ME599-004: Data-Driven Methods for Control Systems
University of Michigan – Winter 2025

Registration
(3 units) Graduate level. A background in classical controls, linear algebra and state-space modeling is strongly recommended.

Lectures
Tuesdays and Thursdays 12:00-13:30 ET, 01/08/2025 – 4/22/2025, DOW 1010

Course Description
Data is vital in control systems. At bottom, data acquisition is essential for feedback in closed-loop systems. But more interestingly, input and output system data, stored over time, can be used to find suitable control signals, or finetune control signals. The focus of this course is to discuss strategies for utilizing system data in these ways. The course will begin with a review of control systems fundamentals including classical, optimal and nonlinear control design. The course will then discuss prominent methods that learn control signals directly with or without a model, namely, reinforcement learning and iterative learning control. This will be followed by indirect methods that learn models for controls including classical system identification, machine learning, and deep learning approaches for dynamical systems. We will conclude by exploring emerging trends such as physics-informed neural networks for controls. Examples that illustrate how to choose an appropriate learning strategy for a given problem will be drawn from various control applications.

Instructor: Uduak Inyang-Udoh
Office: GGBL 3468
Phone: 734-647-4930
Email: udinyang@umich.edu
Office Hours: Tuesdays and Thursdays 14:00-15:00 ET, in office

Graduate Student Instructor (GSI): Yuxin Tong
Email: yuxinton@umich.edu
Office Hours: Monday 13:30-14:30 ET, Wednesday16:00-17:00 ET, in Findley C, GGB

Programming
This course will entail a decent amount of programming in MATLAB.

Website (Canvas): https://umich.instructure.com/courses/737134
We will as well use piazza for communication in this class. You should be automatically added to the piazza page if you have Canvas access.

References (Optional)
1. Brunton and Kutz, *Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control*, 2nd ed., Cambridge University Press, 2022
2. Keesman, *System Identification: An Introduction*, Springer, 2011
3. Duda, Hart, and Stork, *Pattern classification*, Wiley, 2001
4. Moore, *Iterative Learning Control: An Expository Overview* In: Datta, B.N. (eds) Applied and Computational Control, Signals, and Circuits. Springer, 1999
5. Powell, *Approximate Dynamic Programming : Solving the Curses of Dimensionality*, Wiley, 2011
6. Goodfellow, Bengio, Courville, *Deep Learning*, MIT Press, 2016
7. Ljung, *System Identification: Theory for the User*, 2nd ed.,Prentice Hall, 1999

Assessment

Homework Problems – 80%
(Group) Project/Study – 20%
Quizzes (optional) – 4% (Bonus points)

Eight (8) homework problem sets will be issued during the semester. At least one (1) week will be given for completing each. Certain homework problems would have multiple approaches for solving them. A critical leaning outcome of this course is to discern what approach, of potential alternatives, is suitable for a given problem. Hence your solutions should highlight your thought process and outline assumptions you make and why those assumptions are reasonable. Tentatively, assignments are to be submitted on Canvas. We may experiment with using Gradescope but this will be ascertained at a later date. Note that, as indicated in the table below, the homework sets carry different points. This is so that homework sets towards the end of the semester would have lighter loads while you work on your projects.

Homework	*Points*	*Due*	*Posted (On/before)*
1	14	January 28	January 9
2	12	February 11	January 14
3	10	February 20	January 23
4	10	March 4	February 6
5	10	March 13	February 20
6	10	March 25	March 6
7	8	April 3	March 13
8	6	April 15	March 27

The due dates are tentative, and might be moved forward (in time) a couple of days.

There is no midterm or final exam. Instead, a final project/study will be required. The final project will include an initial project proposal, and final deliverables in the form of a written report and short presentation. Portions of the final deliverables will be peer-reviewed (by other students in this class) and the instructor/GSI will assign a final score. The final project is intended as an opportunity for you to exercise the knowledge gained from this course and explore topics that may be beneficial to your graduate research. It is also intended to encourage working with fellow students as a group. Hence, you are expected to work in teams of at least 2, preferably, 3 or 4, or receive the instructor's permission to work by yourself on the project. More details about the project will be uploaded on Canvas.

There will be short unannounced in-class quizzes (that are entirely optional). You can expect about 8 quizzes over the semester. More details about the quiz will be discussed in class. We shall use iclicker for quizzes.

