MECHENG 6193: LEARNING BASED CONTROLS

INSTRUCTOR: Dr. Qadeer Ahmed (ahmed.358@osu.edu)
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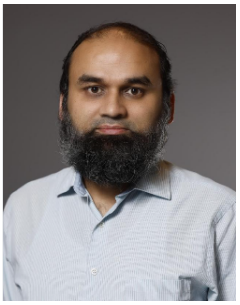

OFFICE HOURS (In person): TBA

COURSE DESCRIPTION

This course explores the synergy between control theory and machine learning, enabling students to design learning-based control systems ensuring adaptability, robustness, stability, and safety. The course focuses on integrating data-driven methods with traditional control techniques to create innovative solutions for real-world applications such as autonomous systems, robotics, advanced manufacturing systems, chemical systems, etc. It applies theoretical concepts to practical engineering problems, incorporating research from past and ongoing projects into the course material, assignments, and an open-ended project. The methods aim to enhance adaptability and decision-making in dynamical systems including autonomous vehicles and robotics.

Course Objectives:

1. Develop the motivation for bridging the gap between conventional control theory and learning techniques.
2. Review the fundamentals of control systems including feedback control, state-space modeling, LQR, and stability analysis.
3. Review the development and solution of optimal control problems using constrained and unconstrained optimization techniques.
4. Review the fundamentals of machine learning (ML) and develop understanding of advanced ML models, including physics-informed ML, while exploring their applications in dynamical systems and controls.
5. Develop understanding of multi-agent system (MAS), traditional reinforcement learning (RL) algorithms (model-based and model-free), deep RL algorithms, and their use in control-oriented applications.
6. Review Model Predictive Control (MPC) and its variants and develop understanding of Learning-based MPC (LMPC) for dynamical systems with a focus on integrating safe sets for secure learning.
7. Develop an understanding of Gaussian process regression (GPR) and its integration with LMPC, focusing on how GPR can be used to handle uncertainties within the LMPC framework.
8. Develop the learning-based controller and perform its stability analysis using quadratic constraints.
9. Develop an understanding of system identification for dynamical systems using Neural ODEs and Generative Adversarial Networks (GANs).
10. Enhance programming and mathematical analysis skills.

PREREQUISITES

- ECE5551, ME5372, ECE 5307, ME5775
- Graduate standing or instructor permission.
- Intermediate knowledge of Matlab/Simulink is required. The course will use Matlab/Python to build and run models, with more advanced tools explained in class.

COURSE FORMAT

- **Mode of Delivery**: 100% in-person.
- **Lecture Schedule:** Tu/Th 09:35am – 10:55am (Baker Systems 128)

CREDIT HOURS AND WORK EXPECTATIONS

- **Credit Hours:** 3
- **Direct instruction**: ~5 hours/week
- **Outside work:** ~10 hours/week (homework, project assignments, review lecture material)

ATTENDANCE AND PARTICIPATION REQUIREMENTS

- **Engagement**: Consistent engagement is expected. Participation in class discussions, group work, and sharing experiences is encouraged.
- **Missed Lectures**: Review missed material before the next lecture. Obtain notes from classmates and attend office hours if needed. If you require further clarification or assistance, please make use of the instructor's office hours.

TEXTBOOKS/REFERENCES

- Albrecht, Stefano V., Filippos Christianos, and Lukas Schäfer. *Multi-agent reinforcement learning: Foundations and modern approaches*. MIT Press, 2024.
- Sutton, Richard S., and Andrew G. Barto. *Reinforcement learning: An introduction*. MIT press, 2018.
- Bertsekas, Dimitri. *Reinforcement learning and optimal control*. Vol. 1. Athena Scientific, 2019.
- Jiang, Zhong-Ping, Tao Bian, and Weinan Gao. "Learning-based control: A tutorial and some recent results." *Foundations and Trends® in Systems and Control* 8, no. 3 (2020): 176-284.
- Course materials (notes, required readings, software) will be available on Carmen.
- Additional readings (books, technical papers) will be posted on Carmen.

COURSE TECHNOLOGY

For technical support, contact the Ohio State IT Service Desk:

- **Self-Service and Chat support:** ocio.osu.edu/help
- **Phone:** 614-688-4357(HELP)
- **Email:** servicedesk@osu.edu

REQUIRED EQUIPMENT

- **Computer**: Access to a computer in the MAE computer lab or any other computer that can connect to Carmen (https://carmen.osu.edu/) for accessing course materials, submitting assignments, and running Matlab for solving assignments. Use Microsoft Office 365 or another editing tool like Overleaf for preparing reports. A personal device is not necessary.

