CS4733/5733: Computer Vision for Autonomous Vehicles

Instructor: Golnaz Haibbi

University of Oklahoma, Fall 2024

Class Hours: Tues/Thurs 13:30-14:45 CST
Instructor E-mail: golnaz@ou.edu
Office Hours (lab sessions): T/Th 12-13, REPF B4
Assignment submission platform: canvas and course Github

Class Room: CEC 438
Course Material: **Canvas**
Instructor Office: DEH 210-F

Course Description

This course delves into the foundational principles of mathematics and the practical implementation of state-of-the-art autonomous navigation algorithms, specifically within the domains of self-driving cars, delivery robots, and autonomous aerial vehicles such as drones. Positioned within the field of robotics, it explores various aspects of autonomous navigation, covering motion planning, computer vision, localization, and mapping.

Course Outcome

During this course, the students will learn broad topics in autonomous navigation system, with focus on 3D trajectory planning and optimization, basics on 3D geometric control, object detection and tracking, Visual Inertial Odometry, place recognition and Simultaneous Localization and Mapping (SLAM), sensor fusion and the extension of the navigation multi-agent coordination and mapping. As a final project, students will integrate three modules of perception, planning, control and implement end-to-end autonomous navigation. This pipeline will be implemented on aerial and ground vehicles such as self-driving cars. The theoretical foundations are complemented with a set of homework assignments which focus on the theory of the course as well as projects based on state-of-the-art racing car and drones. Student will work on the final project which advances the state-of-the-art and can be presented and submitted in a format of a conference paper. This course provides a set of physical racecars for students to design and implement autonomous driving in a mini-city environment as their final project. During the course, we will have guest speakers from industry and academia in robotics and autonomous vehicles.

Course Prerequisites

- (CS2413 or CS2414 or CS5005 and MATH 3333) or instructor's permission

Required System Operation

Students are required to install Ubuntu and use it for their assignments. **There is no support for other operating system**. Students can either install Ubuntu as a dual boot or install Ubuntu solely on their machine.

Recommended Programming Skill

Projects are heavily based on Robotics Operating Systems (ROS) and OpenCV, and the base code is written in C++. Previous experience in robotics and programming in ROS2 would be helpful.

Textbook

There is no required textbook for this course. But the following books are highly recommended:

- Timothy Barfoot, State Estimation for Robotics, Cambridge University Press, 2017. ISBN: 9781107159396.
- Sebastian, Thrun, Wolfram Burgard, Dieter Fox, Probabilistic Robotics, MIT Press, Aug 19, 2005. ISBN-13: 978-0262201629
- Yi Ma , Stefano Soatto , Jana Košecká , S. Shankar Sastry, An Invitation to 3-D Vision: From Images to Geometric Models, Springer, 2003. ISBN: 9780387008936.
- Howie Choset; Kevin M. Lynch; Seth Hutchinson; George A. Kantor; Wolfram Burgard; Lydia E. Kavraki; Sebastian Thrun, Principles of robot motion: theory, algorithms, and implementations, MIT press; 2005 May 20.

Course Leaning Activities and Assignments

Attendance

Attending class and class activity will be a part of the final grade. The class attendance is monitored by TopHat.

Course Assignments

The course has a set of lab assignments with two sections of theory and practice (coding). Theory part focuses on the theoretical aspects of the course and should be done and submitted individually, programming part focuses on the implementation of the materials discussed in the class and should be done in a group of 3. All projects are based on C++ and are implemented in ROS2.

Group Assignments

Grouping for each section is considered separately. This means a group cannot a mixture of section CS4733 and CS5733.

Final Project (Section 5733 only)

Students in 5733 should complete a final project in addition to lab assignments. In final project students integrate all the modules they learn during the semester and implement an end-to-end visual SLAM. students work in group of 3 on the final project. The grading for the final project will be based on:

1. Team presentation, including videos describing the project and its implementation.
2. Final live demo, showcasing the outcome of the project.
3. Technical report, formatted according to IEEE conferences guidelines.

Students in section CS4733 may attend final project, which is a bonus up to %5 of final grade.

CS5733 Outcome as a Research Paper

If the project establishes a new state-of-the-art, it can be considered for submission to a related conference (ICRA, IROS, CVPR, ICCV, ICML, etc).

Robot Operating System (ROS)

The Robot Operating System (ROS) is open source, and it includes a set of software libraries and tools that help you build robot applications. ROS provides components, tools, and interface to build an advanced robot. We extensively use ROS2 in this course.

Course Evaluation and Policy

The grading is based on the set of lab assignments (mini-projects), final exam and class attendance. Final exam includes mathematical derivation and understanding the course fundamental.

