ME569: Powertrain Control

Fall 2021 (3 credits), Mon/Wed 8:30-10:00am

CHRYS 151

Instructors: Professor Stefanopoulou, (annastef) (she/her) with guest instructors
Dr. Michiel Van Nieuwstadt, (mvannie) (he/him) on On-board Diagnostics and
Dr. Jason Siegel (siegeljb) (he/him) on Fuel Cells
GSI: none or TBD ()()

Course statement: The course covers essential aspects of electronic engine control followed by an introduction to fuel cell control. Control problems arising in direct injection, variable valve timing, active boosting, and flexible-fuel vehicles. The course includes models and feedback control design of spark ignition (gasoline). Hybridization auxiliary electrification, and engine control opportunities when connected and automated. A new section on low temperature hydrogen fuel cells is covered at the last third of the class. We will apply simple P, PI, and PID controllers, system identification, averaging, feedforward, feedback, multivariable control, estimation, diagnostics, and machine learning techniques. Engine control challenges and operation in hybrid and plug-in hybrid electric engines along with opportunities in high efficiency operation in connected and automated vehicles will be also introduced. Regulatory aspects and pressures for worldwide shift from ICEs to EVs will be reviewed.

Requirements: * Basic ordinary differential equations (ODE) and control requirements are necessary (see below).
**Matlab and Simulink expertise is necessary.

Home Page: Lecture notes, recording, and handouts will be posted in Canvas.

Email: Canvas emailing and posts will be used to send you announcements. You can always email me with questions **(use ME569F21 in your message subject).** We'll also use slack to share and chat. First describe the problem you are facing in the text of your post. You could **attach a pdf** with your question (m-file, sml-file, and resulting graphs in one PDF). If we need more info, we will ask for it.

Textbook (recommended – not required – can be reached in mirlyn online):

a) "Introduction to Modeling and Control of Internal Combustion Engine Systems" by L. Guzzella and C.H. Onder, Springer-Verlag 2004, ISBN 3-450-22274 http://mirlyn.lib.umich.edu/Record/008158097

b) "Modeling and Control of Engines and Drivelines (Automotive Series)" by Lars Eriksson and Lars Nielsen (Feb 27 2014), ISBN: 1118479998 (available online) https://mirlyn.lib.umich.edu/Record/013562089

c) "Control of Fuel Cell Power Systems: Principles, Modeling, Analysis, and Feedback Design," by Jay T. Pukrushpan, Anna G. Stefanopoulou, and Huei Peng, Springer Verlag, London, UK, ISBN 1-85233-816-4, Sept 2004 available also online: https://link-springer-com.proxy.lib.umich.edu/content/pdf/10.1007%2F978-1-4471-3792-4.pdf

Lecture Format: Offline recordings with notes will be available, but participation and attendance in lectures and office hours will be monitored and rewarded.

Office Hours: After lecture and TBD in zoom and outside as much as possible when in person

Grading: HW (30%), Midterm (30%), Journal Club (30%), Participation (10%)

Homework Format: There will be approximately one HW per week for the first part of the class (before midterm). Typically due on Thu before 5:00 pm EST. Homework problems in this course are hard but rewarding because they are derived from real world problems. Your HW will be submitted to Canvas by the specified time and date.

- The lowest grade will be dropped (so you can miss one HW). No late homework will be accepted!
- You may discuss the homework assignments with each other and with the instructor, but you **must write your own solutions** to the homework which reflect your own understanding of the material.
- You should **not** seek or consult HW solutions from previous years.

Midterm Format: Details might evolve, but here is the current understanding: In-class (or proctored for distance learning section) with 2-3 problems. Open (printed) notes will be allowed. **No electronics or electronic notes will be allowed**. Please prepare for this ahead of time. No collaboration among students, will be allowed during the exam window. The instructors reserve the right to request additional oral-online examination to clarify midterm performance from select students.

Journal Club format: Finding, reading, and presenting, along with critiquing and discussing papers is an important life-learning and team-building skill.

a. Students will form groups of 2-3 and select, read, critique, and present a paper to the entire classroom who will have also skimmed and commented on the paper.

b. Instructors will provide a list of potential topics related to powertrain controls, especially new development in the field. The students will propose topics and papers to the entire class that will then vote & down-select. The instructors will need to approve the papers selected to be studied and presented by the teams.

c. The group will then deep dive on their selected paper and prepare a complete presentation (slides) of the problem, approach, contributions. You will need to understand the paper well enough to come up with meaningful explanations to questions by your peers and the instructors.
d. All the other students will (each Journal Club week) need to read the papers presented and submit at least 2 comments or questions on the paper we'll be discussing for the next lecture.
e. There will be 3 papers presented and discussed every lecture after Thanksgiving (Journal Club period)

Diversity, Equity, and Inclusion:
The instructional team (TBD) considers this classroom to be a place where you will be treated with respect, and we welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, ability – and other visible and nonvisible differences. All members of this class are expected to contribute to a respectful, welcoming and inclusive environment for every other member of the class. We are dedicated to helping each of you achieve all that you can in this class. We may, either in lecture or smaller interactions, accidentally use language that creates offense or discomfort. Should we do this, please contact us separately and help us understand and avoid making the same mistake again.

