Linear Control Systems
(EE-379)
DE-44 Mechatronics
Syndicate– C

Lab Report 4

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Abstract

This report summarizes a lab exercise on PID controller tuning using the Ziegler–Nichols oscillation method. A higher-order system was modeled and tested in Simulink to evaluate P, PI, PD, and PID configurations. Controller parameters were derived experimentally, and step response analysis showed performance trade-offs in speed, stability, and accuracy. The PID controller achieved the most balanced results, demonstrating the effectiveness of the Ziegler–Nichols method for linear control systems.

Introduction

The Ziegler-Nichols method offers an empirical approach to tuning PID controllers by inducing marginal stability in a proportional-only loop to identify critical parameters. This exercise applied the technique to a representative plant, facilitating the design of feedback controllers that minimize tracking error $e(t)=r(t)-y(t)$ $e(t) = r(t) - y(t)$ $e(t)=r(t)-y(t)$. PID control, comprising proportional (P), integral (I), and derivative (D) actions, is ubiquitous in engineering applications such as robotics and process control due to its versatility in addressing rise time, overshoot, settling time, and steady-state error.

The plant under study emulates a third-order linear time-invariant system, common in electromechanical setups like RLC circuits augmented with op-amps for PID emulation. The methodology emphasized systematic gain adjustment and performance evaluation through Simulink simulations, building on prior control concepts.

Objectives

- Implementation of the Ziegler-Nichols oscillation method to determine ultimate gain K_u and period T_u .
- Computation and application of tuning rules for P, PI, PD, and PID controllers.
- Simulation and analysis of closed-loop step responses to assess transient and steady-state performance metrics.
- Evaluation of controller impacts on system stability, overshoot, settling time, and error elimination.
- Reinforcement of PID principles, including gain effects on response characteristics.

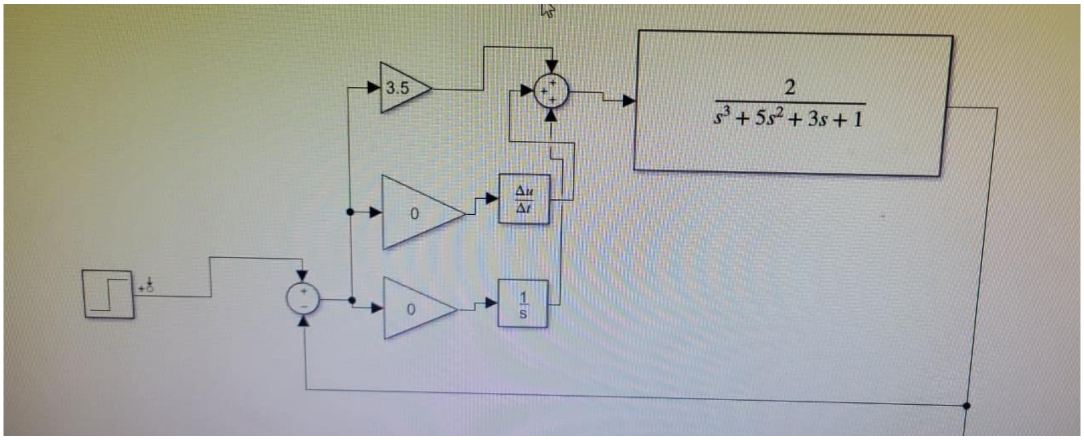
Methodology

1. **Plant Modeling:**
   - Constructed a unity-feedback closed-loop system with plant $G(s) = \frac{2}{s^3+5s^2+3s+1}$.
   - Incorporated a step input (amplitude 1) and scope for output visualization.
2. **Determination of K_u and T_u:**
   - Configured the controller as proportional-only ($K_i = 0, K_d = 0$).
   - Incrementally increased K_p (starting from 0.1, step 0.1) while simulating.
   - Identified $K_u = 7$ as the value inducing sustained sinusoidal oscillations.
   - Measured $T_u \approx 3.63$ seconds from the oscillation period via scope waveform.
3. **Controller Tuning Using Ziegler-Nichols Rules:**
   - **P Controller:** $K_p = 0.5K_u = 3.5$.
   - **PI Controller:** $K_p = 0.45K_u = 3.15, T_i = T_u/1.2 \approx 3.02, K_i = K_p/T_i \approx 1.04$.
   - **PD Controller:** $K_p = 0.8K_u = 5.6, T_d = T_u/8 \approx 0.45, K_d = K_pT_d \approx 2.54$.
   - **PID Controller:** $K_p = 0.6K_u = 4.2, T_i = T_u/2 \approx 1.81, K_i = K_p/T_i \approx 2.32, T_d = T_u/8 \approx 0.45, K_d = K_pT_d \approx 1.90$.
4. **Simulation and Analysis:**
   - Replaced the proportional block with respective PID blocks (using Simulink PID Controller or transfer function equivalents).
   - Executed step response simulations for each configuration over 50 seconds.
   - Extracted metrics: rise time (10-90%), settling time (2% criterion), percent overshoot, and steady-state value.

