ROB 311: How to Build Robots and Make them Move

Professor Rouse, University of Michigan, Fall 2022

Instructor: Professor Elliott Rouse, 2264 Ford Robotics Building, email: ejrouse@umich.edu. Office hours: Tuesday / Thursday: 2:00 – 3:30 in 2264 FRB. Office hours will also be available virtually by appointment at the following URL: https://umich.zoom.us/j/2011200084. Note you must use your U-M account to access the Zoom link.

Course Time:

Lectures: Tuesday / Thursday, 12:00 – 1:30 pm – EECS 1200. If you feel unsafe coming to class, discuss with Prof. Rouse. Any virtual options will use the following Zoom: https://umich.zoom.us/j/95524015388. Note you must use your U-M account to access the Zoom link.

Labs: Wednesdays, 12:30 – 2:30 pm – 1150 Ford Robotics Building (FRB). In person attendance is required.

Course Profile: here.

Course Attendance Policy: All lectures will be recorded and available in Canvas. Synchronous attendance is required, but there may be some flexibility with virtual attendance, if needed. Attendance and class input are part of your final grade.

GSI: Yves Nazon MS, 2100 Ford Robotics Building, nazon@umich.edu. Office hours: 10:00 – 11:00 Monday / Wednesday in 2320 FRB.

Textbook: None – see resources below.

Helpful Resources:

- Code Academy – Learn Python 3 (link)
- Code Academy – Learn Raspberry Pi (link)
- U-M Coursera – Programming for Everybody – basic Python w/IDE (19 hrs) (link)
- Bachelor's Thesis – ETH Zurich, *Modeling and Control of a Ballbot* (link - PDF uploaded to Canvas\Resources)
- Astrom and Murray, *Feedback Systems* (link - PDF uploaded to Canvas\Resources)
- Messner and Tilbury, Control Tutorials for MATLAB and Simulink (link)

Quizzes: At the end of lecture, there will often be brief quizzes to assess your understanding of the current material. The quizzes will be 1 – 3 short answer questions and will be designed to be completed in a few minutes. The quizzes will be used as feedback for us to gauge your understanding of the course content—they will not be graded for correctness. Instead, the quizzes will be graded for attendance that will factor into class participation (10% of the final grade).

Homeworks: There will be ~6 HW assignments due online via Canvas. The homework questions will be short-answer format and emphasize the technical concepts learned in lecture. You are encouraged to use MATLAB or Python where possible on the assignments. Homework solutions will be posted in Canvas, and the lowest homework score will be dropped. Late HWs will be deducted 10% per day.

Project: ROB 311 is a project-based course focused on the building and control of a ball-bot. In teams of two, you will model, design, build, and control a ballot; teams will work during the course lab section on Wednesdays to complete their project. A ball-bot is an underactuated robot that balances on top of a (basket)ball, and rolls the ball to move around the environment. It's an inherently unstable system—since the ball-bot wants to topple off the ball—but with the right design, sensing, and control, you'll be able to get it stable and rolling. The lecture content will consist of learning the technical topics / theory needed, and the labs will focus on the 'hands-on' design, manufacturing, and control of the bot. The last lab will be a competition to see who is able to control their ball-bot with the highest fidelity. Each team of two will need to create a five-page final report that describes your design and control choices for your ball-bot, including data obtained during testing.

Midterm Exam: November 8th, in class.

Final Exam: No final exam—the course-based project is used in lieu of a final exam. Project report will be due on the last day of class.

Final Report: Each team of two will need to create a ~5-page final report. The report will provide information on your design and control decisions throughout the course, and should be supported by rationales, calculations, or data collected during different aspects of testing. To this end, be sure to document your progress during the course / labs so that it's easier to refer back to when creating your report. More information on the final report will be provided later in the semester.

Honor Code: You may discuss the homeworks and the project with each other and with the instructors, but you must write your own solutions / code which reflect your own understanding of the material for the homeworks and project. Sharing / copying of MATLAB code is prohibited and is considered academic misconduct; code is able to be copied / shared for the project within your own team.

Robotics Makerspace: This class will make heavy use of the Robotics Makerspace (1141 FRB). The Makerspace is led by Alyssa Emigh (aemigh@umich.edu, 1180B FRB) which will facilitate 3D printing and laser cutting needed for development of the ball-bot. You will have access to the makerspace during open hours following the completion of Basics I & II. Basics I & II will be completed as part of Homework 1 so please sign complete as soon as possible (link for training).

Provided equipment / tools: Each team will be provided with all materials and tools needed to develop the ball-bot. You will need to return everything at the end of the semester. Please keep track of your tools and major components (wheels, motors, etc.), which will be reused in future offerings of ROB 311—this is essential for classes of this type to be successful in the long term.

Canvas: There are two Canvas sections for the class (ROB 311-001 for lecture and ROB 311-011 for lab). The class will operate out of the 311-001 Canvas page, and the other will be unused. If anything changes, the Professor / GSI will let you know.

