BME 6086-004: Fundamentals of Neural Control

Credits and Contact Hours: 3 Credits (One 180-minutes lecture per week)

Lectures: Wednesdays: 5:00pm – 8:00pm ENGINEERING II – room 323

Instructor: Sabato Santaniello, Ph.D.

Office Hours:
Mondays: 10:30am – 12:30pm (walk-in). BRONWELL – room 308
Otherwise, by appointment as needed.

Textbook:
Neural Control Engineering, Steven J. Schiff (2012). ISBN: 978-0-2620-1537-0

Other Recommended Textbooks:
Dynamical Systems in Neuroscience. Eugene M. Izhikevich (2011). ISBN: 978-026-251-420-0
Biological Learning and Control. Reza Shadmehr, Sandro Mussa-Ivaldi (2012). ISBN: 978-0-2620-1696-4

***Other Supplemental Materials*:**
Course handouts and scientific articles relevant to course topics covered.

Course Website:
Copies of the course syllabus, assignments, and supplemental materials will be posted online at the HuskyCT class site. Students are responsible for announcements and assignments posted on the HuskyCT class site. Please check it regularly.

***Specific Course Information*:**
a. Description:
The use of Control theory to analyze and regulate biological neural systems is rapidly becoming an essential tool to design fast, accurate, and reliable brain-machine interfaces (BMIs) and artificial prostheses. This course introduces fundamental tools to model, estimate, and control the behavior of neural systems of increasing complexity (i.e., from single neurons to large cortical layers), with cutting-edge applications in the field of movement disorders, epilepsy, BMI, and rehabilitation. The first part of the course introduces biophysical-based and empirical models to describe the dynamics of neural systems, and studies the observability/controllability of these systems. The second part explores linear and nonlinear state estimation theory for neural systems with application to neural decoding and optimal state estimation. The third part focuses on designing state-based control algorithms that interact with the proposed models to achieve the assigned goals. The course is organized as a combination of formal lectures on relevant topics and case studies. As part of the workload, each students will be assigned a mid-term and a final project, which require the use of the proposed tools to solve open problems in the control of neural systems.

b. Prerequisite: Undergraduate-level knowledge of signal processing, bioelectromagnetism, and MATLAB (equivalent to CSE 1010, ECE 3101, and BME 3500) is required. Undergraduate-level knowledge of neural physiology (equivalent to BME 4300) is highly recommended.

c. Required, Elective, or Selected Elective*:* Elective.

***Grading*:**

- Homework: 30%
- Midterm Project: 35%
- Final Project: 35%

Topics Covered:

- Hodgkin-Huxley equations
- Single-unit neural models
- Mean-field neural models
- Observability and controllability
- Nonlinear dynamics
- Kalman filter, Unscented Kalman filter
- State-space-based neural decoding
- Feedback control via electric fields
- Motor learning and control
- Optimal feedback control
- Optimization methods
- Numerical analysis in MATLAB

Course Objectives and Outcomes:

The objective of this course is to learn the basic tools for modeling neural time series (e.g., local field potentials, membrane voltage, and electrocorticography) based on physiological knowledge, and to use model-based control tools to design feedback strategies for the estimation and regulation of the neural activity of single neurons, small neural populations, or large volumes. Through a mix of lectures and hands-on experiences, the students will learn how to use advanced modeling tools and numerical methods to describe the temporal dynamics of neural signals, how to design optimal neural prostheses, and how to validate these systems in simulation.

Policies:

a. Policy regarding Grading, Assignments, Class Participation, and Attendance:

Thirty percent (30%) of the final grade will be based upon the scheduled homework. Homework 4 consists in reading a scientific article and present it in class. **Late homework will not be accepted** unless extreme conditions occur (e.g., medical emergency with physician's signature). Thirty-five percent (35%) of the final grade will be based upon presentation (written and oral) of an assigned midterm project. Projects will involve a modeling component, an estimation component, and simulation component, with simulations to be conducted in MATLAB. Thirty-five percent (35%) of the final grade will be based upon presentation (written and oral) of an assigned final project. Projects will involve a modeling component, an estimation and/or control component, and a simulation component, with simulations to be conducted in MATLAB. Participation in class includes answering questions (orally or written), participating in class discussions and demonstrations, and providing feedback. Students are responsible for reading assigned material **before** it is covered in class. Even if the content is not clear, the exposure will familiarize the students with the terminology and allow to focus on understanding the concepts discussed during class. Students are responsible for all announcements and other information covered in class. Students who are late or unable to attend class must obtain missed information from other students.

