

# ME 601 (Lec079) Syllabus - 23Spring



## 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](mailto:xiangru.xu@wisc.edu)

Office hour: Tuesday 1:30-3:00 PM, ME2035

#### Lecture Meeting Time & Location

Monday & Wednesday 2:30-3:45pm, Engineering Hall 2349

#### 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/336418>.

#### 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, differential flatness, feedback linearization.
- Motion Planning & Optimal Control: optimal control theory, trajectory optimization, linear quadratic regulator, search and sampling-based motion planning.
- Planning and Control of Quadcopters: quadcopter kinematics & dynamics, quadcopter control, quadcopter trajectory planning, visual inertial odometry.

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 different notions of stability for nonlinear systems and identify appropriate notions for different applications.
  3. Understand the notions of differential flatness and feedback linearization, and their application in trajectory generation and tracking.
  4. Understand open-loop and closed-loop motion planning & control methods.
  5. Formulate optimal control problems and understand how to use the maximum principle to solve the problem.
  6. Understand linear quadratic regulator and know how to solve it using numerical solvers.
  7. Understand the kinematics and dynamics of quadcopters, implement trajectory generation methods for quadcopters, and design different tracking controllers for quadcopters.
  8. Implement trajectory generation and tracking algorithms using a nano quadcopter.
- 

## Grading & Assignments

### Grading

Grades will be based on scores accumulated from homework, midterm exams, final project, and course participation. The weighting scheme and the grading scale are given below. Grades will be posted on the Canvas website. *Score-related questions must be raised within 72 hours of receiving the score. The instructor reserves the right to increase scores on a particular assignment or exam for the class as a whole at his discretion.*

Grading Weights:

Homework	30%
Midterm Exam 1	20%
Midterm Exam 2	20%
Final Project	25%
Course Participation	5%

Grading Scale:

Score	Grade
>90	A
85-90	AB
80-85	B
75-80	BC
70-75	C
60-70	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, which are tentatively scheduled on Feb 27 and April 10. 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 as a team with another person. This project should use what you have learned in class and its topic could be related to your research or work. Each team member will make equal contribution of the project and if so, every member will be assigned with the same grade. A project proposal will be due no later than March 19. 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. In case you don't have a research project to work on, default project topics that are reasonably challenging will be provided to you. A final project report will be due on May 10.

## Lab

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

## Course Participation

The course requires active participation during class periods and online activities. Points for participation will be given based on the quality of the contributions you make to the course activities. In-class activities will include, but not limited to, lecture attendance, discussions, and group problem-solving; online activities will include, but not limited to, posing and answering questions in Canvas, finishing electronic polling and non-graded questions, and contributing useful contents.

---

## Textbook & Software

### Textbook

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

1. R. Siegwart, I. R. Nourbakhsh, D. Scaramuzza. Introduction to Autonomous Mobile Robots. MIT Press, 2nd Edition, 2011.
2. R. M. Murray, Optimization-based control, 2009. Available in [http://www.cds.caltech.edu/~murray/books/AM08/pdf/obc-complete\\_15Feb10.pdf](http://www.cds.caltech.edu/~murray/books/AM08/pdf/obc-complete_15Feb10.pdf)
3. H. Khalil, Nonlinear Systems, 3rd Edition, Prentice Hall Publisher, 2002.
4. A. E. Bryson, Y-C. Ho, Applied Optimal Control, CRC Press, 1975.

5. S. M. LaValle, Planning Algorithms, Cambridge University Press, 2006.

## Matlab and Simulink 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](#)
- 

## 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.