Accelerated Phase Reconstruction Using Sharable Information from Reference Scan and Its Application for Real-time MR Thermometry

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Target audience: MR researchers on MR thermometry and phase reconstruction.

Purpose: MR thermometry based on proton resonance frequency shift (PRFS) is used for noninvasive temperature monitoring with a high requirement of precise phase differential information [1]. In this method, phase distribution of the reference scan is usually subtracted from subsequent scans to calculate the phase change and get the corresponding temperature map. However, the diverse information of the reference scan is usually overlooked. Thus, based on the demonstration that the correlation between different scans could be used for a more robust reconstruction from under-sampled data [2], a method to accelerate temperature reconstruction using sharable information from previous reference scans is proposed in our research.

Method: A new framework is proposed to exploit the structure and sensitivity information of reference scan and use such sharable information to strengthen the precision of parallel imaging and compressed sensing for phase reconstruction (see Fig.1). The first frame, usually defined as the reference scan, is analyzed in order to extract accurate structure and coil sensitivity information [3]. The acquisition trajectory is also optimized based on the reference scan before the acquisition of normal scans. During the reconstruction of normal scans, parallel imaging and compressed sensing are combined to better reconstruct the phase differential information. Using a similar idea in L1SPIRiT [4], the reconstruction algorithm specially optimized for phase reconstruction is $\arg\min_x = \|Dx-k\|_2^2 + \lambda\|(G-I)x\|_2^2 + \mu\|W_n\Psi(F^{-1}x)\|_1 + \sigma\|W_I\nabla(F^{-1}x)\|_1$, where $\boldsymbol{x}$ is the reconstructed *k*-space of all channels, $\boldsymbol{k}$ contains the partially acquired data and the reconstructed data using parallel imaging from all channels, $\boldsymbol{D}$ is the data fidelity term, $\boldsymbol{G}$ is a general GRAPPA operator for SPIRiT term, Ψ is the wavelet transform, $\boldsymbol{W}_\mathbf{n}$ and $\boldsymbol{W}_\mathbf{I}$ are spatially adaptive weights in wavelet and image domains, which is calculated using the reference scan (see Fig.2c), and ∇ is the gradient operator for complex data containing phase information.

Results: Fully-sampled 2D Cartesian data were acquired during a heating and cooling experiment for phantom performed on a 3T Philips Achieva scanner. The composition of the phantom is: 100% water for the outer ring, 20% fat mixed with 80% water for the central area (see Fig.2b). Dynamic images were acquired using e-THRIVE sequence with the following parameters: 8 coils, 3 coronal slices, TR = 70ms, TE = 5ms, resolution = 1.6×1.6×4 mm^3 , FOV 256×256, flip angle 40° and 30 dynamic frames. The fully acquired data were retrospectively down-sampled with a reduction factor of 4 and 6 using an optimized acquisition trajectory. L1SPIRiT, GRAPPA and GROWL were implemented for comparison. Table 1 displays the RMSE and the corresponding temperature error of different methods at a reduction factor of 4 for the second frame. Fig.2 demonstrates the reconstruction results and corresponding error maps for L1SPIRiT and our method at a reduction factor of 4. Meanwhile, Fig.3 shows the temperature evolution curves for fully-sampled data and reconstruction results using our proposed method for two 5 × 5 areas in the center (mix of fat and water) and on the edge (100% water) of the phantom at a reduction factor of 6.

Discussion: Compared with other methods using parallel imaging and compressed sensing, our proposed method makes good use of the sharable information from the reference scan and achieves a better performance of phase reconstruction for MR thermometry as shown in Table 1. Our proposed method can lead to a temperature error of less than 0.3℃ at an echo time of 5ms. In addition, the acquisition trajectory is optimized in our method. Fig.2 shows that the alias artifacts are significantly reduced in the resultant image using our method in comparison with the L1SPIRiT. Meanwhile, the temperature evolution curves (see Fig.3) reveal a precise agreement of our proposed method with the fully-sampled data. Further study could be done to optimize and apply this framework to all the previous frames and exploit more useful information for better initialization.

Conclusions: Phantom experiments have demonstrated the accuracy and feasibility of our new framework by using sharable structure and sensitivity information from reference scan. The proposed method has the lowest RMSE and temperature error in comparison with previous parallel imaging methods and parallel–CS methods. In the future study, *ex-vivo* and *in-vivo* experiments will be conducted to demonstrate the values of the proposed method in monitoring thermal treatment by improving temporal resolution and providing more accurate temperature information.

References: [1] Ishihara Y, MRM 1995; [2] Huang F. ISMRM 2012; [3] Gong E, ISMRM 2012; [4] Lustig M, MRM 2010.

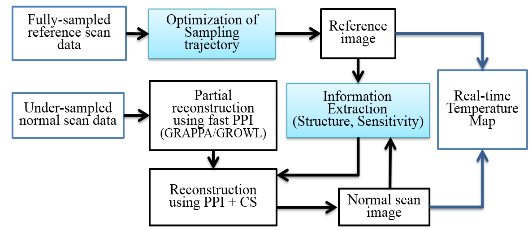

Fig.1 Framework of our proposed method. The reconstruction procedure is optimized for reference scan. Sharable information from reference scan is exploited in reconstruction. An optimized sampling trajectory is also used for new acquisition.

Table 1 Comparison of Different Reconstruction Methods at R=4

Method	RMSE	Temperature Error (TE=5ms)/℃
GRAPPA	0.0947	2.3601
GROWL	0.1005	2.5047
L1SPIRiT	0.0910	2.2679
Proposed method	0.0118	0.2941

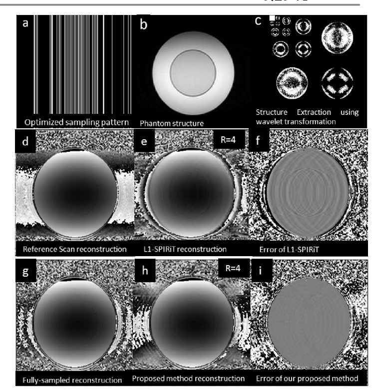

Fig.2 Comparison of our proposed method and L1-SPIRiT at R= 4 for the second frame. The sampling trajectory is optimized (a) and structure (c) and sensitivity information is extracted from the reference scan (b, d). Fully-sampled reconstruction of the second frame (g) is used for comparison. The reconstruction results for L1-SPIRiT (e) and our proposed method (h) are compared by 5-time brightened error maps (f) and (i) respectively.

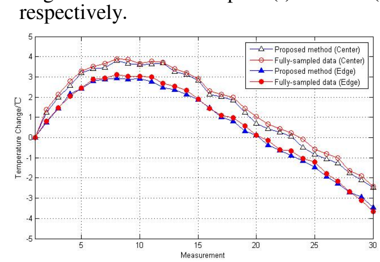

Fig.3 The temperature evolution curves of fully-sampled data (red lines) and reconstruction results using our proposed method (blue lines) for two 5 × 5 areas at a reduction factor of 6.