IoB Minimally Invasive

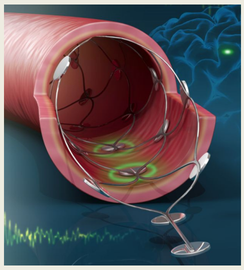
Moonshot Research and Development Program Goal 1 Kanai Project

Brain-Machine Interfaces

David B. Grayden, Clifford Chair of Neural Engineering, University of Melbourne, Australia

Overview

Our groundbreaking brain-computer interface (BCI) research is paving the way for revolutionary advancements in human-machine interaction. We are exploring innovative methods to decode visual information from the brain using endovascular recordings near the visual cortex, potentially enabling object classification through brain signals alone. Our studies also demonstrate that electrical stimulation of the brain through blood vessels can be achieved. Furthermore, our optical BCI system using fluorescent imaging can measure the activities of individual neurons with real-time decoding. Simultaneously, we are harnessing large datasets and machine learning to enhance BCI accuracy and reliability, bringing us closer to practical, home-based applications. These cutting-edge projects promise to transform how we interact with technology.



Endovascular neural interface

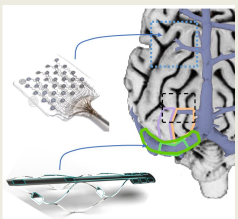
Endovascular Recording and Simulation

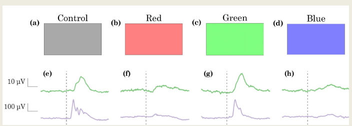
Endovascular recording of visual responses

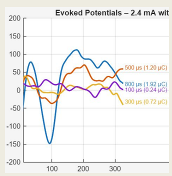
Six sheep were implanted with endovascular electrodes near the visual cortex. Visual stimuli were presented with different colours and with controlled semantic classes: sheep, dog, and flowers, with varying primary visual features: background, image scale, and face vs. full body. A temporal convolutional network was applied to learn to classify the neural recordings. Moderate success was achieved for discriminating colours, and dog and dandelion flower images, while sheep images were not clearly distinguished from flower images. The neural signal can be differentiated when dividing into closeup images of dog or sheep faces vs. full-body images.

Endovascular stimulation of the cerebellum

Endovascular electrodes were manufactured and underwent *in vitro* testing to characterise their electrochemical properties, including impedance analysis, charge storage capacity, and voltage transient measurements. Surface characterization using atomic force microscopy (AFM) and scanning electron microscopy (SEM) was conducted. Results indicated an optimized roughness profile, maximizing charge injection efficiency. Endovascular electrodes were implanted near the cerebellum in sheep along with sub-dural electrodes in the motor cortex region to record cortical evoked potentials elicited by the stimulating the endovascular electrodes. There were prominent responses at approx. 100 ms post-stimulation, suggesting cerebellum activation.



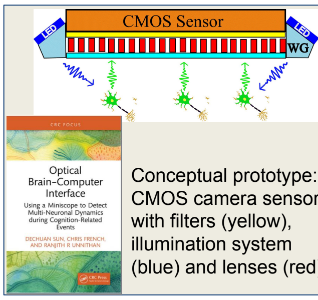




Endovascular and sub-dural neural interface locations; responses to colour stimuli; responses to electrical stimulation.

Optical Brain-Computer Interface

In this project, we aim to develop an optical BCI and associated rapid real-time decoding of the optical signals. We have extensive experience with intracranial neuronal fluorescent imaging with miniaturised fluorescent microscopes. We have found >500 neurons can be tracked for >1 year with minimal signal degradation and very high information content. Notably there is no direct contact with neurons, avoiding the tissue damage and signal impairment occurring with penetrating electrodes. Fluorescent signal in brain cells is achieved by using an innocuous viral vector to express fluorescent proteins and these techniques have been used in non-human primates. A key to implementing this technology as a BCI is the need for rapid real-time decoding of the optical signals. We have recently developed a real-time decoder using machine learning techniques that achieves an extremely high rate of decoding (~200 frames/second).



Conceptual prototype: CMOS camera sensor with filters (yellow), illumination system (blue) and lenses (red)

AI and Machine Learning for BCI Decoding

A deep neural network with an encoder and a decoder-only Large Language Model (LLM) is investigated for subject-specific visual semantic decoding. The encoder maps the ECoG data into high-level neural representations, while the decoder interprets the representations into natural language. The experimental work has focused on exploration of different deep learning algorithm as the encoder for open-vocabulary neural decoding. We employ three encoders, each with a well-known ability to capture sequential dependencies: (1) a convolutional neural network with 1-dimensional kernels (1D CNN) applied to the time domain; (2) a customized transformer that jointly attends to both spatial and temporal dimensions; and (3) a simplified transformer with temporal causal attention.

Future Prospects

Full closed-loop BCI using endovascular electrodes that both record and stimulate to provide human-machine and human-human communication.

High density, minimally invasive neural recording using optical BCI for complex human-machine interactions.

David B. Grayden

Clifford Chair of Neural Engineering, University of Melbourne, Australia

Department of Biomedical Engineering, Faculty of Engineering & Information Technology and the Graeme Clark Institute for Biomedical Engineering. Co-Director of the Victorian Medtech Skills and Devices Hub and Director of the ARC Training Centre in Cognitive Computing for Medical Technologies. Main research interests are in understanding how the brain processes information, how best to present information to the brain using medical bionics, such as the bionic ear and bionic eye, and how to record information from the brain, such as for brain-machine interfaces. Teaches BioDesign Innovation in collaboration with the Melbourne Business School. Co-Director of Biodesign Australia.

Project Faculty: Sam John, Chris French, Takufumi Yanagisawa
Postdoctoral Fellows: Joel Villalobos, Stella Ho, James (Weijie) Qi, Dechuan Sun
Research Assistants: Huakun Xin, Luke Weston
Student: Qi Meng
Collaborators: Joseph West, Ranjith Unnithan, Anthony Burkitt, Yi-De (Frank) Tai, Bryce Widdicombe, Jingyang Liu, Martin Spencer, Jelle H. M. van der Eerden, Po-Chen Liu

Internet of Brains