Engineering Faculty Document No. 47-18
8/20/2018

TO: The Faculty of the College of Engineering

FROM: The Faculty of the School of Biomedical Engineering

RE: New Undergraduate Course, BME 41000, Neural Engineering

The faculty of the School of Biomedical Engineering have approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

BME 41000 Neural Engineering
Term offered: Fall, Lecture 3, Cr. 3.
Prerequisites: BME 30100 or ECE 30100

Description: An introduction to "Neural Engineering" – an emerging field of developing and applying engineering solutions to research or translational problems concerning the brain. The course will cover a broad range of topics about neural sensing, modeling, stimulation, interface, and prosthetics. Course projects are drawn from real-world problems and experimental data.

Reason: This course will be one of a required set of technical electives for the undergraduate program in the Weldon School of Biomedical Engineering (BME). This new course will have direct applications in biomedical applications not found in the other electives. The intent is to help senior (or junior) undergraduate students develop a broad perspective on cutting-edge research and application of neural engineering.

Understanding the brain is one of the grand challenges in the 21st century. Existing progress ranges from new ways to treat brain disorders through engineering to new inspirations from the brain to innovate artificial intelligence. Numerous opportunities in academia and industry are emerging and require a new generation of workforce trained on the related topics. This course is unique and prepares the students for either industrial positions or graduate schools to engage themselves in related fields. In the past two years, 11 and 10 students enrolled for this course and provided very positive feedback.

George R. Wodicka

George R. Wodicka,
Dane A. Miller Head and Professor
Weldon School of Biomedical Engineering

BME 495: Neural Engineering (Fall 2018)

Time: MWF 11:30-12:20PM
Location: MJIS 1083

Instructor:

Zhongming Liu, Ph.D.
Assistant Professor, Biomedical Engineering
Assistant Professor, Electrical and Computer Engineering
College of Engineering, Purdue University
Phone: (765)496-1872
Office: MJIS 2021
Office hour: Friday 12:30-1:30PM
Preferred contact method: via email

Description:

This is a 3-credit course for an introduction to "Neural Engineering" – an emerging field of developing and applying engineering solutions to research or translational problems concerning the brain. The course will cover a broad range of topics about neural sensing, modeling, stimulation, interface, and prosthetics. Some homework assignments and projects in the course are drawn from real-world problems and experimental data.

Objective:

At the end of the course, junior or senior undergraduate students will be able to define and approach engineering problems in brain research, by building up foundational knowledge about neural sensing, modeling, stimulation, interface, and prosthetics. Specifically, students are expected to be able to

1 analyze neural signals in various spatial and temporal scales,
2 examine relationships between neural activity and sensation/behavior,
3 identify existing ways and mechanisms to modulate neural circuit functions,
4 identify existing applications of neural prosthetics, implants, and robotics.

Through learning the above neural engineering knowledge, students are also expected to develop and enhance the general ability to

1. identify, formulate, and solve engineering problems in brain research
2. apply knowledge of mathematics, science and engineering to neural data

Topics:

