Winter 2024
Updated December 23, 2023

AERO 470 Control of Aerospace Vehicles [Falcone] – TTh 9:00-10:30
AEROSP 548 Astrodynamics [Bernstein] – TTh 9:00-10:30
AERO 567 [Gorodetsky] Inference, Estimation, and Learning - TTh 9:00-10:30
AERO 550 (EECS 560) (ME 564) (CEE 571) Linear System Theory [Freudenberg] - MWF 9:30-10:30
AERO 551 (EECS 562) Nonlinear Systems and Control [Bako] – MW 1:30-3:00
AERO 580 (EECS 565) Linear Feedback Control [Seiler] - TTh 10:30-12:00
AERO 740 Model Predictive Control [Kolmonovsky] - MW 4:30-6:00

CEE 576 — Stochastic Systems [Scruggs] – TTh 9:00-10:30

EECS 419 Electric Machines and Drives [Hofmann] – TTh 3:00-4:30
EECS 460 Control Systems Analysis and Design [Seiler] – TTh 1:30-3:00
EECS 461 Embedded Control [Cook] – TTh 9:00-10:30
EECS 467 Autonomous Robotics [Berenson] – MW 3:00-4:30
EECS 498-017/EECS 598-017 Control Theory for Biological Sensorimotor Systems [Li] – TTh 3:00-4:30
EECS 536 Power Markets [Mathieu] TTh 9:00-10:30am.
EECS 560 (AERO 550) (ME 564) (CEE 571) Linear System Theory [Freudenberg] – MWF 9:30-10:30
EECS 562 (AERO 551) Nonlinear Systems and Control [Bako] - TTh 1:30-3:00
EECS 565 (AERO 580) Linear Feedback Control [Seiler] - TTh 10:30-12:00
EECS 567 (ROB 510) (ME 567): Robot Kinematics and Dynamics [Bruder] – MW 10:30-12:00
EECS 568 (ROB 530) (NA 568) Mobile Robotics [Ghaffari] – WF 1:30-3:30

MECHENG 461: Automatic Control [Rouse] -MW 1:30-3:30
ME 542 (AUTO 542) Vehicle Dynamics and Automation [Orosz] - TTh 10:30-12:00
ME545 (ISD546) (CEE577) Dynamics and Control of Connected Vehicles [Orosz] – TTh 1:30-3:00
ME 560 Modeling Dynamic Systems [Gonzalez Villasanti] - TTh 9-10:30
ME 564 (AERO 550) (EECS 560) (CEE 571) Linear System Theory [Freudenberg] - MWF 9:30-10:30
ME 565 Battery Systems and Control [Siegel] – MW 12:00-1:30
ME 567 (ROB 510) (EECS 567): Robot Kinematics and Dynamics [Bruder] – MW 10:30-12:00
ME 568 Vehicle Control systems [Ersal] - MW 1:30-3:00
ME 569 Control of Advanced Powertrain Systems [Stefanopoulou] – MW 9-10:30

NA 568 (ROB 530) (EECS 568) Mobile Robotics [Ghaffari] – WF 1:30-3:00

ROB 498-015, 598-015 Applied Optimal Control [Tilbury & Hubicki, Florida A&M] – TTh 9:30-10:45 (remote)
ROB 498-002, Robot Control [Panagou & Gregg] – TTh 10:30-12:00
ROB 510 (ME 567) (EECS 567): Robot Kinematics and Dynamics [Bruder] – MW 10:30-12:00
ROB 530 (EECS 568) (NA 568) Mobile Robotics [Ghaffari] – WF 1:30-3:00
ROB 550 Robotics Systems Laboratory [Gaskell & Formosa]
ROB 598-008 Soft Robotics [Huang] – TTh 10:30-12:00

MATH 658, Ordinary Differential Equations [Bloch] - MW 10.00-11.30.

> Description: In this course, we will discuss geometrical aspects of the modern theory of ordinary differential equations and dynamical systems, with applications to various mechanical and physical systems. Topics will include: the qualitative theory of ODEs on manifolds, symplectic and Poisson geometry, nonlinear stability theory, Lagrangian and Hamiltonian mechanics, integrable systems, reduction and symmetries, mechanical systems with constraints and controls, and optimal control.

