Feedback Control

07/16/2025

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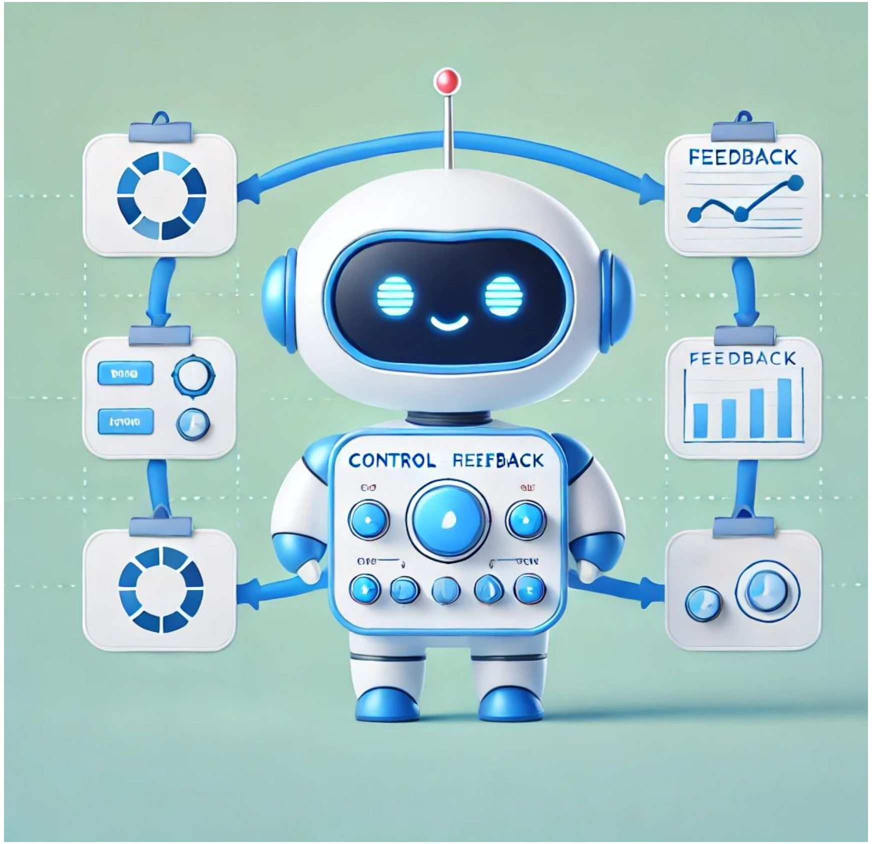
MAYFLOWER
A.S.T.E.M.
ACADEMY



Outline

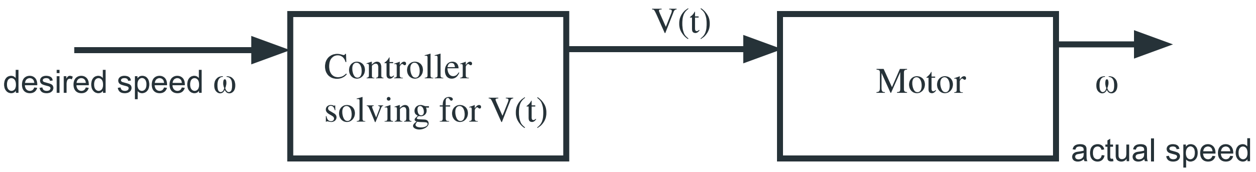
1. Open-loop and Closed-loop Control
2. PID Control Explained
3. PID Math Demystified
4. Project Assignment

1

Open-Loop v.s. Closed Loop Control

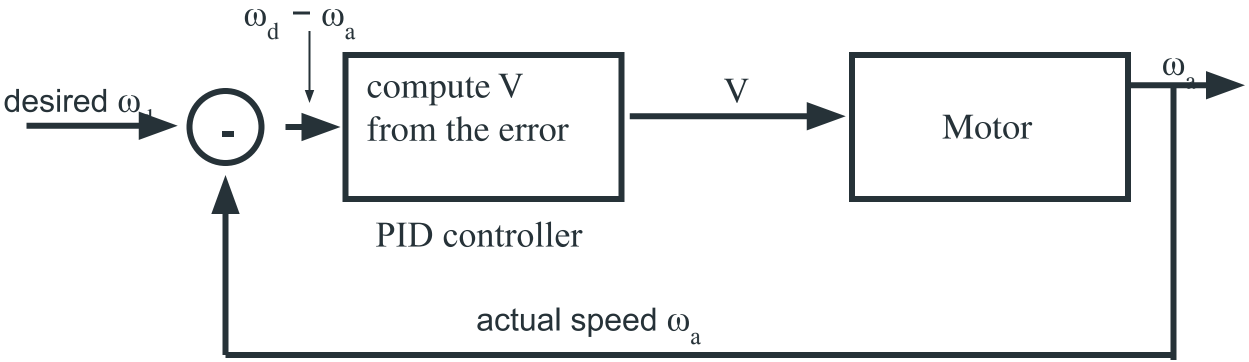
Open-loop vs. Close-loop Control

Open-loop Control:



If desired speed $\omega_d \neq$ actual speed $\omega_{a,}$ So what?

