# CS4733/5733: Computer Vision for Autonomous Vehicles

Instructor: Golnaz Haibbi

University of Oklahoma, Fall 2024

Class Hours: Tues/Thurs 1:30-2:45PM CST
Instructor E-mail: golnaz@ou.edu
Office Hours: T/Th 10-11AM, DEH 245
Assignment submission platform: course Github

Class Room: CEC (Carson Center) 121
Course Material: **canvas.ou.edu/xxx**
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

### Recommended Programming Skill

Projects are heavily based on Robotics Operating Systems (ROS) and OpenCV. Most of the projects are in C++. Previous experience in robotics and programming in ROS is a plus.

## 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 is a part of the grading and students are expected to attend the class discussions.

### Course Assignments

The course has nine lab assignments. Each lab has two parts: homework and project. Homework focuses on the theoretical aspects of the course and should be done and submitted individually, projects focus on the implementation of the materials discussed in the class. All projects are mostly based on C++ and are implemented in ROS. The final project could be in Python or C++.

### Section 5733 additional assignment: Final Project

Students in 5733 should implement complete a final project in addition to other assignments. In final project students integrate all the modules they learn during the semester and implement an end-to-end autonomous navigation. According to students' preference, students work in group of 1-3 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 demo, showcasing the outcome of the project.

3. Technical report, formatted according to IEEE conferences guidelines.

**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 ROS in this course. The second assignment includes ROS installation and prepare the students to implement a simple package in ROS

# 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 and students integrate all the modules they learn during the semester.**

**Late Policy for the assignments and Projects**

Course has a set of milestones and deadlines that you need to follow during the semester. The milestones are guidelines for you to make sure you are on track to complete the assignments on time. 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 lab assignments (up 2 days for each set of assignment). After that your grade is penalized by 10

**Course Evaluation Metrics (Section 4733)**

| | |
|---|---|
| Projects and lab assignment | 65% |
| Final Exam | 30% |
| Class attendance and teammate assessment | 5% |

**Course Evaluation Metrics (Section 5733)**

| | |
|---|---|
| Projects and lab assignment | 60% |
| Final Project Report, Demo, Presentation | 20% |
| Final Exam | 15% |
| Class attendance and teammate assessment | 5% |

**Course Grade Scaling**

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

## 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 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 and guest lectures 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 | 3D Geometry Control | Lab 1 due, Lab 2 out: ROS |
| Week 3 | 3D trajectory and motion planning and optimization | Lab 2 due, Lab 3 out:Geometry controller |
| Week 4 | 3D perspective and Multi-View Vision | Lab 3 due, Lab 4 out: Trajectory Optimization |
| Week 5 | 3D Feature Extraction I | Lab 4 due, Lab 5 out: Feature extraction and matching |
| Week 6 | Feature extraction and matching II | Lab 5 due, Lab 6 out:eature extraction and matching |
| Week 7 | Visual Inertial Odometry (VIO) and state estimation | Lab 6 due, Lab 7 out: State Estimation and 3D reconstruction |
| Week 8 | 3D reconstruction and place recognition | Lab 7 due, Lab 8 out: Machine Learning and Object Detection |
| Week 9 | Machine Learning and computer vision | |
| Week 10 | Visual Simultaneous Localization And Mapping (VSLAM) | Lab 8 due, Lab 9 out: Visual SLAM |
| Week 11 | Visual VSLAM II | Lab 9 Visual SLAM |
| Week 12 | Multi-agent coordination and navigation | Lab 9 Visual SLAM |
| Week 13 | Collaborative SLAM | Final Project (CS5733) period |
| Week 14 | Thanksgiving Week | Final Project (CS5733) and Lab 9 continued |
| Week 15 | Advanced topics in autonomous navigation: robustness and safety | Lab 9 due |
| Week 16 | Guest Lectures | Final Project (CS5733) |
| Week 17 | Conclusion and final project presentation | Final Project(CS5733) due |