Interesting IOE courses
IOE 510 Linear Programming I [Jiang] – TTh 12:00-1:30
IOE 511 Continuous Optimization Methods [Berahas] – TTh 9:00-10:30

CEE 576 — Stochastic Systems

Winter 2022

Instructor:	Jeff Scruggs, 2060 GG Brown, `jscruggs@umich.edu`
Class Time:	9:00-10:30 TTh, 136 EWRE
Office Hours:	W 1-2
Texts:	There is no required text. Supplemental course notes will be provided.
Website:	The `CANVAS` site can be accessed via `https://umich.instructure.com/`
Prereqs:	CEE571/EECS560/Aero550/ME564 or equivalent, CEE373 or equivalent
Grading:	Homework (weekly): 50%, Midterms (2): 15% each, Final: 20%

Course Description

Analysis of discrete- and continuous-time linear stochastic processes in the time and frequency domains. Introduction to Itô calculus and transient mean-square analysis. Continuous-time Poisson counters and Wiener processes. Stochastic response of nonlinear continuous-time systems, and the Fokker-Planck Equation. Approximate techniques for nonlinear stochastic response analysis using statistical linearization and Gaussian closure. Applications of stochastic system analysis to dynamics and vibrations.

Course Details & Requirements

- **Lectures:**
  - Lectures will be delivered in-person between 9-10:30 AM Eastern, on the dates specified on the last page of this syllabus. The lectures will also be broadcast in real-time over Zoom (accessible from the `CANVAS` site), and will be recorded for later viewing. Students are encouraged to attend the lectures in person, if able. However, attendance will not be taken.
  - Lecture content will be presented primarily in the form of slides. These slides will be made available one day prior to the lecture, on the `CANVAS` site, as PDF files. Students are encouraged to look through the slides prior to the lecture recording times, and submit any questions to Dr Scruggs via email. He will attempt to answer all submitted questions in the recordings.
- **Homework assignments:**
  - Homework assignments will be posted directly on the `CANVAS` site the day they are assigned.
  - Due dates are specified on the syllabus, and will also be specified on the assignment.
  - Unless otherwise specified, homework is due by 5pm on the due date.
  - All homework should be submitted electronically through `CANVAS`.
  - Homework will be graded within about 1-2 weeks after it is submitted.
  - Solutions will be posted after the late submission window has ended (as described below).
  - Your lowest homework score will be dropped.
- **Homework submission guidelines**
  - Homework must written neatly. When making diagrams, use a straight edge. Write the steps of your derivations line by line, in order. Put a box around your answers.
  - Dr Scruggs reserves the right to deduct points if an assignment is illegible or poorly organized.

- If your work is illegible you may receive no credit, even if your work might have been correct.

- **Homework late submission policy**
  - For all assignments, students can submit late but will have points deducted, according to the following schedule:

By 5pm 1 day late	:	-20
By 5pm 2 days late	:	-40
By 5pm 3 days late	:	-60

    Late days exclude weekends and university holidays. So, for example, if an assignment is due Friday and you submit it at 6pm on Monday, 40 points will be deducted.
  - Homework submitted later than 5pm 3 days late will not be graded.
  - Sometimes students have unavoidable and unexpected health and/or family issues which prohibit them from being able to comply with homework deadlines. In such cases, please speak to Dr Scruggs directly.

- **Exams**
  - All exams will be open-book and open-Matlab, and will be administered remotely via `CANVAS`.
  - The dates of the exams are shown on the lecture schedule. There is no lecture on the date of each midterm.
  - Collaboration (including via Piazza) on the midterms is prohibited, but the instructor will be available online during the exam time to take questions.
  - Exams will be posted at 9AM on the exam date. They are due at 12PM the next day. (So you have a total of 27 hours to complete each exam.)

- **Letter Grades**
  - For a numerical grade X out of 100, the baseline letter grade is:

A	$X \geqslant 93$	B-	$80 \leqslant X < 83$	D+	$67 \leqslant X < 70$
A-	$90 \leqslant X < 93$	C+	$77 \leqslant X < 80$	D	$63 \leqslant X < 67$
B+	$87 \leqslant X < 90$	C	$73 \leqslant X < 77$	F	$X < 63$
B	$83 \leqslant X < 87$	C-	$70 \leqslant X < 73$		

  - Depending on the distribution of the final grades, the curve may be scaled downward. However, no predictions will be made on the curve.

- **Collaboration:**
  - Discussion and interaction with colleagues on the homework assignments is permitted and encouraged. However, anything you turn in for this class should constitute your own work, and reflect your own understanding of the material. Wholesale copying of your friends' solutions and computer code is never permitted unless explicit permission is given as part of the assignment. Use of solutions to CE576 assignments from prior years is **strictly prohibited**.
  - The submission of another person's intellectual effort on an exam is (obviously) prohibited.
  - Students are encouraged to use the class Piazza forum, which is accessible through `CANVAS`, to interact with each other on the homework assignments. However, please do not post verbatim solutions. The instructor will periodically monitor the Piazza forum to answer questions and participate in discussions.

