Accelerated Model-based Proton Resonance Frequency Shift Temperature Mapping Using Echo-Based GRAPPA Reconstruction

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Target audience: Radiologists and MR scientists working on MR thermometry and fast imaging algorithms.

Purpose: Model-based Proton Resonance Frequency (PRF) shift [1] is a new temperature mapping method which uses multi-echo water-fat signal model to calculate the frequency difference of water and fat. This method is insensitive to inter-frame motion and most of the temperature artifacts, such as susceptibility, field inhomogeneity and field drift. However, it still suffers from intra-frame motion and requires long signal acquisition time. In this research, an accelerated acquisition and reconstruction framework is developed for MR temperature measurements based on the model-based PRF method. This approach provides higher temporal resolution and preserves good temperature accuracy. It is also less sensitive to intra-frame motion because of the shortening of acquisition time.

Methods: Images of 16 different echo times (TEs) were acquired in one RF excitation using a multi-echo gradient-recalled echo (GRE) sequence. Based on the sharable k-space pattern between images of different TEs in the same frame, we used an algorithm called Echo-based GRAPPA to reconstruct the full k-space. The interpolation pattern and kernel are shown in Fig.1. The k-space of 3 different TEs were combined together to perform GRAPPA reconstruction [2, 3]. Fully-sampled raw k-space data was artificially under-sampled using a reduction factor of 6 and 32 auto-calibration signal (ACS) lines in the central k-space. Ex-vivo goose liver experiment with a cooling down process was performed to verify the feasibility of the proposed method. The imaging parameters were: TR 69ms, first TE 2.1ms, △TE 1.8ms, flip angle 40°, BW 1446.1Hz, acquisition matrix size 100 × 100, FOV 180mm × 180mm, slice thickness 6mm. K-t space FOCal Underdetermined System Solver (k-t FOCUSS) [4] was implemented for comparison using the same number of ACS lines and the same reduction factor.

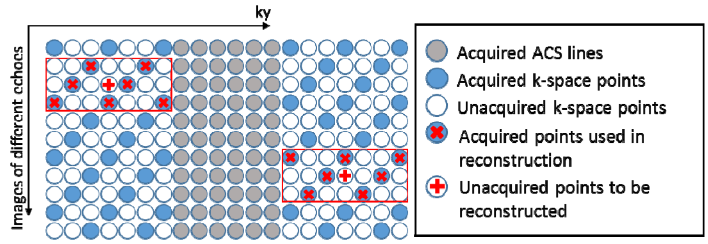

Fig.1 *The interpolation pattern and kernel of the proposed method. (a): The sampling pattern, interpolation pattern and kernel along ky and echo direction. The kernel size is 7 (kx)×7 (ky)×3 (echo). (b): The sampling pattern and interpolation pattern along ky and coil direction.*

Results: Fig. 2 (a-c) show the absolute temperature maps of goose liver using fully-sampled data, Echo-based GRAPPA reconstructed data and k-t FOCUSS reconstructed data at a net reduction factor of 2.3. The temperature error maps of the proposed method and the k-t FOCUSS reconstructed results are shown in Fig. 2 (e-f), respectively. The temperature RMSE of our proposed method is 1.19°C, while the temperature RMSE of k-t FOCUSS is 2.01°C. The temperature evolution curves using different methods for the ex-vivo goose liver experiment are shown in Fig. 3. Three curves in Fig. 5(a) show a cooling down process from 50°C to 47°C of the fully-sampled temperature evolution (red dashed line), the accelerated temperature evolution using Echo-based GRAPPA (blue solid line) and the accelerated temperature evolution using k-t FOCUSS (green solid line), respectively. The temperature for each temporal frame was calculated from averaging a 15 × 20 region in the central part of the goose liver. Fig. 3 (b) shows the comparison of mean absolute temperature error in an 11 × 8 ROI between our proposed method and k-t FOCUSS. The maximum mean absolute error is 1.38°C for our method and 2.79°C for the k-t FOCUSS method.

