3D Acoustic Simulation and Optimization Algorithms for Transcranial Focused Ultrasound Delivered With Robotic Systems

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Neurodegenerative diseases, such as Alzheimer's disease, are one of the leading causes of disability and death worldwide. Current pharmaceutical treatments are hindered by inefficient drug delivery methods to transport medication across the blood-brain barrier (BBB). Fortunately, focused ultrasound (FUS), a rapidly emerging noninvasive therapeutic device, can open the BBB by concentrating ultrasonic energy at a centralized location point in the brain. This increases the bioavailability of therapeutics for improved medical treatment and likelihood of patient survival. Although beneficial in clinical settings, FUS suffers from attenuation and distortion caused by the heterogeneous human skull, yielding a deviation between the focal point of FUS and its target. Finding the optimal FUS transducer for each patient and desired target for treatment is very challenging. In this project, I define this problem as constrained optimization and develop a novel iterative search algorithm to optimize a FUS transducer based on accurate 3D acoustic simulations of transcranial FUS propagation. From digital medical images, I present an automatic, universal framework to reconstruct high-fidelity acoustic and geometric properties of the skull and accurate 3D FUS simulations. Then, I design and develop a novel, graphics-processing-unit-accelerated iterative search algorithm to optimize a FUS transducer that outperforms the state-of-the-art, achieving a high accuracy and minimal error of 3.85 ± 1.37 mm and 3.56 ± 2.12 degrees. The novel modeling, simulation, and search algorithm are integrated into a surgical robot to establish an end-to-end framework for patient-specific FUS treatment, such as BBB opening for drug delivery and thermal ablation of cancerous tumors.

Awards Won:

Air Force Research Laboratory on behalf of the United States Air Force: Glass trophy and USAF medal for each recipient

Air Force Research Laboratory on behalf of the United States Air Force: First Award of $750 in each Regeneron ISEF Category, FOR 2023 ONLY: EBED WILL HAVE TWO

Association for Computing Machinery: Fourth Award of $500

Acoustical Society of America: Third Award of $600.00. In addition, their Mentor will be awarded $150.