Course Syllabus

ECE/BME 418-518
Wearable Biosensors and Microsystems

Fall 2024

Course Description
The aim of this course is assessment of selected approaches to characterize human physiology integrated across device design/instrumentation, physiology, model-based interpretations and data analytics. The first part of the course will introduce the sources of chemical, electrical, and mechanical bio-signals, and the sensing motifs for monitoring each bio-signal. The second part of the course will explore the design, function and limitations of wearable biosensors. Example systems will include wearable electrocardiograms, blood-glucose monitors, electronic tattoos, "smart" clothing, and body area networks. Emphasis will be given to critical comparison of different sensor modalities and how their limitations in realistic applications suggest the selection of one type of sensor over another. This course will provide students with a general overview of wearable biosensors and the necessary technical background to solve basic problems in engineering systems at the interface of biology and electronics.

Learning Outcomes
This course will better prepare students in the up and coming biotechnology and nanotechnology markets. Students will learn the basic sensing principles and sensing elements (chemical, biochemical, optical, semiconductor) and how they can be applied to wearable systems of physiological sensors. Students will also learn various application examples associated with those sensing principles. Upon completion of this course, a student should be able to:

- Explain the functional mechanisms of bioanalytical sensors;
- Understand how to design chemical sensors and biosensors by integrating concepts of molecular recognition, transduction, biomaterials and microfabrication;
- Apply the information to identify the proper sensing system to be used in the determination of physiological parameters;
- Quantitatively analyze biosensor data or performance;
- Critically evaluate biosensors described in the scientific literature.

In addition, the graduate students after completion of the course project will be able to:

- Design wearable biosensors to address a clinical or consumer need with regards to optimization of Functionality, Reliability, and Convenience;
- Formulate a clinical trial or human subjects testing protocol;
- Compose an Executive Summary for a product pitch, and
- Critically review the product market for wearable biosensors and microsystems.

Course Structure
This course meets two times per week from 11:45 AM to 1:00 PM on Tuesdays and Thursdays. These lectures will be used to present new materials, review and discuss research paper(s) that represent typical work in the field, supplemented by video lecture material that is necessary to understand them. All course content will be administered via the course's Moodle Site.

Course Policies
Each student is responsible for all assignments, announcements, and material covered in each meeting and posted to the Moodle Site. Getting involved in discussion and asking questions about the points that are not clear is important for learning the material. Participants are expected to be engaged in class, to learn from the execution of the coursework, and to share their own unique insights into the course material.

Instructors
Dr. Michael Daniele (mdaniel6) - *Instructor*
Email: mdaniel6@ncsu.edu
Phone: 919-513-2654
Office Location: Engineering Building II (EB2)
Office Hours: After class and by appointment; Virtual Hours are available for EOL/DE students

Course Meetings
Lecture: *This meeting is required.*
Days: Tuesday; Thursday
Time: 11:45AM - 1:00PM
Campus: Centennial
Location: 2124 Engineering Building III

Course Materials
Textbooks: None.
Expenses: IOT, Biometrics, or Sensors Demonstration Kit (Optional)
Materials: None.

Requisites and Restrictions
Prerequisites: Senior or graduate standing. Familiarity with basic biology, chemistry and physics.
***Co-requisites*:** None.
Restrictions: None.

General Education Program (GEP) Information
GEP Category: This course does not fulfill a General Education Program category.
GEP Co-requisites: This course does not fulfill a General Education Program co-requisite.

Transportation
This course will not require students to provide their own transportation. Non-scheduled class time for field trips or out-of-class activities is NOT required for this class.

Safety & Risk Assumptions
None.