Section CS5733 includes an additional final project implementing an existing or new visual SLAM on ArcPro Racars.

Late Policy for the assignments and Projects

The assignments submitted after the deadline are considered late assignment and late policy will apply to them. There are a total of five grace days that you can use for your group assignments (up 2 days for each set of assignment).

For both group and individual assignment, that grade is penalized by 15% for every day late. If you submit your assignment after d days dfrom the deadline and your initial grade is G_i, you final grade will be$G_f = max(0, G_i \times (1 - 0.15 \times d))$. There is no exception to extend the deadline. In the case of sickness or other circumstances, you are required to submit your request with related documents.

Course Evaluation Metrics (Section 4733)

Lab assignments	70%
Final Exam	20%
Class attendance and teammate assessment	5%
Teammate assessment	5%

Course Evaluation Metrics (Section 5733)

Projects and lab assignment	60%
Final Project Report, Demo, Presentation	20%
Final Exam	10%
Class attendance	5%
Teammate assessment	5%

Course Grade Scaling

Score	Final Letter Grade
[90,)	A
[80,90)	B
[70,80)	C
[60,70)	D
(,60)	F

Important Note

The course material, schedule and course evaluation weighting is not finalized and it is subject to change.

Communication

Students are encouraged to pose their questions in discussion sections in canvas or in Teams platform allocated to the class, so it may be helpful for other students as well. For any questions regarding the course (homework, projects, grading, lectures material, etc) you can reach out the course instructor via email or canvas or during office hours.

Academic Integrity and Honesty

Copying another's work for homework and project assignments, or possession of unauthorized electronic computing or communication devices in the testing area, is the course violation and grounds for penalties in accordance with school policies. Please see OU's academic integrity website.

Academic honesty is incredibly important within this course. Cheating is strictly prohibited at the University of Oklahoma, because it devalues the degree you are working hard to get. As

a member of the OU community, it is your responsibility to protect your educational investment by knowing and following the rules. For specific definitions on what constitutes cheating, review the Student's Guide to Academic Integrity.

Religious Observance

It is the policy of the University to excuse the absences of students that result from religious observances and to reschedule examinations and additional required classwork that may fall on religious holidays, without penalty.

Reasonable Accommodation Policy

The Accessibility and Disability Resource Center is committed to supporting students with disabilities to ensure that they are able to enjoy equal access to all components of their education. This includes your academics, housing, and community events. If you are experiencing a disability, a mental/medical health condition that has a significant impact on one or more life functions, you can receive accommodations to provide equal access. Possible disabilities include, but are not limited to, learning disabilities, AD(H)D, mental health, and chronic health. Additionally, we support students with temporary medical conditions (broken wrist, shoulder surgery, etc.) and pregnancy. To discuss potential accommodations, please contact the ADRC at 730 College Avenue, (ph.) 405.325.3852, or adrc@ou.edu.

Title IX Resources and Reporting Requirement

Anyone who has been impacted by gender-based violence, including dating violence, domestic violence, stalking, harassment, and sexual assault, deserves access to resources so that they are supported personally and academically. The University of Oklahoma is committed to offering resources to those impacted, including: speaking with someone confidentially about your options, medical attention, counseling, reporting, academic support, and safety plans. If you would like to speak with someone confidentially, please contact OU Advocates (available 24/7 at 405-615-0013) or another confidential resource (see "Can I make an anonymous report?"). You may also choose to report gender-based violence and discrimination through other means, including by contacting the Institutional Equity Office (ieo@ou.edu, 405-325-3546) or police (911). Because the University of Oklahoma is committed to the safety of you and other students, I, as well as other faculty, Graduate Assistants, and Teaching Assistants, are mandatory reporters. This means that we are obligated to report gender-based violence that has been disclosed to us to the Institutional Equity Office. This includes disclosures that occur in: class discussion, writing assignments, discussion boards, emails and during Student/Office Hours. For more information, please visit the Institutional Equity Office.

Foods and Drinks in the Class

Food and drink are not permitted in the classroom or lab, with the exception of covered water bottles, which may be used sparingly in these locations and the cap immediately returned to the bottle after each drink.

Adjustments for Pregnancy/Childbirth Related Issues

Should you need modifications or adjustments to your course requirements because of documented pregnancy-related or childbirth-related issues, please contact your professor or the Accessibility and Disability Resource Center at 405/325-3852 as soon as possible. Also, see the Institutional Equity Office FAQ on Pregnant and Parenting Students' Rights for answers to commonly asked questions.

