

Designing and Building Environmental Monitoring Devices (11:628:313)

CLASS BASICS:

3 Credits, every spring

PREREQUISITES:

Any course equal or greater Precalc II 01:640:112

INSTRUCTORS AND CONTACT INFORMATION:

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Benedict Borer

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Office Hours: By appointment

Please use your Rutgers email account (gorbunov@marine.rutgers.edu, benborer@marine.rutgers.edu) and include a subject line that provides the course number (11:628:313).

COURSE DESCRIPTION:

Reliable monitoring of complex natural systems is a prerequisite to assessing the state of our planet and predicting the impact of natural and human perturbations across scales. Low-power, field-deployable, and scalable sensors offer powerful tools for real-time data and sample collection. This course introduces the fundamentals of sensor and microfluidic device design with a focus on their applications in oceanographic and environmental research. Students will learn the basic principles of sensor design, signal processing, and microfluidic technology, and will engage in hands-on activities to build and test simple environmental sensors. Through individual and team-based projects, students will apply these skills to create prototypes aimed at solving real-world environmental monitoring problems. The goal of this course is to provide hands-on experiential learning opportunities that empower students during their continued academic career and equip them with practical experience desired by future employers.

LEARNING GOALS:

The learning goals for the Marine Science major are posted on our website at <http://marine.rutgers.edu/main/academics/undergraduate>. This course addresses these learning goals by requiring students to:

- 1) Show evidence of scientific literacy and practical skills, and communicate the information effectively both orally and in writing
- 2) Apply basic concepts and practical skills in sensor development and operational use in marine and environmental science
- 3) Develop, conduct, and report on an applied research experience in marine science in collaboration with a scientific mentor.

We will use this course for students to foster the basic principles and skills of sensor design and development required for solving real-world environmental monitoring problems.

COURSE FORMAT:

The course will include theory and concepts of sensor design and development and hands-on training in the design, manufacturing and debugging of electronic circuits and microfluidic devices. Each class will be divided into lecture and lab work for the students to master theoretical and practical skills. The lab projects will include manufacturing, testing, and repair of electronic circuits, data acquisition systems, and microfluidic chips. For instance, students will fabricate, debug, and calibrate a computer-controlled LED driver circuit and a LED based assembly. This device will be connected to and tested on an operational fluorometer instrument to record, in automatic mode, the light curves of fluorescence and photosynthesis in plants and algae. For the final project, students will select and design a microfluidic system (either a microfluidic mixing platform or droplet generator) as a team, fabricate the device using soft lithography and microscale 3D printing, and evaluate the device for its function using fluorescence microscopy. The aim of the project is to foster teamwork, develop skills in manufacturing microfluidic devices, and present findings concisely in an oral format.

The focus will be on providing the students with a range of practical skills and experience for operational use of sensors and instruments, including design, fabrication, and calibration, as well as fostering problem-solving skills for sensor maintenance and repair.

Assigned homework class materials will be listed on the Canvas site.

ASSIGNMENTS & GRADING:

Student achievement of learning goals will be based on a midterm paper, home assignments, participation during the lecture and lab work, and a final presentation:

- Weekly quizzes 10%
- Midterm paper 35%
- Final presentation 35%
- Participation in class and lab work 20%

Midterm paper: The mid-term paper presents brief research on the selected topic related to oceanographic or environmental sensors.

Final project presentation: The final presentation on the microfluidic project focuses on fostering oral skills and will include

- 2-4 short slides summarizing your main takeaways and reactions to the project;
- 2-4 questions about the project, ideally a mix of discussion and clarification questions.

COURSE SCHEDULE:

Week 1:

Class 1: Course overview (Gorbunov and Borer).

Week 2: Basics of electronic design

Class 2: Theory and basic laws of electronics. Function and use of a variety of electronic components (resistors, capacitors, transistors, diodes, integrated circuits (IC), etc.) in electronic circuits.

Class 3: Power requirements for environmental sensors and instruments and power source design: How to choose a proper power source for different sensors (from AC-powered instruments to battery-operated stand-alone sensor modules).

Week 3: Designing and Fabricating Electronic Schematics and Boards

Class 4: Designing electronic circuits as a two-step process (Schematics design and Printed Circuit Board (PCB) layout). Basic principles of schematics. Converting Schematics to PCB, with examples of software packages (such as the PCB Artist).

Class 5: Analog and digital electronic circuits. Converting analog signals to computer electronics.

