ECE1659H: Robust and Optimal Control

Winter 2024

Department of Electrical and Computer Engineering
University of Toronto

Course Description

Convex optimization methods based on Linear Matrix Inequalities (LMIs) have dramatically expanded our ability to analyze and design complex multivariable control systems. This course explores material from the broad areas of robust and optimal control, with an emphasis on formulating systems analysis and controller design problems using LMIs. Topics include: historical context of robust control, fundamentals of optimization, linear matrix inequalities and semidefinite programming. Linear systems theory: Lyapunov inequalities, input-output performance criteria for dynamic systems, dissipative dynamical systems, and the generalized plant framework for optimal control. LMI solutions of $\mathcal{H}_2$ and $\mathcal{H}_\infty$ state and output feedback control problems. Uncertain systems: linear and nonlinear uncertainty modelling, linear fractional representations, robust stability analysis, robust performance analysis. Introduction to integral quadratic constraints.

Prerequisites: Competency in classical control (ECE311/ECE356) and linear systems theory (ECE410 / ECE557 or equivalent) is required. Introductory knowledge of nonlinear dynamical systems and convex optimization would be highly beneficial, but is not strictly required.

Instructor

Prof. John W. Simpson-Porco
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Office Hours: By Appointment
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Web: https://www.control.utoronto.ca/ jwsimpson/

Lecture

Please click here for the most up to date lecture timetable.

Course Website

The course website is hosted via Quercus. General administrative aspects of the course will be communicated via announcements on Quercus. The course website will be available from the first day of class onwards.

Courseware and Supplementary References

There is no required textbook. Complete course notes are available on Quercus. Useful supplementary references include:

- G. E. Dullerud and. G. Paganini. *A Course in Robust Control Theory: A Convex Approach*, Springer, 2000. (url)
- C. Scherer and S. Weiland. *Linear Matrix Inequalities in Control*. (url)
- S. Boyd, L. El Ghaoui, E. Feron and V. Balakrishnan. *Linear Matrix Inequalities in System and Control Theory*, SIAM, 1994. (url)
- G. Duan and H. Yu. *LMIs in Control Systems: Analysis, Design and Applications*, CRC Press, 2013.
- L. El Ghaoui and S. Niculescu (Eds). *Advances in Linear Matrix Inequality Methods in Control*, SIAM, 2000.
- K. Zhou and J. C. Doyle. *Essentials of Robust Control*, Prentice-Hall, 1998.
- S. Skogestad and I. Postlethwaite. *Multivariable Feedback Control Analysis and Design*, Wiley, 2005.
- C. Desoer and M. Vidyasagar. *Feedback Systems: Input-Output Properties*, SIAM, 1975. (url)
- M. Peet. ASU MAE 598/507 (url)
- S. Lall. Stanford ENGR 201A
- C. Scherer and S. Weiland. *LMIs in Control*
- C. Scherer. *Theory of Robust Control*

Piazza

We will use Piazza, linked off of Quercus, as an asynchronous forum for questions and discussion. As group discussion and back-and-forth is extremely valuable, all students are highly encouraged to participate, and a percentage of the course grade is allotted for participation in the Piazza. "Participation" here is broadly defined as positively contributing towards your learning and academic growth and that of your colleagues, and could include asking questions, answering or attempting to answer questions, typing up or linking to related material of interest, etc. Both frequency and quality of participation will be considered in assigning a grade.

As the Piazza is intended for discussion of course content, I reserve the right to moderate any posts which stray too far off topic.

Assignments

There will be four homework assignments, with due dates indicated on Quercus under the "Assignments" tab. Assignments are to be completed in groups of two, and will be graded at a graduate level for completeness, correctness, and clarity of presentation. Please form your group of two via Quercus under the "People/Homework Group" tab. Please also submit your completed assignments via Quercus by the due dates indicated under the "Assignments" tab.

Late submissions will be assessed a penalty of 10% per day or part thereof. Homework partners will receive identical grades.

Project

The course project is described in detail in a handout posted to Quercus. The project is not prescriptive; it should be engaging, self-directed learning. You should therefore invest some significant time into finding a topic that excites you. You could apply the ideas in the course to your own research, explore an advanced topic or research paper that you want to understand, or find an exciting application or case study in which to apply the course methods.

