Smart Throttle Control – Mid-Term Report

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Project: Smart Throttle Control
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1. Summary

Assignment 0: Transfer Functions and Frequency-Domain Analysis

This assignment introduced the **Laplace-domain representation of systems** and the use of **Bode plots** for frequency-domain analysis. What we learned:

- Identification of poles(where the transfer function is infinity) and zeros(where transfer function is zero).
- Understanding how poles and zeros affect Gain, Phase and Stability
- Learned how to make bode plots for simple first order, simple first order with RHP zero, second-order underdamped and lead-type compensator, manually as well as on MATLAB.
- Effects of RHP zeros on phase lag, Second-order dynamics on resonance and Lead-type compensators in adding positive phase.
- Derive transfer functions from differential equations of a simple spring-mass system.

Assignment 1: Time-Domain System Analysis

This assignment focused on **time-domain behavior** of systems using step and ramp responses. This helped connect frequency-domain intuition to observable time responses. What we learned:

- Time-domain performance metrics:
    1. Rise time: time taken by the system to reach from small to large percentage of final output(usually 10-90%).
    2. Settling time: time taken by system to remain in specific range of final value (±2% or ±5% of final value)
    3. Overshoot: amount by which the system output exceeds its final steady-state value
    4. Steady-state error: difference between the desired output and the actual output as time approaches infinity.
- System type classification and its impact on steady-state error

- Use of the Final Value Theorem:

$$\boxed{\lim_{t\to\infty} y(t) \;=\; \lim_{s\to 0} s\,Y(s)}$$

- Relationship between system poles and response speed.
- Effect of adding zeros and static gain on transient and steady-state behavior

Assignment 2: PID Controller Design and Practical Issues

This assignment focused on **feedback controller design**, tuning, and real-world limitations. This assignment emphasized that controller design must consider physical and practical constraints, not just theoretical performance. What we learned:

- Design and tuning of P, PI, and PID controllers.
- **PID Controllers:**
    1. P(Proportional) action responds to the present error and improves response speed.
    2. I(Integral)action accumulates past errors and eliminates steady-state error.
    3. Derivative (D) action reacts to the rate of change of error, improving damping and reducing overshoot.
- Tracking of non-step references (ramp, sinusoidal, multi-step)
- Practical implementation challenges:
    1. Integral windup and anti-windup via back-calculation
    2. Derivative noise amplification and low-pass filtering
    3. Actuator saturation constraints

Assignment 3: Advanced Control Techniques

This assignment extended basic PID control to more advanced and realistic strategies. What we learned:

- Lead compensators for improving transient response without excessive gain increase
- Lag compensators for improving steady-state accuracy
- Feedforward control for proactive disturbance rejection
- Difference between reactive (feedback) and proactive (feedforward) control
- Introduction to **MIMO systems**, coupling, and interaction effects
- Challenges of decentralized control in interacting systems

Tools and Skills Developed

- MATLAB Control System basics.
- Time and frequency domain analysis
- Controller tuning and performance comparison
- Simulation of disturbances and constraints
- Structured technical documentation using MATLAB Live Scripts

2. Project Implementation Plan

Chosen System: Adaptive Cruise Control with Traffic Response

- The goal of the project is to maintain a certain speed for a vehicle even when slopes or traffic occurs on the road.
- Suppose we want to run the vehicle at speed v, the error in the speed would be current speed-v.
- The PID controller: It decides how much throttle to apply based on current error. For this we use a PID controller where P(proportional) reacts to current error, I(integrator) removes long term error and D(differentiator) reduces oscillations.
- Feedforward Control (Proactive Action): Sometimes the system already knows a disturbance is coming so it estimates required throttle before the speed drops. It thus reduces delay and improves comfort.
- Actuator (Throttle Mechanism): Controller output is sent to the electronic throttle which controls engine power. It usually has rate limits and is subject to saturation.
- Feedback Loop (Closing the Loop): Vehicle speed is measured again. New error is calculated, then the controller updates the throttle. This loop runs continuously.

High-Level Workflow:

Reference Speed
↓
Error Computation
↓
Controller (PID + Feedforward)
↓
Throttle Actuator
↓
Vehicle Dynamics
↓
Measured Speed (Feedback)