Linear systems theory is the cornerstone of control theory and a prerequisite for more advanced courses in control, robotics, and optimization. Prerequisites for such a course include undergraduate-level differential equations and linear algebra.

Instructor: Dan Calderone
-- *Lecture:* Tues 6:00- 9:50 PM. https://washington.zoom.us/j/94253099608
-- Office Hours: (TBD)
-- *Contact:* use Canvas's Conversations feature to contact Prof. Calderone

TA: Mengyuan Wang
--*Office Hours:* M 7:00-8:00 pm https://washington.zoom.us/j/94654840895

F 7:00-8:00 pm https://washington.zoom.us/j/91280418447
--*Contact:* use Canvas's Conversations feature to contact Mengyuan.

email: mywang10@uw.edu (please include AE 510 in subject line)

EXTRA: Convex Optimization (Thurs 6-10 PM)
https://washington.zoom.us/j/91815301126

Textbook

Linear System Theory by Chen

Other Resources:
J. P. Hespanha, *Linear Systems Theory,* Princeton University Press, 2009.

Sheldon Axler, *Linear Algebra Done Right,* 2015

Callier and Desoer, *Linear Systems Theory* (classic reference, thorough/dense/hard to read)

Feedback Systems by Murray and Astrom,

The Matrix Cookbook

Media Resources:

3blue1brown
https://www.3blue1brown.com/

Brian Douglas
https://www.youtube.com/channel/UCq0imsn84ShAe9PBOFnoIrg

Steve Brunton

https://www.youtube.com/channel/UCm5mt-A4w61lknZ9lCsZtBw

Tentative Schedule

Linear Algebra Review:

Lecture 1 (01/05) (Vectors & Coordinates) : Matrix multiplication, inner products, projections, norms, vector derivatives, coordinates, matrix inverses, Gaussian elimination, elementary matrices, similarity transforms **(Homework 1)**
References: Chen's chapter 3 & "Linear algebra done right" chapter 1-3

Lecture 2 (01/12) (Systems of Equations, Matrix Rank) : matrix row and column rank, (Grammian) range & nullspace, nullspace computation, systems of linear equations, Fundamental theorem of linear algebra, least squares and minimum norm solutions, (matrix representation theorem, rotation matrices, linear transformations of sets) **(Homework 2)**
References: "Linear algebra done right" 3.B (Null & Range) 3.F (rank, fundamental theorem of linear algebra)

Lecture 3 (01/19) (Eigenvalues): traces and determinants, complex numbers, eigenvalues, left and right eigenvectors, diagonalization, polynomial functions of matrices, spectral mapping theorem, Symmetric and skew symmetric matrices, complex eigenvalues and eigenvectors, Jordan canonical form, nilpotent matrices, Cayley-Hamilton theorem, **(Homework 3)**
References:

Linear Systems: State Space Modeling

Lecture 4 (01/26) (Linear Dynamical Systems): Motivation, intro example, dynamics, vector fields, autonomous systems, matrix exponential, stability, LTI systems, LTV systems, continuous and discrete time (conversion), minimum norm control, phase-plots, **(Homework 4)**
References:

Lecture 5 (02/02) : (Mengyuan) Controllability (Reachability) /observability, stabilizability/detectability, controllability matrix, PBH test, Grammians, (Lyapunov), controllable/observable canonical form, **(Homework 5)**
References:

Lecture 6 (02/09): Review controllable canonical form, pole placement, (multivariable pole placement), state-space PID controllers, observer design, separation principle, Kalman decomposition **(EXAM 1)**
References:

Lecture 7 (02/16): System modeling in state space. (**Homework 6)**
References:

Linear Systems: Frequency Domain

Lecture 8 (02/23): Frequency domain (part 1), Laplace transforms, transfer functions, causality (examples),
poles and zeros, effects of RHP and time delays, Bode plots/transfer function visualization, Nyquist plot, controllability and observability in frequency domain, **(Homework 7)**
References:

Lecture 9 (03/01) : Frequency domain (part 2) Minimal realizations (connections with state space), Z-transforms, roots of unity, shift-matrices, circulant matrices, diagonalization via DFT diagonalization by the DFT, **(Homework 8)**
References:

Lecture 10 (03/08) : Modeling Lecture Part 2 (frequency domain). **(EXAM 2)**
References:

Homeworks:

Homeworks will be assigned each Wednesday after class and **due the following Thursday at midnight in electronic form on Canvas as a .pdf.** Self-grades/error explanations for the previous week's homework will be due at the same time.