Grading

Graduate Grade Components:

Component	Weight	Details
Final Exam	**20%**	Comprehensive Exam
Midterm Exam (Take Home)	**20%**	
Homework	**10%**	2 Independent homework assignments to be submitted.
Article Reading and Critiques	**30%**	State-of-the-art, peer reviewed journal articles will be assigned for reading, followed by a submitted critique/analysis, and in class discussion.
Design or Demonstration Projects	**20%**	Everyone registered for the graduate level of the course (518) is required to design or demonstrate a solution for a biomedical, commercial, or other application of wearable biosensors, prepare an executive summary; validation protocol and product pitch to be shared with the class. The topics will be assigned towards the middle of the semester. Details will be provided in class.

Undergraduate Grade Components:

Component	Weight	Details
Final Exam	**20%**	Comprehensive Exam
Midterm Exam (Take Home)	**30%**	
Homework	**20%**	2 Independent homework assignments to be submitted.
Article Reading and Critiques	**30%**	State-of-the-art, peer reviewed journal articles will be assigned for reading, followed by a submitted critique, and discussions.

Letter Grades

This Course uses Standard NCSU Letter Grading, as percentage of total points earned:

97 ≤ **A+** ≤ 100
93 ≤ **A** < 97
90 ≤ **A-** < 93
87 ≤ **B+** < 90
83 ≤ **B** < 87
80 ≤ **B-** < 83
77 ≤ **C+** < 80
73 ≤ **C** < 77
70 ≤ **C-** < 73
67 ≤ **D+** < 70
63 ≤ **D** < 67
60 ≤ **D-** < 63
0 ≤ **F** < 60

Requirements for Credit-Only (S/U) Grading

In order to receive a grade of S, students are required to take all exams and quizzes, complete all assignments, and earn a grade of C- or better. Conversion from letter grading to credit only (S/U) grading

is subject to university deadlines. Refer to the Registration and Records calendar for deadlines related to grading. For more details refer to http://policies.ncsu.edu/regulation/reg-02-20-15.
Courses at the 500 and 700 level are letter graded. Students cannot enroll in these courses for 'credit only'. Performance in research, seminar and independent study types of courses (6xx and 8xx) is evaluated as either "S" (Satisfactory) or "U" (Unsatisfactory), and these grades are not used in computing the grade point average. For credit only courses (S/U) the requirements necessary to obtain the grade of "S" must be clearly outlined.

Requirements for Auditors (AU)
Information about and requirements for auditing a course can be found at http://policies.ncsu.edu/regulation/reg-02-20-04.

Policies on Incomplete Grades
If an extended deadline is not authorized by the instructor or department, an unfinished incomplete grade will automatically change to an F after either (a) the end of the next regular semester in which the student is enrolled (not including summer sessions), or (b) the end of 12 months if the student is not enrolled, whichever is shorter. Incompletes that change to F will count as an attempted course on transcripts. The burden of fulfilling an incomplete grade is the responsibility of the student. The university policy on incomplete grades is located at http://policies.ncsu.edu/regulation/reg-02-50-3.

Late Assignments
Unexcused late exams, homework, and article assignments will not be accepted.
A grade of 0 points will be recorded.

Attendance Policy
For complete attendance and excused absence policies, please see http://policies.ncsu.edu/regulation/reg-02-20-03

Attendance Policy
Attendance will not formally be taken. Lectures will start promptly. Your punctuality is expected and will be appreciated. Getting involved in discussion and asking questions about the points that are not clear is important for learning the material. Participants are expected to be engaged in meetings, to learn from the execution of the coursework, and to share their own unique insights into the course material.

Absences Policy
Please see the university attendance regulation at http://policies.ncsu.edu/regulation/reg-02-20-03 for further information and definition of excused absences.

Makeup Work Policy
Each student is responsible for all assignments, announcements, and material covered in each class. If excused absences fall a day that an assignment is due, the assignment may be turned in prior to the due date in class, or via electronic mail or upload to the course website on the due date.

Additional Excuses Policy
None.

Academic Integrity
Students are required to comply with the university policy on academic integrity found in the Code of Student Conduct found at http://policies.ncsu.edu/policy/pol-11-35-01

Academic Honesty
See http://policies.ncsu.edu/policy/pol-11-35-01 for a detailed explanation of academic honesty.