  - Violations of the above are violations of the Honor Code. Suspected violations will be taken up with the CoE Honor Council. The participation in such an activity, even if you are submitting your own work, is also a violation of the Honor Code. The text of the Engineering Honor Code is available at: `https://elc.engin.umich.edu/honor-council/`

- **Getting help**
  - Dr Scruggs will hold an office hour each week. You are strongly encouraged to take full advantage of these office hours, especially if you are having difficulties.
  - Office hours will be conducted in-person, in Dr Scruggs's office (2060 GGB). You can also call in to the office hours over Zoom, if you prefer. The Zoom links to call into the office hours will be accessible from the `CANVAS` site.
  - Please feel free to contact Dr Scruggs via email if you would like to schedule separate one-on-one office hours.

- **Disputing grades**
  - You are strongly encouraged to contact Dr Scruggs for any questions or concerns regarding grading on the homework and exams.
  - Final letter grades are non-negotiable. However, a request to re-calculate the grade will be honored, if you feel a mistake has been made.

Class schedule (tenative):

Lec.	Date	Topic	Posted	Due
1	1/6	Course introduction	HW1	
		PROBABILITY REVIEW		
2	1/11	Probability spaces		
3	1/13	Random variables; Distributions; Conditional & marginal probability	HW2	
4	1/18	Expectations & Moments; Uncertainty propagation		HW1
		DISCRETE-TIME STOCHASTIC SYSTEMS		
5	1/20	Stochastic sequences		
6	1/25	Properties of stochastic sequences	HW3	HW2
7	1/27	Gauss-Markov processes		
8	2/1	Gauss-Markov processes (cont'd)		
9	2/3	Stationarity	HW4	HW3
10	2/8	Linear discrete-time systems with Gaussian-distributed inputs		
11	2/10	The discrete-time Kalman filter		
12	2/15	The innovations process	HW5	HW4
	2/17	**Midterm 1**		
		CONTINUOUS-TIME STOCHASTIC SYSTEMS		
13	2/22	Definition of a stochastic process; Intro to Poisson counters		
14	2/24	Poisson counters: Stochastic differential equations	HW6	HW5
	2/28-3/4	SPRING BREAK!		
15	3/8	Poisson counters: Itô calculus, pdf evolution		
16	3/10	Wiener processes: Stochastic differential equations	HW7	HW6
17	3/15	Wiener processes: Itô calculus		
18	3/17	Fokker-Planck equation		
19	3/22	Approximation of nonlinear stochastic response via Gaussian closure	HW8	HW7
20	3/24	Continuous-time linear systems driven by white noise		
21	3/29	Continuous-time Kalman filter & innovations process		
22	3/31	Discrete-time approximation of continuous-time stochastic processes	HW9	HW8
	4/5	**Midterm 2**		
		CONTINUOUS-TIME STOCHASTIC SYSTEMS		
23	4/7	Periodogram analysis of stochastic processes		
24	4/12	Power Spectrum analysis of stationary linear stochastic processes		
25	4/14	Continuous-time stochastic realization theory		
26	4/19	Continuous-time stochastic realization theory (cont'd)		HW9
	4/28	**Final Exam** (24 hours, beginning at 9AM)		

Useful References

Probability space

1. Feller, W., *An Introduction to Probability Theory and Its Applications*, Wiley, 1956. (This two-volume text is still excellent, and was hugely influential.)

2. Capinski, M. and Ekkehard, K., *Measure, Integral and Probability*, Springer-Verlag, 2003. (This provides a nice, not-so-intimidating first-look at concepts from measure theory.)

Discrete-time stochastic systems (including spectral analysis)

1. Anderson, B.D.O. and Moore, J.B., *Optimal Filtering*, Prentice-Hall, 1979. (Dover edition: 2005)

2. Kumar, P.R. and Varaiya, P. *Stochastic Systems: Estimation, Identification, and Adaptive Control*, Pearson Education, Inc. 1986. (SIAM Classics edition: 2016)

3. Stark, H. and Woods, J.W., *Probability and Random Processes with Applications to Signal Processing*, 3^{rd} ed., Prentice-Hall, 2001. (Also covers continuous-time stochastic systems, but has nice introductory content on discrete-time)

General continuous-time stochastic systems (including spectral analysis)

1. Brockett, R.W., *Stochastic Control*, unpublished course notes available at: `http://www.eeci-institute.eu/pdf/M15/M15/RogersStochastic.pdf` (These notes are actually what I learned much of this content from.)

2. Brown, R.G. and Hwang, P.Y.C., *Introduction to Random Signals and Applied Kalman Filtering*, 3^{rd} ed., Wiley, 1996. (Introduction to continuous-time stochastic processes, with probability review. State space is de-emphasized.)

3. Grigoriu, M., *Stochastic Systems*, Springer, 2012. (This text is for those who want a more formalized text that makes use of measure theory)

4. Jazwinski, A.H., *Stochastic Processes and Filtering Theory*, Academic Press, 1970. (Dover edition: 2007) (Classic text, ideas developed in state space from the beginning, covers Gaussian closure techniques.)

