Optical-Electro Neural Interface - from Invasive to Non-Invasive
How AI can help?

Hubin Zhao
Assistant Professor (UK Lecturer) in Medical Technologies

Division of Surgery & Interventional Science
University College London

Dept of Medical Phys & Bio Eng
University College London
Dr Hubin Zhao

- Lecturer @ Division of Surgery & Interventional Science, UCL
- Co-PI of Centre for Rehabilitation Engineering & Assistive Tech, Faculty of Medical Sciences
- Co-PI of DOT-HUB, Faculty of Engineering Science

My Team: **HUB of Intelligent Neuroengineering (HUBIN)**

- Working at the intersection of Advanced Electronics, Neural Engineering, and Medical Technologies
- Particularly interested in wearable, intelligent, medical imaging, sensing and health monitoring technologies and their applications (inc. BCI, HRI, Rehabilitation, etc.)
Current Team Members

Yunyi Zhao, PhD Student
Xinkai Zhou, PhD Student
Yunjia Xia, PhD Student
Jinan Chen, PhD Student
Ting Deng, UG Student
Alex Thomas, UG Student, Co-Supervised

Renas Ercan, Visiting PhD Student
Jingyu Lyu, MRes Student
Sijian Pan, MSc Student
Yuhan Li, MSc Student
Rodrigo Leal, PhD Student, Co-Supervised
Gao Wang, PhD Student, Co-Supervised
Neural Stimulation

Electrical Neural Stimulation

Cochlear Implant

Deep Brain Stimulation
Active Implantable Optrode

Diagram showing the components of an active implantable optrode, including:
- Cortical connector
- Optrode unit
- Lead to optrode unit
- Subcutaneous digital control unit
- Wireless inductance loop
- Passivation can

Diagram also shows the flow of information:
- From electrodes to CMOS electronics
- To LEDs

Diagram includes a section on signal processing:
- LED control
- Amplification
- Filtering
- A-D conversion
- Signal processor
- Pulse encoder
- Memory

The diagram also shows the impact of stimulation:
- Stimulation off
- Stimulation on

Additional sections include:
- Cortex
- Electrode
- LED cluster
- Control line
- Thermal sensor
- Fracture sensor
Optogenetic Implant

Proposed Optrode

Stimulation off  Stimulation on
Chip Design & Implementation

Open Loop
Self-Diagnosis Strategy

Closed Loop
Chip Design & Implementation
Near-infrared spectroscopy

- Tissue is relatively transparent to red and near-infrared (NIR) light
- NIR light can be transmitted through the scalp and skull to the brain and back again
- The principle absorbers of light in biological tissue are the haemoglobins, so NIRS is sensitive to brain oxygenation
- Brain oxygenation is linked closely to brain function
- Functional near-infrared spectroscopy (fNIRS) - the application of near-infrared spectroscopy to study brain function
Diffuse optical tomography (DOT) is a more-advanced offshoot of near-infrared spectroscopy (NIRS)

- To produce 3D brain imaging
- Resolution of high-density DOT approaches to fMRI
- How to achieve a fibreless, truly wearable technology which can provide high-quality 3D brain images?
Fibre-based fNIRS/DOT systems
A fibre-less, high-density CW-DOT system?

REQUIREMENTS:

- Scalable
- Highest possible detection sensitivity
- Dynamic range sufficient to allow measurements from ~10 to > 35 mm
- Low power consumption
- Can conform to the curved scalp
- As little wiring as possible
- Lightweight
The μNTS Mark 2.1: A modular, fibreless DOT system

- A DOT system formed from a network of independent modules
- 24 source and 48 detector locations
- Provides 1152 source-detector channels per wavelength
- Highest sensitivity
- Each module integrates motion sensing
- Total weight ~300g
Motion Sensing

![Image of a person in a research environment with equipment and a 3D diagram showing motion sensing with labels for Body X, Body Y, and Body Z, and a time label of 0.00 s.]
The uNTS: 3D functional imaging during overt movement

- Multiple conditions:
  - Unimanual texting while seated,
  - Unimanual texting while walking,
  - Walking
The ANIMATE project

- The aim - to develop a new wearable functional brain imaging technology to investigate the emergence of cerebral palsy in infants at the cot-side
- Newborn infants vulnerable to brain injury and often go on to develop cerebral palsy
- The early diagnosis of cerebral palsy is critical
Applications in the neonatal and pre-term populations require these wearable DOT technologies to be miniaturized further still.

We have developed a neonatal-specific wearable HD-DOT module as part of the ANIMATE project.

Exploits new PCB technology to produce ultra-low profile, lightweight sensors that can be directly interconnected to form imaging arrays.
The ANIMATE system V1

- To use flexible electronics to construct a miniaturized imaging array
- By combining dual- and triple-hex modules together, to create wide-range of ultra-lightweight, flexible HD-DOT imaging arrays
- This incorporates hundreds of emitters and detectors of near-infrared light to safely image the whole cortex of infant brain
The ANIMATE system V1

(a) Imaging band

(b) Block

(c) Patch
The ANIMATE system V1
The ANIMATE system V1

- 3 dual-hex and 2 tri-hex modules
- 36 source and 48 detector locations
- a 2-3-2-3-2 layout that can provide appropriate coverage for the motor cortex of neonates
- Total weight ~70 g with full encapsulation
The ANIMATE system V1

- 1728 DOT channels per wavelength (including 717 good channels, i.e. SDS ≤ 45 mm)
- Dynamic range: 106.6 dB
The ANIMATE system V2

- ANIMATE v2) implemented using the same individual hexagon. However, a second rigid hexagon is folded back to produce a stacked board pattern.

- To allow us to add connectors that permit the use of short lengths of cabling so as to build a stable daisy-chain of modules.

- To provide a more robust mechanical design, while the shielded cabling and stacked board pattern will provide additional noise isolation.
Our primary research interests including (but not limited to):

- Wearable, Implantable, & Non-Contact Intelligent Imaging, Sensing & Health Monitoring Technologies
- AI Hardware for Medical Imaging and Healthcare
- Technology Developments & Applications for Neural Interface, Human-Robot Interaction
- Advanced Medical Electronics, Microelectronics & Optoelectronics for Healthcare

hubin.zhao@ucl.ac.uk

@HubinZhao
Acknowledgements
Our primary research interests including (but not limited to):

- Wearable, Implantable, & Non-Contact Imaging, Sensing & Health Monitoring Technologies
- AI Hardware for Medical Imaging and Healthcare
- Technology Developments & Applications for Neural Interface, Human-Robot Interaction
- Advanced Medical Electronics, Microelectronics & Optoelectronics for Healthcare

hubin.zhao@ucl.ac.uk