Teams: You will need to find a partner and create a group, ideally by August 30th. If you would like assistance finding group members, feel free to contact the Professor or GSI. Once your group has been formed, please fill out this form. Groups of three will not be allowed unless there is an odd number of students enrolled.

Diversity, Equity, and Inclusion: I consider this classroom to be a place where you will be treated with respect, and I welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, ability – and other visible and nonvisible differences. All members of this class are expected to contribute to a respectful, welcoming, and inclusive environment for every other member of the class. I am dedicated to helping each of you achieve all that you can in this class. I may, either in lecture or smaller interactions, accidentally use language that creates offense or discomfort. Should I do this, please contact me and help me understand and avoid making the same mistake again.

Grade Breakdown:

Homework	20%
Class Participation	10%
Project + Report	40%
Midterm	30%
Final Exam	-

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Date	Class Type	Content / Topics	Assignments / Deliverables
Aug. 30	Class	Introduction, syllabus, design overview	HW 1 assigned
Aug 31	Lab	Soldering ball-bot embedded system	Populate and solder M-bot control boards for ball-bots **Goal:** Groups formed.
Sept. 1	Class	Motors, transmissions, and drivers, part I	
Sept. 6	Class	Motors, transmissions, and drivers, part II	
Sept. 7	Lab	Raspberry Pi's, SSH, and Linux	Learn UM RPi image, download programs, and connect via SSH
Sept. 8	Class	PWM, power, Joule heating / thermal dynamics	
Sept. 13	Class	Transmissions and wheels	HW 1 due HW 2 assigned
Sept. 14	Lab	Intro to Solidworks, plates / mount design	Learn Solidworks and design mounting plate from template
Sept. 15	Class	Rapid manufacturing: 3D printing	
Sept. 20	Class	Rapid manufacturing: laser cutting, waterjet, CNC router	
Sept. 21	Lab	Finish solid modeling, laser cutting, 3D printing	Continue learning Solidworks, design of mounts, and laser cutting chassis; submit 3D printing requests
Sept. 22	Class	Introduction to Mechanics	
Sept. 27	Class	Ball-bot coordinates, overall layout, degrees of freedom	HW 2 due HW 3 assigned
Sept. 28	Lab	Ball bot assembly	Finalize any remaining manufacturing, and assemble ball-bot **Goal:** Ball-bot designed / assembled by lab end
Sept. 29	Class	Kinematics and dynamics of planar ball-bot	
Oct. 4	Class	Common sensors and data acquisition	
Oct. 5	Lab	Intro to Python, plot data lab	Learn / practice python, collect data and setup live plotting
Oct. 6	Class	Digital communication and signal processing	
Oct. 11	Class	Intro to control	HW 3 due HW 4 assigned
Oct. 12	Lab	Communication with RPi Pico, closed loop current-control lab	Intro to RPi Pico, closed loop control of motor current using onboard A/D; write controller / tune PID gains.
Oct. 13	Class	Block diagrams, open / closed loop control, PID	

Oct. 18	No Class!	N/A	
Oct. 19	Lab	Kinematics / upside-down ball-bot kinematics lab	Closed-loop control of ball position, able to be visualized by coordinates added to the basketball; write controller / tune PID gains
Oct. 20	Class	Controller architectures, superposition, and PID	
Oct. 25	Class	Finish control	HW 4 due HW 5 assigned
Oct. 26	Lab	Inner-loop ball-bot balance control via Raspberry Pi	Hardware demonstration of ball-bot balance control; tuning balance controller gains
Oct. 27	Class	Inner-loop ball-bot balance control software overview	
Nov. 1	Class	Inner-loop ball-bot balance control software overview	
Nov. 2	Lab	Begin outer velocity loop control	Begin writing outer velocity loop control by relaying lean angle commands to the balance controller
Nov. 3	Class	Review	
Nov. 8	Class	Midterm exam	
Nov. 9	Lab	Add Bluetooth remote control, test communication	Get Bluetooth connection working for PS4 remote control; test communication
Nov. 10	Class	Reference generation, remote control, global vs. local	
Nov. 15	Class		HW 5 due HW 6 assigned
Nov. 16	Lab	Add Bluetooth remote control, test communication	Finalize velocity controller code + integration with PS4 remote
Nov. 17	Class	TBD content / ball-bot development	
Nov. 22	Class	TBD content / ball-bot development	
Nov. 23	No Lab!	None.	
Nov. 24	No Class!	None.	
Nov. 29	Class	TBD content / ball-bot development	
Nov. 30	Lab	Finalize, add LEDs, get ready for competition	Finish tuning outer-loop velocity control, add I^2C communication for LEDs
Dec. 1	Class	Make up class	
Dec. 6	Class	Make up class	HW 6 due
Dec. 7	Lab	Make up lab	Extra lab for finalizing
Dec. 8	Class	Competition	Project report due