Engineering Tripos Part IIB, 4G10: Brain machine interface, 2023-24

Leader

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Timing and Structure

15 Lectures. Assessment 100% coursework

Prerequisites

3M1, 3G3, 3F2, 3F8 useful

Objectives

As specific objectives, by the end of the course students should be able to:

- exposure to modern technologies for interfacing with the nervous systems.
- an in-depth understanding of a range of signal processing and probabilistic machine learning techniques, taught here in the concrete context of a real-world application: neural data analysis and brain machine interfaces.
- an understanding of the theoretical and practical challenges involved in the design and operation of a BMI
- exposure to the neural basis of motor control in primates
- an appreciation of how BMIs can be used both in clinical applications and in basic neuroscience research into biological learning and neural representations.
- hands-on experience with neural data analysis as part of the coursework

Content

This course will provide a hands-on introduction to a key set of information engineering tools in the context of brain machine interfaces (BMI), an exciting and fast developing bioengineering technology. Following introductory lectures covering an overview of relevant neural circuits and recording and stimulation technology used in BMI, the bulk of the lectures will introduce various modelling, data analysis, and decoding techniques in the context of motor-oriented BMI and motor cortex.

Introduction (1L)

- History, overview and goals of BMI; motivating example.
- Overview of neurons, and sensory- and motor-related circuits involved in BMI.

Hardware technology (3L)

- Introduction to different recording & stimulation technologies (spinal, intracortical, superficial, deep brain).
- Interface technology: motor prosthetics, sensory prosthetics, other clinical applications.

Modeling and data analysis (11L)

- Modeling population activity (4L) ?
    - Statistical methods (probabilistic PCA, factor analysis, Gaussian Process Factor Analysis)
    - Dynamical methods (linear dynamical systems, recurrent nonlinear networks and variational autoencoders)
- Decoding methods (2L):
    - Kalman filter, and a nonlinear/non-gaussian extension of it.
- The full loop of BMI (1L):
    - An example model integrating both control and decoding.
- Using BMI to learn about learning in the brain (2L).
- Challenges of BMI: instability of neural representations (2L).

Conclusion (1L)

- A recent impressive application as a motivating conclusion.

Coursework

Assessment will be 100% coursework: two long programming-based exercises involving (1) implementation of methods learned in lectures, (2) guided development of their extensions, and (3) analysis of real datasets with those methods.

Coursework

Coursework activity #1: rotational dynamics in the motor cortex

An influential theory holds that the motor cortex forms a dynamical system that autonomo
dynamic activity patterns, which are sent as motor commands to the spinal cord to shape
what form do these dynamics take? Many animal movements, which are evolutionarily well-preserved, are of a periodic natur
peristalsis of the gut, etc. This has lead to the hypothesis that the neural dynamics underlying these preserved patterns are e
movements that are not overtly periodic. This coursework explores a dynamical dimensionality reduction method developed t
dynamics in the motor cortex.

Learning objectives:

- implement a method for dynamical dimensionality reduction of neual recordings data
- use linear algebra to solve a constrained least squares minimisation problem,

Coursework
• hands-on experience with neural data analysis, and learning to interpret the patterns analysis, • apply and gain an appreciation for the use of statistical controls to rule out falsely in overfitting.

Booklists

Please refer to the Booklist for Part IIB Courses for references to this module, this can be found on the associated Moodle course.

Examination Guidelines

Please refer to Form & conduct of the examinations [4].

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