Syllabus

CS598KKH Advanced Computational Topics in Robotics

Fall 2024

This course introduces students to foundational mathematical models and algorithms used to implement intelligent behavior in autonomous robots, such as autonomous vehicles, drones, industrial robots, and medical robots. Course material will draw from the following topics:

- **Modeling and representation.** 2D/3D transformations, 2D/3D geometry, forward and inverse kinematics, motion representations, configuration space.
- **Motion planning and control.** Motion planning, task planning, feedback control, optimal and model predictive control.
- **Perception.** Uncertainty modeling, state estimation, visual sensors, 3D mapping, calibration, some computer vision.
- **Software and hardware system integration.** Simulation software, visualization and GUIs, distributed system middleware, performance evaluation.

The content of this course will consist of lectures, homework assignments, and simulation-based programming assignments. Programming will be in the Python language.

This course can be considered as an advanced version of ECE470 / ME445 (Introduction to Robotics) that is intended for graduate students. The breadth of the material is similar, but this course will approach selected topics in greater technical depth and rigor. By the end of this course, students should be better prepared to understand academic papers and implement state-of-the-art methods used in robotics.

Time and Location

09:30AM - 10:45AM Mondays and Wednesdays

2039 Campus Instructional Facility

Instructors

Instructor: Kris Hauser
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https://kkhauser.web.illinois.edu/

Office hours: TBD
Siebel Center for Computer Science, Rm 3233

TA: Shaoxiong Yao
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Prerequisites

Data structures, algorithms, linear algebra, and a second course in calculus (CS 225, CS 374, MATH 241, and MATH 415 or equivalents.) Recommended courses include differential equations, computer graphics, optimization, AI, or ML, but these are not assumed as prerequisites.

Textbook and readings

Most readings will be in the online [Robotic Systems book draft](#). Some readings will be excerpted from the following online texts:

- Lynch, K.M. and Park, F.C. [Modern Robotics](#). Cambridge University Press, 2017.
- Murphy, K.P. [Probabilistic Machine Learning: Advanced Topics](#). MIT Press, 2023.
- Choset, Lynch, Hutchinson, Kantor, Burgard, Kavraki, and Thrun. Principles of Robot Motion: Theories, Algorithms, and Implementations. MIT Press, Boston, 2005.
- Murray, Li, and Sastry. [A Mathematical Introduction to Robotic Manipulation](#). CRC Press, 1994.
- LaValle, S. [Planning Algorithms](#). Cambridge University Press, 2006.
- Szeleski, R. [Computer Vision: Algorithms and Applications.](#)
- O'Kane. [A Gentle Introduction to ROS](#). 2014.

Coursework

Students must read the assigned readings before class and must be prepared to discuss the material during class. Homework / lab assignments will be assigned roughly on a biweekly basis.

Homework must be submitted on the due date electronically at the beginning of class.

Tentative Schedule

- *Week 1-2*: **Mathematical preliminaries**
  Topics: Course introduction, 2D and 3D transformations, coordinate transformations.
  Readings: R.S. Ch. 1-5, Appendix A.1-2
- Week 3-4: **Search and planning**
  Topics: Heuristic search, grid-based motion planning, sampling-based motion planning.
  Readings: R.S. Ch. 8-10, Appendix C
- Week 5-7: **Dynamic systems and trajectory optimization**
  Topics: Differential equations, underactuated systems, unconstrained and constrained optimization, shooting methods, direct transcription methods, constraints and costs.
  Readings: R.S. Ch. 13, 17.1-4.
- *Week 8*: **Feedback control**
  Topics: PID control, feedforward control, model predictive control, real-time motion planning.
  Readings: R.S. Ch. 15, 17.5.
- Week 9-10: **Probabilistic models**
  Topics: Discrete and continuous probability distributions, Bayesian inference, multivariate Gaussian distributions.
  Readings: R.S. Appendix A.3
- *Week 11-13*: **State estimation**
  Topics: Probabilistic filtering, Kalman filter and its variants. Monte Carlo methods and particle filtering. System ID and trajectory prediction.
  Readings: An Introduction to the Kalman Filter, Welch and Bishop, 2006; PML, Ch. 18.
- *Week 14-15:* **Planning under uncertainty**
  Topics: Informative path planning. Markov decision processes, value iteration, policy iteration.
  Readings: R.S. Ch 17

Late assignment policy

Late homework will be accepted with a 10% deduction in grade for each day that the assignment is late. Students with excused absences may receive an extension of the assignment due date.

Excused absences are determined at the discretion of the instructor, and examples of valid excuses include sudden illnesses and deaths in the family. Job interviews, conference travel, and other deadlines will NOT be considered valid excuses for absences, and students are expected to manage their schedule to complete their assignments and readings in advance of such conflicts.

Grading policy

The final grade will be comprised of homework (60%) participation (10%), and final project (30%) grades. The lowest-scoring homework assignment (out of 5 total) will be dropped. The participation grade will be comprised of attendance and in-class discussion.

Final letter grades will be assigned on a curve.

POLICY ON USE OF AI TOOLS IN ASSIGNMENTS: The use of AI-assistance (such as ChatGPT or Github Copilot) in generating text, computer code, or figures is permissible, but students will take full responsibility for ensuring the correctness of the output. Be forewarned that in past offerings of this course, such tools have not generated correct answers to homework problems. The instructors will be prepared to identify the errors in logical reasoning and nonsensical claims that are typically made by such tools, and points will be deducted harshly if errors made in submitted assignments resemble those generated by an AI tool. If a student continues to be over-reliant on such tools after multiple warnings, then they may receive a zero grade on offending assignments. It is recommended to restrict the use of AI tools to less complex tasks, such as correcting grammar or reducing the overhead of writing boilerplate code.

