24-774: Advanced Control Systems Integration – Fall 2022

COURSE DESCRIPTION:

This course focuses on the practical implementation of feedback / feedforward controllers. The entire controller design process is presented, including system modeling and identification, compensator design, simulation, and hardware prototyping. This is a project-based course in which students complete the controller design process on a nonlinear, MIMO hardware system. The goal is train students on the system integration skills necessary for success in industry or experimental laboratory work.

TEXTBOOK:

Given the breadth of course topics, no single textbook has sufficient coverage. Reading assignments will consist of specific topics from the following texts along with tutorial / survey papers from the literature.

- Franklin, Powell, and Workman, **Digital Control of Dynamic Systems,** Ellis-Kagle, ISBN: 978-0-9791226-1-3 (https://www.scsolutions.com/publication/digital-control-of-dynamic-systems-third-edition/)
- Pintelon and Schoukens, **System Identification: A Frequency Domain Approach**, Wiley-IEEE Press (Access Online)
- Kirk, **Optimal Control Theory: An Introduction**, Dover (Access Online)

INSTRUCTOR:

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Office Hours: Fridays 1 – 2 pm

CA:

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CLASS SCHEDULE:

Monday / Wednesday, 9:05 – 10:55 am, MI 348

COURSE OBJECTIVES:

The objectives of this course are to:

1. Introduce students to the full control prototyping process: modeling, simulation, hardware-in-loop, embedded
2. Develop students' skills in realizing effective embedded controllers
3. Prepare students to perform system identification on unknown systems
4. Make students familiar with a variety of common MIMO control techniques, including open loop control and design for repetitive tasks
5. Prepare students to work in teams to solve open-ended control design problems

LEARNING OUTCOMES:

Upon completion of this course, the student should be able to:

1. Use experimental methods to develop a system model
2. Convert continuous time controllers to discrete time and write code to realize the discrete-time compensator
3. Understand the issues in embedded control implementation, including sampling time selection and quantization
4. Design and implement embedded controllers for MIMO systems
5. Effectively document and communicate the control prototyping process

TOPICS:

While this course revolves largely around a semester project, there are several topics that will be discussed and implemented on experimental hardware to prepare students for the project. The main topics to be discussed include:

- Issues in embedded control: sampling rates and quantization, RTOS
- Discretization and realization of controllers designed in continuous time
- Experimental system identification
- Open loop controller design
    - Dynamic programming
    - Model predictive control (*not <u>really</u> open loop*)
    - Input shaping
- Iterative learning control
- "Intelligent" control
    - Fuzzy logic control

The course will be lecture-heavy towards the beginning of the semester, but some scheduled classes will gradually transition into team meetings for the semester project.

LABORATORY ASSIGNMENTS:

Three laboratory assignments will be given in addition to the final project, with due dates on the tentative schedule. These labs will be used to give students practice in implementing control algorithms on different hardware platforms. For laboratory exercises we will use the Quanser QUBE Servo 2 Furata pendulum and the Quanser Aero system. Both systems allow control via Matlab / Simulink and embedded controls options. In each laboratory, both Simulink and embedded implementations will be required.

<u>Lab 1: Motor Speed Control</u>

- Hardware setup
- Basic system identification
- Implement digital controllers

<u>Lab 2: LQG Balancing Control</u>

- Observer design
- LQR balancing control

<u>Lab 3: System Identification</u>

- Closed loop system ID
- System identification toolbox

COURSE PROJECT:

The course project will allow students to implement control algorithms on either a self-balancing robot platform (https://www.elegoo.com/products/elegoo-tumblller-self-balancing-robot-car) or a small quadcopter platform (https://www.bitcraze.io/products/crazyflie-2-1/). In either case, teams will work with the instructor to agree upon project deliverables, which will include at a minimum system modeling / identification, Matlab controller development and simulation, and embedded controller implementation. Both hardware platforms allow the addition of various sensors / hardware to create interesting control challenges. While this is not a mechatronics course, it is likely that the projects will require some level of hardware modification – we will be happy to assist you through the process.

ASSESSMENT AND EVALUATION:

Students will be assessed based on their performance on laboratory exercises and the final project. While there will be no weekly homework, 3 informal laboratory reports will be submitted, along with a report on the final project. In addition, students will be graded on oral presentations and team contributions as assessed by various metrics.