Week 1: Introduction

Lecture 1: Course overview
Lecture 2: Neuron, Circuits and Systems
Lecture 3: Signals and Systems
Week 2: **Neural Sensing** – Electrophysiology
Lecture 4: Membrane potentials, patch clamp, integrate-and-fire model
Lecture 5: Single/multi-unit activity, local field potential
Lecture 6: Electrocorticography, electroencephalography, magnetoencephalography
Week 3: **Neural Sensing** – Macroscopic Imaging
Lecture 7: Magnetic Resonance Imaging
Lecture 8: Functional magnetic resonance imaging
Lecture 9: Intrinsic signal optical imaging and functional near infrared spectroscopy
Week 4: **Neural Sensing** – Microscopic Imaging
Lecture 10: Voltage sensitive dye imaging
Lecture 11: Calcium imaging
Lecture 12: Wide-field vs. multi-photon imaging
Week 5: Neural Modeling – Signal Processing
Lecture 13: Time series analysis, event-related potential/field, filtering
Lecture 14: Spectral analysis, time-frequency analysis
Lecture 15: Principal and independent component analysis
Week 6: **Neural Modeling** – Signal Characteristics
Lecture 16: Oscillatory vs. scale free dynamics
Lecture 17: Correlation and coherence
Lecture 18: Pattern classification
Week 7: **Neural Modeling** – Connectivity
Lecture 19: Structural connectivity
Lecture 20: Functional connectivity
Lecture 21: Network and graph analysis
Week 8: **Neural Modeling** – Computational neuroscience (in vision)
Lecture 22: Feed-forward and feedback networks
Lecture 23: Specialization and integration
Lecture 24: Hierarchical neural networks
Week 9: **Neural Coding** – Encoding
Lecture 25: Direction and velocity tuning of motor neurons
Lecture 26: Location, orientation, color tuning of visual neurons
Lecture 27: Frequency, pitch, phoneme tuning of auditory neurons
Week 10: **Neural Coding** – Decoding
Lecture 28: Decoding motor neuronal activity
Lecture 29: Decoding auditory neuronal activity
Lecture 30: Decoding visual neuronal activity
Week 11: **Brain Computer Interface** – Non-invasive
Lecture 31: Event-related synchronization and desynchronization
Lecture 32: Motor imagery for 1-D, 2-D, 3-D movement control
Lecture 33: Steady-state visual evoked potential and P300 for speller
Week 12: **Brain Computer Interface** – Invasive

- **Lecture 34**: Robotic arm control in primates
- **Lecture 35**: Closed-loop vs. open-loop, and conditioning
- **Lecture 36**: Online / adaptive learning

Week 13: Neural modulation – Non-invasive
- **Lecture 37**: Transcranial magnetic stimulation
- **Lecture 38**: Transcranial direct current stimulation
- **Lecture 39**: Ultrasonic stimulation

Week 14: Neural modulation – Invasive
- **Lecture 40**: Optogenetics
- **Lecture 41**: Deep brain stimulation
- **Lecture 42**: Vagus nerve stimulation

Week 15: Neural prosthetics
- **Lecture 43**: Prosthetic devices and interfaces
- **Lecture 44**: Implants to visual, auditory, and motor systems
- **Lecture 45**: Restore/enhance/replace neural functions

Prerequisites:

College-level math (calculus, linear algebra)
Signal and systems (ECE 301) or bioelectricity (BME 301).

Attendance:

No lecture is available in any textbook or online in its complete form. In-class attendance is mandatory. Please come to lectures on time to minimize disruptions. For very rare cases (e.g. bereavement or military leave), please email the instructor to request necessary absence in a class, at least one day before the class.

Textbook:

Neural Engineering (He B., Ed).
Hand-out and reading materials will be available on Blackboard before each class.

Homework:

Homework is assigned and graded every 2 or 3 weeks, with one homework on each of the following topics, including neural sensing, neural modeling, neural coding, neural prosthetics. Homework may be assigned as "mini-projects" for students to analyze realistic neural data or develop and describe conceptual designs for hardware systems to interface with the brain.

Exams:

There are one mid-term exam and one final exam.

Grading:

Homework (30%)
Mid-term exam (30%)
Final exam (40%)

Numerical ranges for letter grades
A (>=90), A- (85-89), B+ (80-84), B (75-79), B- (70-74), C+ (65-69), C (60-64), ...
Late assignments will be accepted, with 60% grade penalty (the maximum score is 60).

Ethics:

Dishonesty in connection with any University activity, Cheating, plagiarism, or knowingly furnishing false information to the University are examples of dishonesty. The commitment of the acts of cheating, lying, stealing, and deceit in any of their diverse forms (such as the use of ghost-written papers, the use of substitutes for taking examinations, the use of illegal cribs, plagiarism, and copying during examinations) is dishonest and must not be tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest.

See the Purdue's Honors Pledge: "As a boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together – we are Purdue". (https://www.purdue.edu/provost/teachinglearning/honor-pledge.html)

Academic integrity is one of the highest values that Purdue University holds. Individuals are encouraged to alert university officials to potential breaches of this value by either emailing integrity@purdue.edu or by calling 765-494-8778. While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern.

Counseling and Psychological Services (CAPS):

Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at (765)494-6995 and http://www.purdue.edu/caps/ during and after hours, on weekends and holidays, or through its counselors physically located in the Purdue University Student Health Center (PUSH) during business hours.