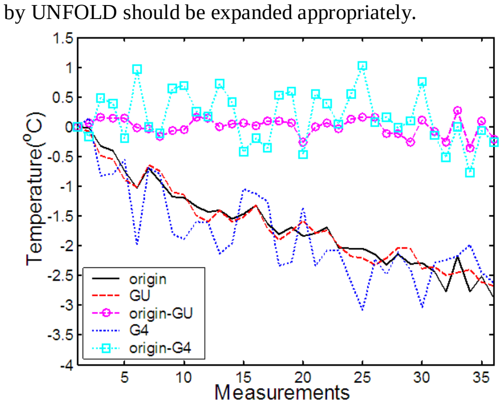

Figure 3. The temperature measurements derived from the complete dataset (solid black line), from the undersampled dataset (reduction factor of 4) processed by the GRAPPA-UNFOLD (dashed red line) and by the GRAPPA (dotted blue line). The differences between the complete dataset results and the GRAPPA-UNFOLD and the GRAPPA results is shown by dashed magenta line with circle and dotted cyan line with square, respectively.

Results

The results of the temperature measurements reconstructed from the complete and undersampled datasets are shown in Fig. 3. The measurements from the complete dataset and the measurements reconstructed by the GRAPPA-UNFOLD method from the undersampled dataset are very similar. The results of the GRAPPA reconstruction from the same undersampled dataset deviate significantly from the true measurements.

Conclusion

For the same speedup factors, the GRAPPA-UNFOLD method yields more accurate phase difference and temperature images than the conventional GRAPPA method alone. These experiments indicate that temperature monitoring using the GRAPPA-UNFOLD method with an acceleration factor of four is feasible.

Reference

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3. Madore, B., Magn Reson Med 2004;52:310-320.