Closed-loop Control: using feedback

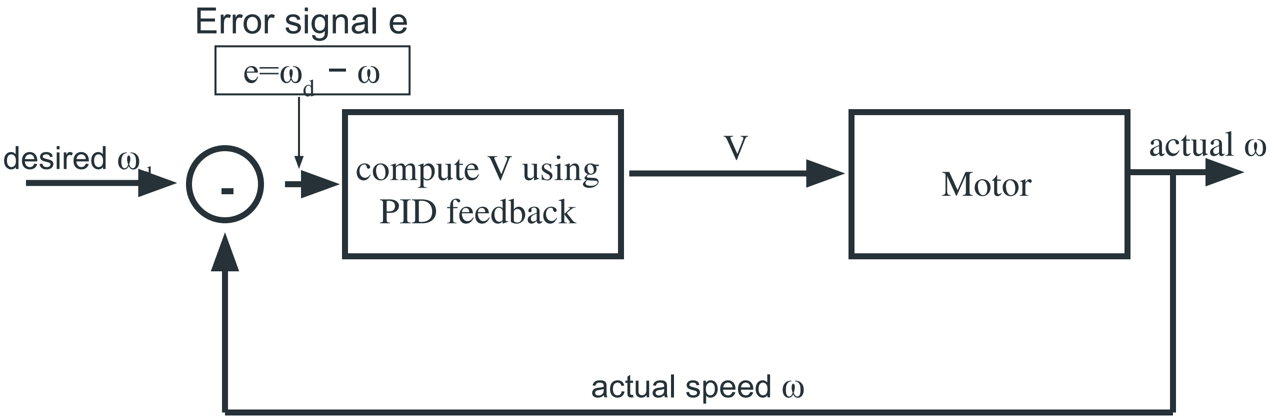


PID Controller

PID control: Proportional / Integral / Derivative control

$$V = K_p\,(\omega_d - \omega) + K_i \int (\omega_d - \omega)\,dt \;+\; K_d \frac{d\,e}{dt}$$

