ECE481A4 Real-Time Applied Nonlinear Control Systems: Syllabus

Fall 2020

Instructor Information

Instructor	Email	Office Location & Hours
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General Information

Why Should you take this course?

Most students, whether undergraduate or graduate, after completing their education come into industry expecting control systems to be as taught in their curricula. Hence, they think all control systems are LTIs. In addition, they believe the design of a control system starts with a transfer function model of a plant and ends with a transfer function model of a controller. However, this is rarely, if ever, the case. This course will try to fill the void between the real-world control systems that engineers deal with and the control systems taught in school. As such, this course will teach students, using only the most necessary mathematical concepts, how to identify real systems, design controllers for them and how to implement these controllers on physical boards and chips to be used in the applications they were designed for.

What will you get out of this course?

Students successfully completing this course will be able to:

1) Identify certain nonlinear plant dynamics from measurements.
2) Determine what controller design method(s) can be used for a given set of design specifications and hardware limitations.
3) Design controllers that appropriately manage the constraints of embedded real time control systems.
4) Code MCU and/or DSP and/or FPGAs and/or ASICs to implement their controllers.
5) Design the controller code to distribute it over several chip layers (i.e. slow part on a DSP and fast part on an FPGA).
6) Follow and select any one out of many different control system design flows used in different industries from concept to implementation.

Description

Using and applying (no proofs or derivations just understanding of the usage, applicability, and modern-day tools) the following topics for real-time control:

1) Numerical ODEs, Numerical Optimizations, Linear Algebra, Complex Analysis, Fuzzy Logic, Neural Networks, Control System and Corporate Finance Metrics, SOS, Discrete Time/Digital Systems, Observers and Estimators, and Linear $\mathcal{H}_2/\mathcal{H}_\infty$, NARMAX System Identification, Nonlinear $\mathcal{H}_2/\mathcal{H}_\infty$, Model-Reference Tracking & Model-Free Adaptive Control, Fuzzy Control, Shallow Neural Networks Control, Fuzzy-Neuro Control, Neuro-Fuzzy Control, Deep Learning.

2) Interrupt Based Control, RTOS Based Control, Microcontroller Based Sensing and Control, PIC Based Sensing and Control, ARM Based Sensing and Control, DSP Based Sensing and Control, FPGA Based Sensing and Control, Augmenting a Classical Embedded Controller, GPUs as AI Controllers, Arduino/RaspberryPi/etc… as AI Controllers, ARM processors as AI Controllers, DSP processors as AI Controllers, FPGAs as AI Controllers.
3) Real-Time Embedded Control System Design and Implementation Walkthrough for the following real industrial systems: Mechanical/Thermodynamic, Power Electronics, RF, Semiconductor/Chemical, Financial/Logistic/Industrial Supply Chain.

Prerequisites

ECE202 with a C or higher; MATH340 with a C or higher.

Expectations and Goals

This course will be a little bit different than your previous university experience**.** The course only assumes the following:

1) You know what a dynamic system is (i.e. Basic ODEs).
2) You know how to write pseudo-code (No need for Object Oriented Knowledge). In other words, if you know how to write a program/function on your TI-89 you are in a very good shape with respect to the course.

The purpose of this course is to augment your knowledge in a fun and easy way. As you will see, my approach to teaching is very different than the standard university methods. I have been through the horrendous experience of being a student in higher education. So, I look more at teaching as a service industry where students are the customers. Students should get an A in the course ***if*** they are serious about the work and I will make sure all students understand and get whatever they expect from the course. Also, whenever you do not understand things please interrupt the lecture or, if you prefer, email me as many questions as you need to.

Evaluation and Grading

Continuous Project: 100%.

The project will consist of an assignment given on a bi-weekly basis (8 assignments). Each assignment will consist of 10% of the course grade (Total of 80%). The project grade will thus be split into 80% for the weekly assignments, 10% for the final implementation and presentation, and 10% for attendance and participation.

Course Materials

Required Texts

1. **Instructor's Lecture Notes.**
2. (Freely Downloadable from the CSU libraries website) **Classical and Modern Controls with Microcontrollers: Design, Implementation and Applications** by Ying Bai and Zvi S. Roth, 1st Edition, 2019, Springer, Online ISBN: 978-3-030-01382-0

Course Schedule

Week	Topic
Week 01	Needed Mathematical Concepts I: Numerical ODEs, Numerical Optimizations, Linear Algebra, Complex Analysis.
Week 02	Needed Mathematical Concepts II: Fuzzy Logic and Neural Networks.
Week 03	Robust Nonlinear Control Systems, Classic Methods I: Control System and Corporate Finance Metrics, SOS, Discrete Time/Digital Systems, Observers and Estimators, and Linear $\mathcal{H}_2/\mathcal{H}_\infty$.
Week 04	Robust Nonlinear Control Systems, Classic Methods II: NARMAX System Identification, Nonlinear $\mathcal{H}_2/\mathcal{H}_\infty$, Model-Reference Tracking and Model-Free Adaptive Control.
Week 05	Robust Nonlinear Control Systems, Modern Methods I: Fuzzy Logic and Shallow Neural Networks.
Week 06	Robust Nonlinear Control Systems, Modern Methods II: Deep Learning.
Week 07	Classical Embedded Control System Design and Coding I: Interrupt Based Control, RTOS Based Control, Microcontroller Based Sensing and Control, and PIC Based Sensing and Control.
Week 08	Classical Embedded Control System Design and Coding II: ARM Based Sensing and Control, DSP Based Sensing and Control, and FPGA Based Sensing and Control.
Week 09	Modern Embedded Control System Design and Coding I: Augmenting a Classical Embedded Controller, GPUs as AI Controllers, and Arduino/RaspberryPi/etc… as AI Controllers.
Week 10	Modern Embedded Control System Design and Coding II: ARM processors as AI Controllers, DSP processors as AI Controllers, and FPGAs as AI Controllers.
Week 11	Mechanical/Thermodynamic Embedded Control System Design and Implementation Walkthrough.
Week 12	Power Electronics Embedded Control System Design and Implementation Walkthrough.
Week 13	RF Embedded Control System Design and Implementation Walkthrough.
Week 14	Semiconductor/Chemical Embedded Control System Design and Implementation Walkthrough.
Week 15	Financial/Logistic/Industrial Supply Chain Embedded Control System Design and Implementation Walkthrough.
Week 16	Review/Deeper Exploration of Certain Topics at the Students' Request.

Project Schedule

Date	Subject	Percent of Grade
Week 2	Mathematical Concepts.	10%
Week 4	Robust Nonlinear Control Systems, Classic Methods.	10%
Week 6	Robust Nonlinear Control Systems, Modern Methods.	10%
Week 8	Classical Embedded Control System Design and Coding.	10%
Week 10	Modern Embedded Control System Design and Coding.	10%
Week 12	Implementation Phase 01: From Design to MATLAB/Simulink.	10%
Week 14	Implementation Phase 02: From MATLAB/Simulink to HDL/C.	10%
Week 16	Implementation Phase 03: Tuning and Optimization of the Designed System.	10%
Final Implementation		10%
Participation		10%