



Purdue University BME 51100 (Fall 2021)

Registration

Biomedical Signal Processing

BME 51100 - MJD (in-person section), EPE, OXE, ONC

Time: TR 09:00 -- 10:15 am

Location: MJIS 1001 (in-person), or remote (synchronous/asynchronous options)

Credits: 3

Instructor

Hari M. Bharadwaj, Ph.D. Assistant Professor of Biomedical Engineering

Assistant Professor of Speech, Language, & Hearing Sciences

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Office Hours: TBA (1 hr/week via Zoom). Also see the "Discussion Forum" section below.

TA: Ravinderjit (Rav) Singh, e-Mail: singh415@purdue.edu

TA Office Hours: TBA

Description

This is a biomedical "data-science" course covering the application of signal processing and stochastic methods to biomedical signals and systems. A "hands-on" approach is taken throughout the course (see section on required software). While an orientation to biomedical data is key to this course, the tools and concepts covered here will provide foundational skills that are useful in many domains. Topics include: overview of biomedical signals; Fourier transforms review and filter design, linear-algebraic view of filtering for artifact removal and noise suppression (e.g., frequency filtering, regression, noise-cancellation, PCA, ICA); statistical inference on signals and images; estimation theory with application to inverse imaging and system identification; spectra, spectrograms and wavelet analyses; pattern classification and diagnostic decisions (machine learning approaches and workflow).

This course is distinct from other classic offerings in ECE/MA/STAT in at least three ways:

1. Relevant theory in signal processing and statistical methods is covered as needed, but a major focus is on implementation/application of the fundamental techniques to real-world biomedical signals.
2. Statistical methods that are typically taught with a "univariate" perspective are expanded to topologically organized high-dimensional data such as time-series and images, and done so motivated by the needs in biomedical applications (e.g., electrophysiology, neuroimaging).
3. This course uses practical applications to integrate probabilistic methods with classic linear-algebraic tools (such as Fourier transforms). These foundational areas are often introduced in separate courses, but are powerful when brought together.

Course Outcomes

1. Understand practical problems in objective analyses of biomedical signals.
2. Understand the theoretical background underlying the use of digital signal processing and statistical techniques for biomedical applications.
3. Identify the best solution for specific problems by considering the benefits and limitations of various digital signal processing approaches.
4. Implement appropriate signal processing algorithms for practical problems involving biomedical signals and systems.
5. Propose, carry out, orally present, and write up in conference-proceedings format, a biomedical-research mini project using signal-processing.

Learning Strategies

In-class lectures and discussions; Hand-solved and computer-programmed problem sets; Research-oriented predefined midterm project; Self-designed final research project

Prerequisites

ECE 301 or equivalent (Signals and Systems), Introductory probability/random process concepts (e.g., ECE 302, STAT 350 etc.), Familiarity with Python (Python will be the default language used in class, but if you strongly prefer using MATLAB instead, that is an option too). If you have questions about whether you have the requisite background, please feel free to get in touch in advance, or within the first week of classes.

Midterm Project (about 2--3 weeks)

A pre-defined midterm project will apply signal processing to a brain-computer interface (BCI) dataset that is based on the so-called "P300" response measured using electroencephalography (EEG). Detailed instructions will be provided to walk through the problem at hand and specify the deliverables. The dataset comes from Hoffmann et al. (2008) and includes measurements both from typical control individuals and individuals with limited muscle control.

Reference: Hoffmann, U., Vesin, J. M., Ebrahimi, T., & Diserens, K. (2008). An efficient P300-based brain-computer interface for disabled subjects. *Journal of Neuroscience methods*, 167(1), 115-125.

Final Project (final 4 weeks or so)

An independent project will apply signal processing to a research question of interest to each student. This project can either be related to ongoing research in a lab or can replicate a published study. The final projects are intended to be extensive as they will hopefully be in an area of direct interest and familiarity to each student. Projects will be presented to the class during the final two weeks of the semester (modeled after a ~10-min conference talk) and will be written up in a final report (modeled after a brief conference proceedings paper, ~2000 words + figures + references). Grading is based on content, oral presentation, and written presentation. Note: content is judged based on what you accomplish by submission of your written report, i.e., you are welcome to keep working after your oral presentation and include a more complete version in your written report.

Tentative Schedule

Although listed below in abstract terms, all topics will be motivated and discussed through representative biomedical examples.

