16-886: *Models & Algorithms for Interactive Robotics*

Spring 2024

Time:	Mon & Wed, 11:00 - 12:20pm
Location:	NSH 3002
Professor:	Andrea Bajcsy (`abajcsy@cmu.edu`)
Office Hours:	TBA, NSH 4629
Website:	TBA

1 Course Description

Robot deployment around real people is rapidly accelerating: autonomous cars navigate through crowded cities on a daily basis, assistive robots increasingly help end-users with daily living tasks, and large teams of human engineers interactively teach robots basic skills. However, robot interaction with humans requires us to re-evaluate the assumptions built into all components of our autonomy algorithms, from decision-making, to machine learning, to safety analysis.

In this graduate seminar class, we will build the mathematical foundations for modeling human-robot interaction, develop the tools to analyze the safety and reliability of robots deployed around people, and investigate algorithms for robot learning from human data. The approaches covered will draw upon a variety of tools such as optimal control, dynamic game theory, Bayesian inference, and modern machine learning. Throughout the class, there will also be guest lectures from experts in the field. Students will practice essential research skills including reviewing papers, writing research project proposals, and technical communication.

2 Prerequisites

The course is open to graduate students without strict prerequisites. Familiarity with differential equations, probability, and linear algebra is highly encouraged. Interested undergraduate students with a strong background may seek approval from the instructor.

3 Grading

Participation	5%	Regular attendance and engagement
Homeworks (x2)	10%	Hands-on coding experience with concepts
Paper Summaries	10%	1-2 paragraph summary of reading on Canvas
Student Presentations	15%	In-class presentations on readings
Midterm Project Report	20%	Literature survey & preliminary results (2-3 pages, 2 column)
Final Project Report	40%	Final project report (5-8 pages, 2 column) and a final presentation

Cutoffs: (A+ for > 95%, A for 90-95%, A- for 85-90%, B+ for 80-85%, B for 75-80%, C for < 75%)
Note: You will not pass the course if you do not submit a final project.

4 Learning Objectives

At the end of this course, you will be able to:

- formalize robot interaction with people,

- apply both statistical and systems-theoretic techniques to interactive robotics,
- generate ideas the frontiers of safe and intelligent robot interaction with humans.

From a research perspective, you will be able to:

- plan a research project and take the first steps (e.g., preliminary results in toy scenario),
- critique research papers,
- prepare a scientific presentation or talk.

5 Readings & Paper Presentations

Reading Notes. There will be regular assigned research paper readings. You are expected to complete all assigned readings before class and come prepared with comments and questions to discuss with the group. You will share 1–2 paragraphs with your takeaways or questions on each reading on Canvas, by **10am ET of the day the reading** will be discussed.

Paper Presentations. The paper discussions will involve role-playing student seminars inspired by Alec Jacobson and Colin Raffel. Students will sign up for paper presentations at the start of the semester. During paper discussion days, **two students** will present on a paper, where each student takes on a unique role:

- ***Student 1****: Scientific peer reviewer*. The paper has not been published yet and is currently submitted to a top conference where you've been assigned as a peer reviewer. Complete a review of the paper answering the key prompts of the official review form of the top venue in this research area (e.g., CoRL, ICRA, RSS, etc.).
- ***Student 2****: Archaeologist*. This student determines where this paper sits in the context of previous and subsequent work. They must find and report on 1) at least one *older* paper cited within the current paper that substantially influenced the current paper and 2) at least one *newer* paper that cites this current paper. Interesting things to note: see what follow-up work contradicts the key takeaways of this current paper

Additionally, the **audience** will take on the role of:

- ***Audience****: Academic researcher*. Our job is to propose potential follow-up projects based on the findings and success of the current paper.

One of the class expectations is that you are not only able to summarize research papers, but also *generate* new ideas! To incentivize idea generation after each reading, we will keep a shared Google Doc where we will document all the ideas we generate throughout the course. During presentation days, one student will be assigned as the scribe for that day, and will take notes about the ideas that are generated.

6 Class Project

Your class project can be either a thorough literature review ($\sim$ 50 relevant papers, organized so that it identifies gaps in the state of the art) or an exploration of an original research idea. You can choose to work individually or in groups of up to three. The deliverables for the project are as follows (due by **midnight ET**):

Project proposal (due on Feb. 5 | 0% of final grade). This is a brief (1–2 page) summary of your final project. Think of this as an extended abstract: you want to motivate the topic you have chosen and the technical questions that you want to investigate. By this stage, you should have decided if you are doing a project on your own or in a group. This required proposal will allow me to give you early feedback and help you refine the project scope.

Mid-term report (due on Apr. 1 | 20% of final grade). This is intended as a checkpoint to ensure that you are making progress towards your final project. The report length should be a typical robotics workshop paper (2-3 pages, double-column). You can either submit a preliminary literature review, or preliminary exploration of your research idea.

Oral project presentation (to be scheduled for May 1 & May 6 | 10% of final grade). Presentations will be 10 minutes long with 3 minutes for questions. A good presentation will clearly identify the problem in the context of state of the art, state the key idea of the project, and include early results if applicable.

Final project report (due on May 6 | 30% of final grade). The final report should present your final findings in a research or survey paper format. Target length should be a typical robotics conference paper (6–8 pages, double-column).

All project deliverables will be submitted through Canvas, which will contain more detailed grading rubrics. Only one submission per team is required as long as all team members are clearly identified. All presentation slides should be submitted by the day before presentations start (**midnight, April 30**).