Your writeup must be submitted as a single self-contained .pdf document, including commented source code for any computational tools used to complete the assignment.

Homework cannot be turned in late for credit other than in exceptional circumstances, and you must request extensions in advance of the homework deadline. Homeworks will be worth 60% of your grade. You are encouraged to work through other examples and exercises as well. Solutions will be provided after each assignment is due.

Self-assessment

To provide training and feedback that helps cultivate self-reflection, you will grade your homework assignments and receive oversight and feedback from the instructional staff regarding the accuracy of your self-assessment. Self-assessment will be due with the next assignment.

Rubric: we will provide detailed solutions on the day of the homework submission deadline, and you will have until the following due date to grade each of your homework problems on a 0,1,2 point scale:
0 points - no effort / not attempted
1 points - attempted, but incomplete or incorrect solution
2 points - complete and correct solution
For any problem that earns a 1, you have the opportunity to explain the error in your solution and how to correct it; if this explanation is correct, you earn the full 2 points on the problem. You do not give yourself the 2 points if you got an incorrect problem and corrected it. The TA and myself will assign you the extra point after going through your homework. **To specify grades and provide explanations of any errors, use the Comment feature in Canvas's Assignment page for the homework.**

Notes and caveats intended to ensure the integrity of this process:
- if you did not attempt the problem initially, you will receive 0 points;
- if you do not grade a problem, you will receive 0 points;
- if you grade incorrectly (i.e. initial solution is incomplete or incorrect and your explanation is incomplete or incorrect), you will receive 1 or 0 at the discretion of the instructional staff (this ensures you cannot simply assign all "2"s, nor can you receive full credit for incomplete or incorrect explanations).

Frequently Asked Questions (FAQ)

Q: should I download my .pdf, add comments (e.g. via Adobe Acrobat), and re-upload the .pdf?

A: That's fine, but it's probably easier to use the in-browser "CrocoDoc" viewing and annotation pane provided in Canvas.

Q: does my .pdf need to contain all of my homework writeup materials, or can some be in an .m file?

A: Your writeup must be submitted as a single self-contained .pdf document, including commented sourcecode for any computational tools used to complete the assignment.

Submission guidelines

Please make homeworks neat and organized. Points may be deducted if not.

You are welcome (and we encourage you) to typeset your homework assignments rather than write them by hand. We will provide both .pdf and .m files for homework assignments and solutions.

If you write your solutions by hand, you must create a legible scan; if you have any doubts about the fidelity of your scans, send a sample to the TA / Prof in advance of the homework deadline.

http://www.howtogeek.com/209951/the-best-ways-to-scan-a-document-using-your-phone-or-tablet/

Exams:

There will be a final exam worth 20% of your grade. The exam will be open-book and will be graded by the professors (rather than being self-graded). Tentatively scheduled for week of Mar 10.

Grades:

Total grades will be determined from homework (80%) and final (20%).

Computing:

Control Tutorials for MATLAB and Simulink

http://ctms.engin.umich.edu/CTMS/index.php?aux=Home

Python:

https://colab.research.google.com/

Live and recorded lectures for this course can be viewed in the Panopto Recordings tab on the lower left of this page. For more information on using Panopto, please visit the **Viewing Panopto Recordings** resource page. We also recommend that you **test your device** .

When viewing the lecture videos, double click on either window to enlarge it to fill the screen.

If you need help accessing course recordings, please **contact our support team** .