# EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots

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**Course Instructor**: Joshua R Smith

**Guest lecturer**: Golnaz Habibi

**Teaching Assistant team**: Boling Yang, Nansong Yi
Emails: jrs@cs.washington.edu (mailto:jrs@cs.washington.edu) , (mailto:planc509@cs.washington.edu,) (mailto:bolingy@cs.washington.edu) golnazh@uw.edu (mailto:forum27@uw.edu) , bolingy@cs.washington.edu (mailto:bolingy@cs.washington.edu) , nansong@uw.edu (mailto:bevans97@cs.washington.edu)

Lectures: Weds, 6pm - 9pm

**Class Wiki Page**:

https://github.com/ece545au20/catkin_ws/wiki (https://github.com/ece545au20/catkin_ws/wiki)

**Office Hours**:

Saturday 9 am - 10 am: Boling Yang -- Zoom ID: https://washington.zoom.us/j/91425311769 (https://washington.zoom.us/j/91425311769)

Sunday 6 pm-7 pm: Nansong Yi -- Zoom ID: https://washington.zoom.us/j/97033634980 (https://washington.zoom.us/j/97033634980)

Monday 6 pm-7 pm: Nansong Yi -- Zoom ID: https://washington.zoom.us/j/97033634980 (https://washington.zoom.us/j/97033634980)

Tuesday 1 pm -2 pm: Boling Yang -- Zoom ID: https://washington.zoom.us/j/92602761872 (https://washington.zoom.us/j/92602761872)

or Friday afternoon by appointment.

**Course Overview**: In this course, we will cover topics related to state estimation (particle filters, motion models, sensor models etc), planning/control (search based planners, lattice based planners, trajectory following techniques etc), and perception and learning (object detection, learning from demonstrations etc.).

Each of the 4 assignments will involve student teams implementing the algorithms learned in lecture on 1/10th sized rally cars. Concepts from all of the assignments will culminate into a partially open-ended final project with a final demo on the rally cars. The course will involve programming in a Linux and Python environment along with ROS for interfacing to the robot.

**Course Goals:** By the end of this course, students will:
1. Become comfortable with tools such as ROS and Python for operating a real robot platform
2. Understand algorithms from state estimation, planning/control, perception, and learning, as well as how each of these areas contributes to the development of autonomous vehicles
3. Implement these algorithms on a real robot platform
4. Analyze both the theoretical and practical strengths and weaknesses of these algorithms

**Prerequisites**:
1. Proficiency in coding in a procedural language (e.g. C, C++, Python, Java, etc) is required
2. Knowledge of basic probability is required
3. Experience with Python is recommended

Grading (Tentative): 60% Assignments, 35% Final Project, 5% Class Participation

**Lecture Schedule**:
• Week 1: Course Logistics. Introduction to Python and ROS
• Week 2: ROS Cont'd. Introduction to Control
• Week 3: PID Control. Model Predictive Control. LQR Control
• Week 4: Bayesian State Estimation. Motion and Sensor Models
• Week 5: Particle Filters for Localization
• Week 6: Introduction to Planning and Search
• Week 7: Planning on Roadmaps. Lazy Search
• Week 8: Model Learning. Introduction to Neural Networks
• Week 9: Introduction to PyTorch. Model Predictive Path Integral Control
• Week 10: Introduction to Deep Reinforcement Learning

**Assignments**: The course will consist of the following six assignments:

1. Getting Started: Introduction to ROS

2. Getting Started: Introduction to Python, Numpy, and the robot

3. Methods for Local Control: Path following / Move to object using images

4. State Estimation: Localization with a particle filter

5. Planning: Navigation in a known map, integration with state-estimation for closed-loop control

You will have 4 free days without penalty for the entire quarter. Late assignments will get a -20% penalty for each day after the deadline.

In addition, a partially open-ended final project will combine concepts from all of these assignments in order to autonomously navigate a track as quickly as possible.

Textbook: There is no required textbook for this course.

**Virtual Machine**:

We will be working with **ROS** (http://wiki.ros.org/) under the Ubuntu Linux operating system. We recommend running Ubuntu, with our pre-installed MuSHR car simulation environment, as a virtual machine. We have pre-installed and configured the software for you. Here are instructions on how to install the virtual machine client and the class virtual machine.

