Simultaneous Temperature and Motion Tracking Using HARP MRI [T-HARP]

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Introduction: We introduce a new method, temperature HARP (T-HARP), for simultaneously tracking temperature and motion changes using CSPAMM tagged MR images and proton resonance frequency (PRF) shift MR thermometry. The method uses isolated spectral peaks in the Fourier domain derived from harmonic phase (HARP) analysis to extract temperature and motion information. We tested the method on a moving gel phantom and a rabbit model using independent temperature verification. Results show that temperature changes can be detected with 2°C accuracy using T-HARP analysis.

Theory: The image *I* arising from a tagged MRI 2D-CSPAMM sequence, is [1]: $I(x,y,TE,t) \propto e^{-i(\phi_e(r,t))} \times (e^{i(\phi_x(r,t))} + e^{-i(\phi_x(r,t))} + e^{i(\phi_y(r,t))} + e^{-i(\phi_y(r,t))})$, where $r=(x, y)$ are the image coordinates, TE is the echo time, t is time, ϕ_e is a background phase, ϕ_x and ϕ_y are the modulation phases due to tagging which contain motion information. Using isolated peak filtering (HARP), four phase images were extracted and combined to yield new phase images. The background phase can be modeled by $\phi_e(x,y) = (\phi_T + \phi_h + \phi_0)(x,y,t)$, where ϕ_h is the phase arising from static field inhomogeity, ϕ_0 is the unknown initial phase, and ϕ_T represents the phase associated with temperature changes. By tracking changes in the background phase and estimating field homogeneity changes we are able to extract relative temperature maps using $\Delta T(x,y,t) = [\Delta\phi_e(x,y,t) - \Delta\phi_h(x,y,t)]/(\alpha \times TE \times \gamma \times B_0)$, where γ is the gyromagnetic ratio, B_0 is the static field and α= -0.01ppm/°C [2]. The remaining phase terms are used to estimate tissue motion and strain changes as in HARP.

Methods: A gel phantom of comparable MR properties to muscle was placed on a non-magnetic cart that moved cyclically (35Hz) within a Philips 3T scanner. An interleaved k-space GRE spiral sequence was applied with 15 interleaves, gated to the cart's motion (Acq. Window, 15 ms; FA, 50°; TE, 4 ms; TR 67.25 ms; Tag Space, 12mm; FOV, 24cm; 10 tagged phases/motion cycle). A tuned dipole antenna connected to a μ-wave generator (2.4GHz) of variable controlled power was inserted in the phantom for local heating. A fiber optic probe (FISO Inc) was inserted near the antenna to measure the temperature. The sequence was repeated in the presence of cyclic motion for 38min, while monitoring both temperature and motion. In vivo experiments were conducted using a similar sequence (with TE =1 ms) on a sedated rabbit, with the microwave heating antenna and fiber optic probe inserted in its thigh.

Results: High resolution anatomical images were first used to identify the location of the FISO probes. The first phase of the tagged images was used to estimate temperature maps after correcting for temporal field variations. Thermal maps from the phantom experiment are shown in figure 1. Figure 2 shows that temperature measured by T-HARP agrees with the probe temperature within 1.7°C (SD). The rigid body motion was estimated (Figure 3) and the temperature map was translated to determine the exact location of the site of thermal activity. Repeat experiments conducted with the moving phantom using 1D and 2D tagging yielded comparable performances for both the tracking of cyclic motion and temperature measurements. The in vivo experiment gave comparable results with an error of ~2°C compared to the FISO probe measurements.

Conclusion: We have demonstrated in phantoms and in vivo that temperature can be extracted from tagged MR images within an accuracy of ~2°C. Tracking changes in both temperature and stiffness during ablation procedures are of clinical value because it provides a means of ensuring a successful ablation [3]. T-HARP allows preservation of functional information in the MRI signal during hyper- or hypo-thermia procedures. Experiments to monitor strain variations due to temperature-induced stiffness changes are underway.

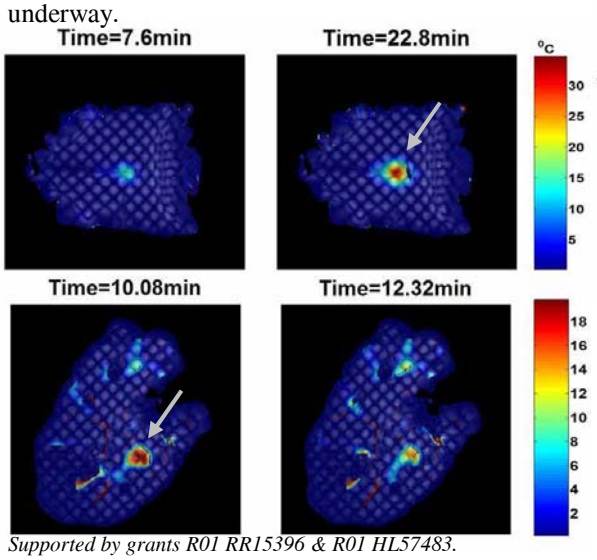


Fig. 1: The generated thermal maps from phantom (top), and in vivo (bottom) overlaying the tagged anatomical images. Arrows point to heating site.

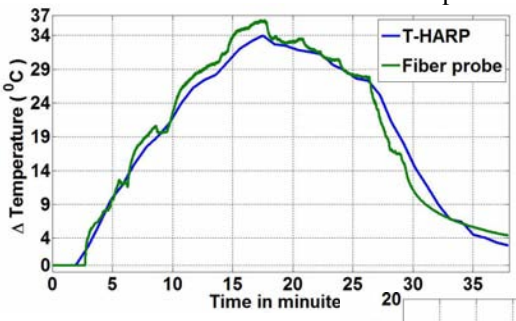
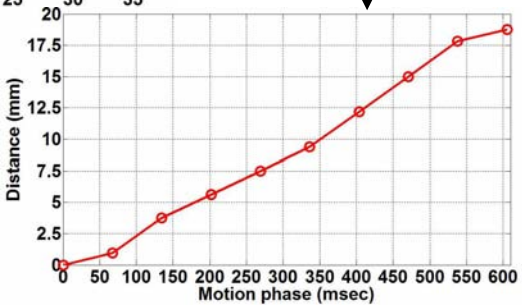


Fig. 2: Fiber optic vs T-HARP Temperature curves in phantom.

Fig. 3: T-HARP displacement estimates for the phantom over its motion cycle.



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References:

1. S. Ryf et al, Magn Reson Med 1999:42:1048-1060. **2.** De Poorter et al, Magn Reson Med 1995:33:74-81. **3.** Y. Le et al, Magn Reson Med 2006:55:700-705.