Auto-Tracking Self-Reference Temperature Mapping during HIFU Transmission: ex-vivo experiments and motion simulations

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Introduction

MR temperature mapping by the proton resonance frequency shift (PRF shift) [1] is a real-time monitoring tool for thermotherapy techniques, such as high intensity focused ultrasound (HIFU) [2]. For the conventional PRF-shift MR thermometry, the temperature change is obtained by subtracting the phase of the pre-heating stage (i.e. reference phase image) from the phase obtained in real-time. However, this method may fail to calculate the correct temperature change if patient moves (e.g. respiratory motion) or the system frequency drifts [3]. An alternative way, referenceless temperature mapping [3], is to estimate the background phase by 2D polynomial fitting instead of referencing to the initial phase. However, this method requires pre-definition of ROI for fitting algorithm and may fail when the patient move too much. In order to solve this problem, an auto-tracking self-reference (ATSR) mapping method was proposed to detect the heated region and define the fitting region automatically. And it was applied on a porcine liver experiment to demonstrate its feasibility.

Material and Methods

The experiment was performed on a 3T MR system (Trio 3T, Siemens). Pulsed-wave HIFU pulses with 83 Watt power were performed on porcine liver tissue, immersed in 25°C degassed water. Magnitude and phase images were acquired by the gradient-echo sequence (TR/TE:29/7.53 ms, flip angle:20°, FOV:160x120 mm^2, matrix size:128x96, slice thickness:3 mm, transmitter coil: body coil, receiver coil: abdominal coil, measurements:120, and the temporal resolution ~1.85 sec). The acquired images were transferred to a personal computer for data processing with Matlab® system (Mathworks, Natick, MA, USA) for auto-tracking self-reference mapping algorithm. To simulate the motion-induced artifact, the image series were randomly shifted -10~+10 pixels (random number: normal distribution with mean of 0 pixels and standard deviation of 5 pixels, i.e. 12.5 mm).

The auto-tracking self-reference (ATSR) mapping method included three steps: 1) high-pass filtering the unwrapped phase image [4] to reveal phase-changed region, 2) eliminating noise and redundant areas, 3) estimating the initial background phase and then calculating relative temperature change. To apply high pass filter, the phase image smoothed by 2D median filter was subtracted from the original phase image. Using high-pass filtered phase as a reference, pixels with spatially rapid phase change can be identified. The detected pixels can be around either noisy region, or heated region. By evaluating the local 2D standard deviation, the noisy regions can be removed. After revealing the heated region, the initial background phase was estimated by 2D polynomial fitting and thus the self-reference temperature map was obtained. The whole process was fully automatic. Neither ROI selection nor user interactions with the algorithm were needed.

Results

Figure 1 shows the temperature map obtained by difference method and ATSR method. Referencing to the map without simulated motion (see fig. 1a), we can notice that the temperature mapping processed by ATSR method (see fig. 1c) looks fairly similar. And simulated motion resulted incorrect temperature mapping by the original difference method (see fig. 1b). More quantitatively, the relative temperature curves of heated-spot estimated by three different processing methods, phase difference without simulated motion (blue line, curve #1), phase difference with simulated motion (green dash line, curve #2), and the ATSR method (red line, curve #3) are shown in Figure 2. Notice that with temperature curve estimated by ATSR is close to the curve estimated by the original phase difference without simulated motion.

Discussion and Conclusions

In this study, 2D polynomial fitting was based on higher order polynomial on the smooth phase-changed and noise-reduced background, whereas higher order polynomial often induced more frequent oscillation. To get better fitting result, the polynomial fitting region should contain area without temperature change to avoid discontinuity of the background phase. Curve #3 obtained by ATSR method shows quantitatively close to curve #1. However, relative temperature less than 10°C was not able to be tracked by our method due to the tiny phase change induced by PRF-shift. Further investigation has to be done to solve this problem. By the motion simulation, the benefit of using ATSR method was shown. The original phase difference method requires referencing to the initial phase image and the movement of the pixels results incorrect subtraction and hence inaccurate temperature estimation. The ATSR method estimates the background phase with self-reference and thus can overcome the motion problem. In conclusion, auto-tracking self-reference temperature mapping method, which can reduce error caused by tissue motion, can be a more reliable and robust tool to real-time monitoring the thermotherapy.

References

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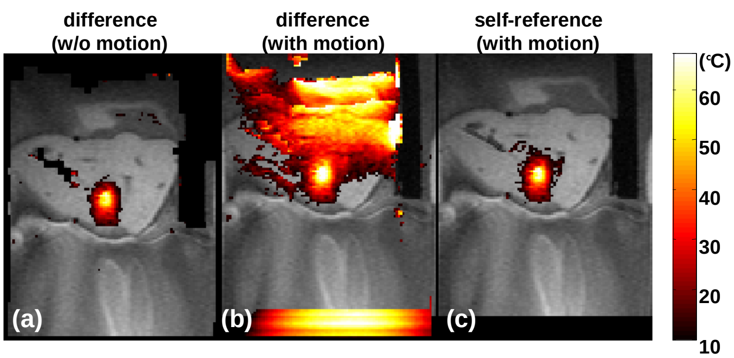

Figure 1 Relative temperature maps. (a): difference method without simulated motion. (b): difference method with simulated motion. (c): ATSR method with simulated motion. Note that the ATSR method produced better temperature map while the tissue moved.

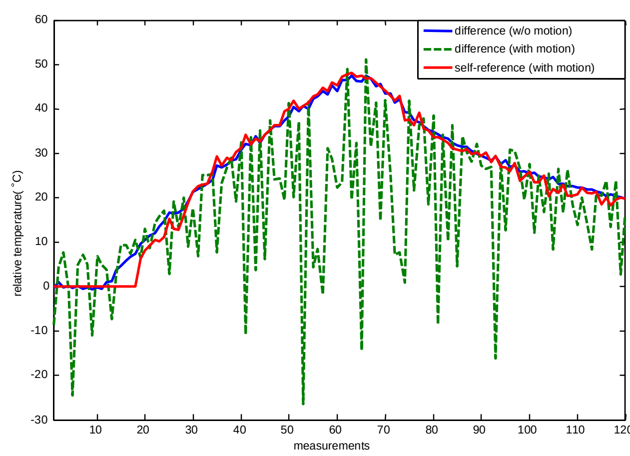

Figure 2 Relative temperature curves obtained with different methods (blue: phase difference without simulated motion, green: phase difference with simulated motion, red: the ATSR method). With simulated motion, ATSR performed much better than the phase difference method.