Week 4: Optical Sources and Detectors

Class 6: Using LED (Light Emitting Diodes) as a source of optical excitation in environmental sensors. Principles of operation and specifications of LEDs.

Class 7: Using optical detectors (photodiodes, PMTs, avalanche photodiodes, multichannel sensors (CCD and photodiode arrays) in environmental sensors. How to choose a detector module, based on sensor requirements and specifications.

Week 5: Optical and Mechanical Design and Sensor Integration

Class 8: Optical design: Theory and practical applications.

Class 9: Mechanical design of oceanographic sensors and instruments: How to make them compact and water-proof.

Week 6: Data Acquisition Systems and Multi-Sensor Instrumentation

Class 10: Using data acquisition systems to read and store sensor data.

Class 11: Flow Cytometry (FC) theory and application for single particle analysis: from biomedical research to oceanography and environmental science. The use of conventional FC instruments and Imaging FCs for taxonomic analysis of phytoplankton and microbes.

Week 7: Project work

Class 12: DMCS Flow Cytometry Lab demonstration.

Class 13: Mid-term paper and roundtable discussion of lab projects.

Week 8: Introduction to Microfluidics

Class 14: Introduction to microfluidics and its analogy to electrical circuits

Class 15: Evolution and history of microfluidics in nature and laboratories

Week 9: Microfluidic Fundamentals

Class 16: The physical laws that govern fluids at the microscale (viscosity, surface tension, laminar flow).

Class 18: Learn how solutes and particles are transported at the microscale (diffusion & advection). Introduction of dimensionless analysis and numbers (Reynolds, Peclet, Schmidt, Sherwood numbers) to classify flow and mixing regimes.

Week 10: Overview of microfluidic design principles

Class 18: How to establish gradients and mixing of solutes, passive filtration systems, inertial microfluidics for particle sorting

Class 19: Microfluidic droplet generators, the advent of digital and passive microfluidics

Week 11: Microfabrication workflow

Class 20: A primer on computer-assisted design (CAD) using Fusion360 (hands-on)
Class 21: Overview of microfabrication techniques (clean-room soft lithography, etching, laser ablation, 3D printing) + defining group projects

Week 12: Fluidic operation and project work

Class 22: The use of 3D printing in soft lithography + preparation of the molds
Class 23: Comparison of pump systems used in microfluidics + fabrication of devices

Week 13: Project work

Class 24: Testing of the fabricated microfluidic devices + observation using microscopy
Class 25: Analysis of the microscopy images + preparation of the presentation material

Week 14: Project work

Class 24: Preparation of the presentation
Class 25: Final presentations + feedback roundtable.

COURSE WEBSITE, RESOURCES AND MATERIALS:

We will use this Canvas website, which includes course materials, and zoom links for virtual classes.

**Please visit the Rutgers Student Tech Guide page for resources available to all students. If you do not have the appropriate technology for financial reasons, please email Dean of Students deanofstudents@echo.rutgers.edu for assistance. If you are facing other financial hardships, please visit the Office of Financial Aid at <https://financialaid.rutgers.edu>.

READING MATERIALS (selected chapters will be used):

1. Horowitz P. and Hill W. The Art of Electronics. 3rd Edition
2. Scherz P. and Monk S. Practical Electronics for Inventors. Fourth Edition.
3. Kingston RH. Optical Sources, Detectors, and Systems. 1st Edition
4. Tabeling P. Introduction to Microfluidics. 2nd Edition
5. Xia Y. and Whitesides G. Soft Lithography
6. Purcell E. Life at low Reynolds numbers

ACCOMMODATIONS FOR STUDENTS WITH DISABILITIES

Disability Services (848) 445-6800 / Lucy Stone Hall, Suite A145, Livingston Campus, 54 Joyce Kilmer Avenue, Piscataway, NJ 08854 / <https://ods.rutgers.edu/> Rutgers University welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact the appropriate disability services office at the campus where you are officially enrolled, participate in an intake interview, and provide documentation: <https://ods.rutgers.edu/students/documentaionguidelines>. If the documentation supports your request for reasonable accommodations, your campus's disability services office will provide you with a Letter of Accommodations. Please share this letter with your instructors and discuss the accommodations with them as early in your courses as possible. To begin this process, please complete the Registration form on the ODS web site at: <https://ods.rutgers.edu/students/registration-form>.