Applications to continuous-time dynamics and vibrations:

1. Lin, Y.K., *Probabilistic Theory of Structural Dynamics*, McGraw-Hill, 1967. (Out of print, but a classic.)

2. Lutes, L.D. and Sarkani, S., *Random Vibrations: Analysis of Structural and Mechanical Systems*, Elsevier, 2004.

3. Soong, T.T. and Grigoriu, M., *Random Vibration of Mechanical and Structural Systems*, Prentice-Hall, 1992. (Out of print)

4. Vanmarcke, E., *Random Fields*, World Scientific, 2010.

EECS 598-17: Control Theory for Biological Sensorimotor Systems

Instructor: Jing Shuang (Lisa) Li
Email: jslisali@umich.edu
I respond to emails within 2-3 working days. Include "EECS 598-17" in the subject line.

Class time: Tue/Thu 3:00-4:30pm
Class location: 133 Chrysler
Office hours: TBD

Course motivation and description

The pursuit of autonomy is a major driving force behind funding, research, and technological advances in both academia and industry. However, despite significant investments and breakthroughs, state-of-the-art systems are often bested by biology. One only has to look across the street at the neighbor's cat to see an example of an autonomous being that is at once more agile, energy-efficient, and robust to environmental variations than our best quadruped robots. How does the cat accomplish these amazing feats of sensorimotor control, and what can we learn from it?

In this course, we will learn how tools from **control theory** can be applied to better understand animal sensorimotor control — that is, how animals use sensory information to inform movements. We will first learn some basics about the fascinating world of biology and neuroscience, then learn how control theory can be (and has been) used to model animal behavior and physiology in the sensorimotor context. Along the way, we will also encounter novel control formulations, and also investigate how bio-inspired controls and algorithms can be applied to improve the robustness and efficiency of engineered systems.

Learning objectives

The main objective of this course is to help students become familiar with the intersection of control theory and biological sensorimotor systems from a research perspective. By the end of the class, students should be able to:

- Describe basic concepts relating to biological sensorimotor control
- Describe the role of control theory as a modeling tool for sensorimotor control
- Integrate concepts from class (and literature) with concepts from their own research to create new directions of investigation

Target audience and prerequisites

Students should have some background knowledge in control theory, preferably time-domain state-space models. We will review (and introduce) various branches of control theory, but the more you know, the easier it will be for you to synthesize concepts learned in class and apply them to your own research. No background in biology or neuroscience is required — we will start from the basics in this class.

Evaluations (Tentative)

Literature review

Students will

- Select a paper that combines biology and control theory
- Read the paper and write a blog post about their selected paper. This blog post should be understandable to someone with a generic STEM background
- Comment on and ask questions about other students' blog posts

Learning objectives

- Gain familiarity with a wide variety of literature in sensorimotor control by writing their own blog posts and reading others' blog posts
- Practice translating domain-specific literature for a broader audience. This is an important skill for interdisciplinary research collaboration

Class project

Students will

- Propose a project to be completed during the semester
    - This can be replication or extension of an existing result, or a new topic
    - Students are encouraged to incorporate ideas from their own research
    - Students and instructor will define project-specific criteria for success
- Work on the project throughout the semester
- Provide intermediate progress reports
- Prepare a final progress report in the format of a short conference paper
- Prepare a final presentation in the format of a conference presentation

Learning objectives

- Gain familiarity with their chosen research/project area
- Practice presenting and writing up research results in a standard format

Depending on the project, there may be post-class opportunities for students to extend their project for an actual conference submission.

Since this is a research-oriented course, we will not have a midterm or final exam.

Topics (Tentative)

1. Introduction and course overview (1 class)
2. Mammalian and non-mammalian nervous systems (2 classes)
3. Neurons and neural communication (2 classes)
4. Motor anatomy and control (2 classes)
5. Sensory modalities: sight, sound, touch, proprioception (2 classes)
6. Sensorimotor anatomy and control (2-3 classes)
7. Sensorimotor learning and adaptation (2 classes)

8. Model organisms and experimental techniques (2 classes)
9. Behavioral models of sensorimotor control (2-3 classes)
10. Optimal control for biomedical engineering applications (1-2 classes)
11. Physiological models of sensorimotor control (5-6 classes)
    a. Sensorimotor delay and optimal control (1-2 classes)
    b. Untangling complicated physiology (2 classes)
    c. Additional features of physiology-constrained control (2 classes)
12. Student-led project presentations (number of classes depends on enrolment)

In addition to the listed topics, the following themes will be interwoven throughout all classes

- How would we model or design this using control theory?
- What unique advantage will control theory provide that other techniques do not?
- Identifying research questions with scientific *and* engineering value
- Rethinking rigor in the face of limited observations, high complexity, and high uncertainty