Syllabus for 16:332:514
Data-Driven Systems and Controls
Spring, 2025

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Learning objectives: This course is designed to provide students with comprehensive knowledge of various data-driven techniques for addressing practical challenges in dynamic systems and controls. The learning journey begins with a solid foundation in linear dynamic system modeling, encompassing both continuous and discrete-time representations, along with feedback control strategies. Students will then learn to reverse engineer linear models directly from data, stabilizing linear systems using data-driven approaches, and designing optimal controllers informed by data. In addition, students will learn more advanced topics, including model-free control techniques such as model-predictive control, extremum-seeking, and machine-learning control.

Pre-Requisite: Students should be familiar with differential equations (01:640:252) and matrix/vector analysis (01:640:250).

Suggested Textbooks:

- Brunton, Steven L., and J. Nathan Kutz. Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control. 2nd ed, Cambridge University Press, 2022.

Homework: Four homework assignments will be given.

- Each homework assignment must be typed on a word-processor. Use of LaTeX is recommended, although other word processing platforms are acceptable.
- Students will be given extra points for clarity on the presentation of their HW.
- Students must upload their homework on Canvas.
- Students are permitted to discuss homework questions with other students, although they are not permitted to discuss solutions except in general terms.
- Solutions for all assigned problems will be provided
- Homework must be submitted by the deadline. Except for exceptional and documented circumstances, late homework are not accepted.

Project: Students should create small groups to work on a research project.
Each group will prepare and submit a written report and prepare a final presentation

The report/presentation should be organized as follows:

- Introduction (Broad overview of the problem under study, why it is important?, applications? Methods used to solve the problem, general conclusions from the study)

- Problem formulation/model: Clearly present the problem to be solved, derivation of the governing equations, physical meaning of the state variables and model parameters
- Data Analysis: Utilize data to learn the underlying model of the system
- Control design: Using the tools learned from class design controllers and implement them in MATLAB
- Conclusions

Grading policy

The course final grade is determined as a sum of the following scores:
Homework: 25%
Midterm Exam: 20%
Project: 30%
Final Exam: 25%

Course grading will be based on the total score (TS) at the end of the semester according to $\mathrm{A}(TS \geq 90)$, $\mathrm{B}^{+}(TS \geq 82)$, $\mathrm{B}(TS \geq 75)$, $\mathrm{C}^{+}(TS \geq 67)$, $\mathrm{C}(TS \geq 60)$, $\mathrm{D}(TS \geq 50)$,

Tentative Lecture Schedule

- Week 1: Review of basic concepts of matrix algebra and differential equations
- Week 2: Singular value decomposition
- Week 3: Modeling dynamic processes
- Week 4: Solutions and stability concepts
- Week 5: Data-driven controllability and observability
- Week 6: Dynamic mode decomposition
- Week 7: Koopman operator theory and data-driven analysis
- Week 8: Feedback stabilization of dynamic systems
- Week 9: Performance guarantees and optimal feedback control
- Week 10: The behavioral approach and data-based systems representations
- Week 11: Data-driven control design: feedback stabilization
- Week 12: Data-driven control design: optimal control
- Week 13: Advanced data-driven controls
- Week 14: Final Presentations

Academic Integrity

Students should familiarize themselves with the Academic Integrity Policy, available online (http://nbacademicintegrity.rutgers.edu). Quoting from these guidelines: The principles of academic integrity require that a student:

- make sure that all work submitted in a course, academic research, or other activity is the student's own and created without the aid of impermissible technologies, materials, or collaborations.
- properly acknowledge and cite all use of the ideas, results, images, or words of others.
- properly acknowledge all contributors to a given piece of work.

- obtain all data or results by ethical means and report them accurately without suppressing any results inconsistent with the student's interpretation or conclusions.
- treat all other students ethically, respecting their integrity and right to pursue their educational goals without interference. This principle requires that a student neither facilitate academic dishonesty by others nor obstruct their academic progress.
- uphold the ethical standards and professional code of conduct in the field for which the student is preparing.

Adherence to these principles is necessary to ensure that:

- proper credit for ideas, words, images, results, and other scholarly work, no matter the form or media, is attributed to the appropriate individual(s).
- all student research and work are fairly evaluated, and no student has an inappropriate advantage over others.
- the academic and ethical development of all students is fostered.
- the reputation of the University for integrity, ethics, scholarship, and professionalism is maintained and enhanced.

Any violations to this policy will be reported to Office of Student Conduct (New Brunswick). Violations of academic integrity will be treated in accordance with university policy, and sanctions for violations may range from no credit for the assignment, to a failing course grade to (for the most severe violations) dismissal from the university.