Due Friday, November 22, 2024, start of class   NO LATE ASSIGNMENTS ACCEPTED!
You may work singly or in pairs (pairs turn in one report with both names, same grade).

The goal of the project is to design a feedback controller $G_C(s)$ in the frequency domain to improve the performance of a chosen real-world single-input, single-output (SISO) linear system. You will evaluate results in MATLAB and Simulink simulation.

Each group will choose their own real-world open-loop system for controller design. For real-world project ideas, see Dr. Bob's site people.ohio.edu/williams/html/PDF/ModelTFAtlas.pdf, controls textbooks, and Internet sites. Each group's project topic must be different; therefore, you must register your intended project with Dr. Bob. If your name doesn't appear on my list, your grade is **ZERO** for the project. The **deadline** for registering is given on the next page.

Specific steps to complete:

0) Find an open-loop system to control, with real-world application that you can explain in your presentation. Approve with Dr. Bob (first-come, first-approved, starting immediately!). Guidelines: SISO, linear, real-world system with an actuator and sensor. Be sure you can get the dynamic equation(s); this is required to start the project. It is entirely acceptable to find the equations and/or transfer functions from Dr. Bob's site ohio.edu/mechanical-faculty/williams/html/PDF/ModelTFAtlas or another valid source, as long as you reference that source properly.

1) Perform system modeling and determine the open-loop characteristics. Plot unit impulse, unit step, unit ramp, and ramped-step responses. Perform the first three response plots using both MATLAB and Simulink to compare. The fourth (ramped-step) is easiest using Simulink. From your $G(s)$, reverse-engineer to find the time-domain ODE. Solve this ODE analytically by hand (any valid method) and compare its plot to your numerical MATLAB/Simulink results (only for one input, most important to your system). See the ME 3012 NotesBook, Section 4.9 for examples.

2) Design a linear feedback controller $G_C(s)$ to achieve desired performance according to stated specifications (you determine the specifications). The important considerations are stability, transient response, steady-state error, input effort, and disturbance-rejection. You must try at least three different forms/methods for $G_C(s)$ – report them all with one selected as the "best". Include an output attenuation correction factor and a pre-filter if necessary in each case. Follow the steps for controller design from the ME 3012 NotesBook for each controller – organize your report according to these steps too.

3) Compare the closed-loop output performance to the original open-loop results (only for the most important input function to your real-world project, e.g. unit step). Also plot input effort vs. time, with and without the pre-filter; comment on real-world feasibility regarding required input. Also, subject your controllers to a disturbance in simulation, plot the responses, and discuss the results. Input efforts and disturbance responses help in choosing the "best" controller.

4) Discussion – comment on tradeoffs, difficulties, real-world considerations, etc.

Each group will present their results orally to the class as scheduled in the syllabus. ALL final reports are due in class on the deadline noted above. Please teach the class via your presentations. You all can cover a broad range of practical applications (attendance is required on all presentation days). Presentations are very important and will form a part of your project grade. Be sure to plan ahead; use a professional PowerPoint presentation with plenty of graphical results. Each member of a team must be heard from.

ME 3012 Capstone Term Project Schedule

- **Register real-world system** with Dr. Bob before class **Monday 9/16/2024**, NO EXCEPTIONS!

- Turn in **Interim Report** at the start of class on **Monday 10/14/2024**: complete system modeling and open-loop analysis (#1 on previous page; also see the first page of the checklist). This must be a technical report – turn in a photocopy so you can keep the original for your final report. NO LATE REPORTS WILL BE ACCEPTED! See the following Checklist – material for the first Checklist page is due, plus clear, concise technical writing, references, appendix – MATLAB/Simulink code/diagram. **If you skip this interim report (or it is late) your maximum final project grade is 70%.**

- **Present results** orally to the class either **Monday** or **Wednesday November 18** or **20**, **2024**. ATTENDANCE IS REQUIRED FOR ALL IN-CLASS PRESENTATION SESSIONS! **If you skip this final presentation your final project grade is 0%.**

- Submit **Final Formal Technical Report** at the start of class **Friday November 22, 2024**, NO EXCEPTIONS!

Suggested Capstone Term Project Written Report Format

MEMO (serves as abstract) – first page, no cover sheet necessary

1. **Objectives**

2. **Physical System Description and Linear Model**

3. **Open-Loop Behavior**

4. **Performance Specifications for Design**

5. **Controller Designs**

6. **Open- vs. Closed-Loop Results and Discussion**

7. **Conclusion**

Appendices
- Validation of Results
- MATLAB code and Simulink diagrams
- References
- Other, as necessary

Your report must be clear and readable. *Brief* yet *complete*. Unlike that last sentence fragment, you must use professional technical writing skills. Make liberal use of figures and plots – pay attention to time scale, square axes (for root-locus). Combine plots where it makes sense to facilitate comparisons and to save paper. Remember, you are welcome to hand-annotate MATLAB/Simulink graphs to emphasize the different variables plotted.

