Machine learning and optimisation for transcranial ultrasound imaging

Supervisors: Dr Carlos Cueto, Dr Lluis Guasch

Rapid brain imaging is central to the diagnosis and treatment of neurological conditions such as stroke or head trauma. Existing imaging methods require large, expensive instruments that are near-impossible to deploy outside specialized environments; this leads to unnecessary delays in diagnosis and treatment, increasing rates of disability and fatality. At our lab, we are building a device that uses ultrasound waves to enable simple, rapid, and affordable imaging of patients' brains. Combined with advanced computer modelling to remove the distorting effects of the skull, this device will enable high-quality imaging of the brain unachievable by conventional ultrasound. This advanced modelling is, however, very computationally intensive, slowing down the generation of reconstructed images. This project will combine machine learning, numerical optimisation, and programming techniques to develop, accelerate, and optimise ultrasound imaging algorithms; ultimately, this project will open the door to generating a final high-quality ultrasound brain image in no more than ten minutes.

The main existing technologies used in 3D medical imaging are magnetic resonance imaging (MRI), x-ray computed tomography (CT), and pulse-echo ultrasound. MRI is high resolution and high accuracy but is time consuming, expensive, and immobile. X-ray CT is cheaper and faster, but it is typically lower resolution than MRI, with poor contrast in soft tissues, and it uses harmful radiation. Conventional pulse-echo ultrasound is cheap, fast, portable and universally safe, but it uses high frequencies that have limited penetration, and that are especially attenuated and distorted by the bones of the skull. Consequently, existing ultrasound technology is unable to image the adult brain successfully within an intact human skull.

Ultrasound at low frequencies can travel right across the head. In our lab, we have combined low-frequency transmitted ultrasound with geophysical imaging technology to produce high-quality images of the human brain. Our technology requires solving a complex numerical optimisation problem and running advanced computer models of wave propagation thousands of times. This results in a large computational complexity and, consequently, long waiting times from the moment ultrasound data is acquired to the moment a final image is produced. To transform this technology into an imaging modality that can be rapidly applied clinically, this project will:

A) Create a general software platform for the rapid integration of machine learning and numerical optimisation techniques with ultrasound imaging workflows.
B) Accelerate image reconstruction algorithms, targeting end-to-end image recovery in less than ten minutes, by developing novel machine learning models, implementing the latest numerical optimisation advances, and optimising code for the most powerful GPU arrays.
C) Quantify the trade-offs between speed and accuracy in image reconstructions of experimental ultrasound data obtained from human volunteers.

The ideal candidate would have a degree in applied physics, mathematics, computer science, engineering, or related fields, good coding skills (Python, C/C++) and a good basis of linear algebra and statistics. It would be desirable for the candidate to have skills in deep learning, numerical modelling and optimisation methods, signal processing, and computational fluid dynamics.

Further information can be obtained directly from Carlos Cueto (c.cueto@imperial.ac.uk), or Lluis Guasch (l.guasch08@imperial.ac.uk). Please, don't hesitate to get in touch if you are interested.