ECE6550 FALL 2023
Linear Systems and Control

Instructor: Prof. Bolin (Bo) Gao

Contact: bgao@gtsi.edu.cn **Office hour**: Wednesday & Friday after 1 pm
Meeting times: Every Wednesday and Friday starting August 21, 2:25 pm - 3:40 pm, Room 406.
We will have a class on Sunday, October 8, 2:25 - 3:40 pm, but no class on Friday, September 29.
Course website: https://gatech.instructure.com/courses/377206
Discussion board: https://piazza.com/class/lluawvaridk65k

Welcome to ECE6254 at Georgia Tech-Shenzhen!

Control theory is the engineering use of feedback signals. It is an essential technology that enables our cars to move, planes to fly, robots to walk, and smart phones to communicate. In this course, we will approach this theoretically-rich and application-driven field from the perspective of linear systems. We will first learn how to model and analyze the long-run behaviors of these systems. We then study two important and interrelated problems, that of controllability and observability, which will inform the design of feedback controllers. Theoretical concepts in this course are illustrated through MATLAB or Python-based programming assignments. Students will also work on a semester-long, self-directed project that makes use of the methodologies developed in this course.

Prerequisites

A student should have a basic grasp of linear algebra, ordinary differential equations, and multivariable calculus. We will review these mathematical concepts at various points of the course. The student should also have had experience in one or more programming language. The assignments of this course will be based on MATLAB or Python (you have the option to choose).

Textbook and References

A set of lecture slides will be provided to you which will serve as the primary reference for our course. The content of these slides will be drawn from the following textbooks:

- *Linear Systems Theory (2nd Edition)* by João P. Hespanha
- *Linear System Theory and Design (3rd Edition)* by Chi-Tsong Chen

Recommended supplementary references

The following closely-related and well-written textbooks will serve as supplementary materials for us. You can consult these textbooks to gain a different perspective or to develop your project ideas.

- “Linear Systems" by P. J. Antsaklis and A. N. Michel
- “Linear Control Theory: The State Space Approach" by F. W. Fairman
- “Numerical Methods for Linear Control Systems" by B. Datta
- “Functional Analysis: An Introduction to Metric Spaces, Hilbert Spaces and Banach Algebras" by J. Muscat

Grade Breakdown

You will be evaluated based on three components: homework, term tests, and a final project. The grade breakdown for each component as is follows:

Homework 20% **Term Test I** 20% **Term Test II** 20% **Final Project** 40%

Homeworks (20%)

There will be a homework assignment roughly every two weeks. A subset of the problems will be randomly drawn and graded based on the clarity and (less so) on correctness of your answers. These assignments will often include several short programming questions. All programming questions should be done in MATLAB or Python. **The homework should be printed out and handed in at the beginning of the class with your name and student ID clearly labeled.**

Term Tests (Test I 20% + Test II 20%)

There are two in-class term tests, which will be closely modeled after your homework assignments. These tests will consists of computational questions that assess your understanding of the material and ability to extrapolate what you've learned to new scenarios. These term tests will take place during regular class hours. The tentative schedule for these tests are set to occur during Week 7 and Week 13 or 14 (dates are to be announced on Canvas). You will not need calculators for the exam.

Final Project (Proposal 5% + Presentation 5% + Report 30%)

A major component of this course involves a final project. Each project will be performed by a team of $1-3$ students. The projects should generally fall under the following categories:

- **Solving a problem using control principles** (e.g., building an autonomous unicycle using output feedback)
- **A survey that deeply explains an advanced area of application and a collection of techniques associated with the application** (e.g., controller design for data driven systems)
- **Independently proposed topic** (e.g., comparison between a group of control techniques for solving a certain problem, project related to your or your team's research or academic interests, theoretical-papers are welcome)

All types of project must involve one or more computer simulation component and utilization of at least one concept that we have discussed in class. Although not required, your team may wish to explore building a physical system. There is no requirement on the programming language for the final project.

Sign-up

A sign-up sheet will be made available to you with a list of pre-determined potential projects. You are welcome to choose and modify upon the projects or propose your own projects. You should have formed a team by the end of Week 2 (9/1, 11:59 pm). If you have not found a team by then, contact me. Each team will be issued a team number. Your team will have the option to choose a team name.

Project proposal (5%)

A project proposal must be submitted **through Canvas** by the end of Week 5 (9/22). The format of the project proposal is as follows.

- A maximum of 2 pages. Clearly pace your tentative project title, team number, (optionally) team name, names of all team members and student IDs at the top of the page. LaTex is strongly recommended for generating your project proposal.
- Page 1 should contain one or two short paragraphs describing your problem, a justification for its relevance, and your preliminary ideas on the next steps.
- Page 2 should contain a description of the potential cost involved, project timeline, responsibility of team members along with any relevant diagrams/figures. This page is optional.

