Biology-Inspired Robotics

University of Washington, Winter 2022

ME 586 (3) *graduate level.*

Syllabus v. 1 *(revised 2022.01.02)*

Meeting time: MW 1-2:20 in Lowe 115 and over Zoom when remote.
Instructor: Prof. Sawyer B. Fuller
`minster@uw.edu` (I will reply to emails within 48 hours, excluding weekends)
Office Hours: After class or on zoom when remote (see link on Canvas site)
Website: `http://faculty.washington.edu/minster/bio_inspired_robotics`
and on Canvas.

1 Summary

Human-made robotic systems are not yet able to match the abilities of their biological counterparts. Robots are *far less robust* to uncertainty and complexity in the environment and their own components, and *far less efficient*. Compared to how a mountain goat can quickly scale a steep cliff, or a honeybee can navigate to and land on a flower buffeted by wind, robotics has a lot of catching up to do.

This course takes the view that there are three key elements that differentiate animals from current robots.

1. *Adaptation*. Through both evolution or learning, animals respond to the world by changing in ways that improves their fitness. This results in the following two characteristics that distinguish them from current robots:

2. *Mechanical Intelligence*. Animals' bodies act in concert with their sensorimotor systems in a much more coordinated fashion. In some cases, this is manifested by an ability to operate *without any feedback whatsoever*.

3. *Parsimony*. The systems that result are *simple* and *energetically efficient*.

The course consists of reading and debating primary research papers that lay out how future robot systems might take advantage of these ideas. We will learn about historical successes and failures. We take particular inspiration from insects, a class of animals that is distinguished by its impressive but parsimonius repertoire of behaviors, and its ability to fly. Problem sets will be assigned to help you learn how to simulate such systems using Python, with an emphasis on control and sensing in flying systems. And as part of the course, we will have the opportunity to create a simulation, or work with physical robots, on which we can attempt to put one or more of these ideas into practice.

2 Course Objectives

This is an advanced, graduate level course designed to help you investigate cutting-edge problems in robotics and biology. The objectives of the course are to:

- Inspire you to explore biology-inspired solutions to challenges in robotics
- Have enough familiarity with Python to do basic robotics and simulation

- Know how to design a controller and sensor-based state estimator (Kalman Filter) for a hovering aircraft
- Be able to name at least three biology-inspired advances in robotics
- Know how to find papers describing these advances online
- Efficiently read, explain, and note strengths and deficiencies in a research paper
- Find good research problems
- Describe and promote your ideas and discoveries

Prerequisites This course assumes an undergraduate-level training in mechanics, dynamics and controls, as is typically covered in a mechanical engineering Bachelor's degree. You should be prepared to do the following:

- Statics - draw a free body force diagram and solve for forces and moments
- Dynamics - write and solve equations for spring-mass-damper systems
- Differential equations - solve first and second-order ordinary differential equations (ODEs)
- Basic linear algebra: familiarity with eigenvectors and state-space dynamical systems (e.g. ME547)

3 Coursework

Coursework consists of three main components:

I. Problem sets Three problem sets will be assigned that are aimed to build basic skills in dynamical systems, simulation, and robotics. We will introduce and use Python because it is emerging as a standard language for research.

II. Reading and reviewing research papers You will read and either summarize or review 5–8 research papers taken from original research in the field of biology-inspired robotics. Your grade for this component of the course will consist of the extent you understand and critically analyze its claims, both in your written review and in-class discussions.

Your participation in in-class discussions is graded and helps the instructor know that you read and understood the paper.

A review submitted on canvas consists of a **paragraph of at least 4 sentences** that *in your own words*

1. succinctly summarizes the main contribution of the paper
2. notes one major strength of the paper
3. notes one major weakness or where it needs correction or improvement, and
4. suggests one question or future work direction that should be followed, or makes some connection to another paper.

Occasionally, the assignment will be something else, such as a comparison between papers, or simply to summarize the paper.

Reviews are submitted in Canvas by submitting a post in reply to the appropriate assignment. While you are encouraged to read other posts to get greater insight into the paper and prepare for discussion, you cannot do so until you have posted your own. *Editing posts is not permitted and will result in a zero score.* This prohibits you from making a blank post and then reading other posts before posting your own.