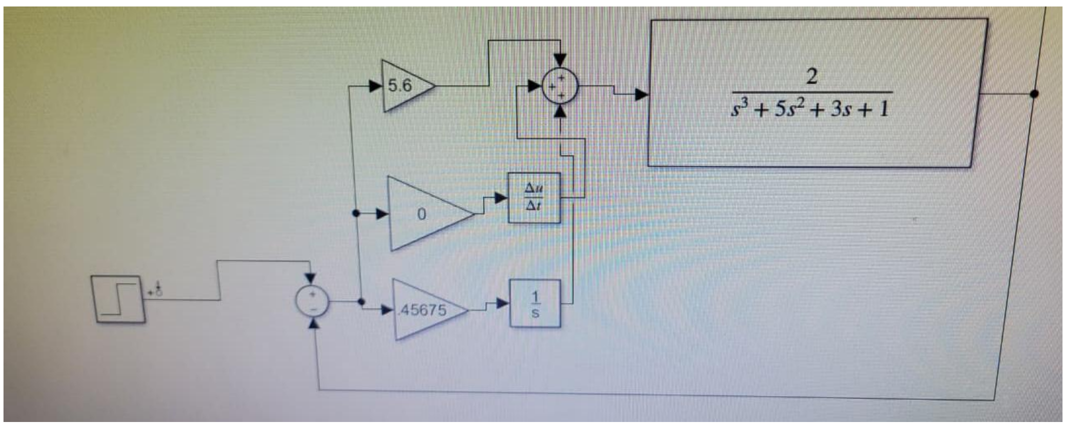
Simulations accounted for derivative action's noise sensitivity by assuming ideal conditions; integral windup was not explicitly mitigated.

Simulink Models:

