CSC477/CSC2630 – Introduction to Mobile Robotics

Fall 2022

Instructor:	Florian Shkurti csc477-instructor@cs.toronto.edu	**Lectures:** Wed 3-5pm ET **Office Hours:** Thu 3-4pm ET, Zoom
TAs:	Yewon Lee Yasasa Abeysirigoonawardena Radian Gondokaryono csc477-tas@cs.toronto.edu	**Office Hours:** Tue 11am ET, Zoom **Office Hours:** TBA, Zoom **Office Hours:** TBA, Zoom

Course Page: http://www.cs.toronto.edu/~florian/courses/csc477_fall22

Cross-Campus Course Delivery:
Lectures for this course will be delivered in person by the instructor at the UTM campus on Wednesdays 3-5pm ET, in MN3190. Lectures will also be livestreamed on Zoom for those joining remotely, and projected in the Myhal Building in the St George campus, room MY580, for students who want to join in person from the St George campus. There will be a videoconferencing setup in MY580 and MN3190, allowing all students to ask questions live. Lectures will be recorded and posted online a few hours after the recording.

Tutorials for this course will be delivered in person by one of the TAs at the UTM campus on Wednesdays 5-6pm ET, in DH2020. Tutorials will also be livestreamed on Zoom for those joining remotely, and projected in the Myhal Building in the St George campus, room MY580, for students who want to join in person from the St George campus. There will be a videoconferencing setup in MY580 and DH2020, allowing all students to ask questions live. Tutorials will be recorded and posted online a few hours after the recording.

Office hours for this course will be delivered on Zoom. In person office hours can be arranged by appointment.

Overview: This cross-listed course (undergraduate version CSC477H, graduate version CSC2630H) course provides an introduction to robotic systems from a computational perspective. A robot is regarded as an intelligent computer that can use sensors and act on the world. We will consider the definitional problems for robots and look at how they are being solved in practice and by the research community. The emphasis is on algorithms, inference mechanisms and behavior strategies, as opposed to electromechanical systems design. The course will broadly cover the following areas:

- *Kinematics and Dynamics:* How can we model robotic systems using approximate physical models that enable us to make predictions about how they move in response to given commands?
- *Feedback Control and Planning*: How can we compute the commands that are required to bring a robotic system from its current state to a desired state?
- *Mapping*: How should we represent 3D maps? How can we weigh noisy measurements from sensors as well as the robot's known pose to build a map of the environment?
- *State Estimation*: The state of the robot is not always directly measurable. How can we determine the relative weighs of multiple sensor measurements in order to form an estimate of the state?
- *Geometry of Computer Vision*: How can we model inputs from an RGB camera? How can we triangulate points seen from two cameras? How can we estimate the camera's position (and therefore the robot's) while it is moving in the environment?

Learning Outcomes: This course aims to help students improve their probabilistic modeling skills and instill the idea that a robot that explicitly accounts for its uncertainty works better than a robot that does not. By the end of the course students will learn to be comfortable with high-dimensional probabilistic modelling, least squares optimization, as well as rigorous translation of robotics problems into optimization problems, as currently used in robotics research. Students will also get practical experience with state of the art robot middleware and simulators (e.g. ROS and Gazebo).

Prerequisites: To answer the questions posed above, we will rely on concepts from linear algebra, optimization, and probabilistic reasoning, which are some of the pillars of modern AI systems. Tutorials will be provided by the teaching assistant to help students develop a solid grasp of this important background material. Algorithm implementation will be done mainly in Python or C++/C if you prefer. If your software engineering background does not include these languages, please talk to the instructor as soon as possible. Students are also going to be introduced to the ROS (Robot Operating System) environment and set of interfaces, as well as to the Gazebo 3D simulation environment, which comprise the state-of-the art tools used by the robotics community today.

Currently, the following are listed as prerequisites on the course timetable:
Required: CSC209H5 and (MAT223H5 or MAT240H5) and MAT232H5 and (STA246H5 or STA256H5) and CSC376H5
Recommended: CSC384H5 and CSC311H5 and MAT224H5

If you lack any of the prerequisites, please reach out to the instructor to discuss if it make sense to receive a waiver. Note that familiarity with basic Linux commands, (e.g. using the terminal, using an editor) is assumed and required. If this is not the case for you, please contact the instructor as soon as possible.

Main References: There is no required textbook for this course. Slides will be provided that will cover the material needed for the class. The following are optional, but recommended textbooks:

- Sebastian Thrun, Dieter Fox, Wolfram Burgard *Probabilistic Robotics*.
- Steve Lavalle *Planning Algorithms*.
- Gregory Dudek, Michael Jenkin *Computational Principles of Mobile Robotics, 2nd edition*
- Peter Corke *Robotics, Vision, and Control*
- Tim Barfoot *State Estimation for Robotics*
- Simo Sarkka *Bayesian Filtering and Smoothing*
- Frank Park and Kevin Lynch *Modern Robotics: Mechanics, Planning, and Control*

Course Communications:

- The official discussion board for the course is Piazza `http://piazza.com/utoronto.ca/fall2022/csc477`
- Announcements will be posted on Quercus `https://q.utoronto.ca`
- Do not email the teaching staff at their personal email addresses, but at csc477-instructor@cs.toronto.edu or csc477-tas@cs.toronto.edu. For emails addressed to the instructor expect a response within 3 days.
- You are welcome to provide anonymous feedback / suggestions for improvement any time during the semester: `https://www.surveymonkey.com/r/H8QH65F`

CSC477 Evaluation:

- 4 assignments worth 15% each = 60%
- 7 take-home quizzes worth 2% each = 14%
- 1 in-person final exam worth 26%

CSC2630 Evaluation:

- 3 assignments worth 15% each = 45%
- 7 take-home quizzes worth 2% each = 14%
- 1 final project worth 41%

There will be 7 take-home quizzes throughout the semester, each worth 2% of the final mark. Quizzes will be administered through Quercus. They will be available for 24 hours after posting, and students will be given 30mins to solve them.

Each student will have 3 grace days throughout the semester for late assignment submissions. Late submissions that exceed those grace days will lose 33% of their value for every late day beyond the allotted grace days. Late submissions that exceed three days of delay after the grace days have been used will unfortunately not be accepted. The official policy of the Registrar's Office at UTM regarding missed exams can be found here `https://www.utm.utoronto.ca/registrar/current-students/examinations`.

Tentative Course Outline By Week:

1. Introduction, Sensors and Actuators
2. Kinematics, Dynamics
3. PID Control, Artificial Potential Fields
4. Planning
5. Reading Week
6. Linear Quadratic Regulator
7. Mapping
8. Least Squares, Graph-Based Simultaneous Localization and Mapping
9. Bayes and Kalman Filter
10. Extended Kalman Filter
11. Particle Filter
12. Camera Optics and 3D Geometry
13. Visual Odometry and Simultaneous Localization and Mapping

Important Due Dates (tentative):

Assignment 1 .... Oct 10, 2022, by 3pm ET
Assignment 2 .... Oct 28, 2022, by 3pm ET
Assignment 3 .... Nov 23 , 2022, by 3pm ET
Assignment 4 .... Dec 7, 2022, by 3pm ET

Quiz 1 .... Oct 5, 2022
Quiz 2 .... Oct 17, 2022
Quiz 3 .... Oct 26, 2022
Quiz 4 .... Nov 10, 2022
Quiz 5 .... Nov 17, 2022
Quiz 6 .... Nov 30, 2022
Quiz 7 .... Dec 6, 2022