$$V = K_p \cdot \left(e \;+\; K_i \int e \;+\; K_d \frac{d\,e}{dt} \right)$$



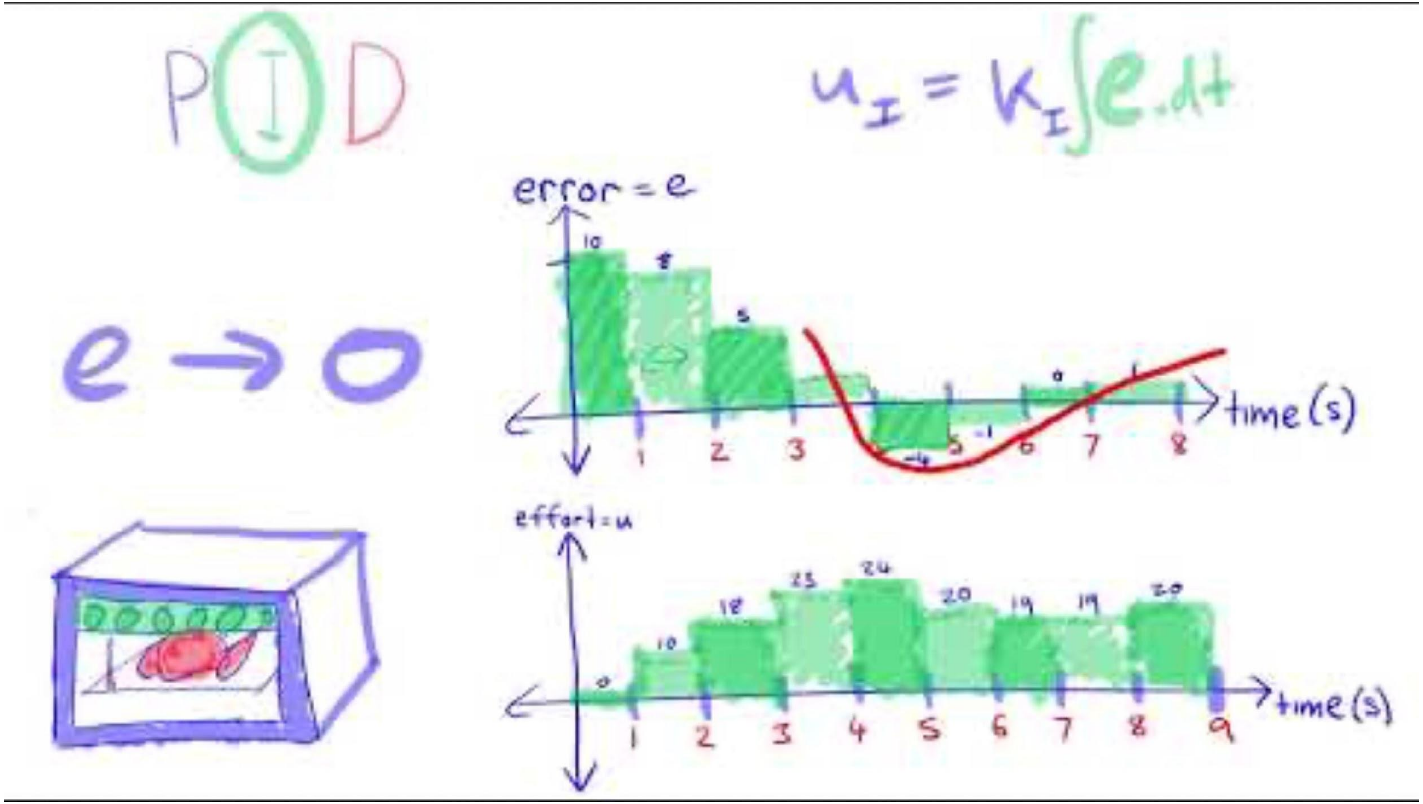
Implementing PID

Use discrete approximations to the I and D terms:

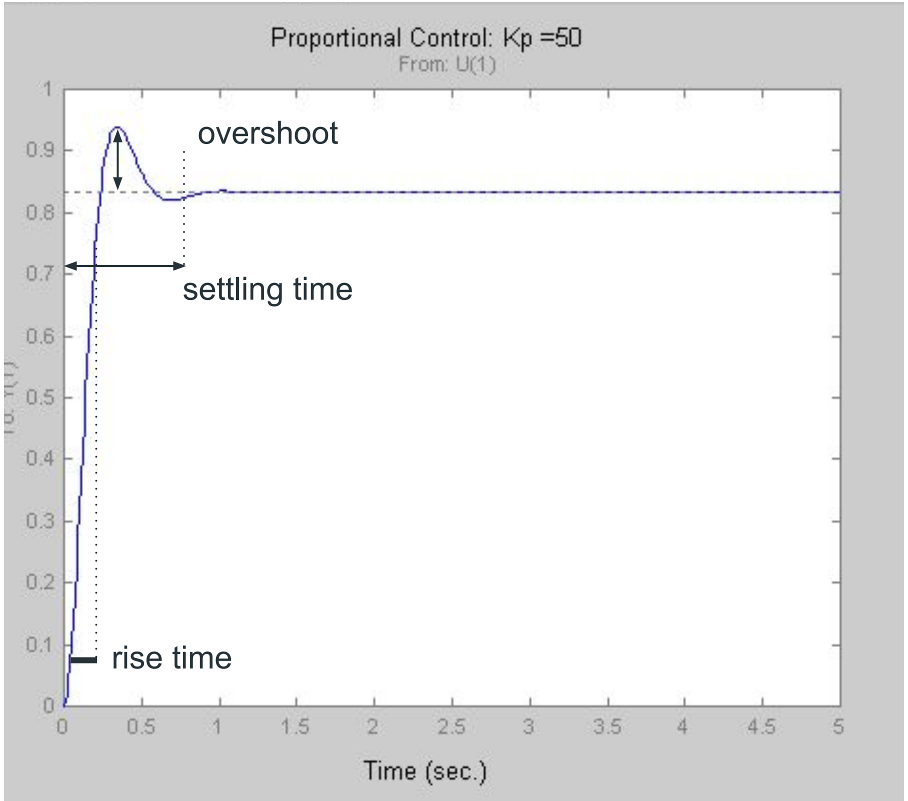
- Proportional term: $e_i = \omega_{desired} - \omega_{actual}$ at time i
  - Integral term: $\sum_{i=0}^{i=now} e_i$
  - Derivative term: $e_i - 2e_{i-1} + e_{i-2}$

2
