MRI guided Focused Ultrasound of moving organs: target tracking with on-line anticipation of periodic displacements

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Purpose/Introduction

High Intensity Focused Ultrasound (HIFU) is a powerful and non-invasive technique for the local deposition of thermal energy deep inside the body [1]. MRI guidance offers the additional benefits of excellent target visualization and continuous temperature mapping using the PRF shift technique [2]. Applying these methods on moving targets such as abdominal organs poses two challenges: 1) motion related thermometry artifacts must be corrected; 2) the ultrasound focal point must be relocated according to the target displacement. Without these corrections, treatment may be inefficient or may induce unwanted destruction of healthy neighboring tissue.

However, MR-data acquisition, image reconstruction and motion analysis introduce latency between the motion estimate and the actual position of the organ which has to be accounted for. Since motion in the abdomen is primarily induced by the respiratory cycle and thus periodic, this study presents a method for motion anticipation which allows to correct the processing latency by exploiting the periodic nature of the respiratory cycle.

Material and Methods:

MRI imaging: Dynamic MR temperature imaging was performed on a Philips Achieva 1.5 Tesla with a single-shot gradient recalled EPI sequence (TE=18ms, TR=1.0s, Matrix: 96x96, 2×2×4.5mm^3).

Focused Ultrasound System: An in-house designed focused ultrasound transducer with 256 elements is placed into the MR-bed, allowing electronic displacement of the focal point over 15mm.

Physiological Phantom: A physiological phantom is mounted on a motorized platform to simulate an abdominal organ (displacement 14mm peak-to-peak, motion period 5s to match the human respiratory cycle). The position of the phantom is measured with an optical position sensor for comparison with the motion correction based on the MR images.

Real-time-processing and treatment strategy: The entire intervention is separated in two phases, the learning phase and the treatment phase.

In the learning phase 50 images are acquired to sample the periodical motion. A complete set of reference magnitude and phase images is constructed and organ displacement is estimated for each image using optical flow registration algorithms on a pixel by pixel basis [3]. From these displacement vector fields, an average global motion vector is calculated. These vectors and the displacement vector fields are stored with the corresponding magnitude images. Subsequently, a spectral analysis of the periodic changes of the global motion vector is performed in order to determine the period cycle.

During the therapy phase, each new magnitude image is compared to the set of reference images using an inter-correlation coefficient. For MR-thermometry correction, the image of the atlas with highest similarity is selected, and the corresponding phase image is used as the reference for temperature computation. The motion field vector estimated from anatomical images is then used to correct the spatial transformation in the obtained temperature map. Finally, the power level of the HIFU-device is adjusted by comparing the current temperature with the desired temperature. For this a PID algorithm is used which accounts for the currently clocked latency. For precise HIFU-tracking the displacement of the organ during the latency period has to be estimated. The criterion used for this anticipation is based on an analysis of the main global motion variation. For this global motion vector is compared to atlas stored global motion vectors, in order to determine the temporal localization of the current image in the global motion cycle. Subsequently, a lookup of the stored motion field vector, corrected by the measured latency, provides the anticipated current position of the organ. The last step is the readjusting of the HIFU-system onto the new anticipated position.

Results and Discussion

Figure 1 shows that the anticipated motion provides a good estimate of the real displacement (accuracy better than 0.33mm). Figure 2 show the temperature maps obtained following 30W acoustic power during 50s. The temperature standard deviation outside the heated region is reduced from 30°C (a) to 0.7°C when the MR-thermometry correction is applied (b). When the position of the focal point is not adjusted during target movement, the energy deposition is spread over 14mm along the displacement direction (b). With HIFU-tracking applied, a well focused temperature rise is observed, indicating that the energy is deposited over the same tissue area during hyperthermia (c).

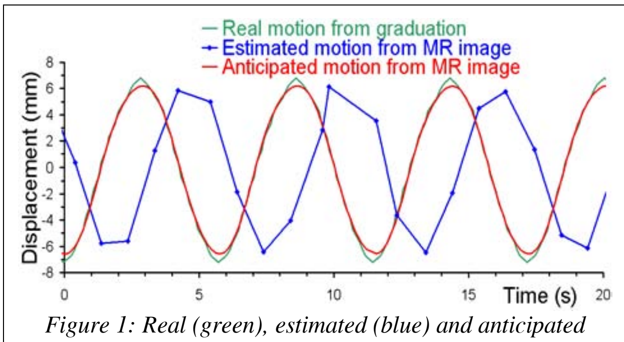

Figure 1: Real (green), estimated (blue) and anticipated position (blue) of the target for a processing latency of 2s.

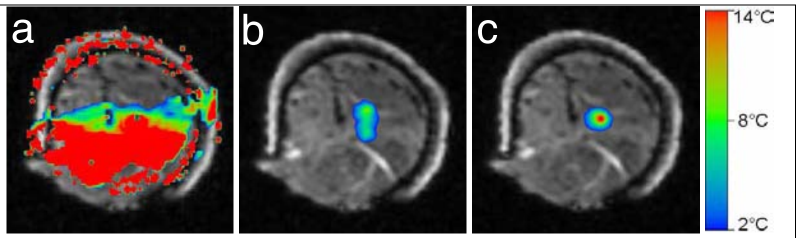

Figure 2: Temperature variation maps obtained from a physiologic phantom under rigid periodical motion without MR-thermometry correction nor HIFU-tracking (a), with MR-thermometry correction but without HIFU-tracking (b). Finally, (c) shows the improved temperature precision and energy deposition when both corrections are applied.

Perspectives and Conclusion

High intensity focused ultrasound treatment of abdominal organs under MR control requires a robust motion compensation that corrects also for data-acquisition, handling and processing latency. The proposed method accounts for the later and provides a correction of the focal point position for periodical movements. Although the method requires a periodic global motion estimator (though of arbitrary shape, not necessary harmonic), complex local deformations such as elastic deformations are also corrected [4].

References

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