Highly accelerated Temperature mapping using nonlocal regularized parallel imaging

S. Fang[1], X. Pan[1], and K. Ying[1]

[1]Department of Engineering Physics, Tsinghua University, Beijing, China, People's Republic of

Introduction: Model-based MR thermometry method based on the proton resonance frequency shift (PRFS) has been proposed to improve the temperature estimate accuracy of conventional phase different method (1). In this method, the temperature independent proton like lipid is employed as the internal reference, and signals at different TEs acquired by multi-echo GRE sequence are fit to a signal model which contains the temperature information. Since more than 8 echoes are usually required to obtain accurate signal fitting and the TR can not be small, the temporal resolution need be improved for real-time temperature monitoring. Parallel imaging (PI) is a successful technique for accelerating the MR data acquisition. But its reconstruction suffers from noise amplification at high reduction factor due to its ill-posedness. Regularization addresses this problem by constraining the reconstruction using prior information, which may introduce bias into the reconstruction (3,4). For temperature mapping, the choice of the prior is more critical since the resultant bias may propagate and accumulate in the afterwards quantification. To increase the temporal resolution of temperature mapping and minimize this bias, we applied highly accelerated PI to temperature mapping and used nonlocal regularization (5) that extracts the prior from the acquired data themselves to stabilize the reconstruction. The method was demonstrated using whipping cream phantom.

Theory: The dilemma of applying regularized PI to MR thermometry lies in that the prior information can be biased from the acquired data. To minimize the bias, it is potentially preferred to exploit the information included in data themselves instead of additional information as a prior for stabilizing the reconstruction. The nonlocal regularization is a natural choice for this purpose since it extracts the prior information directly from the acquired data and no additional information or assumption is needed. It first quantifies the relationship between pixels at different positions by comparing their surrounding patches based on the following equation:

$$w(x,y) = \exp(-\|p(x) - p(y)\|_2^2 / \sigma^2) / W_x,\ W_x = \sum_{y \sim x} w(x,y)$$

where $p(x)$ and $p(y)$ are patches centered at pixel x and y, and σ^2 is the thresholding parameter. Then $w(x,y)$ is used to constrain the pixel intensity differences between x and y using the following cost function:

$$\bar{\mathbf{u}}^{\lambda} = \arg\min_{\bar{\mathbf{u}}} \{ \|\mathbf{A}\bar{\mathbf{u}} - \bar{\mathbf{f}}\|_2 + \boldsymbol{\lambda} \sum_x \sum_{y \sim x} |w(x,y)(\bar{\mathbf{u}}(x) - \bar{\mathbf{u}}(y))|^2 \}$$

where $\mathbf{A}$ is the encoding matrix of parallel imaging, $\bar{\mathbf{u}}$ is the desired image, $\bar{\mathbf{f}}$ is the under-sampled k-space data, and λ is the regularization parameter.

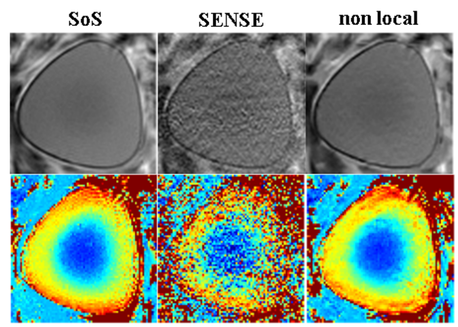

Fig.1: Phantom results of 4-coil for an outer reduction factor of 4 (net reduction factor of 2.7). Top row: the reconstructed image of the first echo for the first frame. Bottom row: the corresponding temperature maps.

Method: The self-calibrated SENSE scheme (2) was employed and the phase information was preserved by multiplying the estimated sensitivity map to the reconstructed image. Finally the temperature maps from each coil are averages to obtain the result map. As for the nonlocal regularization, the same regularization parameter was used for all the images to maintain the data consistent.

Experiments: The phantom experiment was conducted on a 3T MR scanner (Trio, Siemens, Erlangen, Germany) using a four-element receive-only head coil. Whipping cream with original fat content 36% was first boiled with agar and then cooled down to form the solid phantom. The cooled phantom was placed in a container filled of hot water, and then the temperature changing evolution in the whipping cream was measured by a 12-echo bipolar GRE sequence with the first echo time TE_0=3ms and echo spacing ΔTE=3.48ms. Other imaging parameters are: TR=60ms, BW=±38.4kHz, flip angle=25°, FOV=30cm×30cm, slice thickness=5mm, image matrix=192×192 and imaging time=11.5s. A variable density k-space acquisition with 32 fully sampled central lines and an out reduction factor of 4 were simulated to demonstrate the feasibility of the proposed method.

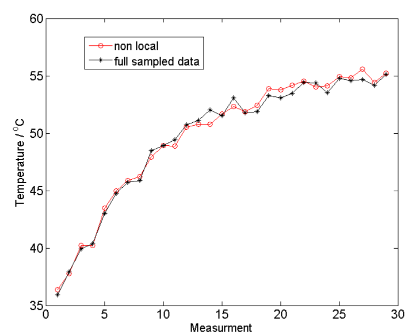

Fig.2: The temperature evolution curves of the fully sampled data and the images reconstructed by the nonlocal regularization. The temperature was averaged in a 5×5-pixel region in the center of phantom.

Results: Figure 1 compares the phantom image and the temperature map reconstructed by the sum-of-square method, un-regularized SENSE, and non-local regularization. The amplified noise in the SENSE reconstructed image severely distorts the temperature distribution in the phantom. In contrast, the nonlocal regularized image effectively suppresses such noise and recovers the spatial temperature distribution to a large degree. Fig.2 shows the temperature evolution curves averaged in a 5×5-pixel region in the center of phantom calculated from full sampled data and the nonlocal regularization, which indicates a very good agreement.

Discussion and Conclusions: Results from the whipping cream phantom indicates that the nonlocal regularized parallel imaging can be exploited to effectively increase the temporal resolution of PRFS. Due to the data-driven property of the nonlocal regularization, the bias introduced by it was quite limited in both spatial domain and time domain, while the noise is effectively suppressed.

References: 1. Pan X. et al., Proc. ISMRM, 2008 (1235). 2. McKenzie C A, et al.,MRM 47:529-538 (2002). 3. Lin FH et al, MRM, 51:559-567(2004). 4. Rudin LI et al., Physica D 60:259-268(1992). 5. Fang S et al, Proc. ISMRM2009 (2724).