Pole Placement with PID Controllers

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Main ILO of sub-module "Pole Placement with PID Controllers"

Design a PID controller to place the closed-loop poles at desired locations

Why Pole Placement with PID?

- Pole placement helps us control system response: speed, overshoot, damping.
- PID controllers can shift poles by adjusting K_P , K_I , K_D .
- This is useful when we want specific time-domain behavior (e.g., settling time, overshoot).

Worked Example: First-Order Plant

Given:
$$G(s) = \frac{1}{s+1}$$
 (first-order system)

Goal: Place closed-loop pole at
$$s = -4$$

Try: Use a proportional controller:
$$C(s) = K_P$$

Closed-loop:
$$\frac{K_PG(s)}{1+K_PG(s)} = \frac{K_P}{s+1+K_P}$$

Compare:
$$s + (1 + K_P) = s + 4 \Rightarrow K_P = 3$$

Second-Order System and PID

Given:
$$G(s) = \frac{1}{s(s+1)}$$
 (2nd order, non-minimum phase)

Controller:
$$C(s) = K_P + \frac{K_I}{s} + K_D s$$

Closed-loop char. poly: Denominator of 1 + C(s)G(s)

Choose desired poles (e.g., $s = -2 \pm j2$):

Desired poly: $s^2 + 4s + 8$

Solve for K_P , K_I , K_D so that closed-loop denominator matches this.

Summarizing

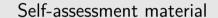
From desired poles to PID parameters

- Pick desired poles based on time response specs
- Derive desired characteristic polynomial
- Write closed-loop transfer function with PID
- Match polynomials & solve for K_P, K_I, K_D
- Note that you may not be able to place the poles where you want (i.e., the system above to do not have solutions)



Python Enables Symbolic Matching of PID Coefficients

sympy



What is the first step in designing a PID controller using pole placement?

Potential answers:

I: Tune K_P using trial-and-error

II: Write the plant transfer function in state-space

III: Choose desired closed-loop poles based on time-domain specs

IV: Set the integral gain to zero initially

What is the main goal of pole placement when designing a controller?

Potential answers:

I: To cancel all poles and zeros of the system

II: To achieve desired time-domain behavior such as settling time and overshoot

III: To make the transfer function purely algebraic

IV: To eliminate the need for feedback

How does the derivative term (K_D) in a PID controller primarily affect the pole placement of a system?

Potential answers:

I: It shifts the system poles toward the imaginary axis

II: It always eliminates steady-state error

III: It has no influence on the pole placement

IV: It influences the damping and stability by modifying the characteristic equa-

What is the key mathematical operation used to design PID gains through pole placement?

Potential answers:

I: Taking the inverse Laplace transform of the plant

II: Eliminating zeros from the open-loop transfer function

III: Matching the closed-loop characteristic polynomial to a desired one

IV: Factorizing the numerator of the open-loop transfer function

In a first-order system controlled by a proportional gain K_P , what is the effect of increasing K_P ?

Potential answers:

I: The pole moves further left on the real axis, increasing system speed

II: The pole becomes complex and causes oscillations

III: The system gain decreases and response slows down

IV: The zero of the system moves into the right-half plane

Which of the following best describes the correct order of steps for PID pole placement design?

Potential answers:

- I: Compute the system output first, then choose PID gains, then set desired poles
- II: Start with experimental PID gains, simulate, and refine based on intuition
- III: Choose desired poles, derive the corresponding characteristic polynomial, and match it with the actual closed-loop polynomial to solve for gains
- IV: Eliminate the need for poles by transforming to frequency domain
- V: I do not know

Recap of sub-module "Pole Placement with PID Controllers"

- Pole placement allows us to achieve desired dynamics
- PID gains shift the closed-loop poles
- Match desired characteristic polynomial with actual one
- Use symbolic or numerical tools to solve for K_P , K_I , K_D