Course Title: BIOEN 316 Biomedical Signals and Sensors
http://courses.washington.edu/bioen316

Instructor: Christopher Neils
cmneils@uw.edu

Credits: 4

UW General Catalog Course Description:

An introduction to the sources, detection, and processing of biological signals of medical importance. Emphasis on understanding the limitations of sensor systems and the implications of digital signal processing in the time and frequency domains, with the goal of selecting systems and methods that improve safety, accuracy and reliability.

Prerequisites by course:

PHYS 122 and one of the following: AMATH 301; CSE 142 and MATLAB for Bioengineers; CSE 160 and MATLAB for Bioengineers. Pre/co-requisite: MATH 307 or AMATH 351. Requires concurrent registration with BIOEN 317.

Prerequisites by topic:

Introductory MATLAB programming, Introduction to computational solutions of ODEs and PDEs, Introductory Electromagnetism, Mechanics (oscillators). Pre/co-requisite: Differential equations.

Overview:

This course introduces the acquisition, processing, and interpretation of biological and medically relevant signals. The course sequence begins with the user and display interface, then moves backward along the signal flow path to finish with details of various biological sensor types. This sequence recognizes that a user is more interested in the output of the diagnostic system than in the output of the transducers and circuitry that compose it. In addition, each stage in the signal flow path provides the motivation for the preceding stage. For example, display systems often require sophisticated digital signal processing, and digitization requires prior analog filtering and amplification. Therefore, the first half of the course introduces techniques to analyze and implement analog and digital frequency filters, operational amplifiers, and signal sampling. By the time students reach the sensors part of the course, they have the conceptual tools to relate what the user sees on the front panel to the signal captured at the sensor. Biomedical sensor technology is treated in depth in the second half of the course, drawing on content in the concurrent Biochemical and Molecular Bioengineering course. Sensor topics include surface and implantable electrodes, photometry, biochemical sensors, force and position detectors, piezoelectric devices, life science microscopes, and surface plasmon resonance. Throughout the course, emphasis is placed on recognizing and accommodating limitations inherent in sensor and signal processing systems.

Textbooks:

Required: None
Recommended:

Circuits, Signals and Systems for Bioengineers, J. Semmlow, 2nd edition.
Medical Instrumentation: Application and Design, by John G. Webster.
Understanding Digital Signal Processing, by Richard Lyons, 1st, 2nd or 3rd edition.
Electric Circuits, by James Nilsson and A. Riedel, 7th edition or newer.

Learning Objectives:

Students will learn the following fundamental concepts:

1) Characteristics, basis and utility of a variety of biomedical signals;
2) Frequency domain analysis via Fourier transforms;
3) Limitations of signal sampling;
4) Basic principles of bio-signal transduction;
5) Characteristics, limitations, and applications of a variety of signal transducers;
6) Bio-signal and medical device terminology.

Students will also develop the following skills:

1) Application of time-frequency transformations and interpretation of the results;
2) Selection and implementation of simple digital and analog frequency filters;
3) Implementation of simple signal acquisition routines using MATLAB or LabView.

Topics covered:

1) Types of medical instruments, sources of biomedical signals.
2) Signal sampling, aliasing, and noise.
3) Fourier series and the frequency domain.
4) Discrete Fourier transforms, digital signal filtering, including finite impulse response filters, convolution, and infinite impulse response filters.
5) Operational and instrumentation amplifiers.
6) Analog filtering, including sensor-circuit interface, impedance, and noise.
7) Photometric, thermal, bioelectric, biomechanical and biochemical sensors, strain gauges and bridge circuits.
8) Ultrasonic transduction.
9) Device fabrication.
10) Electrical safety.

Computer Use:

Homework problems use MATLAB (including Signal Processing Toolbox) for digital filter design and implementation, Excel for signal plotting and statistical analysis, and PSPICE or equivalent to simulate analog circuit behavior. Completion of reading assignments will be tested via brief Catalyst surveys.

Course Structure:

BIOEN 316 employs lectures, practice problems, homework problems, and bi-weekly quizzes.

Lectures: There are three 1-hour lectures per week. No points are awarded or deducted for attendance in lecture. However, students are expected to have attended the relevant lecture(s), or at least have explored the relevant material, before coming to office hours with questions.

Pre-lecture reading assignments may be given for days when there is no quiz or homework due. For some of the material, a Catalyst survey will be used as an incentive. This will be new material, so naturally you will not be expected to understand the more complicated concepts. Nonetheless, the instructor will assume that you have done the reading, and you might be called on to explain what you have read or at least to ask relevant questions.

Quiz sections: There is one 1-hour "quiz" section per week, focusing on practice and application of the concepts and procedures presented during lecture. The maximum size of each section is approximately 20 students, allowing greater interaction with the instructor than is possible in lecture. In a typical section, students are given worksheets with challenge problems; students work in small groups for some portion of the period, then are invited to explain or their answers or solve the problems at the board to develop their problem-solving skills. The instructor provides explanations, examples, etc. as needed.

