Automated Treatment of 3D Tumor Volume With Adaptive Model-Predictive Controller In Vivo

Joshua de Bever[1,2], Nick Todd[2], Allison Payne[2,3], and Robert Roemer[4]

[1]*School of Computing, University of Utah, Salt Lake City, Utah, United States,* [2]*Utah Center for Advanced Imaging Research, Salt Lake City, Utah, United States,* [3]*Department of Radiology, University of Utah, Salt Lake City, Utah, United States,* [4]*Department of Mechanical Engineering, University of Utah, Salt Lake City, Utah, United States*

PURPOSE:

High intensity focused ultrasound (HIFU) combined with magnetic resonance temperature imaging (MRTI) makes possible a completely non-invasive treatment modality, MR guided HIFU (MRgHIFU). However, treatments of large, complex 3D tumor volumes would be difficult for a human to perform efficiently and safely. A highly configurable adaptive model-predictive controller (AMPC) leverages MRTI as a feedback mechanism to automate MRgHIFU treatments while still giving clinicians supervisory control. The AMPC has been tested *in vivo* and it successfully optimized the individual pulse heating and cooling times while protecting healthy tissue. The heating model is adapted dynamically during treatment making the controller's predictions robust to changes in tissue properties and obviating lengthy pre-treatment model identification. The AMPC makes the treatment of complex 3D tumors more efficient, safe, and reliably effective.

METHODS:

The clinician configures the AMPC by identifying two voxel types on anatomical MR images of the patient: (1) Treatment voxel (TV) – tissue to be ablated and (2) Safety voxel (SV) – critical tissue to be protected. The AMPC's task is to deliver a target thermal dose to all TVs as quickly as possible while preserving healthy tissue. Safety is ensured by shutting off the ultrasound beam if any SV exceeds a clinician configured temperature threshold. The set of all TVs is subdivided into one or more treatment cells (TC). Each TC is ablated while the HIFU focal zone is in a single position, and treatment cells are ablated sequentially in the order specified by the clinician. After receiving an MR temperature measurement, the controller dynamically adapts an exponential heating model for each TV in the current cell. The adaptive heating model and a fixed exponential cooling model are used to predict the minimum heating time required such that the target dose will be delivered after the tissue has cooled. After reaching the predicted heating time, treatment progresses to the next cell until all treatment voxels are ablated.

RESULTS & CONCLUSION:

Figure 1a shows the experimental arrangement for all *in vivo* rabbit thigh muscle tests. In one representative example, a 5x5x9 mm 3D target volume consisting of 150 TVs was subdivided into nine treatment cells (figure 1b & 1c). The numbers indicate the cell each TV was assigned to and the sequence of ablation. The circles indicate the focal spot location for each TC. Temperature feedback was provided by a 3D GRE segmented EPI sequence, and figure 1d shows the final thermal dose map with TVs overlaid (black squares) for a single slice of this test treatment. The controller successfully treated the target volume in all tests, and model-prediction saved time by automatically advancing to the next treatment cell before the target dose of 240 CEM was reached. Adaptive model generation allowed the controller to make predictions without pre-treatment simulations or heating pulses.

ACKNOWLEDGEMENTS:

This work is supported by the Mark H. Huntsman Endowed chair, NIH grants R01 CA87785 and R01 CA134599, The Ben B. and Iris M. Margolis Foundation, NSF IGERT Award# 0654414, and the Focused Ultrasound Surgery Foundation.

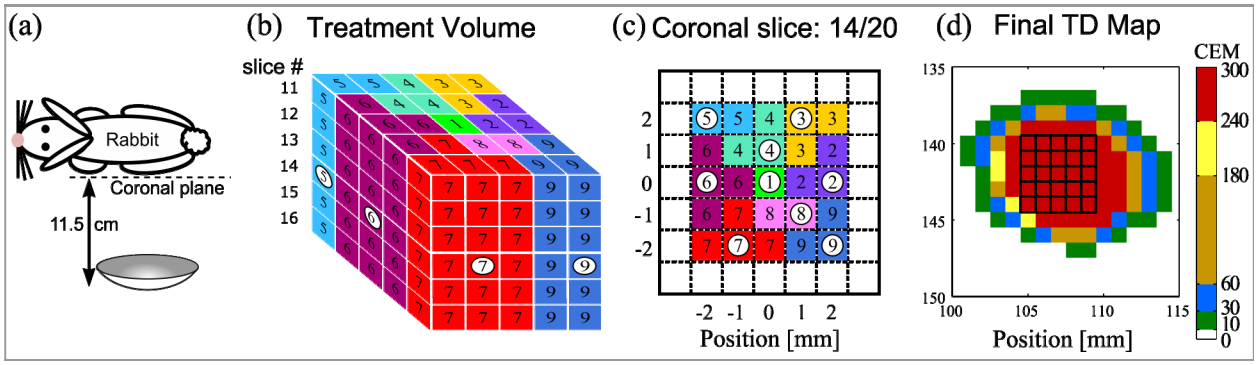

Figure 1: [a] Experimental setup, [b] controller configuration: 3D treatment volume (circled #'s indicate focal zone center and order), [c] controller configuration: central 2D slice through 3D volume, [d] final thermal dose map through central treatment slice.