Academic Honesty

Students agree to be bound by the UIUC Academic Integrity guidelines. Homework assignments are expected to be completed individually. Students are permitted and even encouraged to discuss assignments. However, any attempt to duplicate work that is not your own -- for example, in the form of detailed written notes, copied code, or seeking answers from online sources -- is strictly prohibited and will be considered cheating.

Academic dishonesty will result in a sanction proportionate to the severity of the infraction, with possible sanctions described in 1-404 of the Student Code (https://studentcode.illinois.edu/article1/part4/1-404/). Every student is expected to review and abide by the Academic Integrity Policy as defined in the Student Code: https://studentcode.illinois.edu/article1/part4/1-401/. As a student it is your responsibility to refrain from infractions of academic integrity and from conduct that aids others in such infractions. A short guide to academic integrity issues may be found at https://provost.illinois.edu/policies/policies/academic-integrity/students-quick-reference-guide-to-academic-integrity/. Ignorance of these policies is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask the instructor(s)

if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

Scientific Objectivity and Ethics

Systematic, rational inquiry has been the cornerstone of scientific progress for centuries. Throughout the history of science these principles have been attacked from certain circles, but recent years have seen concerted efforts to discredit and erode the foundations of trust in science through disinformation, misinformation, propaganda, and direct attacks on scientists and scientific institutions. The university system is founded on the pursuit of objective truth via scientific principles, and it should go without saying that success in this course depends on understanding and utilizing these principles. Non-scientific argumentation, disinformation, and falsification of results are strongly discouraged and may result in penalties in a student's grade.

This course is also committed to the ethical use of computing technology. We take the view that technology should be developed for the purpose of bettering the lives of all humans, and that it is important for engineers to understand the potential for disparate impacts of the technology that they develop. Discussions about the ethical aspects of technology will be welcomed and/or encouraged in the classroom at appropriate times.

Anti-Racism and Inclusivity Statement

The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community.

The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable. You can also report these behaviors to the Bias Assessment and Response Team (BART) (https://bart.illinois.edu/). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

Community of Care

As members of the Illinois community, we each have a responsibility to express care and concern for one another. If you come across a classmate whose behavior concerns you, whether in regards to their well-being or yours, we encourage you to refer this behavior to the Student Assistance Center (217-333-

0050 or http://odos.illinois.edu/community-of- care/referral/). Based on your report, the staff in the Student Assistance Center reaches out to students to make sure they have the support they need to be healthy and safe.

Further, we understand the impact that struggles with mental health can have on your experience at Illinois. Significant stress, strained relationships, anxiety, excessive worry, alcohol/drug problems, a loss of motivation, or problems with eating and/or sleeping can all interfere with optimal academic performance. We encourage all students to reach out to talk with someone, and we want to make sure you are aware that you can access mental health support at McKinley Health Center (https://mckinley.illinois.edu/). Or the Counseling Center (https://counselingcenter.illinois.edu/). For urgent matters during business hours, no appointment is needed to contact the Counseling Center. For mental health emergencies, you can call 911.

Disruptive Behavior

Behavior that persistently or grossly interferes with classroom activities is considered disruptive behavior and may be subject to disciplinary action. Such behavior inhibits other students' ability to learn and an instructor's ability to teach. A student responsible for disruptive behavior may be required to leave class pending discussion and resolution of the problem and may be reported to the Office for Student Conflict Resolution (https://conflictresolution.illinois.edu; conflictresolution@illinois.edu; 333-3680) for disciplinary action.

Emergency Response Recommendations

Emergency response recommendations can be found at the following website: http://police.illinois.edu/emergency-preparedness/. I encourage you to review this website and the campus building floor plans website within the first 10 days of class. http://police.illinois.edu/emergency-preparedness/building-emergency-action-plans/.

Family Educational Rights and Privacy Act (FERPA)

Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.

Mental Health

Significant stress, mood changes, excessive worry, substance/alcohol misuse or interferences in eating or sleep can have an impact on academic performance, social development, and emotional wellbeing. The University of Illinois offers a variety of confidential services including individual and group counseling, crisis intervention, psychiatric services, and specialized screenings which are covered through the Student Health Fee. If you or someone you know experiences any of the above mental health concerns, it is strongly encouraged to contact or visit any of the University's resources provided below. Getting help is a smart and courageous thing to do for yourself and for those who care about you.

- Counseling Center (217) 333-3704

- McKinley Health Center (217) 333-2700
- National Suicide Prevention Lifeline (800) 273-8255
- Rosecrance Crisis Line (217) 359-4141 (available 24/7, 365 days a year)

If you are in immediate danger, call 911

*This statement is approved by the University of Illinois Counseling Center

Religious Observances

Students should complete the Request for Accommodation for Religious Observances form should any instructors require an absence letter in order to manage the absence. In order to best facilitate planning and communication between students and faculty, we request that students make requests for absence letters as early as possible in the semester in which the request applies.

Sexual Misconduct Reporting Obligation

The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX and Disability Office. In turn, an individual with the Title IX and Disability Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options.

A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: http://wecare.illinois.edu/resources/students/#confidential.

Other information about resources and reporting is available here: http://wecare.illinois.edu.

Students with Disabilities

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the as soon as possible. To ensure that disability-related concerns are properly addressed from the beginning, students with disabilities who require assistance to participate in this class should contact Disability Resources and Educational Services (DRES) and see the instructor as soon as possible. If you need accommodations for any sort of disability, please speak to me after class, or make an appointment to see me or see me during my office hours. DRES provides students with academic accommodations, access, and support services. To contact DRES you may visit 1207 S. Oak St., Champaign, call 333-4603 (V/TDD), or e-mail disability@illinois.edu. http://www.disability.illinois.edu/.