Fall 2020

Stanford

AA 174A/AA 274A/CS 237A/EE 260A: Principles of Robot Autonomy I

Instructor:
Prof. Marco Pavone
Office: Durand 261
Email: pavone@stanford.edu

Course Assistants:
Somrita Banerjee
Email: somrita@stanford.edu

Abhishek Cauligi
Email: acauligi@stanford.edu

Boris Ivanovic
Email: borisi@stanford.edu

Mengxi Li
Email: mengxili@stanford.edu

Joseph Lorenzetti
Email: jlorenze@stanford.edu

Location and time: Remote: Synchronous, Tuesday and Thursday, 10:30am – 11:50am; Friday 10:00am - 11:20am. Friday lectures are optional for those enrolled in AA 174A. For all others, the homework will require material taught during the Friday lectures.

Course format: This course will be taught in a "flipped classroom" format. We will release pre-recorded lecture videos for each week on the preceding Friday at `https://canvas.stanford.edu/courses/123351`. In class, we will focus on summarizing and highlighting key concepts, providing examples that will further the understanding of course content and help with the homework, and answering questions. Questions can be submitted prior to the lecture through the Google Form `https://forms.gle/8snGsRR6eiYcqsjf7` by 7pm the day before the lecture or asked live. Students should watch the pre-recorded videos *before* attending each scheduled lecture.

Office hours:

Prof. Pavone: Tuesdays, 1:00 – 2:00pm (Remote: Synchronous), and by appointment.

Course assistants: Tuesdays, 2:00 – 4:00pm, and Thursdays, 4:00 – 6:00pm, Remote: Synchronous.

Sections:

- Monday, Wednesday, 10:30am – 12:30pm, Remote: Synchronous.
- Monday, 3:00pm – 5:00pm, Remote: Synchronous.
- Tuesday, 4:00pm – 6:00pm, Remote: Synchronous.
- Thursday, 2:00pm – 4:00pm, Remote: Synchronous.

Units

- AA174A: 5.
- AA 274A/CS 237A/EE 260A: 3 or 4. Taking this class for 4 units entails additionally completing a paper review at the end of the quarter.

Prerequisites:

- Familiarity with programming (e.g., CS 106A or equivalent). Previous experience with Python would be helpful, but is not required.
- College calculus, linear algebra (e.g., CME 100 or equivalent).
- Basic probability and statistics (e.g., CME 106 or equivalent).

Course websites:

- For course content and announcements: `http://asl.stanford.edu/aa274a/`
- For course-related questions: `https://piazza.com/stanford/fall2020/aa274a`
- For homework submissions: `https://www.gradescope.com/courses/175144`
- For lecture videos: `https://canvas.stanford.edu/courses/123351`
- For urgent questions: `aa274a-aut2021-staff@lists.stanford.edu`
- To submit pre-lecture questions: `https://forms.gle/8snGsRR6eiYcqsjf7`

Textbooks: There is no required textbook. Recommended reading material:

- R. Siegwart, I. R. Nourbakhsh, D. Scaramuzza. *Introduction to Autonomous Mobile Robots*. MIT Press, 2nd Edition, 2011, ISBN-10: 0262015358. Price: $38.11.
- S. Thrun, W. Burgard, D. Fox. *Probabilistic Robotics*. MIT Press, 2005, ISBN-10: 0262201623. Price: $52.08.

- S. M. LaValle. *Planning Algorithms*. Cambridge University Press, 2006, ISBN-10: 0521862051. Price: $99.99. Free electronic version available at `http://planning.cs.uiuc.edu/`

Additional ROS reading material:

- M. Quigley, B. Gerkey, W. D. Smart. *Programming Robots with ROS: A Practical Introduction to the Robot Operating System*. O'Reilly Media. 1st Edition, 2015, ISBN-10: 1449323898. Price: $45.15.
- J. M. O'Kane. *A Gentle Introduction to ROS*. 2013, ISBN-10: 1492143235. Price: $12.50. Free electronic version available at `https://cse.sc.edu/~jokane/agitr/`.
- L. Joseph, J. Cacace *Mastering ROS for Robotics Programming*. 2nd Edition, 2015, ISBN-10: 1788478959. Price: $49.99.

Course content: Basic principles for endowing mobile autonomous robots with planning, perception, and decision-making capabilities. Algorithmic approaches for trajectory optimization; robot motion planning; robot perception, localization, and simultaneous localization and mapping (SLAM); state machines; introduction to methodologies for reasoning under uncertainty, e.g., (partially observable) Markov decision processes. Extensive use of the Robot Operating System (ROS) for demonstrations and hands-on activities.

