Three dimensional motion compensation for real-time MRI guided focused ultrasound treatment of abdominal organs

M. Ries[1], B. D. De Senneville[1], G. Maclair[1], M. O. Köhler[2], B. Quesson[1], and C. Moonen[1]

[1]UMR 5231, CNRS/Université Bordeaux 2, Laboratory for Molecular and Functional Imaging, Bordeaux, France, [2]Philips Healthcare, Vantaa, Finland

Purpose/Introduction

MR-guided High Intensity Focused Ultrasound (HIFU) for the ablation of tumors in abdominal organs under free-breathing conditions poses two challenges:

1) The current organ position in 3D-space must be continuously tracked in order to reposition the focal point of the HIFU-device to avoid undesired tissue damage.
2) Phase variations due to the organ displacement must be corrected in real-time to prevent temperature artifacts.

The presented work extends previous work on sub-second target tracking [1] and motion compensated MR-thermometry [2] to address both problems in three dimensions and in real-time. This is achieved by tracking the target position with 2D-optical flow based image registration [3], while out-of-plane motion is compensated by slice tracking based on 2D selective navigator data [4]. This allows real-time 3D positioning of the HIFU beam onto the moving target. The temperature evolution during the intervention is monitored by 3D motion compensated PRF-based MR-thermometry [5]. For this, phase variations are pre-recorded during the respiratory cycle according to the navigator tracking position and subsequently eliminated in real-time from the thermometry data [6]. The feasibility of the proposed method is demonstrated with phantom experiments and an in-vivo ablation of a pig kidney.

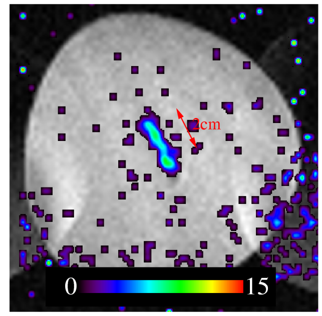

Figure 1: The temperature distribution after 60s of non-compensated HIFU application shows the energy dispersion along the motion trajectory. The motion vector of the phantom is indicated by the red arrow.

Material and Methods:

HIFU-system: Heating was performed with a *Philips clinical HIFU-platform*, a 256 element phased-array transducer which is integrated in the MR-bed and allows a lateral displacement of the focal point of 20mm peak-to-peak with a repositioning frequency of over 15Hz. The driver of the HIFU-system was modified to allow real-time adjustments of the beam position over a dedicated network link.

MRI imaging: Dynamic MR temperature imaging was performed on a *Philips Achieva* 1.5 Tesla with a single-shot gradient recalled EPI sequence (TE=41ms, TR=100ms, Matrix: 128x84, 2.5×2.5×6mm^3, single slice) with the multi-element receive coil integrated in the HIFU-system.

Phantom Experiments: A physiological phantom with relaxation times matched to the human kidney was mounted on a motorized platform to simulate an abdominal organ (displacement 15mm peak-to-peak, motion period 4s to match the human respiratory cycle). Beam steering and MR-thermometry were evaluated to compensate for both in-plane motion and through-plane motion.

In-vivo Experiments:

Motion compensated MR-thermometry was performed for a duration of two minutes on the right kidney of a 45kg pig. After an initial baseline sampling of 30s, a HIFU ablation of 80W acoustic power and 60s duration was performed. The motion induced by the respiratory cycle (8mm amplitude, 6s period) was compensated by adjusting the beam position with an update frequency of 10Hz and resulted in a temperature elevation of 25°C.

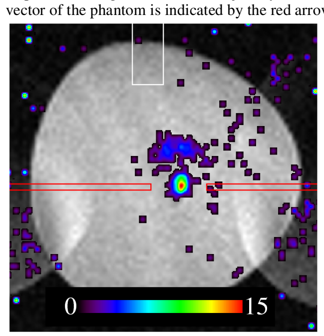

Figure 2: The temperature distribution after 60s of fully motion compensated HIFU application shows that the beam energy is deposited at the predefined location. The slice position displayed in figure 3 (below) is indicated in red and the navigator-beam placement in white.

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] and finally MR-thermometry and thermal dose calculation [2]. The resulting updated target position was sent to the HIFU ablation system resulting in an overall update latency of 62ms (post echo-time).

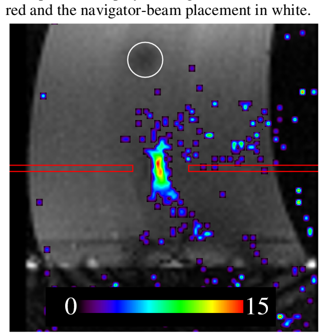

Figure 3: Similar results can be achieved if the acquisition slice is rotated by 90°. In this case in-plane and through-plane motion is compensated. The slice position displayed in figure 2 (above) is indicated in red and the navigator-beam placement in white.

Results and Discussion

Figure 1 shows the temperature distribution after 60s of HIFU-ablation on a moving target without beam-steering. As expected the energy is spread over the entire length of the target trajectory. In comparison, the motion compensated experiment shown in figure 2 allows to deliver the beam energy to a single spot. Due to latency and precision limits of the motion estimation and the beam repositioning, the focal point size (3mm FWHM) was found to have increased by 35% compared to the reference experiment without motion. The experiment shown in Figure 3 demonstrates the ability to correct in-plane and through-plane simultaneously.

Figure 4 shows the overlay of the temperature distribution after 60s of HIFU-ablation in a pig kidney. The proposed method allowed to deliver the HIFU energy to the designated target area without prior knowledge of the organ position.

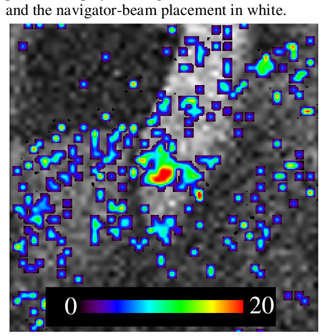

Figure 4: Temperature distribution after 60s of motion compensated HIFU-ablation on the right kidney of a pig.

Conclusion and Perspectives

MR-guided HIFU-ablations of abdominal organs require a robust motion compensation of both, MR-thermometry and target position. The presented in-vivo data shows that real-time MR-thermometry coupled with dynamic beam steering are promising candidates for this role. The possibility to extend the presented methodology to more complex ablation strategies such as motion compensated volume ablations is currently under evaluation.

References

[1] Ries M. et al., [2006], Proc. ISMRM p246. #1132
[2] Köhler M.O. et al., [2007], Proc. ISMRM p198. #1226
[3] Maclair G. et al., IEEE, ICIP 2007, vol.III, 141-44.
[4] Nehrke K. et al., MRI [1999], 17:1173-81.
[5] Quesson B. et al [2000], JMRI, 12(4):525.
[6] Senneville B. et al., [2007], MRM, ;57:319.