You may start working on your project as soon as you have an idea, but I might communicate with your team regarding the feasibility of the project and other considerations after receiving the proposal. Failing to submit the proposal will result in a grade of 0%.

Project presentation (5%)

A presentation of your project will occur on the last day of the class during Week 14. You and your team will describe to the rest of the class the problem you are trying to solve and the solution that your team had came up with. The presentation style should be kept conversational and informal. **The project presentation is graded based entirely on the clarity of your presentation**. Grade is deducted for the whole team if you or your team members cannot adequately explain one or more concept/idea/equation on the presentation slide.

Final report (30%)

The format of this report (maximum 1 + 8 + 2 + 1 = 12 pages) is as follows:

- 1 cover page indicating the title of the project, your team number (and name), names of all students, and percentage of contribution from each student in terms of the over all report.
- You are allowed a maximum of 8 pages of main report (you will not be penalized for having less than 8 pages). The main report should contain an introduction, a related work section, a presentation of your results (and simulation) and conclusion or future work.
- You are allowed a maximum of 2 pages of appendices (additional figures, terminologies, data, tables) and a maximum of 1 page of citations (citation format must be consistent).
- The report should be typed in 12 point font. LaTex is strongly recommended for generating your final PDF report.
- The report must contain a diagram of the overall system showing all inputs, outputs and data/signals flowing between internal components.
- The report should contain a list terminologies used in the report. If this is not included, then they should be clear from the main report.
- Your team will pick the best template for presenting your material. The margin and spacing must be be legible. An unreadable report will receive a grade of 0%.

The final report will be graded out of 100 points based on the following criteria:

- Is the problem you are trying to solve clearly defined? [10 pts]
- Is the problem you are trying to solve relatively under-explored or are there already well-known solutions to your problem? [10 pts]
- Does your report follow report format guidelines? [10 pts]
- Does your report contain a diagram of your control system showing all input and outputs as well as data/signal between each sub-component? If so, is it clear to the readers? [10 pts]

- Is your report well-organized? Does your report make sense when read (does each word, sentence and paragraph make sense)? Is it mostly free of typos and other serious grammatical mistakes? Does it flow logically? Are there sufficient citations? [20 pts]
- Is your report technically sound? Does the experiment/simulation make sense? Are there sufficient mathematical justification or citation for technical claims? Is it mostly free of mathematical mistakes? Are equations clear? Are most mathematical symbols defined? [20 pts]
- Does your report clearly define most concepts and technical terminologies? Is the report self-contained? Are all figures clearly labeled? [20 pts]

A rule-of-thumb is: every time something confusing or unclear appears in the report, a point may be deducted. The final report is to be submitted through Canvas approximately one week after our last class.

Your Final Grade

Final grades at Georgia Tech are entered as **whole letter** grades (**A, B, C, D, F**). These grades correspond to the following percentage:

A 90-100% B 80-89% C 70-79% D 60-69% F 0-59%

If you have performed satisfactorily in this course but was unable to meet the full requirements of the course due to nonacademic circumstances beyond your control, contact me to see if you are eligible for a grade of I (Incomplete).

Tentative Course Schedule

The schedule for each week is shown in the following table.[1] The topics are subject to change based on scheduling as well as the interests or need of the class.

Week	Lecture Content	Reading	Task
Week 1 (8/21-8/25)	**Introduction, State-space representation of physical systems, Linearization,**	LST 1.1 - 1.3, 2.1 - 2.6, LSTD 2.3 - 2.5	A1 Released
Optional Reading	• "The Impact of Control Technology (1st/2nd Edition)" IEEE Control Systems Society • "Characteristics That Make Linear Time-Invariant Dynamic Systems Difficult for Humans to Control" by Mousavi et al., 2021 • "Design of a modular snake robot" by Wright et al., 2007		
Week 2 (8/28-9/1)	**LTI systems, Transfer functions, Matrix exponential, General solution**	LST 3.1 - 3.8, 4.1 - 4.7	
Optional Reading	• "Gain Scheduled Controller Design for Balancing an Autonomous Bicycle" by Wang et al. IROS, 2020	LSTD 4.1 - 4.4	
Week 3 (9/4-9/8)	**Modal decomposition, Phase Portrait**	LST 6.1 - 6.8, 7.1 - 7.6	A1 Due, A2 Released
Optional Reading	• "Feedback linearization based control of a rotational hydraulic drive" by Seo et al., 2007		
Week 4 (9/11-9/15)	**Lyapunov Stability**	LST 8.1 - 8.10, 9.1 - 9.7	
Optional Reading	• "Positive Realness and Absolute Stability Problem of Descriptor Systems" by Yang et al., 2007		
Week 5 (9/18-9/22)	**Controllability and Stabilizability**	LST 11.1 - 11.10	A2 Due, A3 Released
Optional Reading	• "Terminal Sliding Mode Control of MIMO Linear Systems" by Zhihong, Yu, 1997 • "Continuous pole placement for delay equations" by Michiels et al., Automatica, 2002	LSTD 6.1 - 6.2	

