Project 2 title: Machine learning Based Method for Transcranial Ultrasound Imaging and Therapy

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Transcranial focused ultrasound is an emerging technology that makes it possible to deliver ultrasound energy to specific targets inside the brain without surgery. This approach is being actively studied for several important medical applications, including localized thermal treatments, temporary opening of the blood–brain barrier to improve drug delivery, and non-invasive neuromodulation. A major technical challenge for all of these applications is the presence of the skull. Unlike soft tissue, the skull is dense, highly heterogeneous, and varies in thickness and structure from person to person and even across different locations in the same skull. When ultrasound waves pass through the skull, they are slowed down, weakened, and distorted in complex ways. These distortions cause the ultrasound beam to lose focus, shift away from the intended target, and spread out more than desired, which reduces treatment accuracy and limits safety. As a result, improving how ultrasound is focused through the skull is one of the most important steps toward making transcranial ultrasound more reliable and clinically practical.

In this summer research project, the student will work on a learning-based framework that uses ultrasound tomography data and machine learning to correct skull-induced distortions and improve transcranial focused ultrasound. The overall goal of the project is to help develop and test a fast, non-invasive method for predicting how the skull affects ultrasound propagation and for using that information to automatically correct the ultrasound beam before treatment. Rather than relying on X-ray CT scans or slow, computationally intensive physical models, this approach uses patterns in ultrasound measurements and modern machine learning to estimate key skull properties and directly support beam correction within an ultrasound-only system.

The project builds on an existing machine learning pipeline that has already been developed to predict maps of acoustic properties of the skull, such as sound speed, from ultrasound transmission measurements. These predicted maps are then used to calculate small timing adjustments for each element of a focused ultrasound transducer so that all waves arrive at the intended brain target at the same time. This allows the ultrasound waves to combine constructively and form a stronger and more accurate focus.

The first major task of the summer project will focus on understanding and extending this machine learning framework. The student will learn how ultrasound tomography data are generated, how they are organized for neural network training, and how a trained model is used to estimate skull properties. A key part of this task will be to explore how the existing framework can be expanded to operate at lower ultrasound frequencies. Lower frequencies are commonly used in transcranial ultrasound because they penetrate the skull more effectively and experience less signal loss. The student will examine how input data and training strategies need to be adjusted for this lower-frequency range and will help evaluate whether the learning framework can maintain good performance under these conditions.

In addition, the student will work on incorporating information from reflection ultrasound data into the learning process. Reflection images can be used to extract the outer surface of the skull, providing an estimate of skull shape and thickness. The student will help develop methods to extract this skull boundary and include it as an additional feature during training and validation of the neural network. This will allow the student to study whether explicitly providing geometric information about the skull helps the model better predict acoustic properties and ultimately improves the quality of aberration correction.

The second major task of the project will focus on experimental testing of the learning-based correction approach. The student will perform focused ultrasound experiments using an existing human skull specimen in a controlled laboratory environment. Using the skull property maps and phase corrections predicted by the trained machine learning model, the student will apply aberration-corrected focusing and generate focused ultrasound fields through the skull. The resulting acoustic fields will be measured using a small underwater microphone, called a hydrophone, which allows precise mapping of pressure patterns in space.

The student will compare focusing results with and without machine learning–based correction to determine how much improvement is achieved in focal strength, focal size, and targeting accuracy. This will help demonstrate whether the learning framework can meaningfully compensate for skull-induced distortions under realistic experimental conditions. Through this experimental work, the student will gain hands-on experience with transcranial ultrasound setups, focused ultrasound systems, positioning and alignment procedures, and acoustic field measurements.

Overall, this summer project provides hands-on training in machine learning, ultrasound imaging, and experimental validation, while contributing to the development of a fast, ultrasound-only approach for patient-specific transcranial focused ultrasound planning and safer non-invasive brain therapies.