b. Policy Against Discrimination, Harassment, and Related Interpersonal Violence

The University is committed to maintaining an environment free of discrimination or discriminatory harassment directed toward any person or group within its community – students, employees, or visitors. Academic and professional excellence can flourish only when each member of our community is assured an atmosphere of mutual respect. All members of the University community are responsible for the maintenance of an academic and work environment in which people are free to learn and work without fear of discrimination or discriminatory harassment. In addition, inappropriate amorous relationships can undermine the University's mission when those in positions of authority abuse or appear to abuse their authority. To that end, and in accordance with federal and state law, the University prohibits discrimination and discriminatory harassment, as well as inappropriate amorous relationships, and such behavior will be met with appropriate disciplinary action, up to and including dismissal from the University. Additionally, to protect the campus community, all non-confidential University employees (including faculty) are required to report sexual assaults, intimate partner violence, and/or stalking involving a student that they witness or are told about to the Office of Institutional Equity. The University takes all reports with the utmost seriousness. Please be aware that while the information you provide will remain private, it will not be confidential and will be shared with University officials who can help. More information is available at equity.uconn.edu and titleix.uconn.edu.

c. Sexual Assault Reporting Policy:

To protect the campus community, all non-confidential University employees (including faculty) are required to report assaults they witness or are told about to the Office of Diversity & Equity under the Sexual Assault Response Policy. The University takes all reports with the utmost seriousness. Please be aware that while the information you provide will remain private, it will not be confidential and will be shared with University officials who can help. More information is available at http://sexualviolence.uconn.edu/

d. For a complete list of University Policies, Follow the link: http://provost.uconn.edu/syllabi-references/

Academic Honesty and Student Code:

Academic dishonesty of any type will not be tolerated in this class. Students should refer to the Student Code, section on Academic Integrity at http://www.dos.uconn.edu/student_code.html and http://policy.uconn.edu/2014/04/11/policy-on-scholarly-integrity-in-graduate-education-and-research/ for specific guidelines.

Students with Disabilities:

Students who need course adaptations or accommodations because of a disability are invited to notify the instructor as soon as possible. Students with disabilities who believe that they may need accommodations in this class are encouraged to contact the Disability Services Office (http://www.csd.uconn.edu) as soon as possible in order to ensure that such accommodations are implemented in a timely fashion.

Non-Discrimination Policy Statement:

The University of Connecticut does not discriminate on the basis of race, color, religion, national origin, ancestry, disability, genetic information, sex, sexual orientation, gender identity or expression, age, veteran status, marital status or other legally protected characteristics in all programs and activities and supports all state and federal laws that promote equal opportunity and prohibit discrimination, including the provision of reasonable accommodations for persons with disabilities. The University engages in an interactive process with each person making a request for accommodations and reviews the requests on an individualized, case-by-case basis. To request an accommodation or for questions related to the University's non-discrimination policies, please contact: Elizabeth Conklin, J.D. ADA Coordinator, Title IX Coordinator, Associate Vice President, Office of Diversity and Equity, 241 Glenbrook Road, Unit 4175, Storrs, CT 06269 Phone: (860) 486-2943 Email: ode@uconn.edu / Website: www.ode.uconn.edu

Schedule:

A tentative schedule is reported below. Students must check their email for any change.

Week	**Date**	**Subject**	**Assignment Due On**
1	08/31	Singular Value Decomposition	
2	09/07	Kalman Filter and UKF	HW1: 09/14
3	09/14	Models of Neurons	
4	09/21	Equilibria, Limit Cycles, and Bifurcations	HW2: 10/05
5	09/28	Parametric Estimation via Kalman filters	Project 1: 10/19
6	10/05	Mean-Field Models. Observability and Controllability	
7	10/12	Computational Laboratory	HW3: 10/26
8	10/19	**Mid-term project discussion**	
9	10/26	Applications of Neural Control	HW4: 11/16
10	11/02	Brain Machine Interfaces: Encoding Models	
11	11/09	Brain Machine Interfaces: Bayesian Decoding	HW5: 11/30
12	11/16	**Homework 4 discussion**	Project 2: 12/12
13	11/23	**Thanksgiving break**	
14	11/30	Motor Learning, Costs, and Rewards	
15	12/07	Optimal Feedback Control	
Finals	**12/12-17**	**Final project discussion**	

Legend:

HW = Homework assignment; Project = Project assignment