1: **Download and install the VMware client**. All UW students can download the VMware client software for free from **here** (https://e5.onthehub.com/WebStore/ProductsByMajorVersionList.aspx?ws=a4fce2bc-ac2d-de11-a497-0030485a8df0&vsro=8) . For Mac users, download VMware Fusion 12 Player. For Windows users, download VMware Workstation 16 Player.

2: **Download the class VM** We recommend that you use our pre-configured virtual machine (**download MuSHR_Student.ova file from here** (https://drive.google.com/file/d/1k3B6DSLTFJueBLJN0EINJfWLYdPLrJJk/view?usp=sharing) ). Since the development environments, ROS, and robot simulation software are set up correctly in this virtual machine. And you will be able to enjoy the fun of robotics without going through a lot of trouble.

3: **Install & run the VM** Start the VMware client. Import and run the .ova file you downloaded.

**4. Log in to the Ubuntu Guest OS** Use the login information below to sign in to Ubuntu.

**4. Code Editor** We recommend using **VSCode** (https://code.visualstudio.com/) .

User name: robot

Password: prl_robot

If you want to install ROS on your own Ubuntu machine (not recommended), you can use the instructions **here.** (http://wiki.ros.org/ROS/Installation)

**Questions and Discussion**:

We also encourage you to use the discussion board on our Canvas page. If you have any class/lab related questions, check the discussion board first to see if the question has already been asked and answered. Post your questions on the discussion board if you can't find feasible answers. And you are more than welcome to help your classmate if you know the answers to other's questions!

| Week | Date | Lecture Topic | Lecture notes and material | To read | Lab | Lab due |
|---|---|---|---|---|---|---|
| 1 | 9/30/2020 | Introduction; Robotics; Coordinate frames; Car Kinematics; Car HW; Intro to ROS; ROS & car demo | Week1-Intro-sml.pdf<br>Week1-Intro to ROS.pdf | mushr-paper.pdf<br>Lynch-Park-p448-453.pdf<br>Lynch-Park-p441-442.pdf<br>Lynch-Park-p10-15.pdf<br>Ackermann steering geometry.pdf<br>13.1.2.1 A simple car.pdf | PMP_Assignment1.pdf | 10/7/2020 |

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| 2 | 10/07/2020 | Control Systems<br>PID, Pole Placement, LQR, MPC | Week2-Control.pdf | Thrun-Stanley-rob.20147.pdf<br>Steve Brunton's Inverted Pendulum Simulation | PMP_Assignment2.pdf | 10/14/2020 |
| 3 | 10/14/2020 | Control part 2:<br>PID; State Space control; Quaternions; MPC preview | Week3-Control-pt2.pdf | Probabilistic Robotics text (https://docs.ufpr.br/~danielsantos/ProbabilisticRobotics.pdf) | PMP_Assignment3.pdf | 10/21/2020 |
| 4 | 10/21/2020 | MPC; Probability, Pt 1 | b.pdfWeek4-MPC-Prob-pt1-b.pdf | Probabilistic Robotics text | | |
| 5 | 10/28/2020 | Sensor Model & Motion Model for particle filter | Week5-MPC-Pt2-Prob-pt2.pdf | Probabilistic Robotics text | PMP_Assignment4.pdf | 11/14/2020 |
| 6 | 11/05/2020 | Improved Sensor Model, Motion Model, Improved-Resampling, PF Implementation Issues | Week6-Prob-pt3-pt4.pdf | Probabilistic Robotics text | | |
| | 11/12/2020 | No Class | | | | |
| 7 | 11/19/2020 | Intro to Motion Planning(Laplace & RRT) & Heuristic Search (Dijkstra & A*) | Week7-Planning.pdf | LaplacePlanning.pdf<br>Lav98c.pdf<br>kuffner_icra2000.pdf | EEPMP_Assignment5.pdf | |
| 8 | 11/26/2020 | Planning with kinematic constraints;<br>Discuss additional project options;<br>Machine learning; | Week8-ML-pt1.pdf | | | 12/02/2020 |
| 9 | 12/2/2020 | Deep learning<br>Reinforcement learning (Pt 1)<br>RL slides courtesy of Byron Boots | Week9-0-ML-pt2-pt3.pdf<br>Week9-1-EE545_DL.pdf<br>Week9-2-RL-MDPs1.pdf | | | |

