MMAE 543: Modern Control Systems

Scope: This course introduces linear systems theory, covering essential concepts such as system representation, stability, controllability, observability, state feedback, state estimation, and realization.

Grading

Homework[1] (6 sets) 30%   Midterm (W7) 20%   Final Project 50%

Lecture Schedule (14 weeks)

W1	**Introduction to Classical Control**
W2	**Modeling of Control Systems**
W3	**State-Space Representation of Control Systems**
W4	**Similarity Transformations**
W5	**Time Response of Linear Time-Invariant Systems**
W6	**Time Response of Linear Time-Varying Systems**
W7	**Controllability, Observability, and Reachability**
W8	**State Feedback Controller Synthesis**
W9	**Output Feedback**
W10	**State Observers**
W11	**Stability of Control Systems**
W12	**Optimization-Based Control**
W13	**Model Predictive Control**
W14	**Uncertainty and Robustness**

References

1. Åström, K. J., and R. M. Murray. *Feedback Systems: An Introduction for Scientists and Engineers.* Princeton University Press, 2008. (Open-access electronic edition available.)
2. Hespanha, J. P. *Linear Systems Theory.* 2nd ed. Princeton University Press, 2018.
3. Chen, X., and M. Tomizuka. *Introduction to Modern Controls — with Illustrations in MATLAB and Python.* 1st ed., 2023.
4. Lewis, A. D. *A Mathematical Approach to Classical Control.* Lecture notes (Open-access PDF.)
5. Skogestad, S., and I. Postlethwaite. *Multivariable Feedback Control: Analysis and Design.* 2nd ed. Wiley, 2005.

Final Project

Objective: Design, analyze, and evaluate a feedback controller for a *multi-input multi-output (MIMO)* dynamical system (e.g., aircraft, ground vehicle, or robot). If the system is nonlinear, linearize about an operating point and work with the linear model for analysis and design. Close the loop, verify stability, compare two design methods, and quantify robustness.

- Choose a MIMO system (aircraft/vehicle/robot) and derive the state-space model.
- If the system is nonlinear, derive the linearized state-space model.
- Analyze the stability of your system.
- Analyze controllability, observability, stabilizability, and detectability.
- Controller synthesis and closed-loop verification: Design a feedback controller (e.g., pole placement, LQR/LQI, output-feedback/observer-based) and analyze closed-loop stability.
- Comparison: Implement a second method as a baseline or alternative (e.g., compare pole placement vs. LQR; LQR vs. PID).
- Robustness quantification: Obtain gain and phase margins and singular values.
- *Report:* 6–8 pages in IEEE two-column conference format (problem, model/linearization, analysis, design, comparison, robustness, conclusions).
- *Code:* Python (*preferred*), MATLAB, Julia, or C++ (reproducible scripts/notebooks) with a short README file and instructions to run your code. Alternatively, you may include a link to your code on GitHub (preferred).
- *Presentation:* 8–10 minutes in the final week; include a demo (simulation or, optionally, hardware).
- Team policy: Individual or teams of up to 2 students are allowed. Team projects must include a brief contribution statement. Optional hardware implementation may be arranged in the instructor's lab, subject to safety and availability.

[1] Homework should be prepared with LaTeX in the same format as the Final Project. You can also include a link to your homework solution (PDF) with code on GitHub (preferred).