Engineering Tripos Part IIA Project, GG4: Neural Control with Adaptive State Estimation, 2025-26

Leader

Dr Flavia Mancini [1]

Timing and Structure

Students work to their own schedule. A staffed "surgery" runs every weekday 10-11am to give help, advice and feedback.

Prerequisites

Useful: 3F3 (Inference), 3F1 (Statistical Signal Processing), 3F4 (Systems and Control); Python (NumPy, Matplotlib, Jupyter)

Aims

The aims of the course are to:

- To introduce students to simulation and control of partially observed dynamical systems.
- To give practical experience with Kalman filtering for state estimation.
- To explore optimal feedback control using LQR in a closed-loop system.
- To develop collaborative coding, analysis, and presentation skills.
- To foster understanding of robustness in estimation and control under noise and model mismatch.

Objectives

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

- Understand and apply linear state-space models to simulate dynamic systems.
- Implement and tune a Kalman filter to decode noisy observations.
- Design and use an LQR controller for optimal state feedback control.
- Integrate estimation and control in a closed-loop system.
- Conduct experiments to assess tracking accuracy, control effort, and robustness.
- Collaborate effectively to develop shared code and produce a joint presentation.
- Present technical results clearly using plots, metrics, and structured reports.

Content

In this design project, small groups will simulate and control a simplified neural interface system.

A 2D cursor moves in a plane based on a latent trajectory, observed indirectly through noisy neural-like signals. Students will estimate the cursor's hidden state using a Kalman filter and

control its movement toward a dynamic target using Linear Quadratic Regulator (LQR) feedback. Over four weeks, they will explore estimation accuracy, control performance, and

system robustness to disturbances and model mismatch. The project blends inference, control, signal processing, and neural data simulation in a realistic, design-oriented lab.

Overview

This lab explores how brain-machine interface (BMI)-like systems can decode noisy neural

activity to control movement. Students will simulate a cursor being driven toward a target using a linear dynamical system, with neural-like noisy observations and closed-loop control using a

Kalman filter and LQR.

Content

Week 1–2 (Group)

- Intro to state-space models, Kalman filter, and LQR (primer provided).

- Groups set up simulation environment and run example trajectories.

- Implement group simulation code with documentation.

Deliverable: Group simulation code + brief documentation (group mark).

Week 3 (Individual)

- Implement Kalman filter and LQR control loop.

- Test closed-loop performance and robustness.

- Continue experiments for final analysis.

Week 4 (Group & Individual)

- Group presentation: approach, results, lessons learned (group mark).

- Individual final report due end of Week 4: methods, results, discussion (individual mark).

Further notes

Possible extensions:

Add Poisson (nonlinear) neural encoder

Replace LQR with RL-based controller (e.g. policy gradient)

Submit video demo as optional bonus deliverable

Coursework

Group Simulation Code & Documentation (Week 2): 10 marks

Group Presentation (Week 4): 10 marks

Individual Interim Report (end of Week 2: 20 marks

Individual Final Report (Week 4): 40 marks

Examination Guidelines

Please refer to Form & conduct of the examinations [2].

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