ENGN 395
Applied Signal Processing
Instructor: Jon Erickson
Spring 2020
Course Web Page: `http://home.wlu.edu/~ericksonj/sigproc_s2020.html`

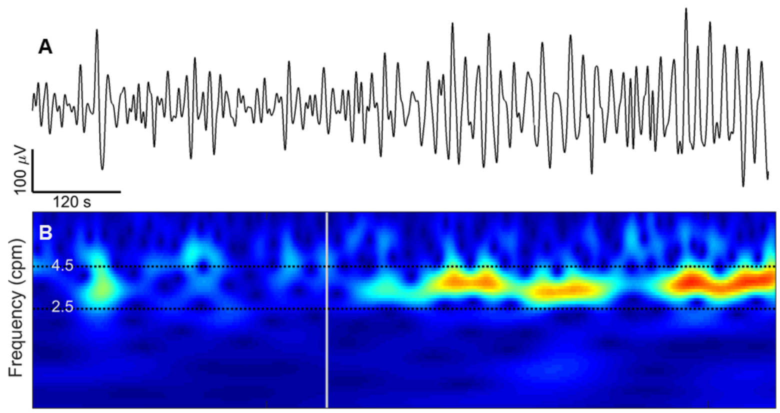

Figure 1: Time domain signal (top); and time-frequency spectrogram (bottom). The "signal" is an electrical recording of colon motor activity made from the abdominal skin surface.

What is Applied Signal Processing?

This course is about what we do with signals after we measure them—i.e., how to ***extract useful information for noisy signals***. It is a project-based course in which we integrate theory and practice applied to real world applications. For example:

1. An Apple (TM) watch measures the electrocardiogram (ECG), electrical signal generated by your heart. How does it analyze this signal to produce a read out of your heart rate, or sound the alarm if it detects signatures of atrial fibrillation? [Answer: QRS peak detection using using the Non-linear Energy Transform]

2. The LIGO observatory recently detected the gravitational waves predicted by Einstein nearly a century ago. Two blackholes spun around each other at increasingly faster rates until they collided. How did physicists quantify this cyclic activity based on changes in light intensity? [Answer: Wavelets]

3. Your mobile device likely contains large numbers of photos, videos, and songs. How does efficiently store and transfer them? And how does audio watermarking combat digital piracy? [Answer: Data compression algorithms based on Discrete Cosine Transforms and Spread Spectrum Channels]

While the techniques we learn in this course we will based on specific case studies, they are also broadly applicable to a wide range of problems: biomedical/health care, robotics, music and speech analysis, civil infrastructure monitoring, geology/geophysics, fluid dynamics, climate science, art history and preservation, and econometrics.

What you'll learn in this course: Course Objectives

You will emerge from this course fluent in theory and application for a variety of widely-used signal processing techniques. To this end students will:

- Learn the underlying theory and math for a variety of signal processing techniques
- Learn to skillfully apply these algorithms to real world data using modern software analysis (e.g. MATLAB)
- Understand the benefits and limitations in deciding which signal processing method is the "best" for a specific application

Course Meeting Info

Lecture and Workshop Time: MTWR 10am - noon
Lab/Project Time MTWR 1 - 3pm
Class Presentations F 10am-noon

Course Flow

This is a hands-on class. The general course flow will be built around individual modules with focused study of a particular technique. Within each module, we'll first look at a motivating example of why we need a signal processing technique (e.g. How are we going to measure heart rate based on the ECG signal?). Together we'll study the math underlying one (or more) applicable techniques to tackle the problem. Then we'll actually apply signal processing techniques to data sets to quantify and asses how well the algorithm works—i.e. see the signal processing in action.

Topics Covered

For a more complete list, please see the Course Schedule on the course website. A summary of the topics we will cover follows below:

1. **Event Detection and Signal Transforms:**

   Gaussian Statistics; Statistical Detection Thresholds Discrete Derivatives; Non-linear Energy Operators;

2. **Digital Filtering:**

   FIR filters; IIR filters; Zero-phase filters

3. **Time-Frequency Analysis:**

   Cross-correlation; Fourier Spectral Analysis; Continuous and Discrete Wavelet Transforms

4. **Blind Source Separation/Mode Decomposition:**

   Principal Components Analysis (PCA); Independent Component Analysis (ICA); Second Order Blind Identification (SOBI); Empirical Mode Decomposition (EMD); Dynamic Mode Decomposition (DMD)

5. **Compressive Sensing:**

   L0, L1, L2 norms; Random and Fourier Basis Selection; Signal Recovery from Incomplete Information

Course Readings

We will use a combination of textbook chapters to learn underlying theory and math. We'll study journal articles to study real world applications of various signal processing techniques. A (partial) list follows:

1. *The Illustrated Wavelet Transform Handbook: Introductory Theory and Applications in Science, Engineering, Medicine and Finance–2nd ed., P.S. Addison, 2017, ISBN: 978-1482251326. [Chapters 1, 2, 3, 6]*

2. *Applied Signal Processing–A MATLAB based proof of concept, T Dutoit and F Marques, 2009, ISBN: 978-0-387-74534-3. [Chapters 1, 7, 8, 9]*

3. *The Scientists and Engineer's Guide to Digital Signal Processing, SW Smith, 1997, ISBN: 978-0966017632. [Chapters 14-21]*

4. *Belouchrani, A., Abed-Meraim, K., Cardoso, J. F., & Moulines, E. (1997). A blind source separation technique using second-order statistics. IEEE Transactions on signal processing, 45(2), 434-444.*

5. *Shlens, J. (2003). A tutorial on principal component analysis: derivation, discussion and singular value decomposition. Mar, 25(1), 16.*

6. *Hyvärinen, A., & Oja, E. (1999). Independent component analysis: A tutorial.*

7. *Huang, N. E., Shen, Z., Long, S. R., Wu, M. C., Shih, H. H., Zheng, Q., ... & Liu, H. H. (1998). The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 454(1971), 903-995.*

8. *Brunton, B. W., Johnson, L. A., Ojemann, J. G., & Kutz, J. N. (2016). Extracting spatial–temporal coherent patterns in large-scale neural recordings using dynamic mode decomposition. Journal of neuroscience methods, 258, 1-15.*

9. *Abbott, B. P., Abbott, R., Abbott, T. D., Abernathy, M. R., Acernese, F., Ackley, K., ... & Adya, V. B. (2017). All-sky search for short gravitational-wave bursts in the first Advanced LIGO run. Physical Review D, 95(4), 042003.*

Integrative Course Assignments

All assignments will be based around applied laboratory work–i.e. building, testing, and analyzing the results of signal processing outputs. As such, assignments will integrate theoretical and practical components. In lay terms, on each assignment, you'll be asked to:

1. Apply signal processing algorithms to real-world data sets

2. Quantify and interpret the quality of signal processing results

3. Describe in mathematically rigorous terms how and why the signal processing technique succeeded (or failed) on a particular data set
4. Compare and contrast the relative strengths of various signal processing methods applied to a particular problem

Each integrative assignment must be revised, as needed, until it crosses a threshold of very good to excellent, marked "VGE". An assignment marked "RR" indicates some aspects of your submission merit significant improvement, and you must submit a revision. In this case, you must meet with the instructor to review your work to discuss what needs to be improved and how to improve it. It is *your* responsibility to stop by office hours and/or set up a meeting time. Grades on these assignments will be awarded as follows, based on when the VGE is achieved:

1. Original submission: A+ (100)
2. Revision 1: A (95)
3. Revision 2: B+ (87)
4. Revision 3: C- (72)
5. Revision ≥ 4: D- (62)

This revision process is intended to help you 1) fully comprehend core concepts in Signal Processing theory and application; and 2) foster your overall scientific writing capability. With a good faith effort from the student, the instructor fully expects that the revision process should typically conclude with the assignment receiving a grade of no lower than B+.

Final Project

There will be one open-ended, integrative final project. While it will serve to help assess your level of mastery of course material, even more importantly, it will also provide an opportunity to work on an active research problem. The final week of the course will be dedicated to tackling this project.

Grading Policies

1. **You must satisfactorily complete all integrative assignments in order to pass this class.**
2. Assignments submitted after the due date without prior approval from the instructor will incur a 5%/day deduction from Integrative Assignment score (50 points total over the term). Of course, reasonable exceptions are made in extenuating circumstances.
3. Numeric grades are tabulated as follows:

Integrative Assignments/Labs	60%
Final Project	25%
Preparedness and Course Participation, Intellectual growth, Independence	15%
Total	100%

COURSE POLICIES

Integrative Assignment Policy

You are allowed and strongly encouraged to discuss integrative assignment problems with class mates, but your written solutions must be generated by you alone. Consultation with or seeking aid from solutions from previous offerings of this course is strictly forbidden.

Lab Work/Data Sharing Policy

This term, you will work with classmate(s) during all workshop/project (aka lab) sessions. It is crucial that both you and your team members actively participate to master the core skill sets in Signal Processing. You are allowed and encouraged to ***share raw data***. However, ***each student must generate his or her own final graphics/figures from (shared) raw data.*** Reasonable accommodations are made by the instructor with regard to sharing files that generated in collaboration with your lab partner, but you must ***ask first***.