- **Other**: a mobile device (smartphone or tablet) or landline to use for BuckeyePass authentication

REQUIRED SOFTWARE

- **A text editor for writing reports** (e.g., LaTeX or Microsoft Word). Note that Microsoft Office 365 is free for OSU Students.
- **Matlab R2022a or Higher:** Free for OSU Students https://osuitsm.service-now.com/selfservice/.

CARMEN ACCESS

You will need to use BuckeyePass multi-factor authentication to access your courses in Carmen.

GRADING POLICY:

HOMEWORK ASSIGNMENTS (50% OF FINAL GRADE):

- **Submission:** Reports should be submitted electronically on CarmenCanvas. Matlab files should accompany the report.
- **Late Submission:** Not permitted without documented medical reasons or family emergencies. Extensions require 48-hour notice. Reports not submitted by the due date will result in a grade of 0 for that assignment.
- **Preparation:** Individual reports must be typed and submitted in .pdf format; handwritten parts will NOT be graded.

FINAL PROJECT (50% OF FINAL GRADE):

- **Scope**: The project will involve applying concepts learned throughout the course, including learning-based controller design, learning-based system dynamics, learning-based uncertainties, etc. This may include the Simulations and performance/stability/safety verification on different dynamic systems, etc. Projects should align with one or more topics from the course and can be considered for any dynamic system application.
- **Submission**:
  1. **Project Proposal:** An electronic submission of a one-page proposal including motivation, method, expected results, and references (not counted towards any page limit).
  2. **Final Report (IEEE format)**: The final report will be part of the grade, assessing the problem statement, proposed solution, technical depth, and ability to provide simulations results effectively, including conclusion, and references.
- **Grading**: The final project will be graded based on:
  1. **Presentation**: The project presentation will be part of the grade, assessing clarity, technical depth, and ability to communicate results effectively.
  2. **Final Report (IEEE format)**: The final report will be part of the grade, assessing the problem statement, proposed solution, technical depth, and ability to provide simulations results effectively, including conclusion, and references.

GRADING SCALE:

The course will be grading using the **absolute** grading scale below. Therefore, the final grade you receive will not depend on the performance of your fellow classmates.

Above 93%: A	88% - 92.9%: A-	85% - 87.9%: B+
82% - 84.9%: B	79% - 81.9%: B-	75% - 78.9%: C+

70% - 74.9%: C	60% - 69.9%: D	Below 59.9%: E

INSTRUCTOR FEEDBACK AND RESPONSE TIME

- **Grading Feedback**: Within 14 days for homework assignments.
- **Email**: Use [ME COURSE NUMBER] in the subject. Expect a response within one business day.

COMMUNICATION GUIDELINES

- **Writing Style**: Use good grammar, spelling, and punctuation.
- **Tone and Civility**: Maintain a supportive learning community.
- **Citing Sources:** Include author, title, and page numbers for textbooks, journal articles, and other course materials.

ACADEMIC INTEGRITY POLICY

OHIO STATE'S ACADEMIC INTEGRITY POLICY

Academic integrity is essential to maintaining an environment that fosters excellence in teaching, research, and other educational and scholarly activities. Thus, The Ohio State University and the Committee on Academic Misconduct (COAM) expect that all students have read and understand the university's *Code of Student Conduct*, and that all students will complete all academic and scholarly assignments with fairness and honesty. Students must recognize that failure to follow the rules and guidelines established in the university's *Code of Student Conduct* and this syllabus may constitute "Academic Misconduct."

The Ohio State University's *Code of Student Conduct* (Section 3335-23-04) defines academic misconduct as: "Any activity that tends to compromise the academic integrity of the university or subvert the educational process." Examples of academic misconduct include (but are not limited to) plagiarism, collusion (unauthorized collaboration), copying the work of another student, and possession of unauthorized materials during an examination. Ignorance of the university's *Code of Student Conduct* is never considered an excuse for academic misconduct, so I recommend that you review the *Code of Student Conduct* and, specifically, the sections dealing with academic misconduct. **If I suspect that a student has committed academic misconduct in this course, I am obligated by university rules to report my suspicions to the Committee on Academic Misconduct.** If COAM determines that you have violated the university's *Code of Student Conduct* (i.e., committed academic misconduct), the sanctions for the misconduct could include a failing grade in this course and suspension or dismissal from the university.