Honor Pledge
Your signature on any test or assignment indicates, "I have neither given nor received unauthorized aid on this test or assignment."

Electronically-Hosted Course Components
Students may be required to disclose personally identifiable information to other students in the course, via electronic tools like email or web-postings, where relevant to the course. Examples include online discussions of class topics, and posting of student coursework. All students are expected to respect the privacy of each other by not sharing or using such information outside the course.

Accommodations for Disabilities
Reasonable accommodation will be made for students with verifiable disabilities. In order to take advantage of available accommodations, students must register with the Disability Resource Office at Holmes Hall, Suite 304, 2751 Cates Avenue, Campus Box 7509, 919-515-7653. For more information on NC State's policy on working with students with disabilities, please see the Academic Accommodations for Students with Disabilities Regulation (REG02.20.01).

Non-Discrimination Policy
NC State University provides equality of opportunity in education and employment for all students and employees. Accordingly, NC State affirms its commitment to maintain a work environment for all employees and an academic environment for all students that is free from all forms of discrimination. Discrimination based on race, color, religion, creed, sex, national origin, age, disability, veteran status, or sexual orientation is a violation of state and federal law and/or NC State University policy and will not be tolerated. Harassment of any person (either in the form of quid pro quo or creation of a hostile environment) based on race, color, religion, creed, sex, national origin, age, disability, veteran status, or sexual orientation also is a violation of state and federal law and/or NC State University policy and will not be tolerated. Retaliation against any person who complains about discrimination is also prohibited. NC State's policies and regulations covering discrimination, harassment, and retaliation may be accessed at http://policies.ncsu.edu/policy/pol-04-25-05 or http://www.ncsu.edu/equal_op/. Any person who feels that he or she has been the subject of prohibited discrimination, harassment, or retaliation should contact the Office for Equal Opportunity (OEO) at 919-515-3148.

Use of Generative Language Models & Other AI Tools (from UNC School of Medicine Dean's Office)
The use of generative AI should be clearly and transparently disclosed and documented. Documentation requirements will vary from research context to research context and from discipline to discipline, but researchers should err on the side of explicitly disclosing any material use of generative AI in their research activities. Here is one perspective, generated by the Association for Computing Machinery:
"If you are using generative AI software tools such as ChatGPT, Jasper, AI-Writer, Lex, or other similar tools to generate new content such as text, images, tables, code, etc. you must disclose their use in either the acknowledgements section of the Work or elsewhere in the Work prominently. The level of disclosure should be commensurate with the proportion of new text or content generated by these tools. If entire sections of a Work, including tables, graphs, images, and other content were generated by one of these tools, you should disclose which sections and which tools and tool versions you used to generate those sections by preparing an Appendix or a Supplementary Material document that describes the use, including but not limited to the specific tools and versions, the text of the prompts provided as input, and any post-generation editing (such as rephrasing the generated text). Authors should also note that the amount or type of generated text allowable may vary depending on the type of the section or paper affected. For example, using such tools to generate portions of a Related Work section is fundamentally different than generating novel results or interpretations. If the amount of text being generated is small (limited to phrases or sentences), then it would be sufficient to add a footnote to the relevant section of the submission utilizing the system(s) and include a general disclaimer in the Acknowledgements section.

If you are using generative AI software tools to edit and improve the quality of your existing text in much the same way you would use a typing assistant like Grammarly to improve spelling, grammar, punctuation, clarity, engagement or to use a basic word processing system to correct spelling or grammar, it is not necessary to disclose such usage of these tools in your Work."

Course Schedule

IMPORTANT NOTE: Direct emails regarding assignments, course content, due dates, *et cetera*, which are not related to personal matters, will not be responded to, and should be directed to the Moodle Message Board.

