ME 601 (Lec079) Syllabus - 24Spring

Introduction to Feedback Control of Autonomous Systems

Course Information

Course Title

ME 601 - Introduction to Feedback Control of Autonomous Systems

Instructor

Prof. Xiangru Xu, Department of Mechanical Engineering, UW-Madison
Office: ME2035
Email: xiangru.xu@wisc.edu
Office hour: Monday 4:00-5:00 PM and Thursday 2:00-3:00 PM in ME2035

Lecture Meeting Time & Location

Monday & Wednesday 2:30-3:45pm, ME 1143

Canvas

This course will use the Canvas learning system. The Canvas page will host all lecture slides, notes, assignments, grades, etc. Please set your settings to receive notifications. Please also check this page regularly to make sure you're on track. The course page is https://canvas.wisc.edu/courses/388508.

Credits

This is a three-credit course with two 75-min lectures per week.

Course Description

This course introduces feedback control theory and motion planning algorithms underpinning autonomous systems, and provides hands-on opportunities to design and implement controllers on a nano quadcopter platform. Topics that will be covered include:

- Feedback Control Fundamentals: state-space modeling, controllability & observability of LTI systems, Lyapunov stability.
- Motion Planning & Optimal Control: optimal control theory, trajectory optimization, linear quadratic regulator.
- Planning and Control of Quadcopters: quadcopter kinematics & dynamics, quadcopter control and trajectory planning.

Students are expected to have good working knowledge of linear algebra, ordinary differential equations, and experience with Matlab. There is no official prerequisite, but knowledge of basic concepts from dynamic systems and controls (e.g. ME340, ME346, ECE332, ECE334) will be beneficial.

Course Learning Outcome

Upon completion of the course, you will be able to

1. Explain and assess controllability, observability, and stability of linear systems.
2. Understand Lyapunov direct and indirect methods for determining the stability of nonlinear systems.
3. Understand open-loop and closed-loop motion planning & control methods.
4. Formulate optimal control problems and understand how to use the maximum principle to solve the problem.
5. Understand how optimal control problems can be solved using direct approaches.
6. Formulate and solve optimal control problems using off-the-shelf numerical software.
7. Understand linear quadratic regulator and know how to solve it using numerical solvers.
8. Understand differential flatness and its application in trajectory generation and tracking.
9. Understand the kinematics and dynamics of quadcopters, implement trajectory generation methods for quadcopters, and design different tracking controllers for quadcopters.
10. Implement trajectory generation and tracking algorithms using a nano quadcopter.

Grading & Assignments

Grading

Grades will be based on scores accumulated from homework, midterm exams, and final project. The weighting scheme and the grading scale are given below. Grades will be posted on the Canvas website. Note: Score-related questions must be raised within 48 hours of receiving the score.

The instructor reserves the right to increase the final scores for the class as a whole at his discretion.

Grading Weights:

Homework	25%
Midterm Exam 1	25%
Midterm Exam 2	25%
Final Project	25%

Grading Scale:

Score	Grade
>90	A
84-90	AB
78-84	B
72-78	BC
66-72	C
60-66	D
<60	F

Homework

There will be homework to be assigned regularly during the semester. Homework may include a variety of activities including mathematical derivations, problem sets, and computer programming. All homework assignments will be posted in Canvas. The due date and instructions will be provided in the assignments. All handwritten homework solutions should be neat, legible, and well organized. Homework with the lowest score will be dropped. **Note: No late homework will be accepted**.

Exams

There will be two in-class, open-book, midterm exams. If you have a valid schedule conflict, please arrange for a make-up exam at least one week prior to the scheduled exam. There will be no accommodations made for last-minute request.

Final Project

You will do a final project of your own choosing, either by yourself or with a partner. You are free to pick a robotic problem and implement the numerical optimal control methods to solve the problem. A project proposal will be due in mid-March. Once I get a chance to read your proposal, I will provide feedback and give you the green light (or not) to move on that project. Feedback will be provided within one week of receiving your proposal so that you can get started as soon as possible. Each team will present their project in late April and submit a final project report in early May. For a team of two members, every member will be assigned with the same grade.

Lab

There will be quadcopter lab sessions for this course in ARC LAB (located in ME 3038) where students will work on quadcopter experiments.

