EECS 598-17: Control Theory for Biological Sensorimotor Systems

Instructor: Jing Shuang (Lisa) Li
Email: jslisali@umich.edu
I respond to emails within 2-3 working days. Include “EECS 598-17” in the subject line.

Class time: Tue/Thu 3:00-4:30pm
Class location: 133 Chrysler
Office hours: TBD

Course motivation and description

The pursuit of autonomy is a major driving force behind funding, research, and technological advances in both academia and industry. However, despite significant investments and breakthroughs, state-of-the-art systems are often bested by biology. One only has to look across the street at the neighbor’s cat to see an example of an autonomous being that is at once more agile, energy-efficient, and robust to environmental variations than our best quadruped robots. How does the cat accomplish these amazing feats of sensorimotor control, and what can we learn from it?

In this course, we will learn how tools from **control theory** can be applied to better understand animal sensorimotor control — that is, how animals use sensory information to inform movements. We will first learn some basics about the fascinating world of biology and neuroscience, then learn how control theory can be (and has been) used to model animal behavior and physiology in the sensorimotor context. Along the way, we will also encounter novel control formulations, and also investigate how bio-inspired controls and algorithms can be applied to improve the robustness and efficiency of engineered systems.

Learning objectives

The main objective of this course is to help students become familiar with the intersection of control theory and biological sensorimotor systems from a research perspective. By the end of the class, students should be able to:

- Describe basic concepts relating to biological sensorimotor control
- Describe the role of control theory as a modeling tool for sensorimotor control
- Integrate concepts from class (and literature) with concepts from their own research to create new directions of investigation

Target audience and prerequisites

Students should have some background knowledge in control theory, preferably time-domain state-space models. We will review (and introduce) various branches of control theory, but the more you know, the easier it will be for you to synthesize concepts learned in class and apply them to your own research. No background in biology or neuroscience is required — we will start from the basics in this class.

Evaluations (Tentative)

Literature review

Students will

- Select a paper that combines biology and control theory
- Read the paper and write a blog post about their selected paper. This blog post should be understandable to someone with a generic STEM background
- Comment on and ask questions about other students' blog posts

Learning objectives

- Gain familiarity with a wide variety of literature in sensorimotor control by writing their own blog posts and reading others' blog posts
- Practice translating domain-specific literature for a broader audience. This is an important skill for interdisciplinary research collaboration

Class project

Students will

- Propose a project to be completed during the semester
    - This can be replication or extension of an existing result, or a new topic
    - Students are encouraged to incorporate ideas from their own research
    - Students and instructor will define project-specific criteria for success
- Work on the project throughout the semester
- Provide intermediate progress reports
- Prepare a final progress report in the format of a short conference paper
- Prepare a final presentation in the format of a conference presentation

Learning objectives

- Gain familiarity with their chosen research/project area
- Practice presenting and writing up research results in a standard format

Depending on the project, there may be post-class opportunities for students to extend their project for an actual conference submission.

Since this is a research-oriented course, we will not have a midterm or final exam.

Topics (Tentative)

1. Introduction and course overview (1 class)
2. Mammalian and non-mammalian nervous systems (2 classes)
3. Neurons and neural communication (2 classes)
4. Motor anatomy and control (2 classes)
5. Sensory modalities: sight, sound, touch, proprioception (2 classes)
6. Sensorimotor anatomy and control (2-3 classes)
7. Sensorimotor learning and adaptation (2 classes)

8. Model organisms and experimental techniques (2 classes)
9. Behavioral models of sensorimotor control (2-3 classes)
10. Optimal control for biomedical engineering applications (1-2 classes)
11. Physiological models of sensorimotor control (5-6 classes)
    a. Sensorimotor delay and optimal control (1-2 classes)
    b. Untangling complicated physiology (2 classes)
    c. Additional features of physiology-constrained control (2 classes)
12. Student-led project presentations (number of classes depends on enrolment)

In addition to the listed topics, the following themes will be interwoven throughout all classes

- How would we model or design this using control theory?
- What unique advantage will control theory provide that other techniques do not?
- Identifying research questions with scientific *and* engineering value
- Rethinking rigor in the face of limited observations, high complexity, and high uncertainty