The final grade in the course will be based on the following:

Lab "reports" (3)	30%
Project proposals (written + presentation)	10%
Project updates (Jira + presentation)	15%
Final demo performance	15%
Final report	15%
Final presentation	10%
Peer evaluations	5%

Grade Scale:

A: A (92-100) A- (90-92)
B: B+ (88-90) B (82-88) B- (80-82)
C: C+ (78-80) C (72-78) C- (70-72)
D: D+ (68-70) D (62-68) D- (60-62)
F: F (<60)

COURSE POLICIES:

TEAMWORK AND PEER REVIEW

All team members must have a strong understanding of the process, decisions, and the state of knowledge of the project. On certain days, team members may be selected at random to present the team's recent progress. All team members are responsible for making sure each member is up to date and involved.

Some teams may experience an imbalance in team member contributions, effort, or reliability. The course instructors are available to provide advice and resolve team inequity and conflict. However, students should view this time as a learning experience: Such situations occur regularly in industry as well. Such challenges are opportunities to develop strategies and to identify the best way to address such issues in the future. In addition, one common question asked at job interviews is: *"Describe a time when you experienced difficulties working in a team or experienced a team failure. What did you do about it?"* This is a good chance to build a strong answer to this question.

Several mechanisms will be used for peer review:

- Between teams: Each team will receive feedback from other teams on proposal and progress presentations. These sessions will sharpen communication skills, help catch oversights and simple mistakes, and identify possible new ideas or areas for improvement in order to strengthen the project.
- Within teams: Every student is required to turn in peer evaluations for each member of their team (including themselves) **twice** during the semester. These reports are primarily to help the instructors identify difficulties and miscommunications, and they will also be used for grading.
- If a student does not contribute to his or her team as evidenced in the peer evaluations, the course instructor may assess the student individually and reserves the right to grade the student based solely on this assessment.

MEETINGS AND PARTICIPATION

Each team will meet with the instructor and TAs occasionally to present progress. **Teams are expected to come prepared to each meeting detailing the work that has been done, questions or difficulties, and what next tasks are planned**. Teams are expected to prepare a PowerPoint presentation (~ 5 slides) to demonstrate their work and receive feedback. This will help the team and the instructors to keep track of the progress of each team. Your meeting grade will have an individual component (your attendance and participation) and a team component (your team's demonstrated progress).

Jira (https://www.cmu.edu/computing/software/all/atlassian/index.html) will be used to help with project management in this course. Each team will work on two-week sprints throughout the duration of the project, with progress meetings used to assess sprint progress and plan future sprints. Jira will also be used to assign individual grades for a portion of the project updates category.

Attendance to lectures, team meetings, and in-class presentations is strongly encouraged. Attendance will be taken during presentations and team meetings.

RECORDING OF IN-PERSON CLASS SESSIONS

For this course, I will be recording class sessions and making them available to you for your personal, educational use. Recordings of class sessions are covered under the Family Educational Rights and Privacy Act (FERPA) and must *not* be shared with anyone outside your course-section. The purpose of these recordings is so students in this course (and only students in this course) can watch or re-watch past class sessions. Feel free to use the recordings if you would like to review something we discussed in class or if you are temporarily unable to attend class.

USE OF TECHNOLOGY DURING CLASS

As research on learning shows, unexpected noises and movement automatically divert and capture people's attention, which means you are affecting everyone's learning experience if your cell phone, pager, laptop, etc. makes noise or is visually distracting during class. For this reason, I allow you to take notes on your laptop, but you must turn the sound off so that you do not disrupt other students' learning. If you are doing anything other than taking notes

on your laptop, please sit in the back row so that other students are not distracted by your screen.

POLICY ON ACADEMIC INTEGRITY

You are encouraged to study in groups and learn from one another, but the work you submit must represent your own intellectual effort. Copying work from other students, past or present, or from any other resource, in any form or to any extent, violates the policy for this course as well as the University's regulations. Such situations will be prosecuted according to Carnegie Mellon University's Policy on Cheating and Plagiarism.