III. Paper presentation and discussion lead Each of the assigned papers will be presented by students in the class. This is to sharpen presentation skills, and to give you a chance to become deeply familiar with a paper. You, along with 1–2 other students, will be assigned a paper and presentation date based on your responses to the paper preferences sheet handed out on the first day of class. Along with those students, you will 1) work together to present the paper, relevant background, and a related or follow-on paper, 2) lead a discussion in class about the paper, and 3) peer review other students' reviews. Your presentation day entails three tasks:

1. **Presentation.** Each student group should aim to make a 20-30 minute informal presentation summarizing the work. It is suggested that you work among yourselves to choose who will present what aspect, but a good option is to for each student to handle one of the following:
   (a) Background and history of the problem. Provide context for the paper, including a summary of previous work. Do reading on the topic beyond the assigned paper, such as what you find by looking up important papers that are cited, do an internet search and a google scholar search of the document, show relevant videos you can find.
   (b) The paper itself
      i. main contributions of paper. **Make sure to include a succinct answer to this question: What was the main thing that was not known before this paper came out?**
      ii. summary of key results
      iii. critique and points for discussion
   (c) If there is a third student in your group, do the same for a related paper such as a follow-on paper (the instructor can often suggest a paper)
2. **Lead in-class discussion**. After the presentation, the 2–3 presenters will **lead a 30-60 minute discussion**. To do this, it is suggested that you prepare three non-trivial questions that result from your attempt to understand the material, its implications, or connections to other work. In addition, *read the reviews* by other students and **incorporate their questions or comments into the discussion**. For example, a discussion prompt could be: "one reader stated that finding x was not supported by the paper's results. Do you agree or disagree?"
3. **Peer review.** Each student who presents a paper, as the expert on that paper, will then perform peer review other students' reviews (you do not need to write a review for the paper you present). By doing this you will learn how other students have performed the same task and find out what kind of writing is effective the perspective of a reader. Grading rubric: **4 pts**: sufficient detail, clearly written, and thought-provoking; **3 pts**: long enough, but could be more thoughtful. **2 pts** = not long, not thought-provoking. 0 pts = no submission. When in doubt, please ask the instructor. **To receive course credit for performing peer review, please submit your grades to the instructor or TA within a week of presenting**. Download the Course Enrollee List from Canvas, insert your grades with Excel or a text editor, and email it.

III. Course project This will be related to some aspect of biology-inspired robotics. Part of the project will consist of a **computer simulation**, a robotics demonstration, or both. Results will be explained through **a poster session** describing the results at the end of the quarter. This assignment may vary from year to year; more specifics will be provided early in the quarter.

- To facilitate consistent progress, there will be a few milestones: (see Canvas for due dates)
  1. Each person/team will submit a <1 page proposal
  2. A short progress update presentation midway through the quarter
  3. During the final week of the quarter, each person/team will give a poster presentation or slide presentation of their work.

Grading The final grade will be weighted as follows (each element may vary by ±5%):

20% problem sets
15% paper reviews
10% participation in class discussions
10% paper presentation
10% peer reviews of paper review
35% term project
  20% proposal
  10% mid-quarter progress update
  70% presentation/poster

If you feel that an assignment was graded incorrectly, please return your work along with a written description of what you believe to be the grading error. But if you request a review, your grade can go up or **down** as a result, depending on the quality of your argument.

You may have three grace periods of two days each that can be used at any time for paper reviews and problem sets, but no more than 1 grace period per assignment. Additional delay incurs a 10% grade penalty per workday. **This does not apply for presentation dates or the final project due date** – these cannot be extended.

Course schedule (subject to change)

Dates	Topic	paper reviews	project/homework
week 1	**Mon:** overview		
	Wed: aircraft dynamics, systems & linearization, Python tutorial		
week 2	**Mon**: paper 0 presentation (parsimony)	paper 0 summary	
	Wed: dynamics II, project & team selection		hw1 due
week 3	**Mon: MLK holiday**		
	Wed: linear quadratic regulator		
week 4	**Mon**: paper 1 presentation (robot learning and evolution)	paper 1 review	
	Wed: sensors & optic flow, Kalman Filter		hw2 due
week 5	**Mon**: paper 2 presentation (mechanical intelligence)	paper 2 review	
	Wed: project work session (and extra time to make up lecture)		proposal due
weeks 6–9	**paper presentations, project work sessions, guest speakers**	paper reviews	hw3 due
Week 10	**project presentations and project peer review**		poster session

Collaboration policy & plagiarism You are encouraged to work with other students to work out solutions to problem sets, the course project, and other parts of the course. But the work you submit must be your own, in your own words.

Plagiarism (copying other people's work without acknowledgement) or cheating will not be tolerated. Please see `http://www.engr.washington.edu/mycoe/am/ampolicy` for the University of Washington's Policy on Academic Misconduct for more information. If the instructors find any evidence of plagiarism or cheating, a grade of zero for the assignment will be received and you may be subject to disciplinary action. If you have any questions, don't hesitate to contact me.