- Example content to be direct to the Moodle Message Board: "When is the Final?" "Can you explain Question 4b?" "I'm confused by Homework 1?" "What format should I submit my assignments in?" "Is my answer correct?"
- Example content suitable for direct email: "I've been sick, can we discuss a possible extension to assignments?"

NOTE: *The course schedule is subject to change, including due dates.*

Lectures — 08/19/24 – 12/5/2024		
20 Aug	**Syllabus Overview**; Intro to Biosensors & Sensors; Classification and Uses Thereof; Modern Healthcare and Translational Research; Wearable Computing; Attributes of Wearable Systems, Challenges and Opportunities	1
22 Aug	Physiology for Biosignals and Biomarkers	2
27 Aug	Biosensors & Biomolecular Recognition (*Video Lecture, No In-Person Meeting*)	3
29 Aug	**SensUs Live Stream**	4
3 Sept	Electrochemical Sensors (**Article 1 Due)**	5
5 Sept	*Case Study: Glucose Biosensors*	6
10 Sept	Biopotential Sources & Signals *(Video Lecture, No In-Person Meeting)*	7
12 Sept	Biopotential Interfaces **(Article 2 Due)**	8
17 Sept	**WELLNESS DAY (No Class)**	9
19 Sept	*Case Study: Electrocardiogram* **(Article 3 Due)**	10
24 Sept	Biophotonic Sensors	11
26 Sept	Optoelectronics **(Homework 1 Due)**	12
1 Oct	*Case Study: Photoplethysmography; Pulse Oximetry*	13
3 Oct	Mid-Term Content Review **(Midterm Exam Due)**	14
8 Oct	Circuits for Biopotential & Electrochemical Measurements	15
10 Oct	Power Consumption; Batteries/Wireless Charging; Wireless Energy Transmission	16
15 Oct	**FALL BREAK (No Class)**	17
17 Oct	Complimentary Sensors: Displacement, Strain, Pressure Sensors **(Article 4 Due)**	18
22 Oct	Complimentary Hardware: Wireless Body Area Networks	19
24 Oct	Alternative Power: Energy Harvesting from the Body **(Article 5 Due)**	20
29 Oct	Alternative Form Factors: Textiles & Sensing	21
31 Oct	Non-Invasive Devices **(Homework 2 Due)**	22
5 Nov	Transcutaneous Devices & Implantable Devices	23
7 Nov	Regulatory and Human Subjects Research Considerations **(Article 6 Due)**	24
12 Nov	**Project Presentations**	25
14 Nov	**Project Presentations**	26
19 Nov	**Project Presentations**	27
21 Nov	**Project Presentations**	28
26 Nov	**Open Hours / Grade Status: No Lecture**	29
28 Nov	**Thanksgiving**: **No Class**	30
3 Dec	**Last Day of Classes: Review**	31
5 Dec	**Final Exam 1200-1430**	32

Reading Schedule

NOTE: *The course schedule is subject to change.*

****Articles Required for Critiques****

1	Gao, Wei, et al. "Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis." Nature 529.7587 (2016): 509.
2	Kim, Choong Sun, et al. "Self-powered wearable electrocardiography using a wearable thermoelectric power generator." ACS Energy Letters 3.3 (2018): 501-507.
3	Lai, Jiewei, et al. "Practical intelligent diagnostic algorithm for wearable 12-lead ECG via self-supervised learning on large-scale dataset." Nature Communications 14.1 (2023): 3741.
4	Lee, H.S., Noh, B., Kong, S.U. et al. Fiber-based quantum-dot pulse oximetry for wearable health monitoring with high wavelength selectivity and photoplethysmogram sensitivity. npj Flex Electron 7, 15 (2023).
5	Oh, Seyong, et al. "Simple, miniaturized biosensors for wireless mapping of thermoregulatory responses." *Biosensors and Bioelectronics* (2023): 115545.
6	Xu, Yuchen, et al. "In-ear integrated sensor array for the continuous monitoring of brain activity and of lactate in sweat." Nature Biomedical Engineering 7.10 (2023): 1307-1320.