TAKE CARE OF YOURSELF:

This past few years have been uniquely challenging. We are all under a lot of stress and uncertainty at this time. Make sure to move regularly, eat well, and reach out to your support system or me (mbedillion@cmu.edu) if you need to. We can all benefit from support in times of stress, and this semester is no exception.

Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at http://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

CREATING A WELCOMING ENVIRONMENT

As engineers we work with a diverse set of colleagues and develop solutions for a diverse set of customers. Treating every individual with respect and empathy is necessary to become an effective engineer. We are diverse in many ways, and this diversity is fundamental to building and maintaining an equitable and inclusive campus community. Diversity can refer to multiple ways that we identify ourselves, including but not limited to race, color, national origin, language, sex, disability, age, sexual orientation, gender identity, religion, creed, ancestry, belief, veteran status, or genetic information. Each of these diverse identities shape the perspectives our students, faculty, and staff bring to our campus. We at CMU will work to promote diversity, equity and inclusion not only because diversity fuels excellence and innovation, but because we want to pursue justice. We acknowledge our imperfections while we also fully commit to the work, inside and outside of our classrooms, of building and sustaining a campus community that increasingly embraces these core values.

Each of us is responsible for creating a safer, more inclusive environment. Unfortunately incidents of bias or discrimination do occur, whether intentional or unintentional. They contribute to creating an unwelcoming environment for individuals and groups at the university. Therefore, the university encourages anyone who experiences or observes unfair or hostile treatment on the basis of identity to speak out for justice and support, within the moment of the incident or after the incident has passed. Anyone can share these experiences using the following resources:

Center for Student Diversity and Inclusion: csdi@andrew.cmu.edu, (412) 268-2150
Report-It online anonymous reporting platform: www.reportit.net username: tartans password: plaid

All reports will be documented and deliberated to determine if there should be any following actions. Regardless of incident type, the university will use all shared experiences to transform our campus climate to be more equitable and just.

ACCOMODATIONS FOR STUDENTS WITH DISABILITIES:

If you have a disability and have an accommodations letter from the Disability Resources office, I encourage you to discuss your accommodations and needs with me as early in the semester as possible. I will work with you to ensure that accommodations are provided as appropriate. If you suspect that you may have a disability and would benefit from accommodations but are not yet registered with the Office of Disability Resources, I encourage you to contact them at access@andrew.cmu.edu.

EXPECTATIONS:

Finally, the following guidelines will create a comfortable and productive learning environment throughout the semester.

You can expect me:

- To start and end class on time.
- To reply to e-mails within 24 hours on weekdays and 48 hours on weekends.
- To assign projects that adequately covers the material and meets the learning objectives of the course while adhering to the time expectations for a 12 unit course.

I can expect you:

- To be attentive and engaged in class.
- To spend an adequate amount of time on the projects / labs each week.
- To engage with both the theoretical and practical sides of the material.
- To seek help when appropriate.

TENTATIVE LECTURE SCHEDULE FOR FALL 2022*

WEEK OF	TOPIC	DELIVERABLE
Aug. 29	Intro to digital control	**Form Teams**
Sep. 5	Digital control fundamentals **(No Class 9/5)**	
Sep. 12	Issues in embedded control, controller realization	**Lab 1 due 9/16**
Sep. 19	System identification	**Lab 2 due 9/23**
Sep. 26	Feedforward control intro, Dynamic programming	**Lab 3 due 9/30**
Oct. 3	Model predictive control, team meetings (project ideas)	
Oct. 10	Explicit MPC, **project proposal presentations**	**Project proposals due 10/12**
Oct. 17	**FALL BREAK**	
Oct. 24	ILC, team meetings (proposal feedback and planning)	
Oct. 31	ILC, team meetings (system modeling and simulation)	**Sprint 1 Review**
Nov. 7	Input Shaping, team meetings (hardware integration)	
Nov. 14	Fuzzy logic control, **project update presentations**	**Sprint 2 Review**
Nov. 21	Fuzzy logic control, (**No Class 11/23)**	
Nov. 28	Technical writing and presentations, team meetings (progress update)	**Sprint 3 Review**
Dec. 5	Wrap-up	
Dec. 12	**Final demonstrations / presentations (final exam schedule)**	**Final report due 12/11**

***NOTE:** This is a tentative outline. It will be modified depending upon our progress through the semester.