3D Navigated Real-Time Thermometry for Abdominal Imaging

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Introduction

High Intensity Focused Ultrasound (HIFU) is a promising non-invasive technique for the local deposition of thermal energy deep inside the human body [1]. MRI guidance of this method offers the additional benefits of excellent target visualization and continuous temperature mapping using the proton resonance frequency (PRF) shift technique [2]. However, PRF-based MR-thermometry on abdominal organs under free-breathing conditions is challenging due to the continuous motion of the target and the associated phase variations.
The presented study addresses both problems by applying the following strategy: The target tissue is observed with high frame-rate MR-thermometry. In-plane motion is compensated in real-time by 2D-optical flow based image registration [3], while out-of-plane motion is compensated in real-time by slice tracking based on 2D selective navigator data [4]. Phase variations during the respiratory cycle are pre-recorded according to the navigator tracking position and subsequently eliminated in real-time from the thermometry data [5]. The feasibility and the precision of this approach are demonstrated in an ex-vivo heating experiment and with in-vivo data of the kidney of a healthy volunteer.

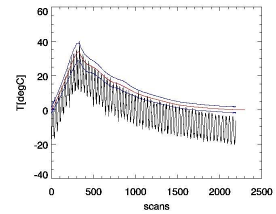

Figure 1. Temperature evolution of the heating experiment obtained by uncorrected MR-thermometry (black), thermal probe reading (red) and the uncertainty based on SNR-measurements (blue).

Materials and Methods

General Strategy: The experiment is divided into two sections, the training phase and the thermometry phase. During the training phase, a lookup-table containing the phase variations due to respiratory motion is generated, which in turn is used in the thermometry phase to correct the PRF-based temperature maps [5]. The movement of the selected target tissue is actively tracked and 3D motion-compensated during the entire duration of the experiment. All imaging was performed on a 1.5T Philips Achieva scanner and 300 training images (~30s imaging) were acquired for all experiments.

Phantom Experiments: An agar-gel phantom was mounted on a motorized platform simulating respiratory motion (motion amplitude 15mm, lateral motion 4mm, T=3s). Heating was provided for 30s (30s after the start of scanning) by delivering 15W of RF-power (Radionics amplifier) to a set of bipolar electrodes (electrode distance ~1cm, impedance 86Ω). For comparison, the temperature was monitored between both electrodes with a Luxtron fiber-optic probe. Imaging was performed with a single-shot gradient recalled EPI sequence (TE=30ms, TR=87ms, Resolution=2.3x2.3x6mm^3, Flip=25˚, 121-binominal water sel. excitation pulse, birdcage receiver coil) in transversal direction, while tracking data was provided with the standard 2D-selective navigator-echo of the Achieva platform [4].

In-vivo Experiments: MR-thermometry was performed during three minutes of free-breathing on a transversal slice through the kidney of a healthy volunteer. To improve the tracking stability and to avoid interference with MR-thermometry, the standard spin-density weighted pencil-beam navigator of the Achieva platform was replaced by a 121-binominal fat sel. pencil-beam. The beam was placed directly on the fat capsule at the apex of the kidney. Imaging was performed with a single-shot gradient recalled EPI sequence (TE=38ms, TR=104ms, Resolution=2.3x2.3x5mm^3, Flip=30˚, 121-binominal water sel. excitation pulse, four element phased array coil).

Image processing and data handling: Slice tracking calculations were performed with the pencil-beam navigator code of the Achieva platform on the CDAS acquisition system itself. The resulting slice position together with the subsequent raw k-space data was streamed with the IMF interventional RT-toolkit to an in-house developed real-time reconstructor which performed the Fourier image reconstruction, the in-plane motion compensation [3], the phase corrections [5] (including a linear drift correction) and finally MR-thermometry [2]. The resulting image latency of the entire processing chain is 55ms (post echo-time).

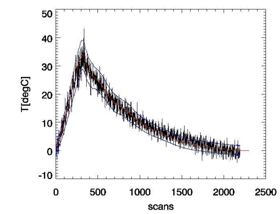

Figure 2. Results of the corrected MR-thermometry (black), which correspond well with the probe-readings (red) and are found within the precision limit imposed by the SNR (blue).

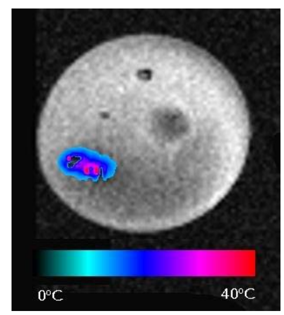

Figure 3. MR-thermometry at peak temperature overlaid over the corresponding magnitude image.

Results and Discussion

Figure 1 shows the result of MR-thermometry with slice-tracking enabled, but without phase correction. The passage of the phantom and thus the imaging slice through the inhomogeneous magnetic field of the MR-system leads to large phase fluctuations which in turn result in artefactual temperature oscillations of over 20ºC. Figure 2 shows that the proposed phase correction based on the tracking data can reduce the temperature variations down to the precision limit given by the SNR of the employed sequence. Figure 3 shows the temperature distribution after 60s of imaging (i.e. at peak temperature) which corresponds well to the data obtained from a static reference experiment (data not shown). Figure 4 and 5 show the result of the uncorrected and the corrected MR-thermometry, respectively, in the same voxel during three minutes of free-breathing. Similar to the results obtained from the phantom data, the large artefactual temperature variations due to the tracking over the respiratory motion cycle can be entirely removed.

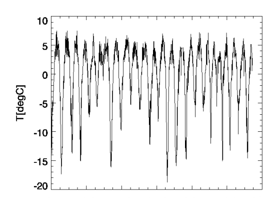

Figure 4. Uncorrected MR-thermometry of a voxel in the left kidney of a volunteer during three minutes of free-breathing.

Conclusions

Continuous and precise MR-thermometry with high temporal resolution is a necessary prerequisite to guide non/mini-invasive thermal-ablations carried out by HIFU or RF-heating on abdominal organs such as liver or kidney. The presented method shows that it is possible to perform real-time 3D-navigated thermometry on abdominal organs during free-breathing over extended periods of several minutes. The achieved precision is within the boundary imposed by the SNR of the sequence.

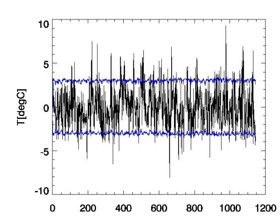

Figure 5. Corrected MR-thermometry of a voxel in the left kidney of a volunteer during three minutes of free-breathing.

References

[1] Hynynen K. et al., Eur J Radiol, 2006, 59:149-56.
[2] Quesson B. et al., JMRI, 2000, 12:525-33.
[3] Maclair G. et al., IEEE, ICIP 2007, vol.III, 141-44.
[4] Nehrke K. et al., MRI, 1999, 17:1173-81.
[5] Senneville B. et al., MRM, 2007, 57:319-30.