Using Icliker for Quizzes

1. If you do not have an icliker account, create one using https://student.iclicker.com/#/account/institute Ensure you create the account using your umich email.
2. (*Optional*) Download the Mobile App
3. If you are enrolled in this course, you should be added to course on iclicker. Otherwise, you can join the course on icliker using https://join.iclicker.com/DAHM.
4. For taking in-class quizzes, use the Web App or Mobile App.

Grades

You are likely to get a grade in the A range if your homework demonstrate you have a very good understanding of the course, and you take advantage of the in-class quiz bonus points. In raw numbers, the following score to grade scale would hold.

Score	*Grade*
>=99	A+
94-98	A
89-93	A-
85-89	B+
81-84	B
75-80	B-

The ***average class performance can pull these numbers down a bit but not up***. So, as you put in the good work, you are likely to get a good grade irrespective of the class average.

Content

1. Data Analysis & Machine Learning Preliminaries

- Fourier Transforms & Applications, Dimensionality Reduction
- Classification: Discriminants, Support Vector Machine, Clustering, Neural Networks

2. Dynamical Systems & Control (P)review

- ODEs, Transfer functions, State Space representations
- Classical and linear controls theories: PID, frequency-domain analysis, state feedback & estimation, Linear Quadratic Regulator (LQR), Model Predictive Control (MPC)
- Nonlinear control

3. Learning Control

- Iterative Learning Control
- Reinforcement Learning (RL)

4. Learning Models for Controls

- Classical System Identification (ID) and Controls: Regression analysis, Frequency & impulse responses, autoregressive models, Nonlinear system ID and adaptive control
- Koopman Operator, Dynamic Mode Decomposition (DMD), Sparse Identification of Nonlinear Dynamics (SINDy)

5. Deep Learning for Controls & Recent Topics

- Multilayer NN, Recurrent NNs, Convolutional NN, Autoencoders, Generative Adversarial Networks; Neural ODEs; Physics-Informed Deep Learning

The objective of this course is to *introduce* approaches for controlling systems using data. Hence, we do not treat the topics exhaustively as they each constitute subjects of entire courses in their own right. Please note that this outline is subject to modifications as is deemed suitable for the class.

Collaboration Policy and Honor Code

You are allowed, and indeed encouraged, to consult with other students and faculty. You may work in groups if desired. However, every student must separately and individually conduct all elements of a submission. This includes creating, editing, and submitting your own report, code, and calculations. Using a template or any partially created elements from another student is not allowed. Suspected violations of this homework policy may be reported to the College of Engineering's Honor Council. Information about the Honor Council can be found at https://elc.engin.umich.edu/honor-council/.

Policy on Generative AI

Learning how to use AI tools such as ChatGPT is important for all of us. Used properly, ChatGPT can enhance our work; used improperly, it can border on plagiarism. If you have used ChatGPT on anything you submit for this class, please include an appendix containing (1) your key conversations/usage of the chatbot, including your original prompts and its responses; and (2) description of how you reworked and revised the content so that your final submission was both *factually accurate* and *reflected your own writing*. If you used ChatGPT to help work on your code, you must fully *understand* the code in its entirety and be able to recreate it when requested. Otherwise, treat the AI tool as a classmate. As such, copying text directly from the AI tool is not permitted.

Accommodation for Students with Disabilities

If you think you need an accommodation for disability, please contact Services for Students with Disabilities (https://ssd.umich.edu/; 734-763-3000 or ssdoffice@umich.edu). For students who are connected with SSD, accommodation requests can be made in "Accommodate". If you have any questions or concerns, please contact your SSD Coordinator or visit SSD's Current Student webpage. SSD considers aspects of the course design, course learning objects and the individual academic and course barriers experienced by the student. Further conversation with SSD, instructors, and the student may be warranted to ensure an accessible course experience.

Auditing the Class

You are welcome to audit this class. To audit this class, it is expected that you

- attend 75% or more of lectures and turn in 25% or more of the homework; or
- attend 50% or more of lectures and turn in 50% or more of the homework; or
- attend 25% or more of lectures and turn in 75% or more of the homework.

Homework turned in should demonstrate that you conscientiously attempted the questions. They would be graded Satisfactory or Unsatisfactory. Please clearly write "AUDIT" on the top of your submission. The number of quizzes you take would be used to measure attendance. Alternately, you can also log into / join the class session on iclicker at the beginning of each class you attend to indicate your attendance. The expectations for auditing are to foster participation in the course; if you would be unable to meet these expectations, please reach out as soon as possible to the instructor to find other possible options.