PID Control Explained

PID Control Explained



Evaluating the response



steady-state error

ss error -- difference from the system’s desired value

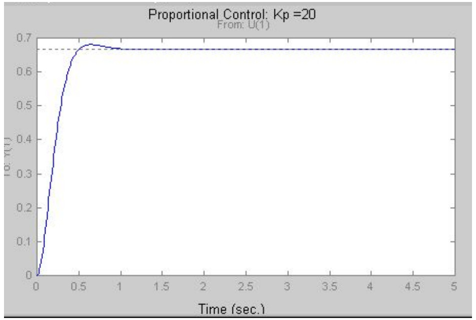
overshoot -- % of final value exceeded at first oscillation

rise time -- time to span from 10% to 90% of the final value

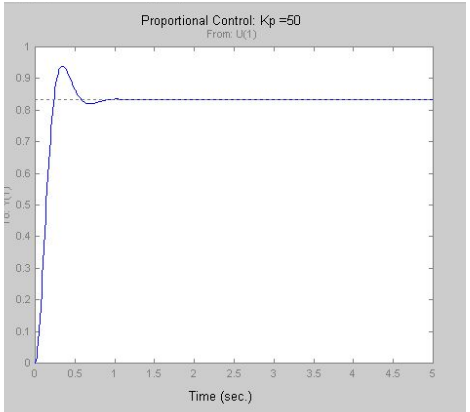
settling time -- time to reach within 2% of the final value