ME 3012 Capstone Term Project Report Checklist   **Dr. Bob**

Name(s): _____

Final report grade: _____

_____   Memo – Abstract with details and summary; briefly discuss project, real-world system, and open- and closed-loop results.

Open-Loop

_____   Real-World System
- System description
- Photograph
- Physical/functional diagram – to show how the overall system works

_____   Modeling
- Assumptions
- FBDs (or thermal, fluid, etc. diagrams)
- ODEs – reverse-engineered from your $G(s)$
- Laplace Transforms – if you derived your own $G(s)$
- Input / Output – identify explicitly in text and on diagrams
- Table of parameter values

_____   Open-Loop Block Diagram
- Distributed blocks with variables and parameters (if applicable)
- Simplified $G(s)$ block with variables and parameters (if applicable)
- Simplified block with numerical $G(s)$
- Identify the Type of your system (0, I, II)

_____   Open-Loop Poles and Zeros

_____   Stability – determine the stability condition for your open-loop system

_____   Open-loop performance specifications

_____   Plots – unit impulse, unit step, and unit ramp responses (arranged logically); all plots must have a title and axis labels with units. Also include the ramped-step response plot. Perform the first three response plots using both MATLAB and Simulink to compare (the results must be the same in each case). The ramped-step response is easiest using Simulink.

_____   Open-Loop System Discussion
- Connect the open-loop poles to the plotted transient responses.
- Do simulated results agree with what you expect for your system, based on Chapter 4? Also, based on expected real-world behavior?
- Real-world issues for your system.

<u>Closed-Loop</u>

_____ Performance Specifications for Controller Design
- Method for determination
- Justify relative to real-world system
- Clearly state desired poles and desired characteristic polynomial
- Plot transient response(s) to demonstrate desired performance

_____ Closed-Loop Block Diagram
- Distributed blocks with variables
- Identify all blocks and variables
- Identify sensor and sensor assumptions

_____ Controller Design – at least 3 different $G_C(s)$; for each:
- Derive $T(s)$ for each controller as a function of the unknown gains
- Parameter matching to design controller
- Clear table of resulting numerical controller gain values; also display in each $G_C(s)$
- Closed-Loop Poles and Zeros
- Stability – determine the stability condition for your closed-loop system
- Closed-loop performance specifications – as-achieved vs. desired
- Pre-filter Transfer Function – if required; if not, explain why not

_____ Plots – choose the one input function (possibly the unit step input) that makes the most sense for your system. All plots must have a title and axis labels with units. On one plot, show open-, closed-, and closed-loop with pre-filter responses, for each controller considered. Clearly identify which curve is which. Practice good graphical communication.

_____ Plot the input effort required vs. time for each controller and compare; discuss.
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_____ Open- vs. Closed-Loop Disturbance Responses – plot and discuss.

_____ Closed-Loop Feedback Controller Discussion
- Connect the closed-loop poles to the transient response
- Do simulated results agree with what you expect for your system?
- Discuss input effort required vs. real-world limits
- Discuss disturbance rejection
- Other real-world issues for your system

_____ Professional oral presentation

_____ Clear, concise technical writing

_____ References

_____ Appendix – MATLAB/Simulink code/diagram

Tips and hints for the Professional Oral Presentation, Dr. Bob

ME 3012 Term Project

- There is a **5 minute time limit**, absolutely enforced. This is a short time so you must **practice** and time yourselves.

- We must hear equally from **all team members**.

- If you skip this oral presentation, your final project grade will be **0**.

- Since there is a short time limit, you cannot possibly present everything – there is no limit on the written report, so that can be complete. Your oral presentation can only cover the **Important Highlights**.

- **Important Highlights** for the ME 3012 Term Project:
    - **Introduction** – real-world application of your control system, with plenty of photos and diagrams, with terms identified.
    - State your **Assumptions** for analysis and controller design.
    - **Results** – present the main MATLAB/Simulink graphs and leave time for discussion of each. All graphs can be given and discussed in the written report, but in general there is not time to cover all in the presentation.
    - You must spend time to **connect your plot results with the behavior of your control system in the real-world**.

- Do not run MATLAB/Simulink during your presentation.

- If you ignore my advice and run your MATLAB/Simulink program anyway, be sure to have everything **hard-coded** so you do not have to type in data to get it running, wasting precious time.

- **Practice** in the classroom during off-hours to ensure everything works as you expect it to.

- Leave time for a **question** or two.

- Remember it is better to **present less and have your audience grasp more** (i.e. do not talk fast to beat the time limit).

- As an audience member behave as politely as you wish the audience to do when you present.