

Real-time MR-Thermometry and Dosimetry for interventional guidance on abdominal organs

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Purpose/Introduction

Real time magnetic resonance (MR) thermometry based on the water proton resonance frequency (PRF) [1] is a promising tool to monitor and control interventional therapies based on thermal ablation [2]. In this work, a computationally efficient pipeline for 2D motion compensated PRF-thermometry and thermal dose measurements on moving abdominal organs is presented [3]. The method is designed to address both, inter-scan and intra-scan artifacts by applying high frame-rate MRI coupled with a real-time image registration of all incoming MR-images. Furthermore, temporal filtering of the temperature maps allows to choose a balance between temporal resolution and the MR-thermometry precision that can be freely adjusted according to the employed interventional modality and the available signal-to-noise ratio of the target. MR-image guidance for interventions, such as high intensity focused ultrasound (HIFU) ablations, require the temperature and thermal dose measurements to be available in real-time and preferably with short latencies. Therefore, all computational intensive calculations are off-loaded to a dedicated graphics processing unit (GPU) to ensure both conditions. The potential of the real-time reconstruction pipeline to remove MR-thermometry artifacts dynamically is evaluated in-vivo on the abdomen of 11 healthy volunteers under free-breathing conditions, and on a porcine kidney during an HIFU-heating experiment.

Materials and Methods

Thermometry processing: Figure 1 gives an overview of the employed data processing sequences. To resolve inter scan motion, a principal displacement component estimation is computed, assuming an affine displacement (6 transformation parameters). This serves as pre-conditioning for a more complex optical flow based motion estimation approach [3]. To address susceptibility related phase changes with motion, a linear relation between motion and registered phase variations is evaluated individually for each voxel [4]. Therefore, during the intervention, the estimated motion is used to obtain a synthetic reference phase map. This phase map is subtracted to the acquired motion registered phase image to suppress the background phase information prior to temperature calculation. A drift correction is applied, by subtracting a global temperature offset obtained from a region of interest, which is chosen in the moving organ, adjacent to the ablation area. Finally, a temporal filtering based on an infinite impulse-response filter was applied on the temperature taking benefit of the motion compensation to improve the precision. The proposed approach combines a CPU/GPU architecture by offloading computational intensive calculations to the GPU (NVIDIA GTX280). GPU Implementation was realized using CUDA [5].

MRI: Dynamic MR temperature imaging was performed on a Philips Achieva 1.5 T with a single-shot gradient recalled echo-planar sequence. The precision of the thermometry was evaluated under real-time conditions on both kidney and liver of 11 healthy volunteers under free breathing. The employed sequence was designed as follows: 3000 dynamic sagittal images, one slice, TR=100ms, TE=26ms, flip angle=35°, FOV=256×168×6 mm³, matrix=128×84.

MRI guided HIFU was performed in vivo in the kidney of a pig under general anesthesia using a MR compatible Philips HIFU prototype (256 elements HIFU transducer, radius=120 mm, aperture=126 mm, ellipsoid focal point=1×1×7 mm³) (Imasonic, Besançon). The MR sequence employed the following parameters: 1500 dynamic sagittal images, one slice, TR=100 ms, TE=41 ms, flip angle=35°, FOV=320×140×6 mm³, matrix=128×56, using the integrated phased array coil of the HIFU system.

Results

The resulting overall latency for the entire pipeline (including 13 ms for data transport and 1.2 ms for image reconstruction) was reduced from 95 ms (CPU only) to 27.3 ms (CPU/GPU). On average over all volunteers, the temperature stability is improved from an initial value of over 8 °C to 1.5 °C (kidney) and 2.16 °C (liver). This precision is furthermore improved by over 20 % if a drift correction is applied. Additional temporal filtering results in a final precision of 0.79 °C in the kidney and 0.98 °C in the liver. Even in this case, the method ensured 2 °C of temperature stability in 70 % of all pixels of both the kidney and the liver. For the porcine HIFU ablation experiment (Figure 2), the overall temperature accuracy over the whole kidney was 0.65 °C ± 0.11 (min=0.4, max=0.99) and an hyperthermia of 12 °C was reached, which leads to a final thermal dose of 10 % of the lethal dose.

Discussion and conclusions

The proposed approach for 2D motion compensated MR-thermometry and dosimetry addresses both, inter-scan and intra-scan motion artifacts, by applying high framerate MRI coupled with real-time processing correction (using GPU hardware) of all incoming MR-images. This allows to achieve a sub-second temporal resolution with very short image latencies. Additional temporal filtering of the temperature maps allows to freely readjust the balance between temporal resolution and additional precision of MR-Thermometry. The method was found robust in all examined cases and well able to follow the temperature evolution of an in-vivo HIFU ablation. This renders the method well suitable for the MR-guidance of hyperthermia ablations in abdominal organs under free-breathing conditions and as the basis for more advanced automatic spatial and temporal temperature control algorithms used in conjunction with dynamic ultrasound beam-steering.

References

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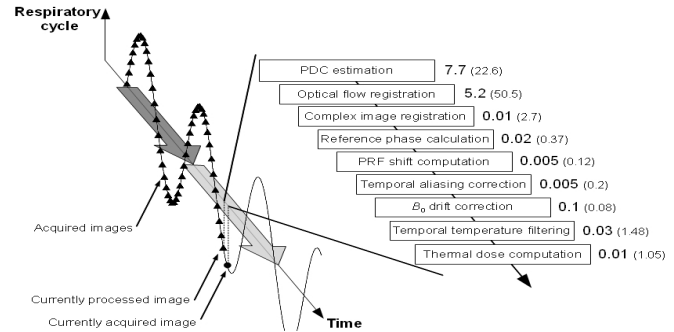


Figure 1. Data processing sequence with separation of the intervention into a pre-treatment step (dark grey arrow) and a hyperthermia step (light grey arrow). Computation times in milliseconds for one image (resolution 128×128) are reported using the CPU/GPU implementation (bold) and CPU only implementation (brackets).

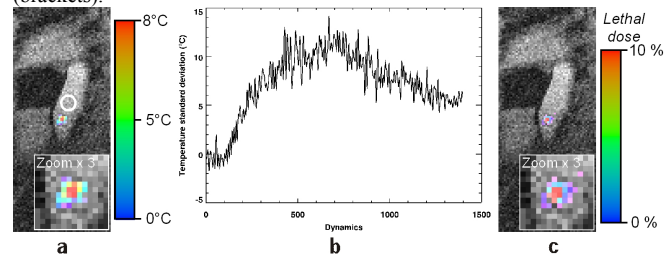


Figure 2. MR-Thermometry results obtained on a porcine kidney during HIFU heating: (a) the temperature distribution obtained after 39 seconds of heating and the ROI used for drift correction overlaid on the anatomical image, (b) the temporal evolution of the temperature at the focal point position, (c) the thermal dose map obtained at the end of the experiment