How can we eliminate the steady-state error?

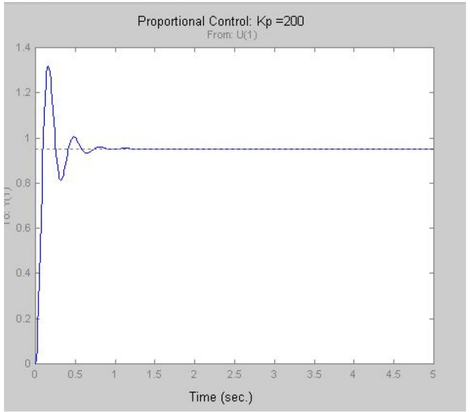
Control Performance, P-type



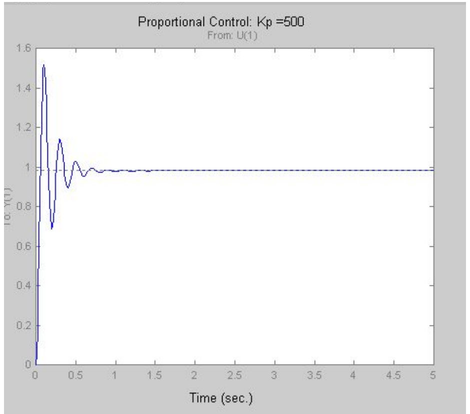
$K_p = 20$



$K_p = 50$

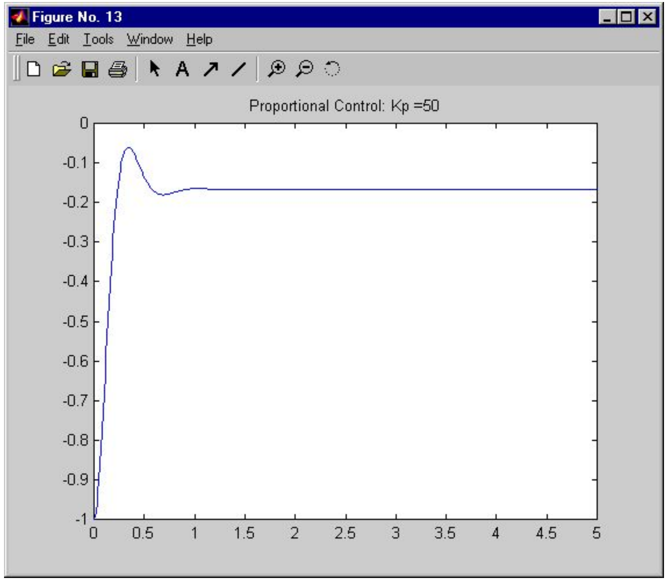


$K_p = 200$

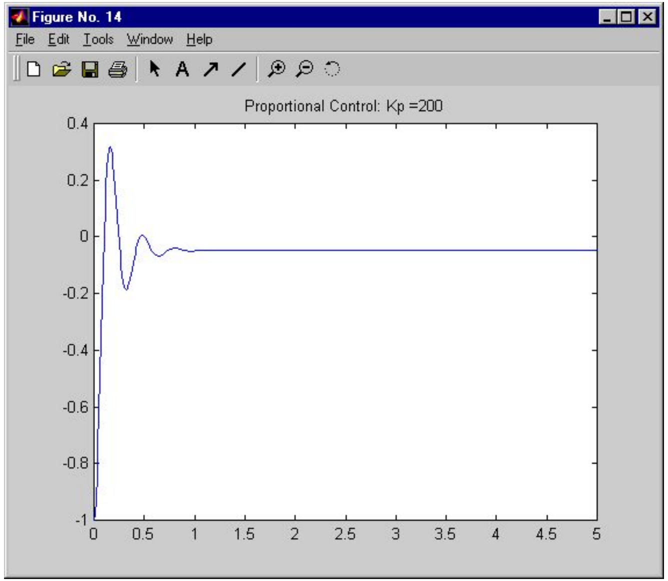


$K_p = 500$

Steady-state Errors, P-type



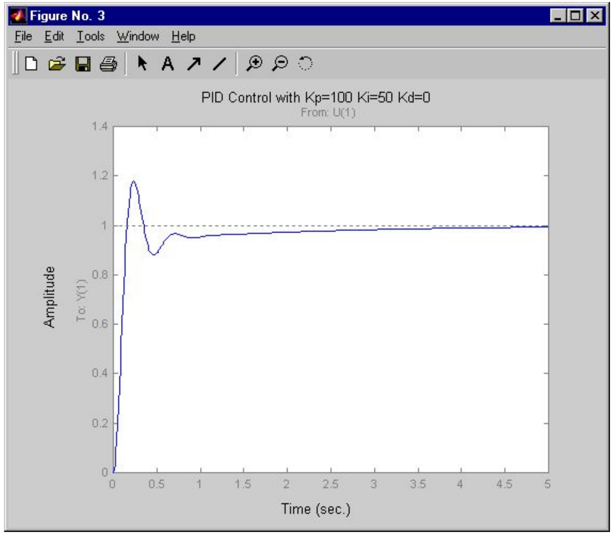
