ECE421/NE420 Neural Interface Engineering

Semester: Fall 2021

Instructor Information

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Office Location	1250 Micro and Nanotechnology Lab
Office Hours	One hour per week; schedule TBA

Course Information

CRN: Credit: 3 undergraduate or 4 graduate hours
Prerequisite: BIOE205 or ECE210 or instructor approval
Meeting Time & Classroom: MWF 10:00-10:50, TBA

Course Description

Course is focused on hardware and software technologies that enable control and readout of neural activity in the brain. Engineering-grounded innovation will accelerate our understanding of the brain, will impact new therapies for restoring lost neural functions, as well as will lead to neural interfaces that will augment our interaction with the world and machines. We will start with general introduction to neurobiology introducing concepts of neural activity, brain chemical and electrical signaling. neuroanatomy, and sensory information processing. We will further focus on using physical, chemical and biological principles to understand technology design criteria governing ability to observe and alter brain structure and function. Topics include noninvasive and invasive brain mapping and stimulation, neural interfaces and neural prosthetics, data processing problems, decoding/encoding techniques based on machine learning, future brain interfaces based on nanotechnology and optogenetics.
The course will be appropriate to graduate level students to receive 4 hours of graduate credit. Graduate students will be required to complete an additional independent project based on reviewing the proposed scientific literature, writing an extended report, and presenting it in the class. Alternatively, to receive this credit, graduate students must complete an independent project based on analysis of publicly available datasets of brain electrophysiological recordings using machine learning based software. The course with additional credit is intellectually challenging for graduates, it has strong emphasis on recent literature and draw actively from the latest relevant research, it is built upon knowledge previously gained, bear a logical relationship to the total offerings with minimal overlap.

Catalog description

Neural signaling, brain functional anatomy, invasive and noninvasive technologies for recording and manipulating of brain activity, deep brain stimulation, sensory organ prosthetics, neurorehabilitation, brain-machine interfaces, limb prosthetics, advanced brain function prosthetics.

Course Objectives

Upon completion of the course, the student should be able to

- Describe basic principles of brain anatomy. Neurons and neural signaling. Modalities of signaling, ionic, gap junctional, synaptic/chemical.
- Describe basic principles and technologies for invasive and noninvasive brain measurement and brain modulation modalities.
- Calculate electric fields inside the brain during stimulation. Describe technologies for Deep brain stimulation.
- Describe basic principles of brain sensory systems and technologies for sensory organ prosthetics including cochlear implants and retinal implants.
- Describe general principles of brain plasticity and modulation technologies for neurorehabilitation.
- Describe noninvasive methods for recording of brain activity. Apply statistical methods for analysis of EEG data and decoding of brain activity. Describe principles of brain-machine interfaces based on EEG.
- Describe invasive methods for recording of brain activity. Describe spiking statistics and calculate statistical measures of spiking activity.
- Describe general principles of organization of brain motor system and technologies for limb prosthetics.

- Describe various spiking decoding algorithms based on probabilistic models, including dimensionality reduction, Kalman filter, generalized linear model. Calculate correlation of spiking activity with behavioral covariates (tuning curve).
- Describe concepts of brain hierarchical cortical processing and foundations of perception. Describe principles of closed feedback loop control. Apply simple models to establish the feedback loop control for sensorimotor prosthetics.
- Describe emerging technologies for whole brain recording and modulation. Describe concepts of dynamic brain networks and future technologies for artificial perception, memory retrieval, and advanced prosthetics.

Course Format

- Three 1-hr weeks lectures.
- Students are expected to spend 3 hours in class per week and 8–10 hours outside of class.

Textbook and Reading Materials

Recommended reading assignments from sections from these reference books:

Principles of Neural Science (PNS), Eric Kandel, James Schwartz, Thomas Jessell , McGraw-Hill Medical, 2000.
Theoretical Neuroscience (TN), Peter Dayan and Larry.F. Abbott, MIT Press, 2001.
From Single Neurons to Networks and Models of Cognition (FSNMC) W. Gerstner, et al, Cambridge, 2014
Neural Engineering **(NE)** (edited by Bin He) Kluwer Academic Press 2005
Bioelectricity: A Quantitative Approach,**(BQA)** Robert Plonsey and Roger C. Barr, Springer 2007
Modelling Organs, Tissues, Cells and Devices (MOTCD), S. Dokos, Springer 2017
Pattern Recognition and Machine Learning (PRML), Christopher Bishop. Springer, 2007

Tentative Schedule

Week	Topic	Reading
1	**Introduction to neurophysiology.** Membrane potential, ion channels, action potential, synaptic transmission. Modalities of neuron signaling synaptic, gap junctions, and chemical communications. Brain anatomy and functional organization.	PNS Ch 1, 2, 7, 9
2	**Modulating the brain.** Noninvasive neuromodulation methods. Electrical stimulation. Limbic system. Deep brain stimulation. Technological challenges.	BQA, Ch.12; MOTCD pp 201-235; NE p.405
3-4	**Sensory organs prosthetics.** Auditory system. Auditory signal processing in cochlear. Cochlear implants. Visual system. Retinal implants. Advantages and challenges.	PNS Ch 26, 31; NE p.635
4-5	**Brain plasticity.** Synaptic plasticity, Hebbian learning rules. Functional electrical stimulation. Peripheral and electro-cortical FES. Neurorehabilitation.	TN Ch.8.2; FSNMC Ch.19.1
6-7	**Recording from the brain.** Noninvasive methods to detect brain activity: EEG, ECoG, MEG, PET, fMRI, infrared imaging. Evoked potentials in EEG. EEG signal processing and decoding. Feature extraction and selection. Performance measures. EEG-based brain-machine interface.	NE p. 223, p.259
8-9	**Brain spiking codes.** Invasive recording methods: electrophysiology, optical imaging, multiphoton microscopy, bioluminescence. Spike detection. Spike sorting. Principal component analysis. Spike train analysis, Spike histogram, Tuning curve, Poisson process.	PNS Ch 21; TN Ch 1
10-11	**Limb prosthetics.** Motor system. Cortical control of movement. Decoding algorithms. Dimensionality reduction. Classification.	PNS Ch 33, 37; PRML Ch.9

	Expectation-maximization. Kalman filter. Firing rate and population codes for limb prosthetics. Advantages and challenges.	
12-13	**Sensorimotor prosthetics.** Hierarchy of sensory processing. Perception. Principles of closed feedback loop control. Sensorimotor brain machine interface. Restoration of the sense of touch.	PNS Ch.21, 22, 23
14	**Beyond BMI.** Novel technologies for large-scale recording and modulation of brain activity. Memory and spatial navigation system. Artificial perception and memory prosthetics.	PNS Ch.65; NE p.725
15	**Dynamic brain.** Modeling complex neural dynamics. Artificial Intelligence for decoding brain network dynamics. Future brain data portals.	FSNMC Ch.16.3

Grading

	3 Hours	4 Hours
Homework:	20%	15%
Exam 1:	25%	20%
Exam 2:	25%	20%
Final Exam:	30%	30%
Graduate Project	NA	15%