Date	Topic	Notes
Aug 24, 26	Introduction; Orientation to Python; Fourier transform and general intuitions about different signal representations (linear-space view)	PS0
Aug 31, Sep 02	Noise reduction (I) -- Triggered averaging; Filter design & trade-offs	
Sep 07, 09	Noise reduction (II) -- Filtering beyond just frequencies using linear-space thinking, noise "cancellation" and regression	PS1 due
Sep 14, 16	Noise reduction (III) -- Multichannel filtering, PCA and applications	
Sep 21, 23	Statistical inference (I) -- Basics, ROC curves, multiple comparisons	PS2 due
Sep 28	Statistical inference (II) -- Inference on 1D signals	
Sep 30	Midterm project overview -- P300 brain-computer interface	PS3 due
Oct 05, 07	Statistical inference (III) -- Review, extension of methods from 1D to images	

Date	Topic	Notes
Oct 12	October Break -- No Class	
Oct 14	Spectral and time-frequency analysis (I) -- Auto/cross-correlation review; Spectrum estimation with preview of bias/variance tradeoff	
Oct 19, 21	Spectral and time-frequency analysis (II) -- Tapering and multitaper methods	Midterm project due
Oct 26, 28	Spectral and time-frequency analysis (III) -- Non-stationary signals and wavelets	
Nov 02	Modeling of biomedical signals and systems (I) -- Introduction to statistical estimation (ML), bias, and variance	
Nov 04	Modeling of biomedical signals and systems (II) -- Regularization (i.e., priors, MAP) and model selection	
Nov 09	Modeling of biomedical signals and systems (III) -- Minimum norm estimation and deconvolution example, Loess regression	PS4 due
Nov 11, 16	Spectral and time-frequency analysis (IV) -- Cross-spectrum, coherence, and phase locking	Final proposal due
Nov 18, 23	Machine learning approaches (I) -- ROC curve review; Linear classifiers and perceptron example; Support vector machines	
Nov 25	Thanksgiving -- No Class	
Nov 30, Dec 02	Machine learning approaches (II) -- The "training → validation → testing" workflow and combating overfitting; unsupervised clustering	
Dec 07	Machine learning approaches (III) -- Worked examples; External resources on neural networks and deep learning	Multiple choice due
Dec 09	Review and consolidation with more examples	
Dec 13--17	Final project presentations during exam week (no exam)	Final report due

Final Grade Composition

Assessment Item	Weight
Problem Sets ("PS" 1 -- 4)	35%
Consolidated Multiple Choice Problem Set	12%
Midterm brain-computer interface project	20%

Assessment Item	Weight
Final (individual) research project	
- Proposal	5%
- Oral presentation	10%
- Content	10%
- Written presentation	8%

Additional bonus points may be assigned for contributions to peer success through the discussion forum.

Learning Resources, Technology, & Texts

Supplemental References

There are no required textbooks. Class notes and code examples will be provided for all topics in some combination of PDFs, web pages, and Jupyter Notebooks.

The following optional additional resources are suggested for students interested in exploring from the ground up on their own.

1. Moon, T. K., & Stirling, W. C. (2005). Mathematical methods and algorithms for signal processing. Prentice hall. ISBN: 9788129709769.
2. Hastie, T., Tibshirani, R., & Friedman, J. (2009). The Elements of Statistical Learning Data Mining, Inference, and Prediction (2nd Illustrated Edition). ISBN: 9780387848587. [Reprint PDF may be available for download from [Trevor Hastie's web page](#)].
3. [Grant Sanderson's \(3blue1brown\) YouTube videos on Linear Algebra](#) provide excellent background on the geometrical thinking that we will exploit in this course.
4. Poor, H. V. (1994). An Introduction to Signal Detection and Estimation. Springer-Verlag. ISBN: 9781441928375.

Required Software

1. Python \geq 3.6 (or MATLAB if you strongly prefer)
2. Any software to typeset PDF documents (e.g., Jupyter notebooks converted to PDF, or Microsoft (TM) Word \rightarrow convert/print to PDF, or LaTeX)
3. Software for final project presentations (e.g., Powerpoint, LaTeXBeamer, etc. converted to PDFs)

Access to Python

As of this writing, Python is one of the most widely used and fastest growing languages for data-science work. It is also free for individual researchers and students. We will use Python ≥ 3.6 and associated scientific packages, namely NumPy, SciPy, matplotlib, pandas, and scikit-learn in this course. It is the responsibility of each student working with Python to find a reliable computing environment in which to do the work for this course. This should be worked out within the first week of class. There are two excellent options that are recommended:

1. **Anaconda distribution:** The Anaconda individual edition is free and can be easily installed on Mac, Linux, or Windows. This will run locally on the computer on which you install (e.g., personal computer, or lab computer). Being able to install and use these data-science tools is a minor but very useful skill in itself. Contained in the Anaconda distribution is Jupyter Notebook, which is an interactive coding environment that makes it easy to intersperse blocks of formatted text, code, and code outputs/figures.
2. **Google Colaboratory:** Google Colaboratory is a cloud computing platform that comes pre-installed with all of the scientific libraries we will need in this course. A Google account is needed to access Colaboratory. Once logged in, users are presented with a Jupyter Notebook environment where you can start writing and running code right away. The code will run on virtual machines spawned from Google's servers. Data and notebooks can be saved on Google Drive (up to 5 GB is free as of this writing). If using this option, you could use your existing google account if you have enough space, or create a new one (for free) for this course.