Labs: BIOEN 316 does not have an integrated lab. However, because many of the concepts and procedures are most effectively learned through practice with individualized help, the BIOEN 317 Signals and Sensors Lab course is a required adjunct to BIOEN 316.

Homework: There will be approximately one homework per week. Homework is not due on the same day every week, because due dates are chosen to match the pace of the course and to avoid conflicts with major assignments in other courses (e.g., midterms in BIOEN 315). Therefore, please refer to the online course calendar. Homework assignments will be due either at the beginning of lecture OR will be submitted on line, depending on the nature of the assignment. Homework turned in late but before solutions are posted may be penalized at 5% per day unless prior arrangements have been made. No points are awarded for homework turned in after solutions are posted, but we will be glad to read and correct the homework so you can learn from it. If you cannot turn in an assignment due to illness, please let the instructors know and we might postpone posting the solution. Students may discuss the problems, solution strategies and MATLAB syntax, but then are expected to produce their own code and report. Similar to the policy in Computer Science, no matter how much others helped you through the learning phase, submitting an individual assignment implies that you are capable of doing that work by yourself and could demonstrate that ability if asked.

Quizzes: There will be four 25-minute quizzes, each of which will be based on a set of practice problems. If you can do the practice problems, you will probably be able to do the quiz. None of these practice problems needs to be turned in. You are welcome to use any resources, such as cramster.com, to help you understand the solutions to these practice problems.

If an in-class quiz must be missed, the instructor should be notified beforehand so arrangements can be made. If a fifth quiz is given (and it might not be), the lowest score will be dropped.

Exams: The final exam will be comprehensive and may include material from the quizzes, homework, and lectures. There will be no midterm exam other than the quizzes.

Grading distribution:

Homework	32%	[Simple practice exercises plus longer problem sets]
Special project	08%	[Essay or video on sensors or contemporary issues]
4 mid-term quizzes	32%	[25 minutes each]
Final exam	28%	[Comprehensive]

It is traditional in my courses that the final grades are adjusted such that the top-performing students earn 4.0, but there is no specified mean grade for the course.

Typical Course Schedule

See the course web site for exact schedule and assignments for the current quarter

Week	Lectures	Homework
1.	**M:** Course introduction; The ECG **W:** Analog to digital conversion **F:** Fourier series with real coefficients **Quiz section:** "Prior knowledge" math & physics review	HW1. Digitization and MATLAB analysis of heart vector
2.	**M:** Fourier series with complex coefficients **W:** Continuous Fourier transforms **F:** Discrete Fourier transforms **Quiz section:** Review FT properties and applications	HW2. Drug concentration as a Fourier series
3.	**M:** Aliasing **W:** Quiz 1: Sampling and Fourier series **F:** Convolution I – time domain **Quiz section:** Convolution practice; Review quiz 1	No HW due (Quiz)
4.	**M:** Convolution II – relationship to frequency domain **W:** Finite impulse response filter – analysis & application **F:** Convolution III – Fourier optics & point spread function **Quiz section:** FIR filter design	HW3. Convolution HW4. FIR filter design
5.	**M:** IIR filters **W:** Quiz 2: Convolution and digital filters **F:** RC and RL filters, I **Quiz section:** Practice Bode plots; review Quiz 2	No HW due (Quiz)
6.	**M:** RC and RL filters, II **W:** RLC filter analysis **F:** RLC filter design **Quiz section:** RLC filter design worksheets	HW5. RC/RL filters HW6. RLC filters
7.	**M:** Transistors and diodes **W:** Quiz 3: passive RLC filters **F:** Instrumentation amplifiers **Quiz section:** Review & questions through quiz 3	HW7. Diodes & photometry
8.	**M:** Operational amplifiers **W:** Electrical isolation and safety **F:** Active filters and comparator circuits **Quiz section:** Filter circuit analysis, practice & examples	HW8. Op-amp circuits
9.	**M:** Memorial day, no school **W:** Schmitt triggers **F:** Ultrasound transducers & Doppler velocimetry **Quiz section:** Quiz 4, Amps & sensors	No HW due (Quiz)
10.	**M:** Ultrasound imaging & HIFU **W:** FET-based sensors; final exam review **F:** Opportunities in bio-instrumentation; course evaluation **Quiz section:** Final exam review	HW9. Video/essay on sensor technology.
11.	**Final exam (comprehensive)**	

Access and Accommodations: Your experience in this class is important to me. If you have already established accommodations with Disability Resources for Students (DRS), please communicate your approved accommodations to me at your earliest convenience so we can discuss your needs in this course.

If you have not yet established services through DRS, but have a temporary health condition or permanent disability that requires accommodations (conditions include but not limited to; mental health, attention-related, learning, vision, hearing, physical or health impacts), you are welcome to contact DRS at 206-543-8924 or uwdrs@uw.edu or disability.uw.edu. DRS offers resources and coordinates reasonable accommodations for students with disabilities and/or temporary health conditions. Reasonable accommodations are established through an interactive process between you, your instructor(s) and DRS. It is the policy and practice of the University of Washington to create inclusive and accessible learning environments consistent with federal and state law.

