A self-reference MR thermometry method utilizing the phase gradient

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INTRODUCTION

In proton resonance frequency (PRF) shift thermometry (1), phase maps acquired before heating (referred to as the baseline phase map) are subtracted from phase maps acquired after heating. However, motion artifacts lead to inaccurate temperature measurements in the PRF shift thermometry method. Alternatively, referenceless (or self-reference) PRF shift thermometry (2, 3) was proposed to remove the inaccuracies associated with motion artifacts by assuming that the thermal treatment is localized to a small area. This method is primarily used when target areas sustain large motion artifacts, and it uses the phase map acquired after heating to estimate the baseline phase map. In referenceless PRF shift thermometry, areas surrounding tissues receiving thermal treatment are used to interpolate the phase of the tissue area receiving thermal treatment. Previous referenceless PRF shift thermometry methods have utilized phase unwrapping to calculate the temperature change (2) or avoided the phase unwrapping process by fitting the complex-valued image (3). In this abstract, we propose to modify the method in (2) and sidestep the phase unwrapping procedure by utilizing the phase gradient to calculate the baseline phase map. This is done by implementing an expansion in terms of a given polynomial basis.

THEORY AND METHODS

In PRF shift thermometry, the temperature change is given by $\Delta T = (\varphi - \varphi_e)/(\gamma \alpha B_0 \mathrm{TE})$ where φ denotes the phase map after heating, φ_e denotes the baseline phase map, γ denotes the gyromagnetic ratio of hydrogen, and α = –0.01 ppm/°C is the PRF change coefficient. In self-reference thermometry, the baseline phase map is estimated from the post-heating phase map. A frame region of interest (ROI) is usually selected around the area to be heated. The inner border should be chosen outside the heating region and the outer border should be located within the object, as shown in Figure 1(A). The phase map in the ROI is modeled as

$$\varphi(x,y) = \sum_{n=0}^{N} \sum_{m-0}^{n} a_{n,m} f_{n-m}(x) f_m(y) \qquad [1]$$

where $\{f_n\}$ denotes a complete polynomial basis on domain D. The x-component of the phase gradient is

$$\nabla_x \varphi(x,y) = \sum_{n=1}^{N} \sum_{m-0}^{n-1} a^{x}_{n,m} f'_{n-m}(x) f_m(y) \qquad [2]$$

where $a^x_{n,m}$ denotes the expansion coefficients calculated from the x-component of the phase gradient. The expansion components, calculated from $\nabla_x\varphi(x,y)$, can be found using the weighted least squares (WLS) procedure. A similar procedure can be utilized to calculate the y-component of the phase gradient. Once the expansion coefficients are calculated from the components of the phase gradient, the total expansion coefficients are found by averaging $a^x_{n,m}$ and $a^y_{n,m}$ when $1 \le m \le n-1$ and $1 \le n \le N$. In the case where $m = 0$, the total expansion coefficients are $a^x_{n,m}$. In the case where $m = n$, the total expansion coefficients are $a^y_{n,m}$.

A simple binary weighting function was used in the WLS procedure, where areas surrounding the heated region were given a weighting of 1 and areas within the heated region were given a weighting of 0. The phase gradient was calculated using the method described in (4).

RESULTS AND DISCUSSION

MR thermometry data was simulated by imposing a 2D Gaussian function (3) onto phase maps of two acquired MR data sets, a phantom data set and a human brain data set. The peak of the Gaussian function was 1 radian (with a mean of μ = 0.5, standard deviation of σ = 4), which corresponds to a temperature elevation of approximately 10°C assuming the resonance frequency was 128 MHz and the TE was 12 ms. Both data sets were acquired using a 3.0 T GE Signa HDX MR Scanner (GE Medical Systems, Milwaukee, WI). The phantom data set was obtained using a gradient refocused echo (GRE) sequence with the following parameters: TE / TR = 10 / 150 ms, matrix size = 128 x 128, FOV = 18 cm. The human brain data set was obtained using a GRE pulse sequence with the following parameters: TE / TR = 6 / 150 ms, matrix size = 128 x 128, FOV = 24 cm.

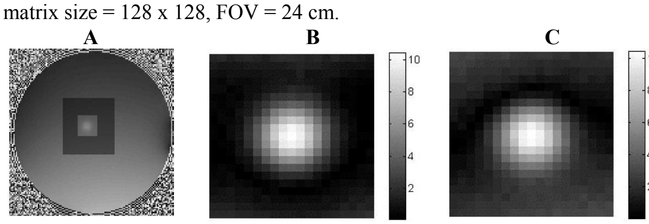

Figure 1. A: A view of the phantom phase map with the ROI highlighted. B: Estimated temperature map from the proposed thermometry method, implemented with the standard polynomial basis using an expansion order of 6. C: Estimated temperature map from the proposed thermometry method, implemented with the basis consisting of Chebyshev polynomials of the first kind using an expansion order of 6. Both B and C are enlarged version of the inner square inside the ROI.

The proposed thermometry method was implemented using two complete polynomial bases: the standard polynomial basis, $\{1, x, x^2, x^3, \ldots\}$, and a basis consisting of Chebyshev polynomials of the first kind, $\{1, T_1(x), T_2(x), T_3(x), \ldots\}$. The results from the phantom data set with simulated PRF shift are displayed in Figure 1. Both expansions give accurate estimations of the temperature change on the phantom data set. The results from the human brain data set with simulated PRF shift are displayed in Figure 2. The expansion in terms of Chebyshev polynomials of the first kind gives a more accurate estimation of the temperature change in the human brain data set. The maximum estimates for the temperature changes in both data sets are displayed in Table 1.

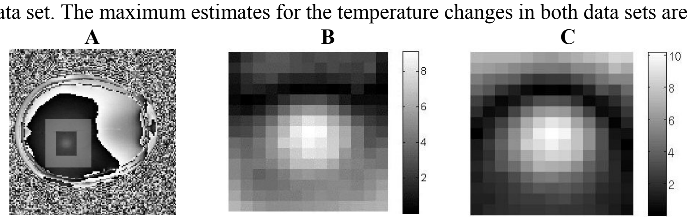

Figure 2. A: A view of the human brain phase map with the ROI highlighted. B: Estimated temperature map from the proposed thermometry method, implemented with the standard polynomial basis using an expansion order of 6. C: Estimated temperature map from the proposed thermometry method, implemented with the basis consisting of Chebyshev polynomials of the first kind using an expansion order of 6.

In summary, a method for referenceless PRF shift thermometry was introduced. The performance of the proposed method was tested on data sets with a simulated PRF shift. Future work on this topic will include the evaluation of the proposed method on experimental data sets.

Data Set	Standard Polynomial Basis	Chebyshev Polynomial Basis
Phantom	10.43 °C	10.46 °C
Human Brain	9.15 °C	10.22 °C

Table 1. The maximum temperature estimates for the two data sets considered in this abstract.

References: (1) Rieke and Pauly JMRI 27:376-390. (2) Rieke, *et al* MRM 51:1223-1231. (3) Kuroda, *et al* MRM 56:835-843. (4) Liang IEEE TMI 15:893-897.

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