6.1 Project Proposal Tips

If you are doing a *research project*. You should 1) motivate the problem, 2) describe how state of the art tackles this problem, 3) what is missing from state of the art, 4) what is your key idea, and 5) describe the scope of what you would investigate (e.g., toy example that you want to study that exhibits your problem, simulator you will use, preliminary data you want to collect, etc.).

If you are doing a *literature survey*. You should 1) describe the topic area, 2) describe the method for how you will find papers (e.g., what conferences, keywords, etc.), 3) describe the inclusion criteria (i.e., what makes a paper relevant for your survey?), 4) provide 5-10 initial papers, 5) describe the key dimensions in which you are categorizing your topic area. For an example of a strong literature survey see:

> Rudenko, Andrey, et al, "Human Motion Trajectory Prediction: A Survey". The International Journal of Robotics Research 39.8 (2020): 895-935.

7 Resources

While there is no official textbook for this course, the following are companion textbooks can provide useful further reading:

* Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach*
* Tamer Basar and Geert Jan Olsder, *Dynamic Noncooperative Game Theory*, 2nd Edition
* Dimitri Bertsekas, *Reinforcement Learning and Optimal Control*
* Thomas B. Sheridan, *Humans and Automation*
* Jorge Nocedal and Stephen J. Wright, *Numerical Optimization*

8 Attendance

Class attendance and participation are key for both your and your peer's success in this class. You are expected to attend class in person during the scheduled time, including the final presentations. I understand that occasionally you may have challenges attending (e.g., illness, religious observance, etc.). However, if you anticipate having a challenge regularly attending class, please contact me.

9 Academic integrity

Honesty and transparency are important features of good scholarship. On the flip side, plagiarism and cheating are serious academic offenses with serious consequences. If you are discovered engaging in either behavior in this course, you will earn a failing grade on the assignment in question, and further disciplinary action may be taken.

I encourage you to work together on projects and homework assignments and to make use of campus resources like Student Academic Success Center (SASC) to assist you in your pursuit of academic excellence. However, please note that in accord with the university's policy you must acknowledge any collaboration or assistance that you receive on work that is to be graded, either from a person, reference, or a tool (including AI-generation tools like ChatGPT).

10 Late Policy

All homeworks and assignments are assigned due dates and should be submitted through the relevant Canvas portal. If you cannot submit an assignment on time, my default will be to reduce the grade by 10% for each 24 hour period, up to three days, that the assignment is late. This will be automatically applied; you do not have to request it. After three days, the assignment will receive a zero. If you experience an unforseeable emergency and would like me to consider waiving the late penalty, please email me as early as possible to discuss this request. The 10% per day deduction does not apply to unexcused late presentations, which will receive a zero immediately, because they will affect our ability to hold class. Re-scheduling presentations will be based on schedule availability and the professor's discretion.

11 Accommodations for students with disabilities

If you would like to receive accommodation for a documented disability, please first contact Disability Resources (`access@andrew.cmu.edu` or 412-268-2013). Let me know as soon as possible so we can discuss reasonable accommodations. If you suspect that you may have a disability and would benefit from accommodations but are not yet registered with the Office of Disability Resources, I encourage you to contact them at `access@andrew.cmu.edu`.

12 Student wellness

Take care of yourself. Do your best to maintain a healthy lifestyle by eating well, getting enough sleep, and taking some time to relax. This will help you achieve your goals and cope with stress. If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at http://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

13 Schedule (tentative)

Week	Day	Date	Topic	Info
1	M	Jan 15	— *MLK Jr. Day (No Class)* —	
1	W	Jan 17	Introduction	
2	M	Jan 22	Dynamical systems model of interaction	
2	W	Jan 24	Refresh: Optimal control	
			Part 1: Safe Interaction	
3	M	Jan 29	HJ Reachability I	
3	W	Jan 31	HJ Reachability II	HW 1 Released
4	M	Feb 5	Multi-agent safety I	**Project proposal due**
4	W	Feb 7	Multi-agent safety II	
5	M	Feb 12	Computational tools for safety	
5	W	Feb 14	Safety filtering & planning	**HW 1 Due**
6	M	Feb 19	Safe robot learning	
6	W	Feb 21	Context-aware and human-centric safety	
			Part 2: Robot Learning From Humans	
7	M	Feb 26	Nosily-rational human models	
7	W	Feb 28	Game theoretic models	HW 2 Released
8	M	Mar 4	— *Spring Break (No Class)* —	
8	W	Mar 6	— *Spring Break (No Class)* —	
9	M	Mar 11	Reward learning I (single agent)	
9	W	Mar 13	Reward learning II (multi-agent)	
10	M	Mar 18	Policy learning	**HW 2 Due**
10	W	Mar 20	Learning from sub-optimal demonstrations	
11	M	Mar 25	RL from human feedback	
11	W	Mar 27	Shared autonomy	
			Part 3: Frontiers of Interactive Robotics	
12	M	Apr 1	Sources of human feedback	**Mid-term report due**
12	W	Apr 3	Repeated interactions & influence	
13	M	Apr 8	Active robot learning	
13	W	Apr 10	Reward specification challenges	
14	M	Apr 15	Representation learning	
14	W	Apr 17	Opportunities and challenges of multi-modality	
15	M	Apr 22	What is safety beyond collision-avoidance?	
15	W	Apr 24	*Guest Lecture*	
16	M	Apr 29	*Guest Lecture*	**Slides due Apr. 30**
16	W	May 1	— *Presentations* —	
17	M	May 6	— *Presentations* —	**Final report due**