Arbitrary Region of Interest Definition for Referenceless Magnetic Resonance Temperature Imaging

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Purpose

Magnetic resonance temperature imaging (MRTI) facilitates monitoring of minimally invasive thermal ablation therapy procedures. The commonly used proton resonance frequency shift approach determines temperature differences based on reference phase images acquired before heating. Therefore, this method is error-prone for monitoring abdominal organs due to background field changes from breathing motion. To overcome this issue referenceless algorithms [1,2] have been proposed. Recently, a new physics model based method [3] was presented, which estimates background phase by solving the Dirichlet problem in a circular region of interest. In this work, we modified this algorithm to enable arbitrary regions of interest (ROI).

Methods

In the following, the algorithm is introduced for a 2D image ($n \times n$ px). However, it can be easily extended to 3D. In a first step, the user selects an arbitrary ROI of pixels, where the background phase is required to calculate temperature change. The phase values of the $n \times n$ image matrix are stored in a vector $\phi \in \mathbb{R}^{n \cdot n}$ and the Laplacian $L \in \mathbb{R}^{n \cdot n \times n \cdot n}$ is calculated. If pixels i and j are neighbors, then L_{ij} is set to -1. The diagonal values L_{ii} are set to k_i, where k_i is the number of neighbors of pixel i. Then, the discretized Dirichlet problem equals:

$$D[\phi] = \frac{1}{2}\phi^T L \phi \qquad (1)$$

The linear equation system is sorted by pixels inside the ROI, $\phi_{in} \in \mathbb{R}^m$, with variable phase and pixels outside the ROI, $\phi_b \in \mathbb{R}^{n \cdot n - m}$, with fixed phase, where m is the number pixels inside the ROI. Equation 1 may be decomposed to [4]:

$$D[\phi_{in}] = \frac{1}{2}\begin{bmatrix} \phi_b^T & \phi_{in}^T \end{bmatrix}\begin{bmatrix} L_b & B \\ B^T & L_{in} \end{bmatrix}\begin{bmatrix} \phi_b \\ \phi_{in} \end{bmatrix} = \frac{1}{2}(\phi_b^T L_b \phi_b + 2\phi_{in}^T B^T \phi_b + \phi_{in}^T L_{in}\phi_{in}) \qquad (2)$$

The solution of the Dirichlet problem is a harmonic function ($\nabla^2 \phi_{in} = 0$) that minimizes $D[\phi]$. Therefore, the derivative $D'[\phi_{in}]$ is set to 0:

$$D'[\phi_{in}] = 2B^T\phi_b + 2L_{in}\phi_{in} \overset{\text{def}}{=} 0 \qquad (3)$$

This linear equation system is solved using the conjugate gradients algorithm.
The prototype of the algorithm was implemented with *MathWorks Matlab R2011*. Processing was performed on a laptop (*Dell Latitude E6420*, *Intel Core i5-2520M*, 4 GB RAM).

Results

For common ROIs in a 2D image (256×256 px) the processing time is less than 0.1 s. Figure 1 shows an image of a laser induced interstitial thermal therapy of human liver with a user-defined ROI. Based on the measured phase (Fig. 2) inside the bounding box (cf. Fig. 1) and the estimated background phase (Fig. 3), a temperature map was calculated (Fig. 4). The mean temperature of the corresponding reference-based temperature map (Fig. 5) was shifted by 20.6 °C, due to motion induced background field changes. Before heating, root mean square errors of 2.8 °C / 19.7 °C (referenceless/reference-based) were found.

Discussion

The proposed algorithm allows for improved MRTI of abdominal organs and facilitates arbitrary ROI definition. The processing time for common ROIs of less than 0.1 s allows for online updates of temperature maps. Such an approach can be powerful when needing to effectively apply nearly harmonic referenceless approaches to arbitrarily shaped heating profiles or accommodate heating near boundaries. A full investigation of these implications is warranted.

Acknowledgements

References

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[2] Grissom WA, Lustig M, Holbrook AB, et al. *Magn Reson Med*. 2010;64(4):1068-1077.
[3] Salomir R, Viallon M, Kickhefel A, et al. *IEEE T Med Imaging*. 2012;31(2):287-301.
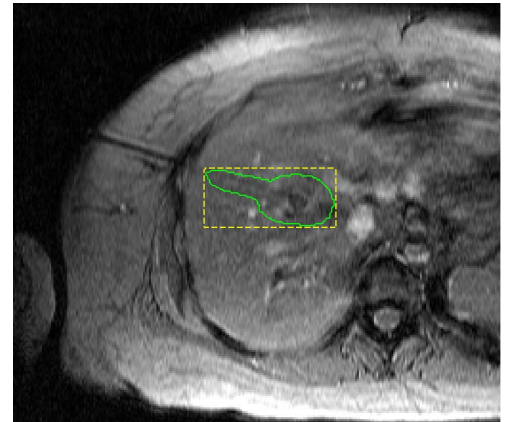[4] Grady L. *IEEE T Pattern Anal*. 2006;28(11):1768-1783.

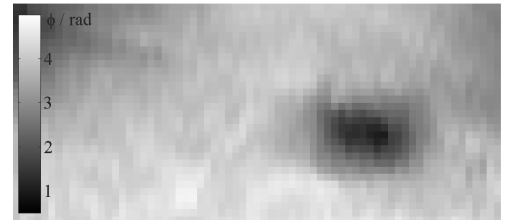**Fig. 1:** Magnitude image (human liver) with ROI (green) and bounding box (yellow).

Fig. 2: Cropped unwrapped phase image of heated region inside bounding box (cf. Fig 1).

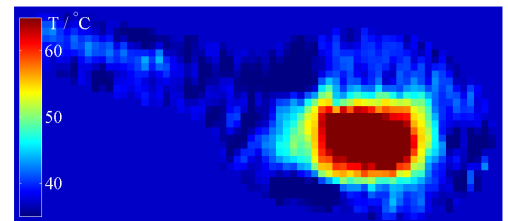**Fig. 3:** Estimated background phase of heated region inside bounding box (cf. Fig 1).

Fig. 4: Referenceless temperature estimation of heated region inside ROI (cf. Fig 1).
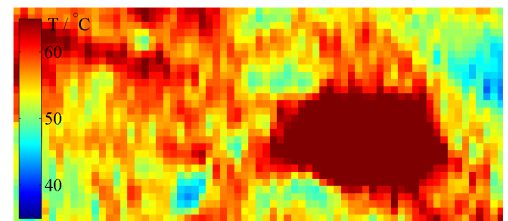

Fig. 5: Reference-based temperature map of bounding box with motion artifacts (overestimated temperature).