$K_p = 50$

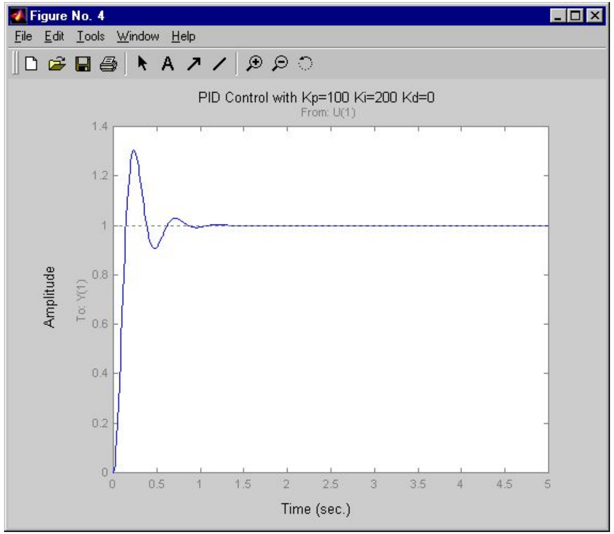


$K_p = 200$

Control Performance, PI - type

$K_p = 100$

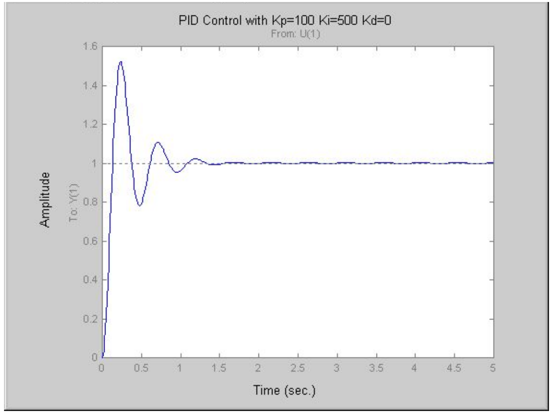


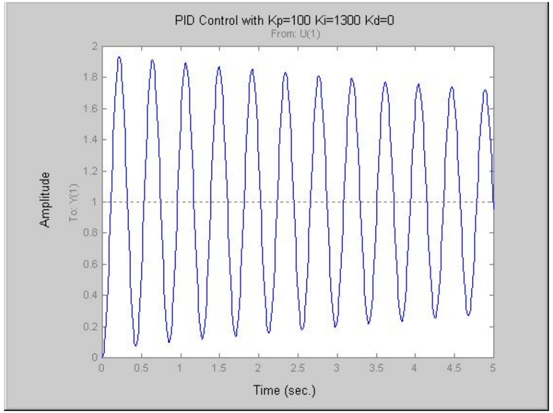


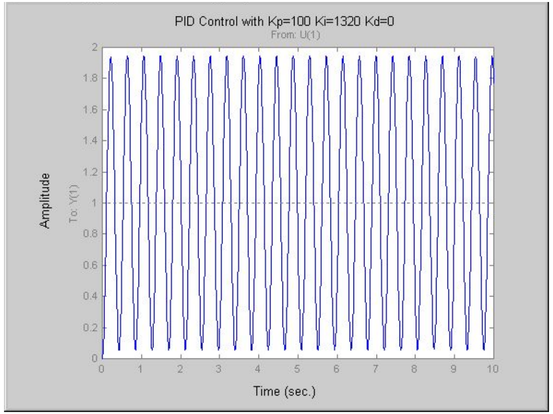
$K_i = 50$ $K_i = 200$

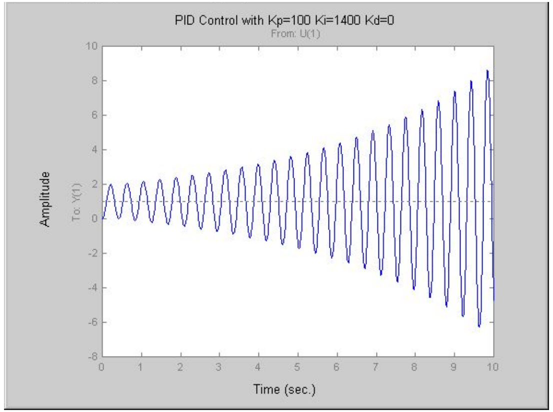
You’ve been integrated...