The scientific libraries across MATLAB and Python have many similarities. Thus, if you are primarily a MATLAB user, it is quite feasible to use this course as an opportunity to try or switch to Python. Excellent [online tutorials](#) are available for scientific Python. Office hours and the forum discussions are available to supplement your existing familiarity with Python.

If you are a MATLAB user looking to start using the Python data science ecosystem, one useful resource is [NumPy for MATLAB users](#).

Access to MATLAB

Although we will use Python by default for discussion in class, the scientific libraries are very similar across MATLAB and Python. Code illustrated with one language is replicable in the other. Thus, if you strongly prefer using MATLAB, that is an option accommodated in this course. You are welcome to solve assignments and projects using MATLAB code; the problems/projects themselves are language-agnostic. It is the responsibility of each student choosing to working with MATLAB to find a reliable computing environment in which to do the work for this course. MATLAB should be available on all ITAP machines on campus. As of this writing, all members of the Purdue community should have access to the [latest version of MATLAB for free via Purdue's campus-wide license](#). You could run MATLAB on the cloud using MATLABonline, similar to using Python with Google Colaboratory. The [Purdue MATLAB portal](#) also provides links to many tutorials. Office hours and forum discussions are available to supplement your existing familiarity with MATLAB.

Brightspace

Materials, assignments, and grades for the course will be posted on [Brightspace](#). Although Brightspace will serve as the starting point for all course material, some material will be hosted elsewhere and links will be provided on Brightspace. These include code blocks and Jupyter/IPython Notebooks on [GitHub](#) and [Google Colaboratory](#).

Also, online fora such as [Cross Validated](#), [Signal Processing Stack Exchange](#), and others may already have answers to many questions that typically come up. However, note that it is possible for online resources to have erroneous information. Learning to evaluate and use crowd-sourced online references is an important skill in the modern-day data scientist's repertoire.

Discussion Forum

Outside of class, we will use a discussion forum (details TBA) for Q&A and discussion. Rather than emails, this is the preferred channel. Using a discussion forum allows for getting you help fast and efficiently from classmates, and instructors. You are encouraged to ask *and answer* questions about logistics, content, assignments, and projects -- you can even do so anonymously. In particular, requesting and sharing general and specific Python/MATLAB "how to" knowledge is encouraged. However, please do *not* share explicit code blocks or solutions to homework sets, projects etc. You are also encouraged to share any ideas, articles, or videos that you think would benefit others. Information about the specific discussion platform to use will be posted on Brightspace.

Problem Sets & Project Submissions

For PS1 -- 4 and the multiple choice problem set, submitted work will consist of electronic files. All assignments are due by the specified due date (and time). Electronic material will consist of your *.PDF file containing your solutions and figures. In some cases, submission of code itself and/or data files (e.g., *.mat data files) ¹ may be requested. If multiple files are requested, all electronic files should be bundled together as one ZIP archive before submitting to Brightspace. Note that there is a problem set #0 (PS0), which is designed for reviewing MATLAB/Python use and is intended for self appraisal and need not be submitted.

There is a quota of **three total late** days you can use throughout the semester to manage unanticipated pressing events that may prevent you from submitting assignments on time. Save and use them judiciously. You can use all three days for one assignment or spread them over (up to) three assignments. Note however that part-day delays (e.g., late by 2 hours) will count as 1 whole day of quota being used up. No submissions will be accepted, even if you have unused late days, after Dec 17, 2021 (Friday of final exam week). Exceptions will be made to the 3-day rule only in unavoidable circumstances (e.g., extended health² issue) about which you discuss with the instructor as soon as the situation permits, and make alternate arrangements.

Mental Health Statement

For general information about mental health, see the [National Institute of Mental Health \(NIMH\) website](#).

If you find yourself beginning to feel some stress, anxiety, and/or feeling slightly overwhelmed, one option is to try [WellTrack](#) (available for free with your Purdue login, sign in to find information and tools at any time), or other mobile apps such as [Calm](#), [Aura](#), [Headspace](#), etc.