The project deliverables are a proposal, a final presentation, and the slides from the final presentation. The proposal due date is indicated on Quercus under "Assignments". Final presentations will be scheduled for the last week of the term. Late submissions will be assessed a penalty of 10% per day or part thereof.

Grading Scheme

Homework	40%
Piazza Participation	10%
Project	50%

Notice of Video Recording and Sharing

At times during this course, some interactions including your participation may be recorded on video and will be available to students in the course for viewing remotely and after each session. Course videos and materials belong to the instructors, the University, and/or other source depending on the specific facts of each situation, and are protected by copyright. In this course, you are permitted to download session videos and materials for your own academic use, but you should not copy, share, or use them for any other purpose without the explicit permission of the instructor. For questions about recording and use of videos in which you appear please contact the course coordinator.

Academic Integrity Policies

Please see here and here.

Land Acknowledgement

I (we) wish to acknowledge this land on which the University of Toronto operates. For thousands of years it has been the traditional land of the Huron-Wendat, the Seneca, and most recently, the Mississaugas of the Credit River. Today, this meeting place is still the home to many Indigenous people from across Turtle Island and we are grateful to have the opportunity to work on this land.

Inclusivity, Accommodations and Mental Health Support

Statement on Inclusivity You belong here. The University of Toronto commits to all students, faculty and staff that you can learn, work and create in a welcoming, respectful and inclusive environment. In this class, we embrace the broadest range of people and encourage their diverse perspectives. This team environment is how we will innovate and improve our collective academic success. You can read the evidence for this approach here.

We expect each of us to take responsibility for the impact that our language, actions and interactions have on others. Engineering denounces discrimination, harassment and unwelcoming behaviour in

all its forms. You have rights under the Ontario Human Rights Code. If you experience or witness any form of harassment or discrimination, including but not limited to, acts of racism, sexism, Islamophobia, anti-Semitism, homophobia, transphobia, ableism and ageism, please tell someone so we can intervene. Engineering takes these reports extremely seriously. You can talk to anyone you feel comfortable approaching, including your professor or TA, an academic advisor, our Assistant Dean, Diversity, Inclusion and Professionalism, the Engineering Equity Diversity and Inclusion Action Group, any staff member or a U of T Equity Office.

You are not alone. Here you can find a list of clubs and groups that support people who identify in many diverse ways. Working together, we can all achieve our full potential.

Statement on Accommodations The University of Toronto supports accommodations for students with diverse learning needs, which may be associated with mental health conditions, learning disabilities, autism spectrum, ADHD, mobility impairments, functional/fine motor impairments, concussion or head injury, blindness and low vision, chronic health conditions, addictions, deafness and hearing loss, communication disorders and/or temporary disabilities, such as fractures and severe sprains, or recovery from an operation.

If you have a learning need requiring an accommodation the University of Toronto recommends that students register as soon as possible with Accessibility Services.
Phone: 416-978-8060
Email: accessibility.services@utoronto.ca

Statement on Mental Health As a university student, you may experience a range of health and/or mental health challenges that could result in significant barriers to achieving your personal and academic goals. Please note, the University of Toronto and the Faculty of Applied Science & Engineering offer a wide range of free and confidential services that could assist you during these times.

As a U of T Engineering student, you have an Academic Advisor (undergraduate students) or a Graduate Administrator (graduate students) who can support you by advising on personal matters that impact your academics. Other resources that you may find helpful are listed on the U of T Engineering Mental Health & Wellness webpage, and a small selection are also included here:

- Accessibility Services & the On-Location Advisor
- Graduate Engineering Council of Students' Mental Wellness Commission
- Health & Wellness and the On-Location Health & Wellness Engineering Counsellor
- Inclusion & Transition Advisor
- U of T Engineering Learning Strategist and Academic Success
- My Student Support Program (MySSP)
- Registrar's Office
- SKULE Mental Wellness
- Scholarships & Financial Aid Office & Advisor

If you find yourself feeling distressed and in need of more immediate support resources, consider reaching out to the counsellors at My Student Support Program (MySSP) or visiting the Feeling Distressed webpage.