Lab 06: Multi-loop PID Control Simulation

CHEN4011: Advanced modeling and Control

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1 Objectives

i. To develop a MATLAB Simulink model for multi-loop PID control of a 2×2 MIMO process.
ii. To apply and compare different PI controller tuning methods for multi-loop systems.
iii. To evaluate the performance of the tuned controllers for setpoint tracking, disturbance rejection, and robustness under model uncertainty.

2 Problem Statement

In many industrial systems, processes involve multiple inputs and multiple outputs (MIMO) that are dynamically coupled. Controller design for such processes requires careful pairing of manipulated and controlled variables and effective tuning of multiple loops.

Consider the 2×2 MIMO process represented by the transfer function matrix:

$$G(s) = \begin{bmatrix} \frac{22.89e^{-0.2s}}{4.572s+1} & \frac{-11.64e^{-0.4s}}{1.807s+1} \\ \frac{4.689e^{-0.2s}}{2.174s+1} & \frac{5.80e^{-0.4s}}{1.801s+1} \end{bmatrix} \quad (1)$$

This process exhibits cross-coupling between manipulated inputs and controlled outputs. To achieve satisfactory performance, an appropriate controller pairing strategy must be chosen, and decentralized controllers must be tuned for each loop.

3 Methodology

1. Controller Pairing and Decoupling
   - Use a controller pairing method (e.g., Relative Gain Array to select suitable input–output pairings.
   - Reduce the decentralized system to a diagonal form by defining two Effective Open-Loop Transfer Functions (EOTFs).
2. PI Controller Tuning
   - Apply two different tuning methods for the decentralized loops (e.g., Ziegler–Nichols, IMC tuning, or other methods).

- Design two sets of PI controllers based on the chosen methods.
- Implement the controllers in MATLAB Simulink.

3. Setpoint Tracking Tests
   - Perform simulations for sequential setpoint changes:
     - +1 unit step change in y_1 setpoint
     - +1 unit step change in y_2 setpoint
   - Record and compare the closed-loop responses under both tuning methods.
4. Disturbance Rejection Tests
   - Apply +1 unit step disturbances directly to the outputs y_1 and y_2.
   - Compare controller performance for disturbance rejection between the two tuning methods.
5. Robustness to Model Errors
   - Introduce model mismatches:
     - Gain errors of ±10%
     - Dead-time errors of ±20%
   - Simulate the closed-loop system under these uncertainties.
   - Compare and summarize the effect of model mismatch on each tuning method.

4 Report Format

Your report (5 pages maximum) should include the following:

0. Submission Details Include a brief table at the beginning of the report with the following information:

Lab Title:	Lab 06 - Multi-loop PID Control Simulation	Student Name	ID
Unit:	CHEN4011	Student 1	12345678
Date:	12 August 2025	Student 2	87654321

1. Objective & Problem Statement

   Briefly describe the motivation for multi-loop control, challenges of coupling in MIMO processes, and the aim of this lab.
2. Methodology & Implementation

- Describe the pairing strategy and how EOTFs were obtained.

- Provide tuning equations and explain the two tuning methods used.
- Show Simulink model diagrams of the multi-loop control system.

3. Results

- Show time-domain responses for:
  - Sequential setpoint changes
  - Disturbance rejection
  - Robustness under model mismatch
- Provide well-labeled plots (axes, legends, units).
- Summarize controller settings and key performance metrics (e.g., IAE, settling time, overshoot) in tables.

4. Analysis and Discussion

- Compare controller pairings and explain the chosen configuration.
- Discuss which tuning method gave better results for setpoint tracking.
- Discuss which method performed better for disturbance rejection.
- Comment on robustness under gain and dead-time errors.
- Summarize strengths and weaknesses of each tuning method.

5. Conclusion

- Summarize overall findings from the simulations.
- Identify the best tuning method for this MIMO process and justify your choice.
- Reflect on the practical significance of multi-loop control in industrial systems.

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5 Assessment Rubric (20 Marks Total)

No	Section	Marks	Evaluation basis
1.	Objectives & Problem	2	Clarity of problem definition; articulation of objectives
2.	Methodology and Implementation	6	Pairing analysis; EOTFs; PI tuning details; Simulink implementation

No	Section	Marks	Evaluation basis
3.	Results	4	Quality, labeling, and completeness of plots and tables; setpoint and disturbance tests
4.	Analysis and Discussion	6	Comparison of tuning methods; insight on robustness; identification of best method
5.	Conclusion and Presentation	2	Coherent summary; quality of writing, formatting, and visual presentation