Referenceless Thermometry in the Presence of Phase Discontinuities Between Water and Fat

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Introduction Referenceless proton resonance frequency (PRF) shift thermometry [1] is inherently robust to tissue motion because the subtraction of a baseline phase image acquired prior to heating is not necessary. Instead, the background phase is estimated in every individual image from a frame region of interest (ROI) surrounding the heating region. In the simple approach, only aqueous tissue is present in the frame ROI.

For thermal ablation of the prostate, both adipose and aqueous tissues are present in the frame ROI. Referenceless temperature estimation still works when the echo time TE is chosen such that water and fat are exactly in-phase in order to prevent phase discontinuities between the two tissue types which would distort the phase estimation. Determination of the exact in-phase TE is difficult in practice since it depends on the body temperature of the subject and the spectral components of the fat.

We propose an extension to referenceless thermometry where the background phase is estimated from water and fat, allowing for a constant phase offset between the two tissues and thereby eliminating the constraint of an in-phase echo time TE. The method is demonstrated during in vivo canine prostate ablation.

Methods Images at three different echo times (14.3 ms, 21.4 ms, 28.6 ms) are acquired in two acquisitions. These correspond to phase angles between water and fat of 2π, 3π and 4π at 0.5T. From a 3pt-Dixon decomposition, binary masks of regions that contain water or fat are created.

For referenceless temperature mapping, a frame region of interest is selected around the prostate, as seen in Fig. 1a. The unwrapped phase (Fig. 1b) in aqueous tissue in this region is approximated by a polynomial, P_W. The phase in adipose tissue is described by the same polynomial, but has a constant phase offset from water that varies with echo time, such that $P_W = P_F + c$. With the binary fat/water maps, the polynomial coefficients including the offset c are determined in the least squares sense using a weighting by the image magnitude squared. The extrapolation of the fitted polynomial to locations within the prostate serves as an estimation of the baseline phase.

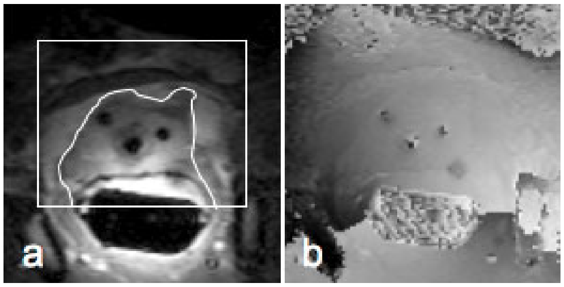

Figure 1: Magnitude image (a) showing the frame region around the prostate and unwrapped phase image (b).

Images were acquired during thermal ablation of the prostate in a canine model using a transurethral ultrasound applicator [2] on a 0.5T GE Signa SP scanner. Imaging parameters were TR/BW1/BW2/flip/FOV/slice = 150 ms/12.5 kHz/12.5 kHz/60/20x16 cm/5 mm. Temperature maps were reconstructed with referenceless reconstruction with and without the described phase offset correction and compared to those obtained with conventional baseline phase subtraction.

Results Figure 3 shows a comparison of the three temperature maps. Conventional baseline subtraction (a) gives reasonable temperature maps, but suffers when tissue motion is present (arrows). Although an in-phase echo time was chosen for referenceless reconstruction (b), small phase discontinuities between water and fat (seen in Fig. 1b) cause errors in the temperature estimation (arrow). Allowing for an offset between water and fat in the phase estimation with referenceless reconstruction (c) improves the quality of the temperature maps.

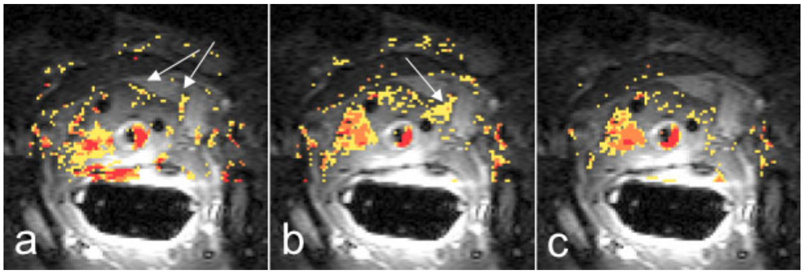

Figure 2: Temperature maps generated with conventional baseline subtraction (a) and referenceless reconstruction without (b) and with (c) phase offset correction.

Discussion This referenceless method allows temperature estimation with any echo time and takes advantage of both aqueous and adipose tissues present in the frame ROI. Two image acquisitions are needed to acquire all necessary echoes for the 3pt-Dixon decomposition, such that the binary masks are updated every other image. However, since motion experienced during prostate ablation is small from image to image, the same binary mask can be used for the reconstruction of two consecutive temperature maps. The temperature measurements can be made from each acquisition, so that the temporal resolution of the thermal measurements is not compromised.

Since fat and water areas are handled separately in the reconstruction, it is also possible to correct the phase in fatty regions for chemical shift before the polynomial fit [3].

Using binary maps to locate water and fat regions works well in the prostate images, since the regions are discrete and most pixels contain only either water or fat. Use of the method in more heterogeneous tissues, where the majority of pixels contain varying amounts of water and fat (e.g. breast tissue) will require further development of the reconstruction algorithm.

References [1] Rieke V., et al, Magn Res Med. 51(6):1223-31 (2004).
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