Contact:
011 Mary Gates
Box 352808
Seattle, WA 98195-2808
uwdrs@uw.edu
206-543-8924 (Voice & Relay)
206-616-8379 (Fax)

Course Outcomes and Assessment:

BIOEN 316 presents, in interactive lectures and assignments, the fundamentals of electrical and optical signal analysis. As such, this course addresses certain ABET outcomes at multiple levels.

Specific outcomes addressed by BIOEN 316 and their assessment mechanisms to be used by the department for program assessment are:

(A) *An ability to apply knowledge of mathematics, science and engineering.*

> (Apply digital signal processing theory to signal analysis and filtering; analyze and design analog circuits for signal filtering and amplification.)

Concepts and techniques are presented in lecture, practiced in homework, explored in lab, and reinforced with biweekly quizzes. Student competency is assessed primarily with a final exam question, worth 5-10% of the course grade, that asks students to outline a system to acquire and display a given surface biopotential or optically acquired signal.

(L) *An understanding of biology and physiology.*

> (Describe sources of electrophysiological signals and the instrumentation used to measure these signals.)

Lectures and readings will include explanations of muscle fiber contraction as the source of the EMG, cardiac physiology as the source of the ECG, anatomical interfaces as the reflecting features in ultrasound imaging, and arterial pulsations as the basis for pulse oximetry. Student knowledge will be developed through homework assignments and assessed via a final exam question that will be worth ~5% of the course grade. A typical question would ask students to illustrate conduction pathways through the heart, describe briefly how neuromuscular signals produce a measurable ECG, and describe a few pathologies that can be detected using an ECG.

(M) *An ability to apply advanced mathematics, science and engineering to solve the problems at the interface of engineering and biology*.

> (Design analog circuits for signal filtering and amplification; analyze these circuits using differential equations and complex frequency-domain methods & Fourier transforms.)

Examples in lecture and homework are framed around biomedical measurements, so students relate the biomedical need for the measurement with the applied formulas and the performed calculations. Concepts are reinforced in bi-weekly problem sets. Achievement will be assessed via a midterm quiz or final exam questions, worth 5-10% of the course grade, that asks students to design and analyze electronic circuits that are appropriate for a given biological signal and output function.

(Y) An ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems.

> (Identify ways that sensors interact with biological systems and the resulting effects on biological measurements. Identify ways to minimize problematic interaction of biological sensors and measurements.)

Student knowledge will be developed through lectures and a written assignment that address the following: (1) considerations for external and internal measurements, such as motion artifact for surface bio-potentials, injury or infection from invasive devices, and encapsulation of implantable devices, (2) ways to improve the quality of information obtained, for example by surface treatment of implantable devices, or signal processing to remove artifacts, and (3) ways to decrease invasiveness, such as optical instruments, and increased lifetime of implantable devices to reduce surgical frequency. Student knowledge will be assessed via a final exam question, worth ~5% of the course grade, that asks students to explain one or more methods that have been used in the past to minimize the impact of biofouling, to improve patient electrical safety, to reduce the need for invasive measurements, or to accommodate measurement artifacts through signal processing. If practical, it will also ask how statistical methods can be used to reduce signal noise.

Other outcomes of high relevance:
The following learning outcome is highly relevant to the content and practice in BIOEN 316, but will not be used for program assessment.

(e) *An ability to identify, formulate, and solve engineering problems.* Examples in lecture and on problem sets will show how practicing bioengineers have identified needs in the biomedical community, and the strategies they have used to achieve solutions through engineering.

(j) *A knowledge of contemporary issues*. Example: The appropriateness of some diagnostic tests is the subject of some debate. In some cases the tests have a higher probability of producing a false positive result than a true positive result. Another example is computed axial tomography, which can be effective at detecting tumors but which also produces radiation that has been liked to carcinogenesis.

Relationship of Course to Departmental Objectives:
The goal of our Bachelors program in Bioengineering is to prepare our graduates for industry, graduate programs, and medicine. BIOEN 316 contributes to this goal by preparing students to do the following:

1. Earn advanced degrees and/or obtain employment in bioengineering-related fields, such as medicine, device development, or biotechnology.
2. Advance their careers by obtaining appropriate educational and professional qualifications.
3. Serve their profession and community.
4. Contribute to responsible development of new technical knowledge.
5. Take leadership roles in addressing domestic or global bioengineering-related issues.

BIOEN 316 introduces junior-level Bioengineering students to fundamentals of signal analysis and manipulation including universal quantitative analysis tools such as Fourier analysis, analysis of electrical and optical signals that are ubiquitous in biosensing, as well as their qualitative understanding of the performance of frequency-domain filters and various biomedical sensors. This background is expected to increase their potential for employment.

BIOEN 316 introduces students to the terminology and procedures used in a variety of engineering disciplines and in the medical profession. In this way, it prepares our students to pursue opportunities for professional growth and eventually take leadership roles, across an expanding range of fields and thereby increases their potential impact in their profession and community.