Combined Magnetic Resonance Imaging and Ultrasound Echography Guidance for motion compensated HIFU Interventions

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Introduction

Recently, it has been demonstrated that high intensity focused ultrasound (HIFU) systems based on a phased-array transducer technology in combination with advanced real-time MRI guidance allow to perform motion compensated ablations on continuously moving organs, such as the liver and the kidney [1]. For full MR-guidance of this type of interventions, MRI has to full-fill two roles simultaneously: First, MRI has to provide anatomical information with high spatio-temporal resolution and low image latency in order to obtain target tracking information required for HIFU-beam steering. Second, motion corrected MR-thermometry represents the basis for retro-active control of the beam power and allows monitoring the progression of the ablation process. Although both roles are compatible, the need to full-fill their particular requirement simultaneously, leads generally to a sub-optimal volume coverage and precision of the thermometric measurements. As a potential alternative, this feasibility study investigates the possibility to use ultrasound (US) echography as an additional imaging modality for continuous target tracking, while performing simultaneously real-time MR-thermometry to guide the HIFU ablation process.

Materials and Methods

Acquisition strategy: The simultaneous use of all three modalities (Echography, MRI and HIFU) is complicated by their mutual interferences: High power US emissions lead to strong echography artefacts, while the use of diagnostic echography equipment in an MRI-system leads to RF-contamination of the MRI-acquisition. To overcome these limitations, MRI data sampling and HIFU were performed simultaneously, while echography was applied during the preparative and trailing RF-pulses, gradients and delays of the MRI-sampling period, as shown in Figure 1.

Tracking strategy: Two tracking approaches were investigated: In the first approach, displacements were directly estimated on the echography images and the HIFU beam position corrected on-the-fly. In the second approach, echography was used indirectly for target tracking: During a preparative step, motion was estimated on MR-images and associated with the corresponding speckle pattern of the echography image. This information was used to calibrate a model, based on principal component analysis, of the motion vectors [2], which allows resynthesizing the organ position during the subsequent HIFU therapy based on echography alone. Except the model calibration, all processing steps were executed in real-time by offloading computationally intensive tasks to a GPU-architecture (NVIDIA Tesla 2050) using CUDA.

Phantom: 350g of porcine muscle tissue were mounted on motorized platform in order to simulate respiratory induced motion (motion periodicity 3s, amplitude 1.5cm ptp).

MR-imaging: Motion corrected [3] dynamic PRF-temperature imaging was performed using a single-shot EPI-sequence in a Philips Achieva 1.5 T MRI with the following parameters: Single slice, frame rate of 10 Hz, TR=100 ms, TE=25 ms, flip angle=35°, FOV=103×300 mm², voxel size=2.3×2.3×7 mm³. For the indirect US-tracking experiments motion was estimated during the learning step from magnitude images on a voxel-by-voxel basis using an optical flow based image registration [3].

US-imaging: A diagnostic echography system (Echoblaster 64 Telemed Ltd.Vilnius/ Lithuania) was equipped with a blanking electronic and stripped from all ferromagnetic materials in the imaging head. The system acquired 2D b-mode images with a frame rate of 20 Hz, FOV=150×50 mm², nominal resolution=2.3×0.8 mm². All images were contrast enhanced using the local monogenic phase [4] and an optical flow based image registration [5] was applied on a voxel-by-voxel basis to establish the displacement vectors.

HIFU: HIFU heating was performed for 75s with 35 Watts of electrical power using a Philips Sonalleve HIFU system, which is integrated into the patient bed of the MR-system. The focal point position was updated with a frequency of 10Hz based on Kalman filtered motion trajectory [1].

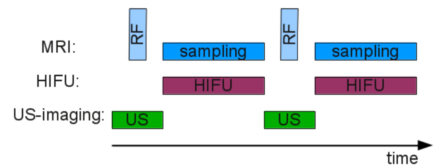

Figure 1. Timing diagram of the combined US- and MR-acquisition during the HIFU ablation.

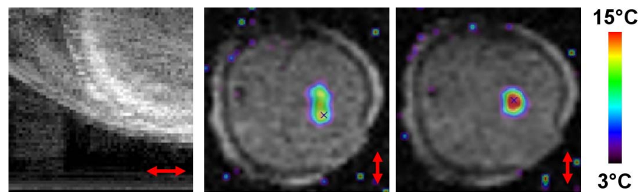

Figure 2. Left: Echography of the moving target which served for tracking. Middle/right: T_2^* weighted MRI with overlaid temperature after 75 s of sonication. Note the energy spread along the target trajectory for the uncompensated experiment (middle), compared to the focused energy deposition when dynamic beam steering is applied (right). The direction of the target is indicated by the red arrow, respectively.

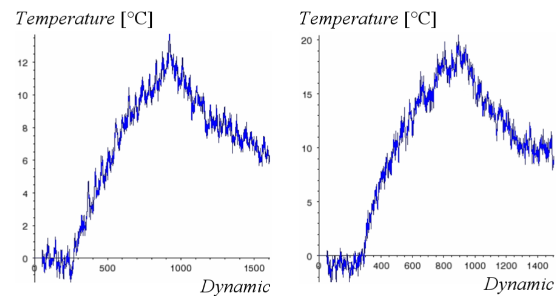

Figure 3. Temperature evolution obtained in a voxel located in the heated region (black cross in Figure 2) without (left) and with beam steering (right).

Results and Discussion

While the non-tracked experiment disperses the HIFU energy along the motion trajectory, both echography-based tracking approaches were able to focus the beam energy to the designated target position during the intervention, as shown in figure 2. This resulted in a 50% higher peak temperature as shown in figure 3. Compared to MRI based target tracking with simultaneous MR-thermometry, using echography for tracking allows optimizing the MRI acquisition during therapy entirely for the requirements of MR-thermometry. This allows sacrificing temporal resolution to achieve a larger volume coverage and higher thermometric precision. Indirect echography-based tracking does not require the ablation-area to be directly in the FOV of the echograph and allows to use the superior soft tissue contrast of MRI for a precise characterization of the motion cycle. Furthermore, all computationally intensive steps are concluded before the HIFU intervention starts, which reduces the tracking latency. In comparison, direct echography tracking does not require to learn the motion pattern prior to the intervention and is therefore able to address spontaneous motion. On the other hand, the increased tracking latency of 60ms has to be compensated by a motion predictor [1]. The main drawback of the proposed approach is a reduction of the duty-cycle of the HIFU system due to the blanking and the added complexity of having to acquire, process and combine in real-time echography images and MRI in order to achieve retro-active control of the HIFU system.

References

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