$K_p = 100$









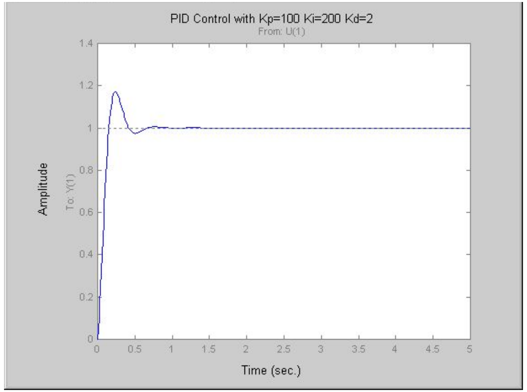
instability &
oscillation

Control Performance, PID-type

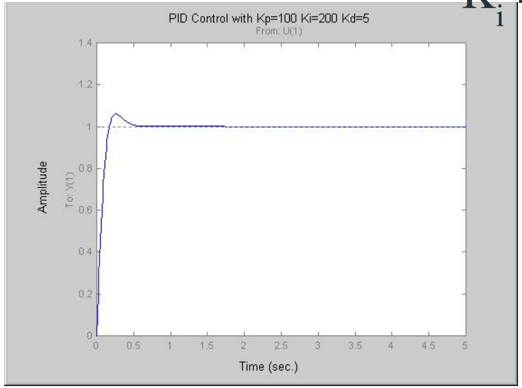
$K_p = 100$

$K_i = 200$

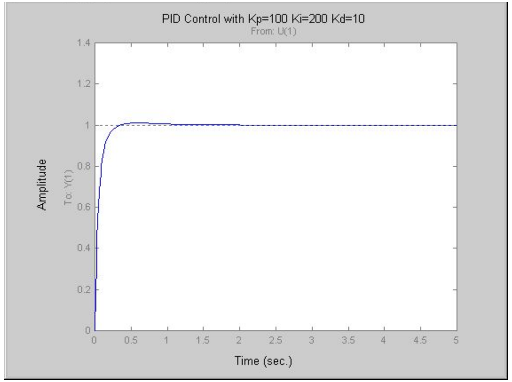
$K_d = 2$



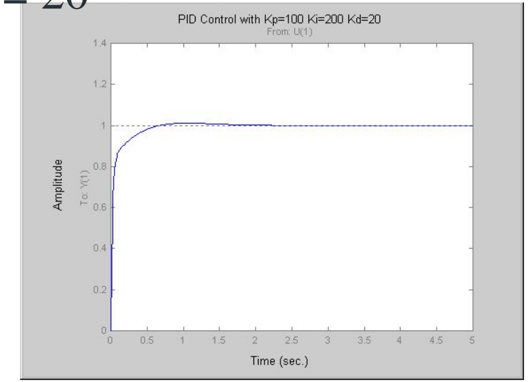
$K_d = 5$



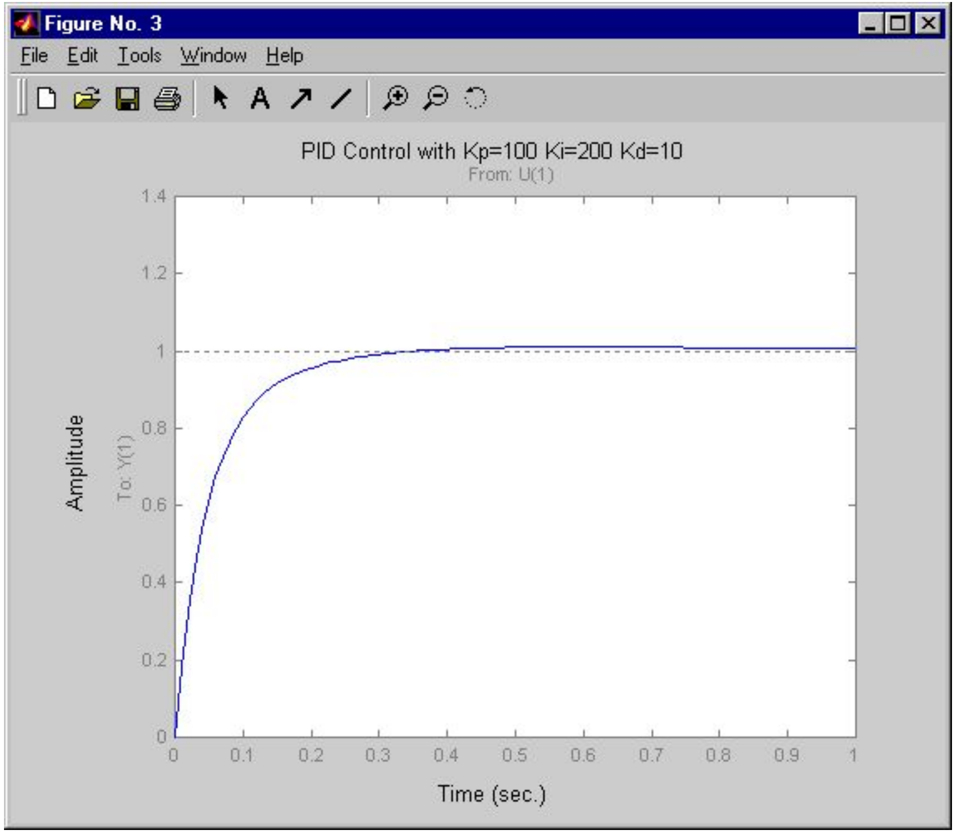
$K_d = 10$



$K_d = 20$



PID final control



PID Tuning

How to get the PID parameter values ?

(1) If the system has a known mathematical model (i.e., the transfer function), analytical methods can be used (e.g., root-locus method) to meet the transient and steady-state specs.

(2) When the system dynamics are not precisely known, we must resort to experimental approaches.

Ziegler-Nichols Rules for Tuning PID Controller:

Using only Proportional control, turn up the gain until the system oscillates w/o dying down, i.e., is marginally stable. Assume that K and P are the resulting gain and oscillation period, respectively.

Then, use

for P control	for PI control	for PID control
$K_p = 0.5\ K$	$K_p = 0.45\ K$	$K_p = 0.6\ K$
	$K_i = 1.2 / P$	$K_i = 2.0 / P$
		$K_d = P / 8.0$

Ziegler-Nichols Tuning for second or higher order systems

4

Project Assignment

Project Assignment

Use ultrasonic sensor as the feedback sensor, implement PID controller to make the 4WD robot approaching the wall 4 meters away as fast as possible, as close as possible.

Hints:
Approaching the wall □ no collision with the wall, "no overshoot"

As fast as possible □ minimize settling time

As close as possible □ minimize steady state error

Thank you, enjoy the design!

