A Computationally Efficient Real-Time Hybrid MR Thermometry for MRI-guided RF Ablation

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Introduction: MR-guided RF ablation is a promising technique for the treatment of cardiac diseases such as atrial fibrillation. Reliable and non-invasive thermal mapping is important for monitoring the progress of thermal ablation therapies and ensuring patient safety and treatment efficacy. Proton resonance frequency (PRF) shift MR thermometry has been the method of choice. The PRF method relies on the subtraction of intra-treatment phase images from that of a pre-treatment baseline phase image, making it very sensitive to motion and magnetic field changes. Two techniques have been proposed and used to address motion: multi-baseline method and referenceless method [1-2]. Multi-baseline method relies on a set of pre-treatment baseline images covering the cardiac or respiratory cycle as reference but is influenced by MR scanner static magnetic field drifts. Referenceless method estimates background phase from the current image itself, assuming that background phase changes smoothly and can be modeled using a low-order polynomial fitting. RF electrode-induced perturbation causes non-smoothness in the background phase, leading to large inaccuracies in temperature measurements. Previous hybrid methods that have been proposed to overcome these shortcomings [3] are not computationally efficient for real-time MR thermometry. In this work, we present a computationally efficient and simplified real-time hybrid MR thermometry technique for monitoring MR-guided thermal therapies.

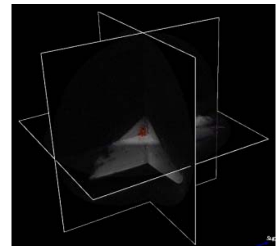
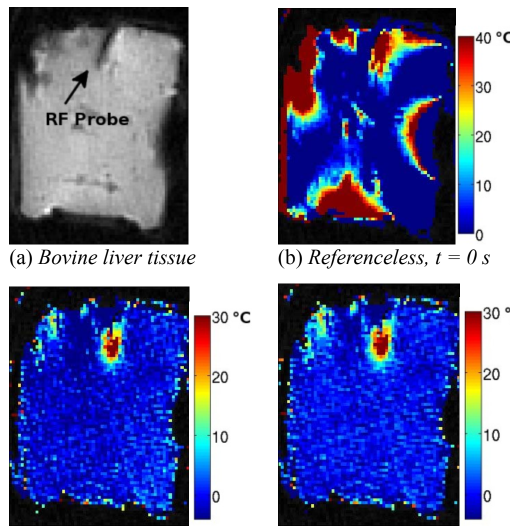


Figure 1: *3-plane real-time visualization of MR temperature mapping in ex vivo liver tissue.*

Materials and Methods: All experiments were performed on a 1.5 T scanner (Signa, GE Healthcare, Waukesha, WI). A 6F catheter with a bipolar RF ablation tip was built and used for ex-vivo ablation of excised bovine liver tissue. A commercially-available RF generator was used to deliver 3-10 Watts of power during RF ablation. Tissue temperature was also measured with fiber optic temperature probes (Neoptix, Quebec, Canada). Images were acquired using a 2D fast gradient-echo spiral imaging sequence with 5 interleaves (TE = 3.7 ms, TR = 28 ms, slice thickness = 8 mm, FOV = 24 cm, acquisition matrix = 134 x 134), allowing 7 Hz frame rate. The MR imaging and thermometry techniques were implemented using the RTHawk real-time acquisition and reconstruction platform (HeartVista, CA) and Vurtigo visualization platform (Sunnybrook, Canada) that allow for multiple plane scanning and visualization as seen in Figure 1.

To assess the robustness of our hybrid MR thermometry method, in-plane linear motion was introduced by the built-in rocker capability of the MR scanner table (5 mm distance, speed = 5 mm/s) during temperature mapping. Forty pre-treatment images were acquired and stored in a lookup table as baseline image. Due to the high temporal resolution of the baseline images, the need to compute the weight value for each baseline image [3] became insignificant and no image registration was necessary. Each image acquired during hyperthermia was simply matched to one of the images in the lookup table based on the intercorrelation coefficient. A referenceless method based on the reweighted least-square regression, which is computationally more efficient than the L1 regression used in [1], was applied to each subtracted phase image to further reduce artifacts and account for bias caused by the static magnetic field drift.



(a) *Bovine liver tissue* (b) *Referenceless, t = 0 s*

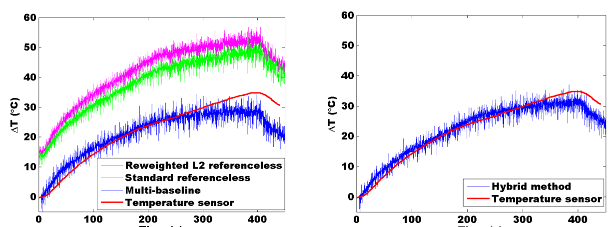
(c) *Multi-baseline, t = 330 s* (d) *Hybrid, t = 330 s*

Figure 2: *MR image and temperature map of bovine liver tissue during RF ablation*

Results and Discussion: The *ex vivo* bovine liver tissue was ablated for about 6.5 minutes and cooled off for one minute. Figure 2 (a) shows the *ex vivo* liver image with the RF ablation electrode whose presence caused distortion to the local magnetic field, resulting in rapid phase change that cannot be accounted for by the referenceless method. Local anatomical structures also caused additional artifacts. Large temperature offsets are clearly visible in Figure 2 (b) even before heating. Figure 2 (c-d) shows the temperature maps at 330 s obtained with the multi-baseline method and hybrid method, respectively.

Figure 3 shows a plot of temperature measurements obtained with the discussed PRF methods using the average values from a 5 x 4 ROI at the hot spot. Temperature data from fiber optic sensors measurements are plotted as well. In Figure 3 (a), both referenceless methods show a large temperature offset because of the phase disturbance from the RF applicator. Compared with the multi-baseline method, the temperature measurements obtained with the hybrid method shows reduced bias from B0 field drift correction (Figure 3 (b)). Statistical analysis also indicates that the hybrid method provides more noise reduction than the multi-baseline method.

The processing pipeline has been implemented in C++ and JavaScript and required no more than 100 ms to recon the spiral images with the specified matrix size on a dual processor dual core Intel Xeon 3.0 GHz with 4 GB of RAM. The hybrid analysis with a subdomain of the image took about 50 ms. These results clearly demonstrate that the proposed hybrid method is computationally efficient and suitable for real-time temperature monitoring of MRI-guided RF ablation.



(a) (b)

Figure 3: *Comparison of MR thermometry measurements on the hot spot.*

Conclusion: We have presented a hybrid thermometry method that allows temperature measurements in the presence of motion and RF ablation electrodes. The proposed hybrid technique has been shown to be suitable for monitoring temperature changes in real-time on general-purpose computing hardware during MR-guided RF ablation.

References: **[1]** Grissom W, *et al*, Magn Reson Med 2010; 64:1068-1077; **[2]** Denis B, *et al*, Magn Reson Med 2010; 64:1373-1381; **[3]** Grissom W, *et al*, Med Phys 2010; 37:5014-5026; **[4]** Vigen K, *et al*, Magn Reson 2003; 50:1003-1010;