If you need further information about other options and resources, please feel free to reach out to me (the instructor), or your academic advisors. For support/more information, you could also see the [Office of the Dean of Students](#). Hours: M -- F, 8 am -- 5 pm.

If you find yourself struggling to find a healthy balance between academics, social life, stress, etc., consider signing up for free one-on-one virtual or in-person sessions with a [Purdue Wellness Coach at RecWell](#). Student coaches can help you navigate through barriers and challenges toward your goals throughout the semester. Sign up is completely free and can be done on BoilerConnect. If you have any questions, please contact Purdue Wellness at evans240@purdue.edu.

If you or someone you know is feeling overwhelmed, depressed, and/or in need of mental health support, services are available. Purdue University is committed to advancing the mental health and well-being of its students. For help and to speak with a clinician, contact Counseling and Psychological Services (CAPS) at (765) 494-6995 or by going to CAPS' office on the second floor of the Purdue University Student Health Center (PUSH). For urgent situations after hours, on weekends and holidays, call (765) 494-6995 to speak with a clinician. Please see the [CAPS website](#) for further information.

"Protect Purdue" Classroom Guidance

The [Protect Purdue Plan](#), which includes the [Protect Purdue Pledge](#), is campus policy and as such all members of the Purdue community must comply with the required health and safety guidelines.

Any student who has substantial reason to believe that another person in a campus room (e.g., classroom) is threatening the safety of others by not complying may leave the room without consequence. The student is encouraged to report the behavior to and discuss next steps with their instructor. Students also have the option of reporting the behavior to the [Office of the Student Rights and Responsibilities](#). See also Purdue University [Bill of Student Rights](#).

Emergency Preparedness

In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructor's control. Relevant changes to this course will be posted onto the course website or can be obtained by contacting the instructor via email. You are expected to read your @purdue.edu email on a frequent basis.

Academic integrity

See <https://www.purdue.edu/odos/academic-integrity/> -- *"Purdue University values intellectual integrity and the highest standards of academic conduct. To be prepared to meet societal needs as leaders and role models, students must be educated in an ethical learning environment that promotes a high standard of honor in scholastic work. Academic dishonesty undermines institutional integrity and threatens the academic fabric of Purdue University. Dishonesty is not an acceptable avenue to success. It diminishes the quality of a Purdue education, which is valued because of Purdue's high academic standards. Fostering an appreciation for academic standards and values is a shared responsibility among students, faculty, and staff. The information on this website is directed to students to define academic dishonesty and how to avoid it."*

Furthermore, the Purdue Honor Pledge Task Force, a student organization responsible for stewarding the mission of the Honor Pledge and encouraging a culture of academic integrity has fashioned the following pledge: *"As a Boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together -- We are Purdue."*

Nondiscrimination Statement

Purdue University is committed to maintaining a community which recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Purdue's nondiscrimination policy [can be found here](#).

Attendance Policy

Lectures will offered via face-to-face meeting in class, synchronously via livestream (access details TBA), and asynchronously via recorded video (uploaded to Brightspace within about 24 hours after each lecture). If registered for the in-person section, attendance is generally expected, but will not be a factor in the final grade. If you need to be absent for any unavoidable reasons, please inform the instructor in a timely manner, when possible. In such cases, it is your responsibility to catch up with the material that you miss using the asynchronously available video recordings. If extended absence and schedule adjustments are necessitated by unavoidable circumstances, please contact the instructor for making alternate arrangements as soon as the situation permits. Note that office hours and the discussion forum are available to assist you as well.

Guidance on class attendance related to COVID-19 are outlined in the [Protect Purdue Pledge](#) for Fall 2021 on the [Protect Purdue website](#).

If you become Quarantined/Isolated

If you become quarantined or isolated at any point in time during the semester, support is available from the [Protect Purdue Health Center](#). See the PPHC website [for details](#). Importantly, if you find yourself too sick to progress in the course, notify me via email. We will make arrangements based on your particular situation. The Office of the Dean of Students (odos@purdue.edu) is also available to support you should this situation occur.

Students with disabilities

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at: drc@purdue.edu or by phone: 765-494-1247.

Course Evaluation

During the last two weeks of the course, you will be provided with an opportunity to evaluate this course and your instructor. Purdue uses an online course evaluation system. You will receive an official email from evaluation administrators with a link to the online evaluation site. You will have up to two weeks to complete this evaluation. Your participation is an integral part of this course, and your feedback is vital to improving education at Purdue University.

[1]: Note that `.mat` is MATLAB's extension for HDF5 format files. It is also a recognized format with Python via the `scipy.io` module

[2]: Mental health *is* health