Manipulation, Estimation, and Control

16-642 Fall 2024

Last update Aug 22, 2024

**Meeting Times:** MW 9:30 am - 10:50 am

**Location:** Newell Simon Hall (NSH) 3002

**Course Website:** CMU Canvas <https://canvas.cmu.edu/courses/41691>

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# **Course Introduction**

**Overview:** This course provides an overview of the current techniques that allow robots to move around, interact with the world, and keep track of where they are. The kinematics and dynamics of electromechanical systems will be covered with a particular focus on their application to robotic arms. Some basic principles of robot control will be discussed, ranging from independent-joint PID tracking to coupled computed torque approaches. State estimation techniques including the Kalman filter will be covered, especially as they are used in solving common problems faced in robotics applications.

**Textbook:** There is no assigned textbook for this class. However, there are some books that you might find useful as reference material for various parts of the class:

* A more detailed treatment of the material from our lectures on *Control* can be found here:

K.J. Astrom and R.M. Murray. Feedback *Systems: An Introduction for Scientists and Engineers*, Princeton University Press, 2008.

* A more detailed treatment of the material from our lectures on *Estimation* can be found here:

S. Thrun, W. Burgard and D. Fox. *Probabilistic Robotics*, Intelligent Robotics and Autonomous Agents series, 2005.

* A more detailed treatment of the material from our lectures on *Kinematics and Dynamics* can be found here:

M.W. Spong, S. Hutchinson, and M. Vidyasagar. *Robot Modeling and Control*, John Wiley and Sons, Inc., 2006.

**Course Canvas:** The course canvas site will be the primary means of disseminating information about the course throughout the semester. Assignments and important announcements will be posted here. Lecture slides will also be posted here before the start of each lecture. Posted lecture slides are meant as supplemental material only. ***There is no substitute for attending class live and taking your own notes during lectures.*** So please attend them!

**Course Piazza:** Piazza will be mainly used for posting and discussion questions etc. The system is highly catered to getting you help fast and efficiently from classmates, TAs, and myself. Rather than emailing questions to the teaching staff, I encourage you to post your questions on Piazza.

**Prerequisite knowledge**: There are no formal prerequisites for this class. Informally, a year of calculus, a year of programming, and familiarity with matrix algebra will greatly increase your chances of success in this class. Also helpful, but not required, is a course on classical mechanics.

**Learning Objectives:**

By the end of this course, students are expected to be able to do the following:

* Simulate and analyze the dynamic behavior of physical systems through ordinary differential equations and difference equations.
* Derive transfer function representation of linear systems from ordinary differential equations and difference equations using Laplace and z transforms.
* Predict qualitative and quantitative behavior of continuous- and discrete-time linear systems by examining transfer function poles.
* Derive the single transfer function of systems composed of multiple component linear systems combined in series, parallel, and feedback configurations.
* Synthesize PID feedback controllers to achieve desired step-response characteristics.
* Analyze transient behavior of linear and nonlinear state-space systems via eigenvalues and Lyapunov theory.
* Construct state feedback controllers and state observers for linear state space systems via pole placement and linear quadratic regulator.
* Understand the Kalman filter equations, and implement an extended Kalman filter for robotic state estimation and SLAM.
* Understand pose graph estimation techniques, and implement them for problems such as SLAM and vision-based odometry.

# **Course Activities and Grading**

Problem sets (4) 60%

Exam I 20%

Exam II 20%

Above 90 is an A, from 80 to 90 is a B, etc. We may lower the thresholds slightly but we will not

raise them. Regardless of the grading system, you are required to submit all four homework assignments and take both exams to receive a passing grade for the class.

**Problem sets:**

* Problem sets will be handed in electronically via Canvas.
* The cutoff for submission is **11:59 pm** of the posted due date.
* You are given in total **72-hour grace period** (self-granted extensions) which you can use to give yourself extra time without penalty. For example, if you use a 10-hour grace period for your first problem set, then you have only 62 hours left for your grace period for the other three problem sets.
* Late work handed in when you have run out of grace will not be accepted.

**Exams:** There will be two in-class exams, one assigned on **October 9** and one assigned on **December 4**. Exams will be “take home”, open note, open internet, and must be completed within a 24-hour window. Details about exam rules will be given later in the semester. Submitting an exam late will result in a zero, unless there is a dire medical or family emergency; in such cases, you must discuss with the instructor prior to the exam. Job interviews, special courses, and other enhancing experiences, although wonderful, are not reasons to miss an exam. These tests are arranged in advance so that you can plan your schedules accordingly.

# **Other Topics**

**Attendance:** Class attendance and participation are important parts of this course. You are expected to attend class at the scheduled time, and in person. However, I understand that there may be situations that make attendance difficult (e.g., religious observance, university-sanctioned event, illness). I don’t need to be told about one-time attendance issues, but if you anticipate having a challenge regularly attending class, please contact me. We do not support remote attendance in general. But if, occasionally, you can only attend remotely, **please email me and we will send you a Zoom link**.

**Take care of yourself:** 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.

If you or someone you know is feeling suicidal or in danger of self-harm, call someone immediately, day or night:

CaPS: 412-268-2922

Re:solve Crisis Network: 888-796-8226

If the situation is life-threatening, call the police:

On campus: CMU Police: 412-268-2323

Off campus: 911

**Accommodations 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.

**Academic Integrity**: Academic Integrity is a core CMU value, and as a member of the CMU community, it is important that the work you turn in for this class is wholly your own. As your instructor, I will strive to ensure that you develop the necessary knowledge and skills to meet the learning objectives for this class, just as it is your task to put in the effort to complete the work and ask for help if you need it. In this class, students are encouraged to collaborate on assignments, but each student must submit their own unique solution. Rote copying from another student's solution, or from a common group solution, is in violation. Plagiarism and cheating will not be tolerated. I follow CMU’s academic integrity policy:

<http://www.cmu.edu/policies/student-and-student-life/academic-integrity.html>

All content produced for this class must be original to the submitter(s) unless noted. Any sources of information should be cited correctly. Any material taken directly from a source, including figures, must be clearly quoted and attributed. Plagiarism is a very serious offense and will be treated as such. If you have any questions about whether something is allowable, please email me.

In particular, **students may NOT use generative AI in any form**. To best support your own learning, you should complete all graded assignments in this course yourself, without any use of generative artificial intelligence (AI). Please refrain from using AI tools to generate any content (text, video, audio, images, code, etc.) for an assignment or classroom exercise. Passing off any AI generated content as your own (e.g., cutting and pasting content into written assignments, or paraphrasing AI content) constitutes a violation of CMU’s academic integrity policy. If you have any questions about using generative AI in this course please email or talk to me.