Covid related issues:
As of Friday Aug 27 2021, more than 92% have reported their full vaccination status to the University. We will still be wearing masks in classroom. If a person is not wearing a mask correctly 1. We will ask the person to put on a mask correctly. 2. If the person does not have a mask we will offer them an extra one. All classrooms will have extra masks If the person refuses, we will ask the person to leave the class. If the person does not leave the class we will make the following announcement: "Anyone who does not feel comfortable in this situation may leave the classroom, and by the way this includes me (the instructor). I am going to my office and I will resume the lecture on Zoom in 5 minutes."

If we know the student's name, we will refer the matter to the Office of Student Affairs.

Eating and drinking are generally not permitted in the classroom. Taking a mask off briefly for occasional drinks of water, coffee, juice, etc. is acceptable.

Course Outline:

		Fall 2021		Issue
1	30-Aug Mon	Vehicle Fuel Efficiency, Emissior	Anna	HW1 control
2	1-Sep Wed	Throttle, Pumping, Filling	Anna	
3	6-Sep Mon	Labor day		
4	8-Sep Wed	Air Charge Estimation	Anna	HW2- model + MAF
5	13-Sep Mon	AFR feedback	Anna	
6	15-Sep Wed	AFR feedback, Switching Sensor	Anna	HW3 - AFR
7	20-Sep Mon	Idle Speed Control (ISC-model)	Anna	
8	22-Sep Wed	ISC-Throttle ISC-control	Anna	HW 4 -- ISC
9	27-Sep Mon	ISC-Throttle & Spark Control	Anna	
10	29-Sep Wed	Flex Fuel Vehicles (FFV)	Anna	HW 5 -- ISC Multivari
11	4-Oct Mon	ETOH Estimation using lambda	Anna	HW5 Valve timimg
12	6-Oct Wed	Drivability & Variable Valve Timing	Anna	HW-6 - Etoh
	11-Oct Mon	Fall break		
13	13-Oct Wed	review & Old/New powertrains	Anna	
14	18-Oct Mon	exam	Anna, Michiel	Exam
15	20-Oct Wed	Turbocharging	Michiel	
16	25-Oct Mon	Mild Hybrids	Anna	HW7 TC
17	27-Oct Wed	Aftertreatment	Michiel	
18	1-Nov Mon	On-Board Diagnostics (OBD)	Michiel	HW8 OBD
19	3-Nov Wed	OBD & Machine Learning	Michiel	
20	8-Nov Mon	FC - basics & polarization	Anna- Jason	HW9 Polarizartion
21	10-Nov Wed	FC - system, air path	Anna- Jason	
22	15-Nov Mon	FC - hybrid	Anna- Jason	HW10 thermal
23	17-Nov Wed	FC -- thermal	Anna- Jason	
	22-Nov Mon	Thx recess		
24	24-Nov Wed	Journal Club	Anna, Michiel, Jason	3 papers
25	29-Nov Mon	Journal Club	Anna, Michiel, Jason	3 papers
26	1-Dec Wed	Journal Club	Anna, Michiel, Jason	3 papers
27	6-Dec Mon	Journal Club	Anna, Michiel, Jason	3 papers
28	8-Dec Wed	Journal Club	Anna, Michiel, Jason	3 papers
				15 papers -->30-40 s

Open to graduate or senior students in Mechanical, Electrical, Chemical, Aerospace, and Marine Engineering with basic control engineering and dynamics background (ME360 and ME461 equivalent). Permission from the instructor is required for senior undergraduate students.

As you know ME461 is a pre-requisite for this class. Below is a list of the MATH and Controls notions I will be using a lot in the class and you should know.

1. Ordinary Differential equations

2. Linearization

3. Laplace and transfer functions (poles, zeros, DC gain)

4. Frequency Domain Representation of systems and signals: bandwidth, roll-off rate, DCgain, natural, damped frequencies ...

5. Stability, characteristic equation, eigenvalues

6. Time responses, overshoot, undershoot, settling time, damping ratio, time constant, rise time ...

7. States, state-space representation

8. Basics of PID controllers, Root locus ...

Items 1-6 are a must! Do not take this class if you do not know or feel comfortable with 1-6. You can probably study items 7-8 and catch up while taking this class.

Below are some recommended books for Control and Systems Review:

a. Modern control systems / Richard C. Dorf, Robert H. Bishop.
b. Feedback control of dynamic systems / Gene F. Franklin, J. David Powell, Abbas Emami-Naeini.
c. Modern control engineering / Katsuhiko Ogata.
d. Control systems engineering / Norman S. Nise.

My favorite is **b. Chapter 1-4 (you can find it in the library)**

For review of Internal Combustion Engine (ICE) principles, read the 1st chapter of Internal Combustion Engine Fundamentals by John B. Heywood

Matlab and Simulink are required.
You will need Access to a computer that has at least the student version of Matlab and it its toolboxes.
To review use any Mathworks free tutorials or the homebrew
http://ctms.engin.umich.edu/CTMS/index.php?aux=Basics_Simulink

Do not take the class if you have never used Simulink and/or Matlab m files.