If you have any questions about the above policy or what constitutes academic misconduct in this course, please contact me. Other sources of information on academic misconduct (integrity) to which you can refer include:

- The Committee on Academic Misconduct web pages (COAM Home)
- *Ten Suggestions for Preserving Academic Integrity (Ten Suggestions)*
- *Eight Cardinal Rules of Academic Integrity* (www.northwestern.edu/uacc/8cards.htm)

ARTIFICIAL INTELLIGENCE AND ACADEMIC INTEGRITY

You can use any generative AI tool for completing the HW and assignments in this class, but you are required to clearly stating how you used such tools, what software you used, what you did to verify the correctness of the output from such software.

COPYRIGHT DISCLAIMER

The materials used in connection with this course may be subject to copyright protection and are only for the use of students officially enrolled in the course for the educational purposes associated with the course. Copyright law must be considered before copying, retaining, or disseminating materials outside of the course.

STUDENT RESOURCES AND SUPPORT SERVICES

STATEMENT ON TITLE IX

All students and employees at Ohio State have the right to work and learn in an environment free from harassment and discrimination based on sex or gender, and the university can arrange interim measures, provide support resources, and explain investigation options, including referral to confidential resources.

If you or someone you know has been harassed or discriminated against based on your sex or gender, including sexual harassment, sexual assault, relationship violence, stalking, or sexual exploitation, you may find information about your rights and options at titleix.osu.edu or by contacting the Ohio State Title IX Coordinator at titleix@osu.edu. Title IX is part of the Office of Institutional Equity (OIE) at Ohio State, which responds to all bias-motivated incidents of harassment and discrimination, such as race, religion, national origin and disability. For more information on OIE, visit equity.osu.edu or email equity@osu.edu.

YOUR MENTAL HEALTH

As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce a student's ability to participate in daily activities. The Ohio State University offers services to assist you with addressing these and other concerns you may be experiencing. If you find yourself feeling isolated, anxious or overwhelmed, please know that there are resources to help: ccs.osu.edu. You can reach an on-call counselor when CCS is closed at (614) 292-5766 and 24 hour emergency help is also available through the 24/7 National Prevention Hotline at 1-(800)-273TALK or at suicidepreventionlifeline.org. The Ohio State Wellness app is also a great resource available at go.osu.edu/wellnessapp.

STUDENT EMERGENCY FINANCIAL SUPPORT

The **Student Advocacy Center** staff members are continuing to serve students during normal business hours and are accepting online appointments.

The **Student Emergency Fund** is available to students who may otherwise be at risk of dropping out of college due to an unexpected financial emergency. If you, or a student you know, are experiencing an unplanned expense, the Student Emergency Fund may be an option. Their office is accepting applications and may be able to award up to $1,000 to eligible students. **Learn more and apply**.

The Together As Buckeyes emergency grants program, funded primarily by the federal Coronavirus Aid, Relief and Economic Security (CARES) Act, is available to all students — undergraduate, graduate and professional — through the Student Financial Aid office. To apply for a grant, students need to complete a one-page Emergency Request form and provide any supporting documentation. The Office of Student Financial Aid will process applications after determining eligibility based on each student's circumstances and guidance from the U.S. Department of Education. Franklin County Department of Job and Family Services has amended its Prevention, Retention and Contingency Program to provide targeted relief for families impacted by the COVID-19 pandemic. The Franklin County COVID-19 Response PRC Program provides eligible families with $500 in one-time cash assistance to help address emergent needs and expenses brought about by the public health emergency. Families can apply online today.

The **Student Wellness Center** offers financial coaching through the Scarlet and Gray Financial nationally recognized peer financial coaching program. Through the program, students will learn about financial goal setting, banking basics, budgeting, credit education, debt repayment education and saving and retirement education. Learn more.