[1] LST = Linear Systems Theory (João Hespanha), LSTD = Linear System Theory and Design (Chi-Tsong Chen)

Week	Lecture Content	Reading	Task
Week 6 (9/25-9/28)	**Pole placement, State feedback control**	LST 12.1 - 12.7, 14.1 - 14.7, LSTD 8.1 - 8.2	
Optional Reading	•"Harmonic pole placement" by Riedinger and Daafouz, 2022		
Week 7 (10/8 -10/13)	**Observability and Detectability**	LST 15.1 - 15.13, LSTD 6.3	A3 Due, A4 Released
Optional Reading	• "Data-Driven Criteria for Detectability and Observer Design for LTI Systems", Mishra et al., 2022		**Term Test 1 [10/8]**
Week 8 (10/16-10/20)	**Output Feedback Control**	LST 15.1 - 15.13, LSTD 8.3 - 8.6	
Optional Reading	• "Output Feedback Stabilization of Networked Control Systems With Random Delays Modeled by Markov Chains" by Shi and Yu, 2009		
Week 9 (10/23-10/27)	**Kalman Decomposition**	See Notes	A4 Due, A5 Released
Optional Reading	• "Fundamental Limit on SISO System Identification" by Li et al., 2022		
Week 10 (10/30-11/3)	**Optimal Control**	LST 10.1 - 10.7	
Optional Reading	• "From LQR to Static Output Feedback: a New LMI Approach" by Rodrigues, 2022		
Week 11 (11/6-11/10)	**Optimal Control, Cont'd**	See Notes	
Optional Reading	• "MPC for stable linear systems with model uncertainty" by Rodrigues et al.		A5 Due, A6 Released
Week 12 (11/13 - 11/17)	**Tracking and Disturbance Rejection**	See Notes	
Optional Reading	• "Robust perfect adaptation in bacterial chemotaxis through integral feedback control" - Yi et al., 2000		
Week 13 (11/20-11/24)	**Recent Developments**	See Notes	A6 Due
Optional Reading	• "A Tour of Reinforcement Learning: The View from Continuous Control" by B. Recht		**Term Test 2 [11/23]**
Week 14 (11/27-12/1)	**Project Presentation**		**Final report due 12/9 11:59 pm via Canvas**

Important Administrative dates

- August 21: First day of classes
- August 25, by 4:00pm ET: Deadline for registration and class schedule changes
- August 25: Deadline for Submitting Online Application for Graduation (OAG) for fall graduation
- August 28, by 4:00pm ET: Deadline to pay tuition & fees
- September 29 – October 6: Mid-Autumn Festival & Chinese National Day holiday break
- October 28, by 11:59pm ET: Deadline for dropping a course with "W" grade
- October 28: Deadline to change grade mode (pass/fail/letter grade)
- December 7 - 14: Final exams for on-site classes/ video classes from GT-Atlanta
- December 19, 6:00pm ET: Grades are available

Additional Policies

Academic integrity

Any student suspected of cheating or plagiarizing on a test or homework will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations. Redistributing materials from this course (e.g., contributing to test banks, CourseHero, Chegg, or similar sites) is prohibited. For additional information, please visit: `https://policylibrary.gatech.edu/student-life/academic-honor-code`.

Collaboration and group work

Students are strongly encouraged to discuss homework problems with each other. However, each student must write up and turn in their own solutions. Suspicious homework submissions will be immediately be referred to the Office of Student Integrity.

Absences, late homeworks, and missed tests

You will not be penalized for any excused absences (such as: illnesses, religious observances, career fairs, job interviews). I cannot accept late homeworks in the absence of prior approval. If you expect to miss an exam, please contact me as soon as you realize this so we can make alternative arrangements. We may consider options to take the exam at an alternate time or instead may adjust the grading allocation to place more emphasis on other exams, depending on the circumstances.

Re-grading policy

Re-grading request should be submitted via email to the instructor. Your letter must include student name, student ID and a justification for the request, which refers specifically to the student's answers and course material. Requests without this justification will not be considered. The deadline for requesting a re-grade is one week after the marks are returned. Remarks may result in a decrease of the grade.

Accommodations

If you are a student with learning needs that require special accommodation (e.g., disability, distress), contact the me as soon as possible, to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail me as soon as possible in order to set up a time to discuss your learning needs.

Student-Faculty expectations

Respect for knowledge, hard work, and cordial interactions will help build a positive environment that is conducive to our learning. See `www.catalog.gatech.edu/rules/22` for of some basic expectation that you can have of us and that we have of you.