EECS 562 / AE 551: Nonlinear Systems and Control. Winter 2023

Mon Wed 1:30pm – 3pm, Room: 1500 EECS

Instructor: Dr. Dimitra Panagou, Associate Professor of Robotics and Aerospace Engineering
Office: 3260 Ford Robotics Building, Phone: 763-2355
Email: dpanagou@umich.edu
Office Hours:
Remotely on Tue 1pm-3pm; Wed 8:30am-9:30am. Zoom link information and sign up here
If you prefer to schedule an in-person meeting (during or outside office hours), email me.

GSI: Hardik Parwana
Email: hardiksp@umich.edu
Office Hours: TBD

Discussion sessions: Every Week: TBD

The discussion sessions are OPTIONAL (i.e., not for credit) and will be taught by the GSI. They will cover material related to the lectures and homework. The aim is to help develop relevant mathematical background, mostly through worked examples, and to better prepare students for the project, problem sets, and exams. If you cannot attend the discussion sections, do not worry; the material will be posted on Canvas. However, students are encouraged to attend if possible so that they may benefit from asking questions and participating in class discussions. Finally, no attendance is taken. This is purely a voluntary activity designed to help you succeed in the course.

Prerequisites: EECS 560/AE 550 and Matlab.

Textbook: Hassan Khalil, Nonlinear Systems. Third Edition. Prentice Hall. 2002

Course Outline: EECS 562 and AEROSP 551:

(Official course description) Introduction to the analysis and design of nonlinear systems and nonlinear control systems. Stability analysis using Lyapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods selected from linearization, absolute stability theory, vibrational control, sliding modes and feedback linearization.

(Real course description) The course will be roughly 20% mathematical basics and fundamentals of differential equations, 50% stability theory, and 30% feedback design. The field of nonlinear control system analysis and design is extremely vast, and is still very much incomplete. A lot is known, and much, much more is unknown. We will go through many proofs. We will try our best to illustrate ideas on examples. Many of the examples will seem simplistic, as they will be chosen to illustrate concepts or computations, AND to be doable on the whiteboard or a homework set. You will be able to find many papers in the literature where the material we cover is used in real engineering systems. Everything we cover in the course will have practical implications, even though you may not see this right away.

Grading

Homework ……. …. 15%
Project ……. 15%
Midterm Exam ……. 35%
Final Exam…..... . …. 35%

Grading Policy: Late homework is **not** accepted, and deadline extensions are **not** granted. I will discard the **two** homework sets with the lowest grades when computing your final grade.

Homework Deadline: The deadline for homework submissions will (tentatively) be on Thursday at 11:59pm. The Canvas site will remain open until for 15 minutes past the deadline (i.e., until Friday at 12:15am), to accommodate any last-minute network/technical issues. Past that time the site will close and no submission will be possible. **It is your responsibility to make sure that your homework is uploaded on Canvas before the deadline.**

Project: The project is like an extended homework problem. It uses linearization methods to control the classic inverted pendulum on a cart; you will have very precise instructions on what to do, and a written report to turn in. There is no oral report. The goal is for you to apply what you learned in linear systems theory (i.e., EECS 560) to a nonlinear system. In later homework sets, we will design nonlinear controllers that perform much better!

Midterm Exam (In Class): Tentative Date: Mid to late March. You will have at least a 2-week notice on when the exam will take place.

Final Exam (In Class): Firm Date by the Registrar: Tuesday April 25th, 1:30pm-3:30pm.

Piazza site

Piazza (accessible through Canvas) is meant to facilitate discussions primarily among the students. You are encouraged to answer questions if you can. The instructor and the GSI will sporadically check the site, i.e., do not expect that your question will be answered immediately. Please refrain from discussing the exact homework/project solutions prior to their due date.

To enroll on the Piazza site: https://piazza.com/umich/winter2023/eecs562001wn2023

Additional References

H. Khalil, Nonlinear Control, Pearson, 2015 [A newer textbook by our textbook's author. It focuses much more on feedback control and less on stability analysis. Some of you may like this book.]

