

MR thermometry in moving objects using a novel referenceless and user-independent approach

B. Madore¹, R. Chu¹, C-S. Mei^{1,2}, and L. P. Panych¹

¹Radiology Department, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States, ²Department of Physics, Boston College, Chestnut Hill, MA, United States

Introduction: The simplest way to generate temperature maps based on proton resonance frequency shifts involves phase subtractions with a prior-to-heating time frame. In the presence of motion this approach is not practical, as many changes may occur in time besides heating. The referenceless approach [1-3] has proved very effective for generating temperature measurements in moving objects, but it requires prior knowledge of where the heating will occur. While the location targeted for ablation is of course known with precision, there might be unexpected secondary heating sites. A modification to the referenceless approach was proposed where prior knowledge of the heating location is not required [4]. The strategy in [4] is purely spatial and detects heating spots as (sharp) variations in the phase maps that cannot be well fitted using smooth functions. Such variations can however be caused by other processes besides heating, such as susceptibility-induced phase shifts. The proposed algorithm can be seen as an improvement on the referenceless approach.

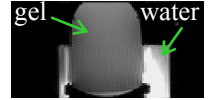


Fig. 1

Theory: The proposed algorithm makes use of essentially all of the information available to detect heat-spot locations: Both phase and magnitude channels, the entire time axis from the beginning of the treatment up to the current time t (i.e., the algorithm is causal), the known timing of transducer firings, and motion information from registration software. An example from a heating experiment in a gel phantom (Fig. 1), with table movement, is shown in Fig. 2. Based on the knowledge that the transducer was turned on for 30 s and then turned off, Fig. 2a gives a rough estimate of what a resulting heating curve might look like. It is a function that goes up for 30 s, and then goes down asymptotically toward zero. The acquired images were registered, and measured position is shown in Fig. 2a (displacement amplitude ≈ 2 cm). In the present special case of rigid-body motion, all voxels undergo the same displacements, but a more general non-rigid case with location-dependent displacements could readily be handled by the proposed algorithm. The first and second derivatives of displacement are shown in Fig. 2c and d, respectively. The present problem is expressed as a linear system: $\mathbf{D} = \mathbf{A} \mathbf{c}$, where \mathbf{D} is a column vector with t entries containing image data, \mathbf{A} is a $t \times n$ matrix featuring the motion and heating information from Fig. 2, \mathbf{c} is a column vector with n entries. In the present example $n =$ number of temporal functions $= 8$ (DC, displacement x , speed v , acceleration a , x^2 , v^2 , a^2 , and heating).

Results: Once a system of equations is solved for \mathbf{c} , the coefficient c_h associated with the heating function is of particular interest. Maps of c_h are shown on the top row of Fig. 3 for different time points (matrix size=64x96, FOV=13x26cm, resolution=2.0x2.7x8.0mm, TR=5.2ms, time resolution=96xTR=500 ms). Voxels associated with large c_h values can be interpreted as undergoing temporal changes very compatible with heating, as opposed to motion. The method is very robust in its detection of hot spots whenever the approximate heating function (Fig. 2a) proves significantly different from motion-related functions (Fig. 2b-d). For small t values, very little heating has happened yet, and accordingly the algorithm cannot clearly detect any hotspot. As time passes, heated locations can be detected with increasing clarity. The bottom row of Fig. 3 shows a filtered version of the top row, using an edge-enhancing filter. As early as 10 s into the heating period, after only a 2 °C increase, the focus region could already be discerned in the spatially-filtered results (Fig. 3, bottom row). As time passes, the algorithm can pick up heated locations with such clarity, despite all the motion-induced effects also present, that even the slightly heated cone-shaped region between transducer and focus point can be discerned (green arrow, Fig. 3).

Discussion: The referenceless thermometry approach [1-4] is built around the idea that non-heated locations around a heated region can be used to estimate the underlying phase at the heated location, i.e., the phase 'plateau' onto which is seated the heating-induced phase 'mountain'. The output of our proposed algorithm (Fig. 3, bottom row) is used to determine which voxels are not undergoing heat-related changes and can be used to estimate such plateau. At any given time point in our causal algorithm, all locations that appear black in the lower row of Fig. 3 can be used to fit a smooth phase function, allowing temperature at the hot spot to be evaluated and temperature curves to be generated (not shown here).

Conclusion: Temperature measurements in moving objects can be obtained in a way that is both referenceless (does not require a baseline reference image) and unsupervised in the sense that it does not require any prior knowledge about hot spot locations.

References:

- [1] Rieke *et al.* MRM 2004;51:1223. [2] Rieke *et al.* IEEE TMI 2007;26:813.
[3] McDannold *et al.* JMRI 2008;28:1026. [4] Grissom *et al.* ISMRM 2009: pp 445.

Acknowledgments:

Useful discussions with Dr. Nathan McDannold and support from grant U41 RR019703 are acknowledged.

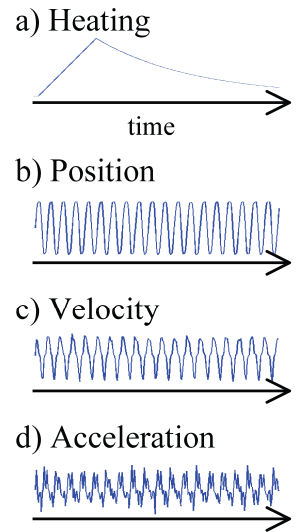


Fig. 2

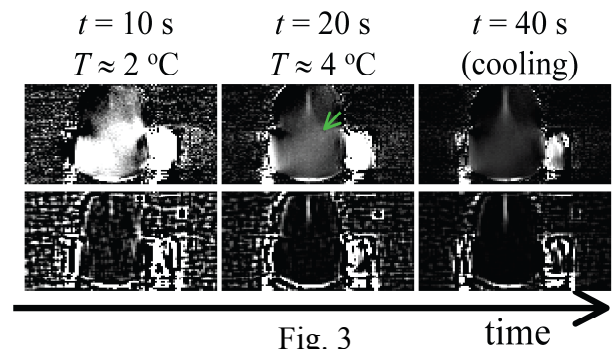


Fig. 3