IMPERIAL

PhD Project Description

Project Title

3D imaging of brain blood flow using ultrasound

Supervisors

Lead Supervisor: Dr Carlos Cueto

Co-supervisor(s): Dr Lluis Guasch, Dr Sophie Morse

Research Group

Transmission and Reflection UltraSound Tomography (TRUST)

Project Summary

Imaging blood flow in the brain is crucial to diagnose neurological disorders such as strokes and aneurysms, understand their root causes, and develop better treatments. However, no imaging method currently exists that can capture the dynamic, multi-scale nature of brain blood flow with sufficient detail, across all relevant patients, and in every possible setting. Using ultrasound waves, this project will experimentally develop and validate a portable, 3D technology capable of imaging vessels (arteries and veins) as small as a few microns at a speed of thousands of frames per second. The project will include the fabrication of experimental analogues of the brain, the design of ultrasound contrast agents, the development of novel acquisition sequences and the imaging of human volunteers. Through these developments, it will help establish the first truly universal imaging modality for studying blood flow in the human brain. This has the potential to change how we study and treat the brain and its disorders, across laboratories and clinics.

Research Context and Objectives

Neurological disorders are globally the most common cause of disability and second most common cause of death. These disorders are often associated with changes and impairments in brain blood flow, which makes imaging brain vessels crucial to both clinical diagnosis and scientific research. However, currently available tools, with magnetic resonance imaging (MRI) preeminent among them, are insufficient to universally interrogate the living brain: (1) the vasculature is inherently dynamic, but existing tools only capture static snapshots; (2) the brain vasculature spans scales ranging from centimetres to microns and velocities ranging from a few meters to less than one millimetre per second, but MRI lacks the resolution and sensitivity to capture this full spectrum; (3) MRI scanners are large, claustrophobic, and require that patients remain still, which prevents imaging patients continuously or while moving freely, as well as scanning people with movement disorders, claustrophobic, or obese.

Ultrasound is singularly positioned to address these issues, but the skull bone, a sound distorter, has prevented its transcranial application. This project will exploit advances that have already revolutionised imaging in geophysics, which we have recently used to prove that it is possible to image the brain structure through the skull, and will benefit from the recent construction in our lab of the first bespoke devices for 3D ultrasound brain imaging. At the same time, the project will incorporate recent advances in ultrasound contrast agents and super-resolution techniques inspired by Nobel-winning research in optical microscopy. Hinging on these disruptive advances, this project will combine signal processing, programming, and laboratory work to develop and validate, both experimentally and in human volunteers, a new ultrasound modality for brain blood flow imaging.

Objectives of the project:

A) Develop methods for fabricating experimental models of the macro- and micro-vessels in the human brain using 3D-printing techniques.

B) Fabricate bespoke ultrasound contrast agents and characterise them using a combination of ultrasound sensors and ultra-high speed cameras.

C) Produce 3D images of experimental models of the brain vessels; this will include investigating the trade-offs of different acquisition sequences, designing experimental setups, acquiring and processing ultrasound data, and developing new imaging algorithms.

D) Generate the first ever 3D ultrasound image that maps blood flow across the whole brain in human volunteers.

Collaborators and partners on the project:

The student will have ample opportunity to work closely with collaborators across ESE and the Department of Bioengineering at Imperial. There will also be opportunities to work closely with neuroscientists at UCL, experts in contrast agents at Oxford and our industry partners at Sonalis.

Further reading:

Lluis Guasch, et al., *Full-waveform inversion imaging of the human brain*, npj Digital Medicine (2020) - https://doi.org/10.1038/s41746-020-0240-8

Javier Cudeiro, et al., *Design and Construction of a Low-Frequency Ultrasound Acquisition Device for 2-D Brain Imaging Using Full-Waveform Inversion*, Ultrasound in Medicine and Biology (2022) - https://doi.org/10.1016/j.ultrasmedbio.2022.05.023

Thomas Robins, et al., *Dual-Probe Transcranial Full-Waveform Inversion: A Brain Phantom Feasibility Study*, Ultrasound in Medicine and Biology (2023) - https://doi.org/10.1016/j.ultrasmedbio.2023.06.001

Who are we looking for?

We are looking for a candidate with an excellent background in applied physics, engineering, or related fields, with some experience in signal processing, and basic coding skills (Matlab, Python, etc.). It would be desirable for the candidate to have skills in computer-aided design and 3D printing, and some previous laboratory experience.

During the project, the student will develop extensive experimental ultrasound, experimental design and construction, and data processing skills. There will also be opportunities for the student to develop skills in contrast-agent fabrication and characterisation, numerical modelling and imaging methods.

We will encourage and support students to develop their careers, including by presenting at international conferences, carrying out relevant internships and publishing in high-impact journals. This will be a highly collaborative project, with opportunities to interact with groups across the Departments of ESE and Bioengineering, with collaborators at UCL and Oxford, and with our industry partners.