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Online improvement of the reliability of PRF based temperature maps displayed during laser-induced thermotherapy of liver lesions

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Introduction

The proton-resonance frequency (PRF) shift technique exploits the phase of the MR signal that is proportional to the temperature of the observed tissue. That is, temperature changes are derived relative to a reference image acquired before the thermotherapy. However, the phase of the MR signal is also altered by motion of the observed tissue in imperfect magnetic fields and susceptibility variations between different tissues.

Therefore, it is necessary to perform online corrections for phase variations that are not temperature related. In this abstract, a method is proposed to online improve the integrity of temperature maps obtained by the PRF method. First, outliers and motion corrupted temperature values are identified and then the temperature data is fitted solving Pennes' bioheat equation.

Subjects and Methods

The temperature maps used to evaluate our method were acquired during a laser-induced thermotherapy of liver lesions at a 1.5 T MR scanner (Siemens MAGNETOM Avanto) using a respiratory belt-triggered gradient-echo sequence.

In order to improve the integrity of the temperature maps, a curve $T_{fit}(x,t)$ is fitted to $T_{meas}(x,t)$ solving Pennes' bioheat equation [1, 2] (separate abstract). During the procedure not $T_{meas}(x,t)$ but the temperature calculated from the fit is displayed. For a meaningful fit, outliers resulting from susceptibility variations and motion corrupted temperature values have to be identified and excluded from the calculation. This is done by omitting single temperature values with $T_n - T_{n-1} > 40$ and all temperature values when motion relative to the reference image is detected. To detect motion, normalized mutual information (NMI) [3] was found to be a suitable similarity measure between the reference and the current magnitude image. NMI (Equation 1) measures the information shared between two distributions. The lower NMI the higher the probability for motion between Mag_{ref} and Mag_n.

$$NMI(Mag_{ref}; Mag_n) = \frac{H(Mag_{ref}) + H(Mag_n)}{H(Mag_{ref}, Mag_n)}$$

$H(Mag_{ref})$: Shannon entropy of Mag_{ref},

$H(Mag_n)$: Shannon entropy of Mag_n,

$H(Mag_{ref}, Mag_n)$: joint entropy.

Equation 1: *Normalized Mutual Information.*

Results

The NMI threshold was set to 0.5. As illustrated in Figure 1, the improved fit taking into account information about motion and excluding sudden extreme temperature changes significantly reduces noise in the march of temperature. Noise in non-heated areas is reduced by more than reduces noise in the march of temperature by more than 50 percent.

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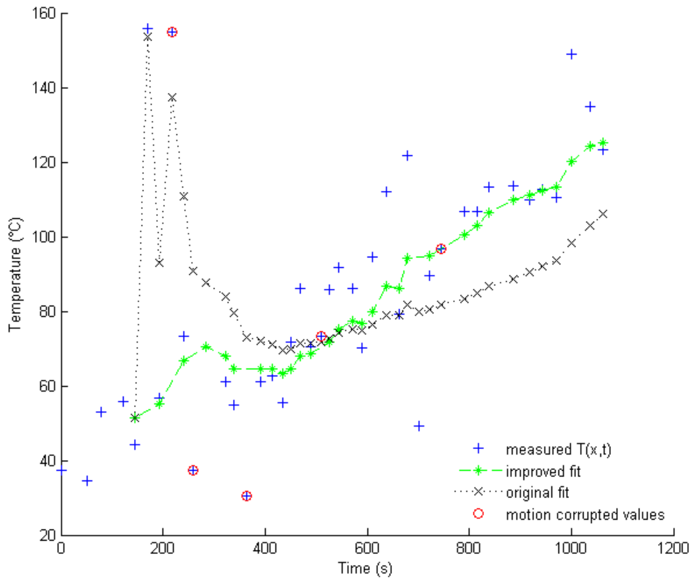

Figure 1: Temperature over time for a voxel in the centre of the laser-induced ablation zone. Comparison between the original fit based on the solution of Pennes' bioheat equation and the fit excluding motion corrupted values and sudden extreme temperature changes.

Discussion and Conclusion

We have demonstrated the feasibility of using normalized mutual information to detect and exclude outlier temperature measurements due to organ motion. Future work will include clinical testing, and extension to other organs with different types of motion.

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