Final Project Policy

You will work in teams of 2-3. You may of course fully collaborate with your team member(s), but collaboration and discussion with anyone else is strictly prohibited.

Academic Honesty

According to the White Book[1], the Honor System is the "fundamental principle that a spirit of trust pervades all aspects of student life." The system is one of "mutual trust" which clearly establishes that "Students should do their own work, *represent themselves truthfully, and claim only that which is their own*" (emphasis added by JE). The system is not designed to "work against or frighten" students, rather it was designed to allow students "unparalleled academic freedom."

You are expected to abide by the W&L Honor System at all times. Any suspected Honor Violation will be reported to the Executive Committee. In such an event, the instructor reserves the right to assign a grade of zero on that assignment and/or a failing grade for the course. (I believe in my heart that this policy will never ever come into play, but I am, more or less, legally compelled to explicitly state it in the official course syllabus.) Specific policies regarding homework assignments, lab reports, and exams are described in detail below. If you are ever in doubt about whether an action is within bounds, please consult with me first.

Special Academic Accommodations

Washington and Lee University makes reasonable academic accommodations for qualified students with disabilities. All undergraduate accommodations must be approved through the Office of the Dean of the College. Students requesting accommodations for this course should present an official accommodation letter within the first two weeks of the (fall or winter) term and schedule a meeting outside of class time to discuss accommodations. It is the student's responsibility to present this paperwork in a timely fashion and to follow up about accommodation arrangements. Accommodations for test-taking should be arranged with the professor at least a week before the date of the test or exam.

[1]Full text of White Book available at `http://www.wlu.edu/x48217.xml`

Attendance Policy

Class Periods

You are *strongly encouraged* to attend all lectures—hopefully they are worth attending. We'll be doing a lot of hard thinking, working on problems, learning by doing in the lab (but minimal straight-up old school lecture). In order to make optimal use of our 90 min together, *before class* please read and/or watch assigned material, and do your level best to understand core concepts. (Learning how to learn...a life-long skill...two for the price of one in Circuits...hooray!)

If you miss class for a legitimate reason—illness, family emergency, etc.—I will make every effort to help you get caught up as soon as possible. You must notify me (in person or via email) of a planned excused absence prior to day you will miss to briefly explain the circumstances. In the event of an unexcused absence (i.e., "Whoops, I slept in"; "I had paper due for another class"; "I left a day early for Thanksgiving Break", etc.), you are solely responsible for staying up to date with class notes and news—in which case, I strongly recommend talking to a Circuits buddy.

Lab Periods

The laboratory sessions are crucial for learning hands-on, practical skills relating to electric circuits. Therefore, *you must satisfactorily complete all labs during the assigned laboratory period.* Of course, any extenuating circumstances will be carefully considered, should they arise. If you are unable to attend a laboratory session on the assigned day for a legitimate reason, notify me *in person or by email before the lab* to explain the circumstance, and I will arrange for a time to make-up the lab, and do everything reasonable within my power to help you with the lab. *In the event of an unexcused absence, you are still required to complete the laboratory, but no assistance from the instructor and/or TA will be offered.*

Note on Athletics

Sanctioned athletic competitions, but not practice sessions, qualify as an excused absence. Please notify me of an athletic absence well in advance of the athletic event.

Sick Day Policy

If you are feeling ill, please stay home, get some rest, get a friend to bring you notes from class and chicken soup and get better soon! It is in everyone's best interest for you to minimize interpersonal contact when you are feeling sick, especially when you are symptomatic. I trust your judgment and do not require a doctor's note. However, please remember to contact me regarding this absence, and feel better soon!.

Electronic Devices and Texting

Figure 2: Circuits is a No Texting Zone.

I would like to believe I am a pretty easy-going, congenial guy, but the one thing that absolutely drives me bonkers is texting during class. The two-hands under the desk, half-blank stare is obvious. So, thank you in advance for powering down your mobile device, and for respecting the strict no-texting policy.

If you must have your phone on for tending to, say, a medical or family emergency, please inform me before the start of class.

Regarding laptops in class: There isn't really any compelling reason why you would use one in Circuits on a day-to-day basis, and a grand total of zero students have sought to use one in 8 previous years I've taught this course. However, if you have insist on using a laptop, please ask me first—any reasonable requests will be entertained and carefully considered (but I do not promise to grant it). All of this said, there are days when we will make use of Matlab or other software packages to perform analysis; you'll be given ample advance notice.

Suggestions and Feedback

Suggestions for improvement, constructive criticism, and positive feedback are welcome at anytime (especially during this first offering of the course!) Please do not hesitate to approach me with any concerns you may have about this course. I take your feedback very seriously and will sincerely respond to all received comments. It is the main mechanisms by which the course will improve over time (sometimes instantaneously, when possible!).