M. Vidyasagar, Nonlinear Systems Analysis, Second Edition, Prentice Hall, 1993.

M. Kristic, I. Kanellakopoulos and P. Kokotovic, Nonlinear and Adaptive Control Design, Wiley Interscience, 1995.

J.-J. E. Slotine and W. Li, Applied Nonlinear Control, Prentice Hall

S. Sastry, Nonlinear Systems Analysis, Stability, and Control, Springer, 1999.

R. Freeman and P. Kokotovic, Robust Control of Nonlinear Systems, Birkhauser, Boston, 1996.

A. Isidori, Nonlinear Control Systems, Springer-Verlag, third edition, 1995.

A. Kelkar and S. Joshi, Control of Nonlinear Multibody Flexible Structures, Springer Lecture Notes in Control and Information Sciences 221, Springer, 1996.

P. Kokotovic, H. Khalil and J. O'Reilly, Singular Perturbation Methods in Control: Analysis and Design, Academic Press, 1986.

H. Nijmeijer and A.J. van der Schaft, Nonlinear Dynamical Control Systems, Springer-Verlag, New York, 1990.

R. Sepulchre, M. Jankovic and P. Kokotovic, Constructive Nonlinear Control, Springer, 1997.

G. Tao and P. Kokotovic, Adaptive Control of Systems with Actuator and Sensor Nonlinearities, Wiley Interscience, 1996.

Bacciotti, Andrea, and Lionel Rosier, Liapunov functions and stability in control theory, Springer Science & Business Media, 2006. (A good reference on Lyapunov theory)

C. T. Chen, Linear system theory and design. Oxford University Press, Inc., 1998. (Very good reference for revision/overview of Linear System Theory)

Expectations and Hints

Required Background: If you have completed the graduate linear systems course at Michigan, EECS 560 = AERO 550, then you have adequate background and do not need to read further. If you have not had that course, then the key things you should learn on your own are:

(a) Stability of a linear time-invariant state variable model: $\dot{x} = Ax$, with $x_0 \in \mathbb{R}^n$. You need to learn when a linear time-invariant model is stable in the sense of Lyapunov, when it is asymptotically stable in the sense of Lyapunov, and when it is unstable. The conditions are given in terms of the eigenvalues of A, and its Jordan canonical form.

(b) Stabilizability of a linear time-invariant control system: $\dot{x} = Ax + Bu$, with $x \in \mathbb{R}^n$ and $u \in \mathbb{R}^m$ When does there exist a linear state variable feedback $u = Fx$ such that the closed-loop system $\dot{x} = (A + BF)x$ is asymptotically stable? It is enough to know that a sufficient condition is for the system to be completely controllable, and that complete controllability can be checked via the Kalman controllability rank condition. Also, you can compute the feedback using the place command in Matlab.

(c) Observability and (full-order) Luenberger observers for a linear system: $\dot{x} = Ax + Bu$, $y = Cx$

(d) We do not use much from undergrad control. However, late in the course, during a two week period, we will use transfer functions, transfer matrices, and Nyquist plots.

Overall, I think this is a great course. I welcome you to take it. HOWEVER, if you have not yet completed the graduate linear systems course, you need to learn on your own the topics listed above. It is NOT enough to be taking the course concurrently with EECS 560 / AE 550.

Hints on Organizing your Study: Learning the material is not so different than learning a new game, sport, or dance. It takes repetition and practice. Here is one very good method (per Professor Grizzle):

(a) Read the book before coming to class. Just scan the material to see what the general concepts are, and which part is the most difficult for you.

(b) Take good notes in class. Re-read your notes before going to the next class. Some students find it advantageous to re-copy their notes after class and to add remarks in the margins. Another good idea is to summarize the key parts of the lecture in half a page or less.
(c) Re-read the appropriate part of the textbook after attending the lecture. This time, spend extra effort to learn the main ideas.

Following the above gives you a minimum of four passes through the material. This will give you a high probability of storing the material in your long-term memory instead of in your short-term memory.

Note: You are encouraged to discuss homework assignments and the project with your fellow students at the conceptual level, but you must complete all calculations and write-up, from scrap to final form, on your own. In particular, verbatim copying of another student's work is forbidden. You are not permitted to consult homework solutions from previous terms.