FOOD ASSISTANCE

It's a common idea that pervades American culture: when you're in college, it's simply a rite of passage to sustain yourself on cheap, unhealthy food. We disagree. We highly recommend OSU's **Buckeye Food Alliance** Lincoln Tower 150 food pantry (https://www.buckeyefoodalliance.org) and the MidOhio Foodbank (https://www.midohiofoodbank.org). The **Buckeye Food Alliance** will remain open to support students in need. Starting Monday, March 23 the pantry will be open Monday/Thursday 10 a.m. – 2 p.m.; Tuesday/Wednesday 4 – 8 p.m. and Friday 11 a.m. – 3 p.m. If these times do not work for your schedule, you can schedule a special appointment by contacting Nick Fowler at fowler.318@osu.edu.

ACCESSIBILITY ACCOMMODATIONS

REQUESTING ACCOMMODATIONS

The university strives to make all learning experiences as accessible as possible. If you anticipate or experience academic barriers based on your disability including mental health, chronic or temporary medical conditions, please let me know immediately so that we can privately discuss options. To establish reasonable accommodations, I may request that you register with Student Life Disability Services. After registration, make arrangements with me as soon as possible to discuss your accommodations so that they may be implemented in a timely fashion. **SLDS contact information:** slds@osu.edu; 614-292-3307; 098 Baker Hall, 113 W. 12th Avenue.

ACCESSIBILITY OF COURSE TECHNOLOGY

This online course requires use of Carmen (Ohio State's learning management system) and other online communication and multimedia tools. If you need additional services to use these technologies, please request accommodations with your instructor.

- CarmenCanvas accessibility
- Streaming audio and video
- CarmenZoom accessibility

COURSE TOPICS LIST

Date	Units	Lecture	Topic	HW
1/7/2025	1	Lecture 1	Introduction to Learning Based Control (LBC)	
1/9/2025	2	Lecture 2	Feedback Control using State Space models	
1/14/2025		Lecture 3	Optimal Controls with Un-constrained/ Constrained Optimization	
1/16/2025	3	Lecture 4	Introduction to Machine learning (ML)	
1/21/2025		Lecture 5	Final Project Overview	Project Proposal Assigned
1/23/2025		Lecture 6	Machine Learning (ML) Algorithms	
1/28/2025		Lecture 7	Deep Learning Models	Project Proposal Due
1/30/2025		Lecture 8	Introduction to Multiagent System (MAS)	Project Report (PR)- 1 Assigned
2/4/2025		Lecture 9	Introduction to Reinforcement Learning (RL)	

2/6/2025	4	Lecture 10	Types of RL (Monte Carlo Methods)	
2/11/2025		Lecture 11	Types of RL (Temporal difference Learning (TDL), Q Learning, SARSA)	
2/13/2025		Lecture 12	Deep Reinforcement Learning (Deep Q Learning, AC, A2C, A3C)	PR-1 Due /PR-2 Assigned
2/18/20252		Lecture 13	Model-free RL Algorithms (Dyna, Dyna Q Algorithm)	
2/20/2025		Lecture 14	Reinforcement Learning (RL) for Controls	
2/25/2025	5	Lecture 15	Physics Informed Neural Network (PINN)	
2/27/2025		Lecture 16	Application of PINN for Electric Drive System	PR-2 Due /PR-3 Assigned
3/4/2025	6	Lecture 17	Model Predictive Control (MPC)	
3/6/2025		Lecture 18	Learning Safe MPC for Autonomous Racing car	
3/11/2025		Lecture 19	Gaussian Process Regression (GPR)	
3/13/2025		Lecture 20	Learning Uncertainties Using GPR within MPC Framework	PR-3 Due / PR-4 Assigned
3/18/2025-3/20/2025		Spring Break		
3/25/2025	GL	Lecture 21	Model Predictive Control (Exploiting Machine Learning for Approximation & Design)	
3/27/2025	GL	Lecture 22	Control with learning on the fly (learning the unknown parameters)	
4/1/2025	GL	Lecture 23	Humanoid robotics (Safety)	
4/3/2025	7	Lecture 24	Learning the Controller Using Machine Learning (ML)	PR-4 Due
4/8/2025		Lecture 25	Stability Analysis of Neural Network Controller (NNC) with Quadratic Constraints	
4/10/2025	8	Lecture 26	System Identification	
4/15/2025		Lecture 27	System Identification using Neural ODEs	
4/17/2025	9	Lecture 28	Generative AI and Generative Adversarial Networks (GANs)	Final PR Submission
4/22/2025 4/24/2025		End semester project presentations		