Respiratory gating of MRgHIFU treatments in vivo using an optical motion tracking system

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Objectives. The use of external optical system has been demonstrated for the prospective and retrospective correction of rigid displacement of the anatomy during MR acquisition [1]. The purpose here was to use in-bore digital camera for monitoring in real time fiducial markers attached to the skin as direct estimators of the respiratory phase, in the context of interventional MRI for moving organs. Contrarily to conventional mechanical sensors (abdominal belt or pressure cushion) that are indirect predictors of organ motion [2], are operated user-dependent and may complicate the abdominal interventional procedures, our approach is versatile, user-independent and enables a large field of view for the motion estimation. We employed the in-bore optical tracking system for the detection of the quiet-phase of exhalation, this information being used for MRgHIFU treatment preparation and execution in sheep kidney and liver *in vivo*.

Material & Methods.
A consumer-grade USB digital camera was adapted in order to ensure its MR-compatibility (magnetic parts were removed and RF-shielding was added). Additional source of light was added (high power white LEDs) to improve the image quality. In-house written C++ application based on OpenCV libraries was used to generate the triggers via a conventional DAC interface. Landmarks were automatically set on sharp edge-features in the optical ROI and their displacement was followed using a calculation of the optical flow based on iterative Lucas-Kanade method in pyramids [3].

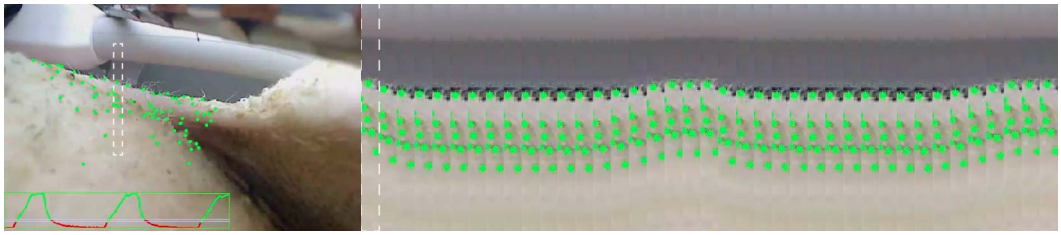

Figure 1. Webcam-based tracking of landmarks on a sheep skin, used as external sensor for the gating/triggering of HIFU sonications.

An RF-spoiled segmented EPI gradient echo sequence was used for PRFS-based MR-thermometry (MRT) and acoustic radiation force (MR-ARFI) acquisitions. The MR-ARFI sequence included an additional symmetric bipolar motion encoding gradient (MEG) in the slice-select direction (max amplitude = 38 mT/m, slew rate = 100 T/m/s, duration = 4 ms) between the RF excitation pulse and the EPI readout. The main imaging parameters were: FOV = 128x128 mm, voxel = 1x1x5 mm, TE(ARFI) = 16 ms, TE(MRT) = 9 ms, echo spacing = 1.58 ms, HIFU-dedicated 3 channel interventional matrix coil. HIFU system consisted of a 256 multi-element transducer with a maximum acoustic power of 260 W, emitting 5.5 ms-long bursts for ARFI acquisitions and CW inside the gating window for ablative sonications. MR-guided HIFU *in vivo* liver (trans-costal) and kidney experiments were performed in sheep under general anesthesia and mechanical ventilation. For MR-ARFI acquisitions, twin successive acquisitions with alternating MEG polarity inside the same quite phase of respiration were used to encode the HIFU-induced tissue-displacement [4,5]. The repeatability of organs position was studied by measuring the in-plane position of their edges on magnitude images.

Results. The detection of the quiet-phase of exhalation based on in-bore optical acquisition allowed robust triggering of MR acquisitions and yield accurate ARFI and thermal maps (respective standard deviation of 0.3 µm and 0.3 °C), without measurable motion-induced artifacts (like ghosting). The overall latency of the tracking system was found less or equal to 60 ms (maximum 35 ms for image reconstruction and external sender plus maximum 25 ms for optical flow calculation). The respiratory intra-cycle drift during the exhalation induced average kidney shift of 230 µm between the twin MR-ARFI measurements, while the peristaltic drift-corrected standard deviation of respiratory inter-cycle organ position was found to be 70 µm.

Conclusion. The use of in-bore optical tracking of the patient skin for the respiratory triggering/gating of MR-ARFI, MR-thermometry and HIFU sonication was demonstrated *in vivo* in sheep kidney and liver. This modality is "no touch" and keeps free of any external acoustic obstacle the HIFU beam entry window.

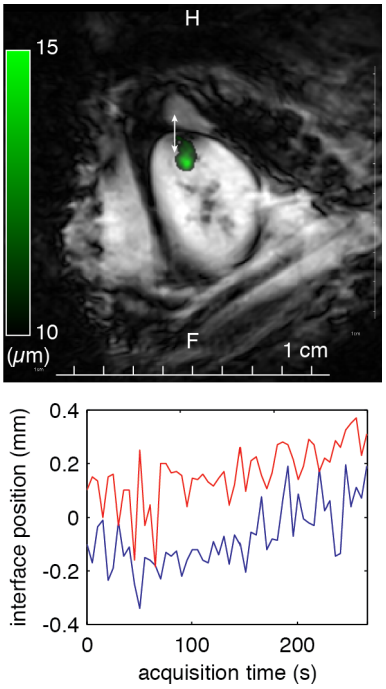

Figure 2. Example of respiratory-triggered MR-ARFI acquisition in a coronal plane. Note the kidney border detected along the H/F direction. This value is plotted vs. time for the twin acquisitions of the same respiratory cycle (resp. red and blue curve).

References. [1] Zaitsev et al. 2006, Neuroimage [2] Odille et al. 2008, MRM [3] Bouguet 2000, OpenCV documentation [4] Plewes et al. 1995, JMRI [5] Le et al. 2006, MRM