MRI guided Focused Ultrasound of moving tissues: Accelerated MR-thermometry and motion analysis for subsecond target tracking

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Purpose/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, the use of MR-controlled HIFU for the ablation of tumors in abdominal organs under free-breathing conditions poses two challenges:

- Phase variations due to the organ displacement must be corrected in real-time to prevent temperature artefacts.
- The current organ position must be continuously tracked in order to reposition the focal point of the HIFU-ablator to avoid undesired tissue damage.

The presented work is a feasibility study to explore the possibilities of real-time MR-thermometry and beam steering which links four key technologies: Fast temperature imaging [3], a lookup-table based MR phase-image correction scheme which is suitable to correct periodic motion [4], fast optical-flow based MR-image registration [5] and a phased array Focused Ultrasound (HIFU) ablator with subsecond response time [6].

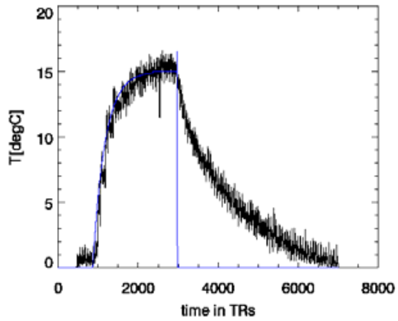

Figure 1 : Target temperature profile (blue) and measured temperature (black) at the hot-spot of the motion compensated heating experiment.

Material and Methods:

<u>MRI imaging:</u> Dynamic MR temperature imaging was performed on a Philips Achieva 1.5 Tesla with a dual-shot gradient recalled EPI sequence (TE=18ms, TR=45ms, Matrix: 128x64, $2\times2\times4mm^3$, single slice) with a surface coil placed around the phantom.

<u>Focused Ultrasound System:</u> Heating was performed with an in-House built 256-channel focused ultrasound transducer permitting independent phase and amplitude control of each channel. The system is integrated in the MR-bed and allows a lateral displacement of the focal point of 15mm peak-to-peak with a maximal repositioning frequency of 15Hz.

<u>Physiological Phantom:</u> A physiological phantom with relaxation times matched to the human kidney was mounted on a motorized platform to simulate an abdominal organ (displacement 12mm peak-to-peak, motion period 3s to match the human respiratory cycle).

<u>Real-time-processing and treatment strategy:</u> K-space data was exported from the Philips acquisition system using TAO (The Ace ORB [7], a real-time implementation of the CORBA communication protocol) to a four processor AMD Opteron reconstructor which performs Fourier reconstruction, optical-flow based 2D image registration, lookup-table based phase correction, temperature calculation, and HIFU power and aim control functions in ~35ms (Matrix 128x128). The entire intervention is separated into two phases: the learning phase and the treatment phase [4]. In the <u>learning phase</u> (duration 7s), 75 images are acquired to sample one entire period of the motion cycle. A complete set of reference magnitude and phase images is established and organ displacement relative to the first image is estimated for each image using optical flow based 2D-registration algorithms on a pixel by pixel basis [5]. Subsequently, during the <u>therapy phase</u>, each new magnitude image is compared to the set of reference images using an inter-correlation coefficient. For <u>MR-thermometry correction</u>, the image of the atlas with highest similarity is selected, and the corresponding phase image is used as the reference for temperature computation. Then, the motion vector field estimated from anatomical images is used to register the obtained temperature map to the original position of the organ and to re-aim the focal point of the HIFU-device to the current location of the chosen target. Finally, the power level of the HIFU-device is adjusted by comparing the current temperature with the desired temperature using an adapted PID algorithm [8].

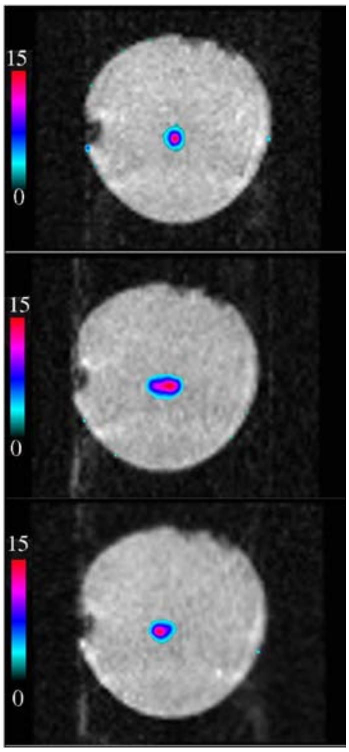

Figure 2 : Snapshot of the temperature distribution after 200s of heating for the static experiment (top), under motion, but without compensation (middle) and under motion with applied motion compensation (bottom).

Results and Discussion

Figure 2 shows the temperature distribution during the static, the non-motion compensated and the motion compensated heating experiments. Motion tracking allows a controlled temperature rise as shown in Figure 1, in a well-contained area comparable to the static experiment. The slightly larger hot-spot size can be explained by an asymmetric focal point enlargement caused by off-axis focusing of the HIFU-system and by residual lag in the beam-tracking caused by image processing latency.

Conclusion and Perspectives

This study demonstrates the feasibility of real-time MR-thermometry and beam steering for High Intensity Focused Ultrasound ablations on moving targets with an update rate >10Hz as a step towards controlled thermo-ablations on abdominal organs. For in vivo experiments, several problems still have to be addressed: Firstly, data acquisition and processing inevitably cause latency between data acquisition and re-aiming. Therefore, a suitable latency compensation has to be applied. Secondly, although the displacement of abdominal organs is predominantly linear and can thus be covered by 2D imaging, residual motion orthogonal to the imaging plane has to be addressed.

References

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