Spectrum-Based and Least-Square PRF Hybrid method for MR Temperature Mapping

Shuo Chen[1], Xinwei Shi[2], Feiyu Chen[2], Karen Ying[3], and Shi Wang[3]

[1]*Engineering Physics, Tsinghua University, Beijing, China,* [2]*Biomedical Engineering, Tsinghua, Beijing, China,* [3]*Engineering Physics, Tsinghua, Beijing, China*

Introduction: MR thermometry provides a promising technique to monitor temperature change noninvasively for different body parts in thermal therapy. Traditional proton resonance frequency shift (PRFS) method [1] can measure temperature in aqueous tissue. However, it suffers from confounding factors including presence of lipid protons, motion and B0 field drift. To solve these problems, a spectrum-based method using fat as internal reference has been proposed in our previous work [2], but it can only be used in tissues containing both water and fat. In the present work, a Spectrum-Based/Least-Square PRF hybrid method is proposed to measure temperature in both water-only and water-fat mixed tissues simultaneously and improve the accuracy of PRF at the same time.

Theory: Similar to the spectrum-based method, the hybrid method requires images acquired at several different echo times. The signal acquired at TE_n from a voxel can be modeled as $s(TE_n)=\sum_i \rho_i e^{j\Phi_i} e^{(-1/T_{2i}^*+jw_i)TE_n}$ (1), where ρ_i, Φ_i and T_{2i}^* are the magnitude, initial phase and T_2^* of water and fat. The resonance frequencies of water and fat are $w_1=\alpha\gamma B_0(\mathrm{T}-\mathrm{T}_{ref})+\psi$ (2), $w_2=\gamma B_0\Delta_{f\text{-}w}+\psi$ (3), where ψ represents local B0 field inhomogeneity, $\Delta_{f\text{-}w}$ is fat-water chemical shift, $\Delta\mathrm{T}$ denotes local temperature change. As described in *Fig 1*, a water-fat separation method named IDEAL [3] is performed on the data acquired before heating to distinguish water-only voxels from water-fat mixed ones. In water-fat mixed voxels, temperature change can be calculated using the spectrum-based model. In water region, the non-constant signal phase factor in *Eq.1* is $\Phi_w(TE_n)=\alpha\gamma B_0\mathrm{T}\cdot TE_n+\psi\cdot TE_n$ (4). The phase difference among different time frames is $\Delta\Phi_w(TE_n)=\alpha\gamma B_0\Delta\mathrm{T}\cdot TE_n+\Delta\psi\cdot TE_n$ (5), where $\Delta\psi$ denotes B0 field drift. With multi-echo signal, i.e. multi-phase measurements, $\Delta\mathrm{T}$ can be calculated through linear least-square fitting by *Eq.5* and $\Delta\psi$ effect can be corrected by subtracting the fat frequency shift estimated in water-fat mixed voxels since the fat frequency shift contains only field drift related information.

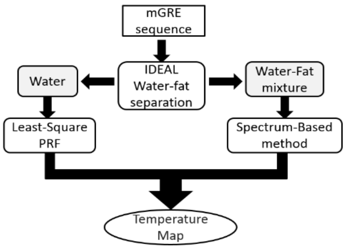

Fig1: Schematic diagram of the new hybrid method of Spectrum-Based and Least-Square PRF

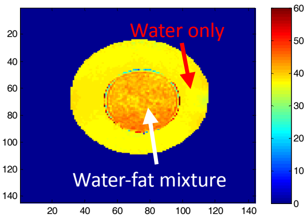

Fig2: Phantom temperature map

Method: To test the hybrid method, a colloidal phantom consisting of water only and water-fat (peanut oil) mixture (see *Fig.2*) was first heated and then scanned with a Philips Achieva 3.0T scanner system (Philips Healthcare, Best, Netherland) using an 8-channel head coil and a standard 16-echo mFFE sequence. The imaging parameters of mFFE were: TR/TE$_1$/ ΔTE =69/2.1/1.8msec, FOV=23cm×23cm, slice thickness = 6mm, flip angle=40^0, acquisition matrix=144×144, receiver bandwidth=1436Hz, scan time=8.9s. 120 time frames were acquired continuously. A fiber optic thermometer (Luxtron) was positioned in the water-only region as the golden-standard temperature measurement.

Results: *Fig.2* shows the temperature map of the phantom calculated by the proposed method. Since the water-fat mixed part in the center was heated separately, the temperature in this region is generally higher than the surrounding part. The temperature change throughout the whole experiment calculated by the proposed least-square PRFS method and traditional PRFS method is compared in *Fig.3*. The temperature calculated by our method is more accurate and stable than traditional method. *Fig.4* demonstrates the temperature evolution curves of Least-Square PRF with and without field drift correction, compared with fiber optic readings. The temperature calculated by our method shows a better agreement with the fiber optic readings since the field drift effect has been removed from the fat frequency shift without using a reference scan in our method. The huge temperature error at the 60th frame caused by starting another dynamic scan is also eliminated by our method.

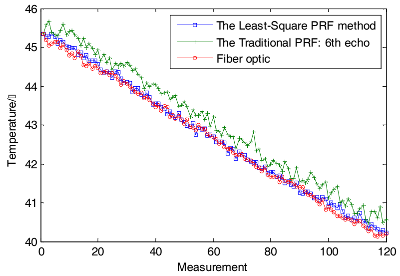

Fig3: Temperature evolution curves calculated by Least-Square PRFS and single echo PRFS method, averaged in a water only area of 3*3 pixels

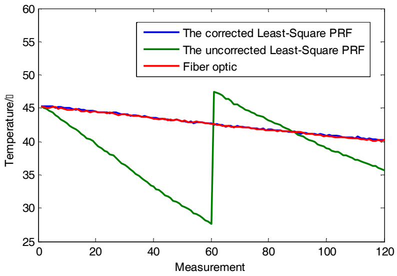

Fig4: Temperature evolution curves measured by Least-square PRFS (corrected and uncorrected) averaged in a water-only area of 5*5 pixels compared with fiber optic measurement.

Discussion and Conclusion: The proposed hybrid method can provide an accurate measurement of temperature in both aqueous and water-fat mixed tissues without increasing scan time or additional reference scan. The temperature-independent fat resonance frequency is utilized to correct for B0 field drift effect in the local voxel in the previous spectrum-based method, while now this correction scheme is extended to water-only voxels. In addition, 16-echo signals are used in this hybrid method to calculate temperature in aqueous tissue by least-square fitting. Phantom experiments demonstrate that this method is more accurate and stable than traditional PRF using only 1-echo signal. In-vivo experiments can be conducted in our future study to further test the stability and feasibility of the proposed method.

References: [1] Ishihara Y, MRM 1995. [2] Li C. et al., MRM 62:1251–1260, 2009. [3] Reeder S.B. et al., MRM 51:35-45, 2004.