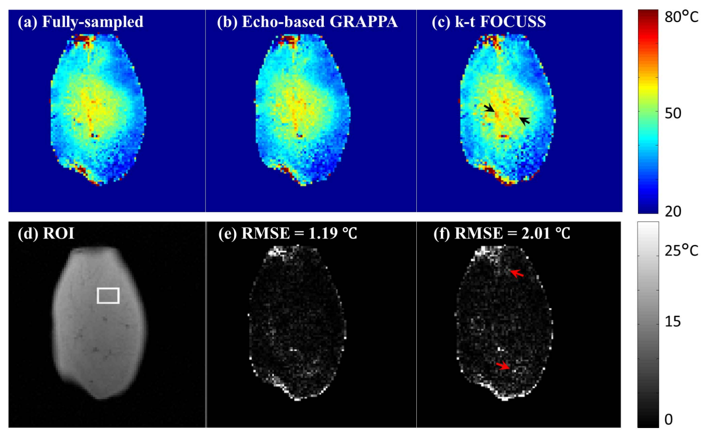

Fig.2 *Absolute temperature map for the temperature measurement using fully-sampled data (a), reconstructed data using Echo-based GRAPPA (b) and k-t FOCUSS (c) at a net reduction factor of 2.3. The ROI of evaluating temperature measurement is shown in the white box (d). Temperature error maps of Echo-based GRAPPA and k-t FOCUSS are shown in (e) and (f), respectively.*

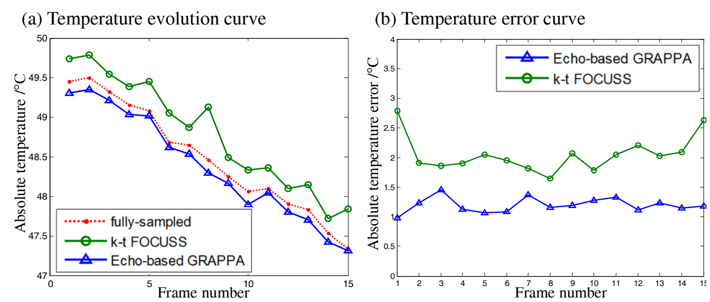

Fig.3 *Temperature evolution curve (a) and temperature error curve (b) for the temperature measurement using Echo-based GRAPPA and k-t FOCUSS at a net reduction factor of 2.3. Fully-sampled temperature measurement is plotted for comparison. During a 15-frame measurement, the temperature dropped about 3°C.*

Discussion: In Fig.2, the proposed method shows fewer temperature artifacts than k-t FOCUSS, pointed by the black and red arrows. K-t FOCUSS shows larger temperature RMSE and temperature uncertainty than the proposed method at the same reduction factor. In this experiment, the temporal resolution is improved from about 10 seconds/frame to 4 seconds/frame using the proposed method. In the future, this method can be further implemented as an efficient acquisition and reconstruction framework for real-time temperature measurement, particularly used for tissue composed of both fat and water.

Conclusion: In this research, we proposed an acceleration method for model-based PRF temperature mapping using Echo-based GRAPPA. This method can accelerate the MR temperature monitoring at a net reduction factor of 2.3. The temperature uncertainty and temperature RMSE are less than 1.4°C based on the ex-vivo goose liver experiment. This technique is also insensitive to inter-frame motion compared with other MR temperature measurement methods. When combined with other traditional methods, the combined method can measure the temperature of tissue with multiple compositions.

References: [1] Li et al. *Magn Reson Med*, 2009; 62: 1251-60. [2] Griswold et al. *Magn Reson Med*, 2002; 47: 1202-10. [3] Huang et al. *Magn Reson Med*, 2005; 54: 1172-84. [4] Jung et al. *Magn Reson Med*, 2009; 61: 103-16.