Course goals: To learn the *theoretical*, *algorithmic*, and *implementation* aspects of main techniques for robot autonomy, in particular modeling & controls, motion planning, perception, localization & SLAM, state machines, and decision making. To learn how to apply such techniques in applications and research work by leveraging the Robot Operating System (ROS). With this class, the student will:

- Gain a fundamental knowledge of the "autonomy stack" behind self-driving cars, drones, and mobile autonomous robots in general;
- Be able to apply such knowledge in applications and research work by using ROS;
- Devise novel methods and algorithms for robot autonomy.

Course structure and homework policy: The class comprises four modules, roughly of equal length, namely:

1. motion control and planning (09/15 – 10/02);
2. robotic perception (10/06 – 10/16);
3. localization and SLAM (10/20 – 11/05);
4. state machines, decision making, and system architecture (11/10 – 11/19).

There will be a total of **four** problem sets. Rules:

- Because of the multiple topics that will be pursued in the course, it is important to keep up with the assignments. To account for unforseen extraordinary circumstances, students are given a total of 6 free late days that may be used for the homeworks; a maximum of 3 late days will be allowed on a given assignment.
- Cooperation is allowed in doing the homework. You are encouraged to discuss approaches to solving homework problems with your classmates, however **you must always prepare the solutions on your own**. You **must** write on your problem set the names of the classmates you worked with. Copying solutions, in whole or in part, from other students or any other source will be considered a case of **academic dishonesty**.
- **Homework submissions must be typeset** (e.g., in LaTeX or Word.)

Sections: In addition to lectures, students are expected to sign up for a 2 hour section time that they will attend once per week. These sections will provide a chance for students to work on hands-on exercises that *complement* the lecture material and develop skills necessary for the final project. Part of your grade will come from attending, participating in, and completing tasks in your section each week. You must sign up for a section time using the link posted on the course website by 09/18/20. These sign ups are first-come first-serve.

Participation on Piazza: Piazza will be the main tool for class discussion. A student will get an extra point each time he/she (1) asks a question about lecture material; (2) answers a question about lecture material; or (3) answers a question about homework. Questions or answers should be endorsed by one of the CAs in order to receive credit. A student can accrue a maximum of five extra points. Additional details will be provided in a pinned note on Piazza.

Final project: For the final project, students will be assigned the task of deploying the autonomy stack incrementally built through the problem sets on a TurtleBot robot within a simulation environment (namely, Gazebo), with the ultimate goal of enabling self-driving capabilities in a mock urban environment. This task will involve combining *all* the skills the students have learnt from the class. More details about the final project will be given during the week of October 26, 2020.

Course grade calculation:

- (20%) final project.
- (60%) homework.
- (20%) sections.
- (extra 5%) participation on Piazza.

Schedule:
⋆ lectures for AA 274A / CS 237A / EE 260A only (optional for AA 174A)

Date	Topic	Assignment
09/15	Course overview, mobile robot kinematics	
09/17	Introduction to the Robot Operating System (ROS)	
09/18	*No lecture*	HW1 out
09/22	Trajectory optimization	
09/24	Trajectory tracking & closed loop control	
09/25	⋆ Advanced methods for trajectory optimization	
09/29	Motion planning I: graph search methods	HW1 due, HW2 out
10/01	Motion planning II: sampling-based methods	
10/02	*No lecture*	
10/06	Robotic sensors & introduction to computer vision	
10/08	Camera models & camera calibration	
10/09	⋆ Stereo vision	HW2 due, HW3 out
10/13	Image processing, feature detection & description	
10/15	Information extraction & classic visual recognition	
10/16	⋆ Modern robotic perception	
10/20	Intro to localization & filtering theory	HW3 due, HW4 out
10/22	Parameteric filtering (KF, EKF, UKF)	
10/23	⋆ Nonparameteric filtering (PF)	
10/27	EKF localization	Final project released
10/29	EKF SLAM	
10/30	⋆ Monte Carlo localization and particle filter SLAM	
11/03	Multi-sensor perception & sensor fusion	
11/05	Software for autonomous systems	
11/06	*No lecture*	
11/10	State machines	HW4 due
11/12	Decision making under uncertainty	
11/13	*No lecture*	Final project check-in
11/17	Reinforcement learning	
11/19	Conclusions	
11/20	**Final Project Demo**	

Students with documented disabilities: Students who may need an academic accommodation based on the impact of a disability must initiate the request with the Office of Accessible Education (OAE). Professional staff will evaluate the request with required documentation, recommend reasonable accommodations, and prepare an Accommodation Letter for faculty. Unless the student has a temporary disability, Accommodation letters are issued for the entire academic year. Students should contact the OAE as soon as possible since timely notice is needed to coordinate accommodations. The OAE is located at 563 Salvatierra Walk (phone: 723-1066, URL: `https://oae.stanford.edu/`).