University of Michigan College of Engineering Honor Code

All students are presumed to be decent and honorable, and all students are bound by the College of Engineering Honor Code. You may not seek to gain an unfair advantage over your fellow students; you may not consult, look at, or possess the unpublished work of another without their permission; and you must appropriately acknowledge your use of another's work. Any violation of the honor policies will be reported to the Honor Council.

For more information about the Standards of Conduct, Honor Code, and Statement of Student Rights and Responsibilities, please consult the following resource:
https://bulletin.engin.umich.edu/rules/

Course Culture

The engineering field does not operate separately from our identities, and we must work together to create an inclusive climate in our classroom. All of you are part of this class and belong here, and I will do everything in my power to ensure that all students in this course are supported and have an equitable learning opportunity. I am committed to a class culture that welcomes and serves students of all ages, ethnicities, genders and expressions, national origins, religious affiliations, sexual orientation, disabilities, socioeconomic backgrounds, and other visible and nonvisible differences.

I will foster a respectful, welcoming, and inclusive environment and expect each student to contribute. If at any time the words or actions of myself or your classmates make you feel uncomfortable, please let me know so that I can take appropriate and timely action if necessary. Your suggestions are encouraged and appreciated at any time. Please let me know by email if your pronouns or name differ from those on record with the university.

Student Mental Health

Stress and anxiety are more common than the national average among undergraduate and graduate students. These environmental stressors, combined with past and current personal circumstances, can severely affect a student's academic performance and their quality of life in general. Unfortunately, the symptoms of these mental health difficulties often go unnoticed. I encourage you to be supportive of

your classmates as you share this learning experience. The Department, the University, and I are committed to advancing your mental health and well-being. I would also like to make you aware of the available resources to help address any learning or emotional barrier you may be experiencing.

The UM Counseling and Psychological Services provide resources for students who feel overwhelmed, depressed, anxious, or need support. To learn more about the resources they offer, please visit their webpage: https://caps.umich.edu/mitalk

Student Accommodations

I am deeply committed to building an accessible learning environment that fosters the academic success of all students, and I aim to abide by any accommodations granted by the University Services for Students with Disabilities (SSD) Office.

If you have a disability, you can request accommodations to the SSD office at https://ssd.umich.edu/ or by phone: (734)763-3000. They will then issue a verified individual services accommodation (VISA) form. You should email me this form so I can provide the accommodations.

University of Michigan Policy & Procedures on Student Sexual & Gender-Based Misconduct & Other Forms of Interpersonal Violence

The University of Michigan supports its educational mission by fostering a community based on civility, dignity, diversity, inclusivity, education, equality, freedom, honesty, and safety. Consistent with these values, the University is committed to providing a safe and non-discriminatory learning, living, and working environment for all members of the University community. The University does not discriminate on the basis of sex or gender in any of its education or employment programs and activities. Please consult the following website for policy details and related support resources: https://sexualmisconduct.umich.edu/

Land Acknowledgment

The University of Michigan resides on the ancestral, traditional, and contemporary lands of the Anishinaabeg: The Three Fire Confederacy of the Ojibwe, Odawa, and Potawatomi Nations, and the Wyandot Nation. Acknowledging the past in itself is not enough to account for the ongoing consequences of colonization but, developing a thorough understanding of the past may empower us to strive for a future that supports equity, inclusion, and justice for all individuals.

Useful links

Undergraduate anonymous reporting form

Graduate anonymous reporting form

Religious/Cultural Observance

Students who have religious or cultural observances that coincide with this class should let the Instructor know via email within the 3 weeks from the start of the course. Students who expect to miss classes or other assignments as a consequence of their religious observance will be provided with an alternative opportunity to complete their academic responsibilities.

Other Resources

Diversity, equity, and inclusion resources: https://aero.engin.umich.edu/info/dei-resources/

Academic, financial, and wellness support: CARE center https://care.engin.umich.edu

Network and computer support: CAEN https://caen.engin.umich.edu

Laptop loaner program: https://its.umich.edu/computing/computers-software/sites-at-home

Feel free to reach out to me to talk about any of the above issues that concern you. I am available for individual meetings outside regular class and office hours.