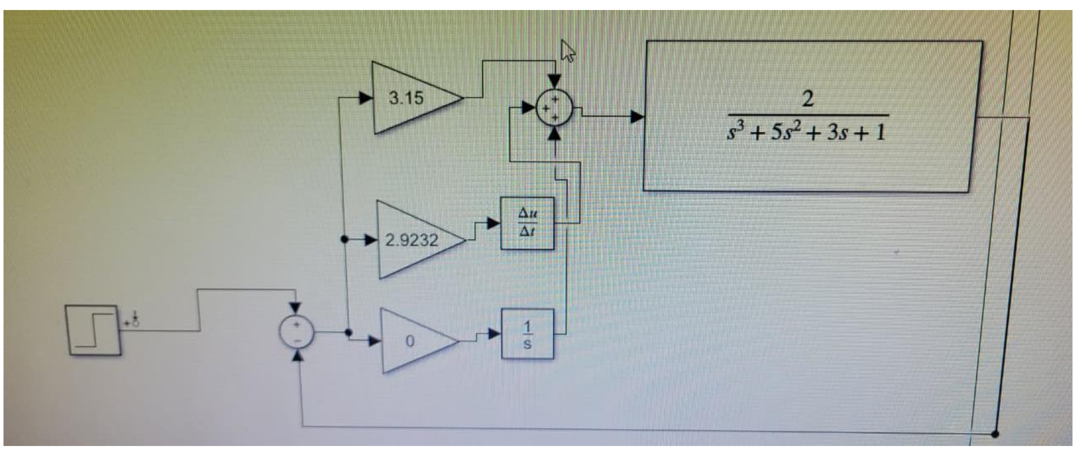
P Controller



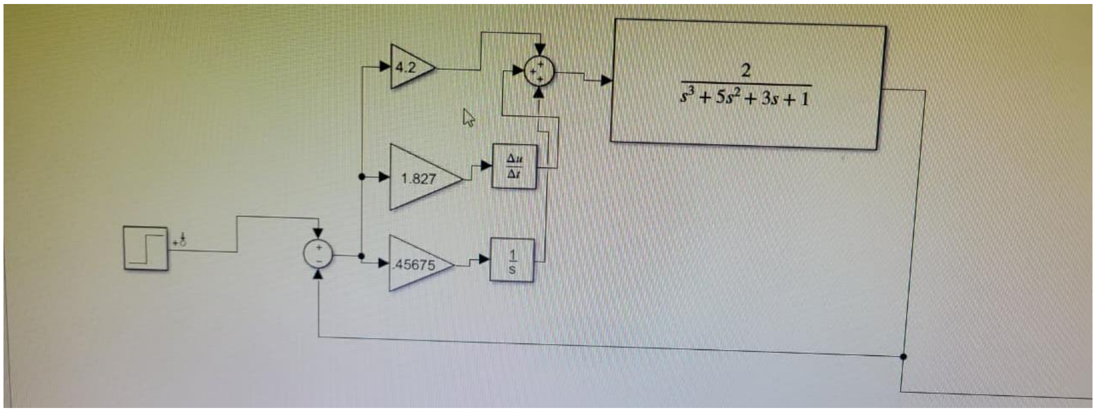
PI Controller:



PD Controller:



PID Controller:



Results

The MATLAB simulation produced the following output:

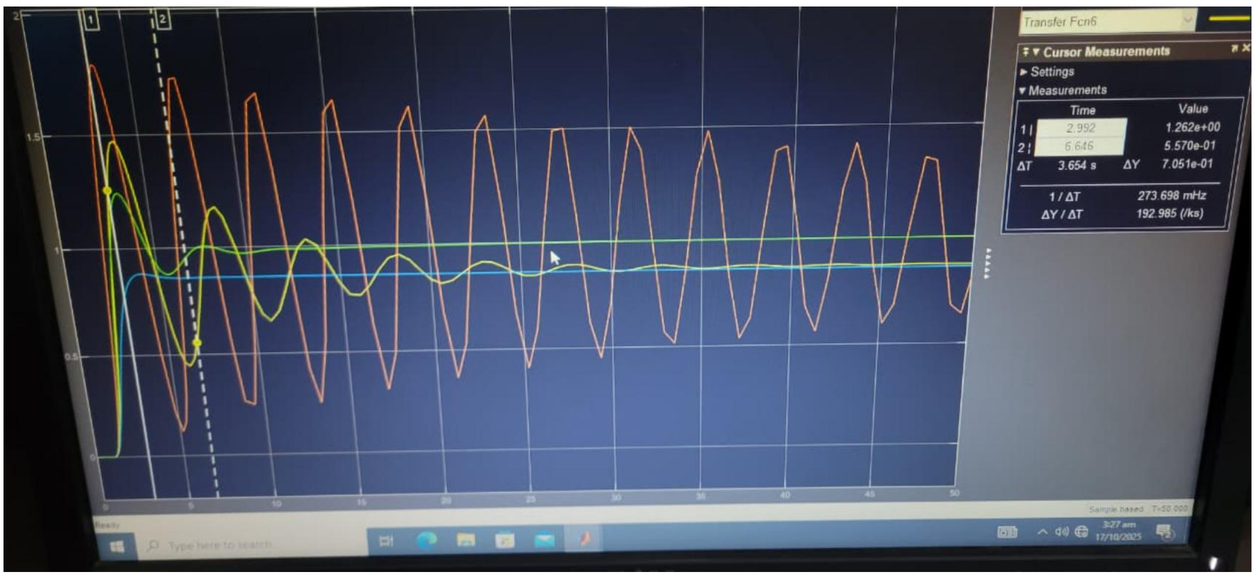


Figure 1 :Blue- pd, green- pid, red- p, yellow- pi

Discussion

The Ziegler-Nichols method successfully identified tuning parameters, aligning with observed Simulink behaviors (e.g., oscillations at $K_p \approx 5.6 - 7$). The PD configuration excelled in transient speed (shortest rise and settling times), validating derivative damping. However, PI's prolonged settling highlights integral saturation risks in higher-order systems; anti-windup techniques could mitigate this. PID offered comprehensive error rejection, though overshoot remained notable—fine-tuning beyond empirical rules (e.g., reducing K_p slightly) might optimize further.

Discrepancies in steady-state values for P and PD stem from the type-0 plant, where DC gain $G(0) = 2$ yields $y_{ss} = \frac{K_p \cdot 2}{1 + K_p \cdot 2} < 1$. Integral action resolves this. Limitations include the method's assumption of sustained oscillations (not always achievable) and sensitivity to plant variations. Extensions could incorporate disturbance rejection or robust tuning via root locus.

Conclusion

The exercise demonstrated the Ziegler-Nichols method's practicality for PID design, enabling effective controller implementation for the given plant. Simulations confirmed theoretical expectations: P for speed, I for accuracy, D for stability, and PID for integration. Acquired insights into gain trade-offs enhance proficiency in feedback system optimization, with applications to real-time control in mechatronics