Textbook & Software

Textbook

There is no required textbook. Some relevant textbooks are listed below:

1. Numerical Optimization of Dynamic Systems, Moritz Diehl and Sebastien Gros, 2016. [Available online https://www.syscop.de/files/2015ws/noc-dae/00-book.pdf]
2. Feedback Systems - An Introduction for Scientists and Engineers, Karl Johan Astrom and Richard M. Murray, Princeton University Press, 2009. [Available online https://www.cds.caltech.edu/~murray/books/AM08/pdf/am08-complete_22Feb09.pdf]
3. R. Siegwart, I. R. Nourbakhsh, D. Scaramuzza. Introduction to Autonomous Mobile Robots. MIT Press, 2nd Edition, 2011.
4. H. Khalil, Nonlinear Systems, 3rd Edition, Prentice Hall Publisher, 2002.

Software

MATLAB and Simulink software are required. There are four ways to access the software:

1. [recommended] Download and install in the local computer via Campus Software Library. Instructions for download and installation can be found here: https://kb.wisc.edu/page.php?id=82710. Select the latest version. Simulink and MATLAB

toolboxes will be installed as part of the standard installation package.
2. Remote access with XenApp and VPN
3. Online at the Mathworks website. You must create an account using your UW-Madison email
4. Use any computer in a CAE Lab

We will also use Casadi for solving optimization and optimal control problems. You can download and learn Casadi from its website https://web.casadi.org/.

Additional Course Information and Academic Policies

Academic Integrity Statement

By virtue of enrollment, each student agrees to uphold the high academic standards of the University of Wisconsin-Madison; academic misconduct is behavior that negatively impacts the integrity of the institution. Cheating, fabrication, plagiarism, unauthorized collaboration, and helping others commit these previously listed acts are examples of misconduct which may result in disciplinary action. Examples of disciplinary action include, but is not limited to, failure on the assignment/course, written reprimand, disciplinary probation, suspension, or expulsion.

Common examples of academic misconduct include:
- cheating on an examination
- contrary to the stated rules of the course
- submitting a paper or assignment as one's own work when a part or all of the paper or assignment is the work of another
- submitting a paper or assignment that contains ideas or research of others without appropriately identifying the sources of those ideas
- stealing examinations or course materials
- submitting, if contrary to the rules of a course, work previously presented in another course
- tampering with the laboratory experiment or computer program of another student
- knowingly and intentionally assisting another student in any of the above, including assistance in an arrangement whereby any work, classroom performance, examination or other activity is submitted or performed by a person other than the student under whose name the work is submitted or performed

For detailed information, see https://conduct.students.wisc.edu/academic-misconduct/

Course Evaluation

Students will be provided with an opportunity to evaluate this course and your learning experience. Student participation is an integral component of this course, and your feedback is important. Students are strongly encouraged to participate in the course evaluation.

UW-Madison now uses an online course evaluation survey tool, AEFIS. In most instances, you will receive an official email two weeks prior to the end of the semester when your course evaluation is available. You will receive a link to log into the course evaluation with your NetID where you can complete the evaluation and submit it, anonymously. Your participation is an integral component of this course, and your feedback is important to me. I strongly encourage you to participate in the course evaluation.

Academic Calendar & Religious Observances

See: https://secfac.wisc.edu/academic-calendar/#religious-observances

Accommodations for Students with Disabilities

The University of Wisconsin-Madison supports the right of all enrolled students to a full and equal educational opportunity. The Americans with Disabilities Act (ADA), Wisconsin State Statute (36.12), and UW-Madison policy (Faculty Document 1071) require that students with disabilities be reasonably accommodated in instruction and campus life. Reasonable accommodations for students with disabilities is a shared faculty and student responsibility. Students are expected to inform Prof. Xiangru Xu of their need for instructional accommodations by the end of the third week of the semester, or as soon as possible after a disability has been incurred or recognized. Prof. Xiangru Xu will work either directly with the student or in coordination with the McBurney Center to identify and provide reasonable instructional accommodations. Disability information, including instructional accommodations as part of a student's educational record, is confidential and protected under FERPA. See McBurney Disability Resource Center.

Diversity & Inclusion

Diversity is a source of strength, creativity, and innovation for UW-Madison. We value the contributions of each person and respect the profound ways their identity, culture, background, experience, status, abilities, and opinion enrich the university community. We commit ourselves to the pursuit of excellence in teaching, research, outreach, and diversity as inextricably linked goals. The University of Wisconsin-Madison fulfills its public mission by creating a welcoming and inclusive community for people from every background – people who as students, faculty, and staff serve Wisconsin and the world.