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| | | | Week9-3-RL-MDPs2.pdf | | | |
| 10 | 12/9/2020 | Reinforcement learning (Pt 2)<br>Recent research using learning<br>Course Summary | Week10-2-RL-Boling.pdf<br>Week10-Summary.pdf | | | |
| Exam week | 12/16/2020 | Final project presentations | | | | |
| Exam week | 12/18/2020 | Final report due | | | | |

# Course Summary:

| Date | Details | |
|---|---|---|
| Wed Sep 30, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654672&include_contexts=course_1397408) | 6pm to 10pm |
| Wed Oct 7, 2020 | Assignment 1 (https://canvas.uw.edu/courses/1397408/assignments/5770857) | due by 5:59pm |
| | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654673&include_contexts=course_1397408) | 6pm to 10pm |
| Tue Oct 13, 2020 | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726334&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Oct 14, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654674&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Oct 17, 2020 | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726321&include_contexts=course_1397408) | 8pm to 10pm |
| Sun Oct 18, 2020 | Assignment 2 (https://canvas.uw.edu/courses/1397408/assignments/5784213) | due by 5:59pm |
| | EE P 545 A Au 20: Nansong's Office Hour (https://canvas.uw.edu/calendar?event_id=1734217&include_contexts=course_1397408) | 6pm to 7pm |
| Tue Oct 20, 2020 | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726335&include_contexts=course_1397408) | 1pm to 2pm |

| Date | Details | |
|---|---|---|
| Wed Oct 21, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654675&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Oct 24, 2020 | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726322&include_contexts=course_1397408) | 8pm to 10pm |
| Tue Oct 27, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735977&include_contexts=course_1397408) | 1pm to 2pm |
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726336&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Oct 28, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654676&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Oct 31, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735985&include_contexts=course_1397408) | 9am to 10am |
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726323&include_contexts=course_1397408) | 8pm to 10pm |
| | Assignment 3 (https://canvas.uw.edu/courses/1397408/assignments/5795333) | due by 11:59pm |
| Tue Nov 3, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735978&include_contexts=course_1397408) | 1pm to 2pm |
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726337&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Nov 4, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654677&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Nov 7, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735986&include_contexts=course_1397408) | 9am to 10am |
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726324&include_contexts=course_1397408) | 8pm to 10pm |
| Tue Nov 10, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735979&include_contexts=course_1397408) | 1pm to 2pm |
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726338&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Nov 11, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654678&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Nov 14, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735987&include_contexts=course_1397408) | 9am to 10am |
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726325&include_contexts=course_1397408) | 8pm to 10pm |

| Date | Details | |
|---|---|---|
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726326&include_contexts=course_1397408) | 8pm to 10pm |
| Tue Nov 17, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735980&include_contexts=course_1397408) | 1pm to 2pm |
| | EE P 545 A Au 20: Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1726339&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Nov 18, 2020 | Assignment 4 (https://canvas.uw.edu/courses/1397408/assignments/5818032) | due by 5:59pm |
| | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654679&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Nov 21, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735988&include_contexts=course_1397408) | 9am to 10am |
| Tue Nov 24, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735981&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Nov 25, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654680&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Nov 28, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735989&include_contexts=course_1397408) | 9am to 10am |
| Tue Dec 1, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735982&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Dec 2, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654681&include_contexts=course_1397408) | 6pm to 10pm |
| | Assignment 5 (https://canvas.uw.edu/courses/1397408/assignments/5852746) | due by 6pm |
| Sat Dec 5, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735990&include_contexts=course_1397408) | 9am to 10am |
| Tue Dec 8, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735983&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Dec 9, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654682&include_contexts=course_1397408) | 6pm to 10pm |
| Sat Dec 12, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735991&include_contexts=course_1397408) | 9am to 10am |
| Tue Dec 15, 2020 | Boling's Office Hour (https://canvas.uw.edu/calendar?event_id=1735984&include_contexts=course_1397408) | 1pm to 2pm |
| Wed Dec 16, 2020 | EE P 545 A Au 20: The Self Driving Car: Introduction To Ai For Mobile Robots (https://canvas.uw.edu/calendar?event_id=1654683&include_contexts=course_1397408) | 6pm to 10pm |
| Fri Dec 18, 2020 | Final Project (https://canvas.uw.edu/courses/1397408/assignments/5877807) | due by 11:59pm |

| Date | Details |
| --- | --- |
| | Quad Chart (Final project) (https://canvas.uw.edu/courses/1397408/assignments/5877823) |