Final Exam Preparation Period

Pre-finals week will be defined as the seven calendar days before the first day of finals. Faculty may cover new course material throughout this week. For specific provisions of the policy please refer to OU's Final Exam Preparation Period policy.

Emergency Protocol

During an emergency, there are official university procedures that will maximize your safety.

- **Severe Weather:** If you receive an OU Alert to seek refuge or hear a tornado siren that signals severe weather.

  1. Look for severe weather refuge location maps located inside most OU buildings near the entrances
  2. Seek refuge inside a building. Do not leave one building to seek shelter in another building that you deem safer. If outside, get into the nearest building.
  3. Go to the building's severe weather refuge location. If you do not know where that is, go to the lowest level possible and seek refuge in an innermost room. Avoid outside doors and windows.
  4. Get in, Get Down, Cover Up
  5. Wait for official notice to resume normal activities.

  Additional Weather Safety Information is available through the Department of Campus Safety.

- **Armed Subject/Campus Intruder**

  If you receive an OU Alert to shelter-in-place due to an active shooter or armed intruder situation or you hear what you perceive to be gunshots:

  1. Avoid: If you believe you can get out of the area WITHOUT encountering the armed individual, move quickly towards the nearest building exit, move away from the building, and call 911.
  2. Deny: If you cannot flee, move to an area that can be locked or barricaded, turn off lights, silence devices, spread out, and formulate a plan of attack if the shooter enters the room. 3. Defend: As a last resort fight to defend yourself. For more information, visit OU's Active Shooter page. Shots Fired on Campus Procedure-video

- **Fire Alarm/General Emergency:** If you receive an OU Alert that there is danger inside or near the building, or the fire alarm inside the building activates:

1. LEAVE the building. Do not use the elevators
2. KNOW at least two building exits 3. ASSIST those that may need help 4. PROCEED to the emergency assembly area 5 ONCE safely outside, NOTIFY first responders of anyone that may still be inside building due to mobility issues. 6. WAIT for official notice before attempting to re-enter the building. OU Fire Safety on Campus

Mental Health Support Services

If you are experiencing any mental health issues that are impacting your academic performance, counseling is available at the University Counseling Center (UCC). The Center is located on the second floor of the Goddard Health Center, at 620 Elm Rm. 201, Norman, OK 73019. To schedule an appointment call (405) 325-2911. For more information, please visit University Counseling Center.

Pre-Finals Week Policies

During pre-finals week, all normal class activities will continue; however, no assignment, test, or examination accounting for more than 3% of the course grade may be assigned, unless it is assigned in advance of pre-finals week and worth less than 10%, or scheduled at least 30 days prior if worth more than 10%. No activity or field trip may be scheduled that conflicts with another class. There are some exceptions and nuances, so please review the Final Exam Policies prior to designing your course schedule.

Course Structure and Tentative Schedule (Subject to Change)

This course is adapted from the open source course: Visual Navigation for Autonomous Vehicles, which has been taught at MIT for five years with a great success and the current instructor of CS4733/5733 (Golnaz Habibi) was the co-instructor of VNAV course at MIT(16.485). The open-source version of the course is available **here**. The course consists of a set of lab assignments along with in-person lectures by instructor and guest lecturer invited from industry and academia in a the domain of Autonomous vehicles and computer vision. Here is the tentative schedule for the course:

Week	Lecture	Lab
Week 1	Introduction	Lab 1 out:Ubuntu, basic C++, Git
Week 2	introduction to ROS2	Lab 2: Introduction to ROS2
Week 3	3D perspective and Multi-View Vision 3D Feature Extraction I	Lab 3: Feature matching
Week 4	Feature extraction and matching II	Lab 3: Feature extraction and matching
Week 5	Visual Inertial Odometry (VIO) and state estimation	Lab 4: Multi-view geometry and correspondence for 3D reconstruction
Week 6	3D reconstruction and place recognition	Lab 4: Multi-view geometry and correspondence for 3D reconstruction
Week 7	Machine Learning and computer vision	Lab 5: GTSAM
Week 8	Visual Simultaneous Localization And Mapping (VSLAM)	Lab 6:Pose Estimation
Week 9	Visual VSLAM II	Lab 7: Control
Week 10	3D Geometry and Control	Lab 8
Week 11	3D trajectory and motion planning and optimization	
Week 12	Multi-agent coordination and navigation	Final Project (CS5733)
Week 13	Collaborative SLAM	Final Project (CS5733)
Week 14	Thanksgiving Week	Final Project (CS5733)
Week 15	Advanced topics in autonomous navigation: robustness and safety	Final Project (CS5733)
Week 16	Guest Lectures	Final Project (CS5733)
Week 17	Conclusion and final project presentation	Final Project(CS5733) due