ABSENCE POLICY

If you have a question, need clarification, or have a penetrating insight to offer, do it with the class as a whole rather than starting a side conversation. The ringing/beeping/chiming/singing of cell phones or other electronic devices is disruptive during class. Please make sure to disable audible alarms during class. Also, class time is not the time for you to be checking your email or surfing the web. Attendance at all class meetings is expected because of the importance of in-class discussion. If you are not in class, you are not learning; you are wasting your time and money. We ask that you make every effort to log into to class on time, and once there, stay.

ACADEMIC INTEGRITY

The university's policy on Academic Integrity is available at <http://academicintegrity.rutgers.edu/academic-integrity-policy>. The principles of academic integrity require that a student:

- properly acknowledge and cite all use of the ideas, results, or words of others.
- properly acknowledge all contributors to a given piece of work.
- make sure that all work submitted as his or her own in a course or other academic activity is produced without the aid of impermissible materials or impermissible collaboration.
- obtain all data or results by ethical means and report them accurately without suppressing any results inconsistent with his or her interpretation or conclusions.
- treat all other students in an ethical manner, respecting their integrity and right to pursue their educational goals without interference. This requires that a student neither facilitate academic dishonesty by others nor obstruct their academic progress.

- uphold the canons of the ethical or professional code of the profession for which he or she is preparing.

Adherence to these principles is necessary in order to ensure that

- everyone is given proper credit for his or her ideas, words, results, and other scholarly accomplishments.
- all student work is fairly evaluated and no student has an inappropriate advantage over others.
- the academic and ethical development of all students is fostered.
- the reputation of the University for integrity in its teaching, research, and scholarship is maintained and enhanced.

Failure to uphold these principles of academic integrity threatens both the reputation of the University and the value of the degrees awarded to its students. Every member of the University community therefore bears a responsibility for ensuring that the highest standards of academic integrity are upheld.

Intellectual Property: Almost all original work is the intellectual property of its authors. These works may include syllabi, lecture slides, recorded lectures, homework problems, exams, and other materials, in either printed or electronic form. The authors may hold copyrights in these works, which are protected by U.S. statutes. Copying this work or posting it online without the permission of the author may violate the author's rights. More importantly, these works are the product of the author's efforts; respect for these efforts and for the author's intellectual property rights is an important value that members of the university community take seriously. For more instructions on copyright protections at Rutgers University, please refer to the Rutgers Libraries.

STUDENT WELLNESS SERVICES

Access helpful mental health information and resources for yourself or a friend in a mental health crisis on your smartphone or tablet and easily contact CAPS or RUPD.

Counseling, ADAP & Psychiatric Services (CAPS): (848) 932-7884 / 17 Senior Street, New Brunswick, NJ 08901/ www.rhscaps.rutgers.edu.

CAPS is a University mental health support service that includes counseling, alcohol and other drug assistance, and psychiatric services staffed by a team of professional within Rutgers Health services to support students' efforts to succeed at Rutgers University. CAPS offers a variety of services that include: individual therapy, group therapy and workshops, crisis intervention, referral to specialists in the community and consultation and collaboration with campus partners.

Violence Prevention & Victim Assistance (VPVA): (848) 932-1181 / 3 Bartlett Street, New Brunswick, NJ 08901 / www.vpva.rutgers.edu.

The Office for Violence Prevention and Victim Assistance provides confidential crisis intervention, counseling and advocacy for victims of sexual and relationship violence and stalking to students, staff and faculty. To reach staff during office hours when the university is open or to reach an advocate after hours, call 848-932-1181.

Disability Services: (848) 445-6800 / Lucy Stone Hall, Suite A145, Livingston Campus, 54 Joyce Kilmer Avenue, Piscataway, NJ 08854 / <https://ods.rutgers.edu/>. Rutgers University welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact the appropriate disability services office at the campus where you are officially enrolled, participate in an intake interview, and provide documentation: <https://ods.rutgers.edu/students/documentation-guidelines>. If the documentation supports your request for reasonable accommodations, your campus's disability services office will provide you with a Letter of Accommodations. Please share this letter with your instructors and discuss the accommodations with them as early in your courses as possible. To begin this process, please complete the Registration form on the ODS web site at: <https://ods.rutgers.edu/students/registration-form>.

Scarlet Listeners: (732) 247-5555

<https://rutgers.campuslabs.com/engage/organization/scarletlisteners>.

Free and confidential peer counseling and referral hotline, providing a comforting and supportive safe space.