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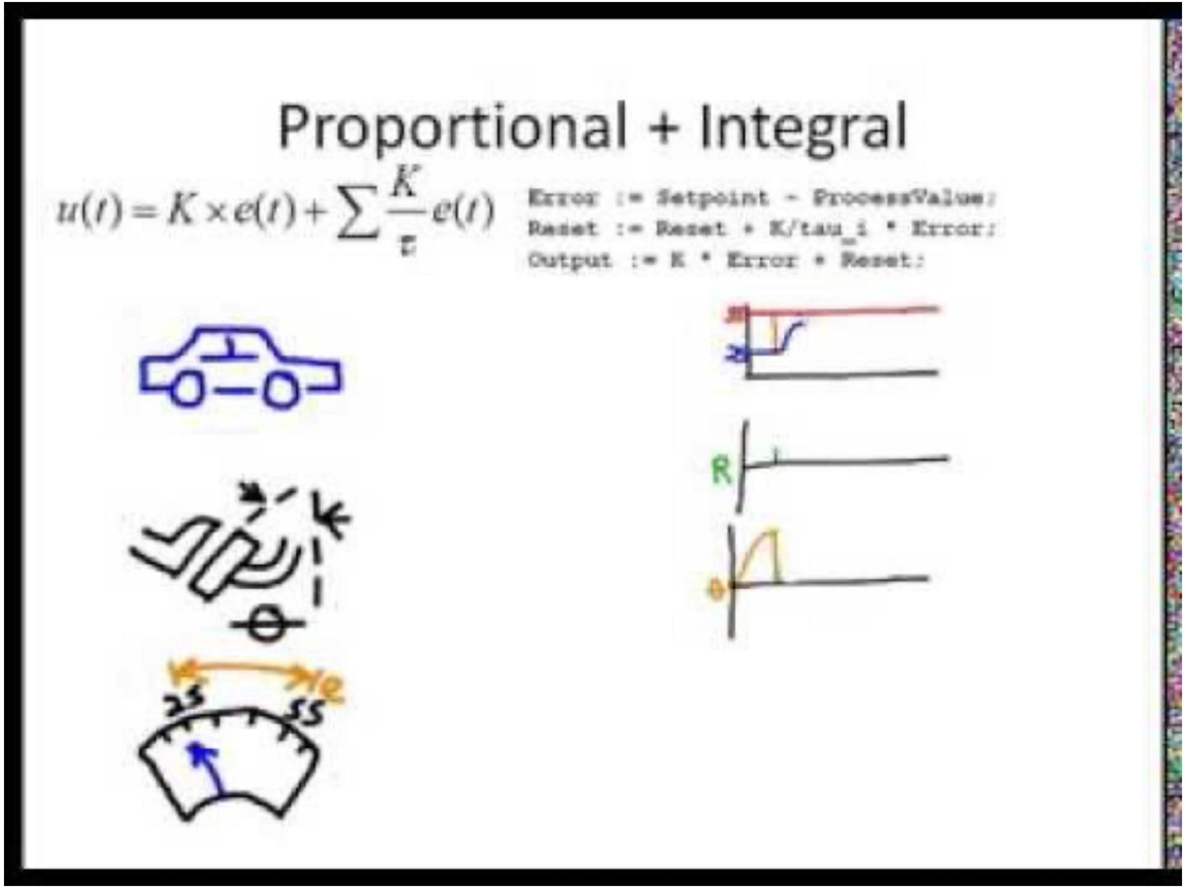
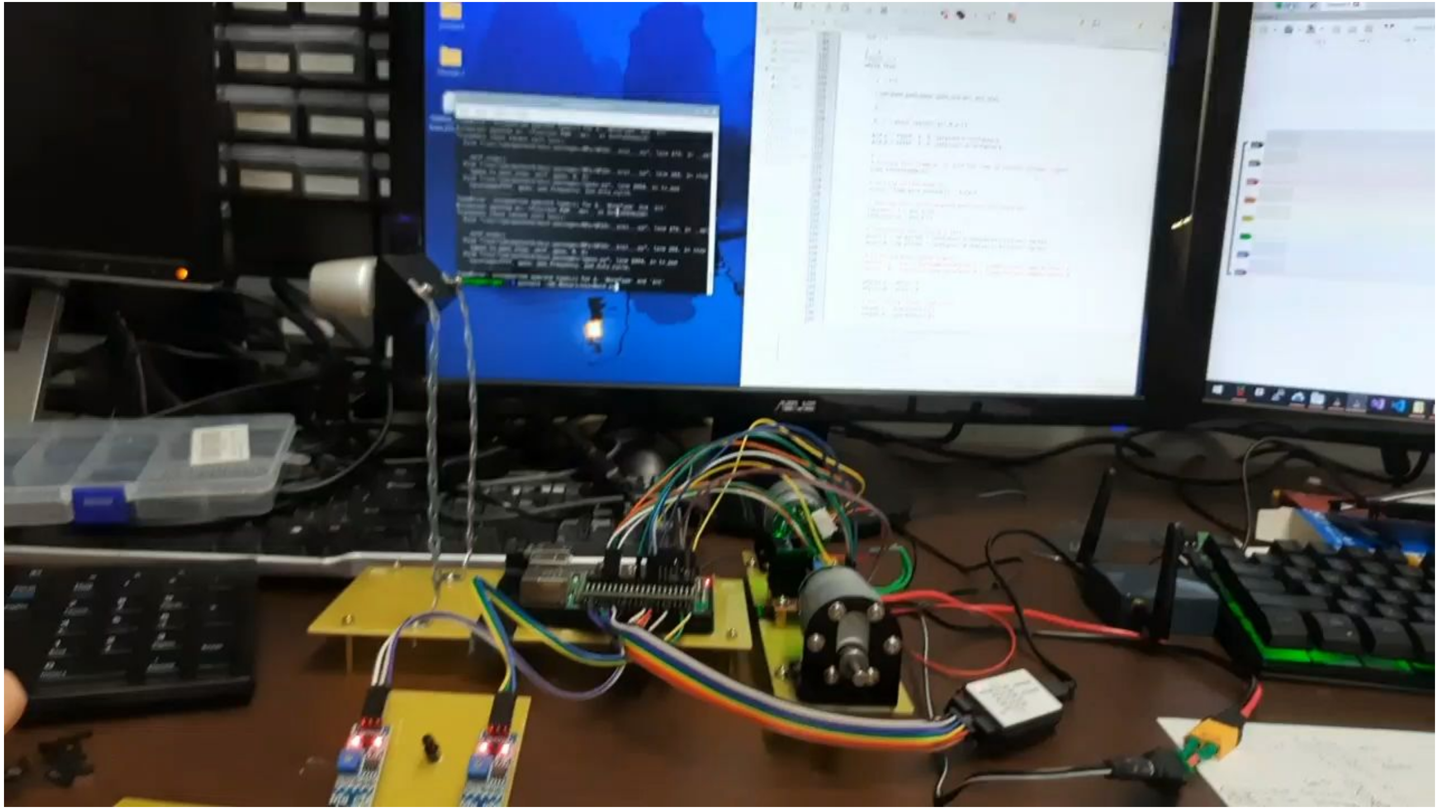
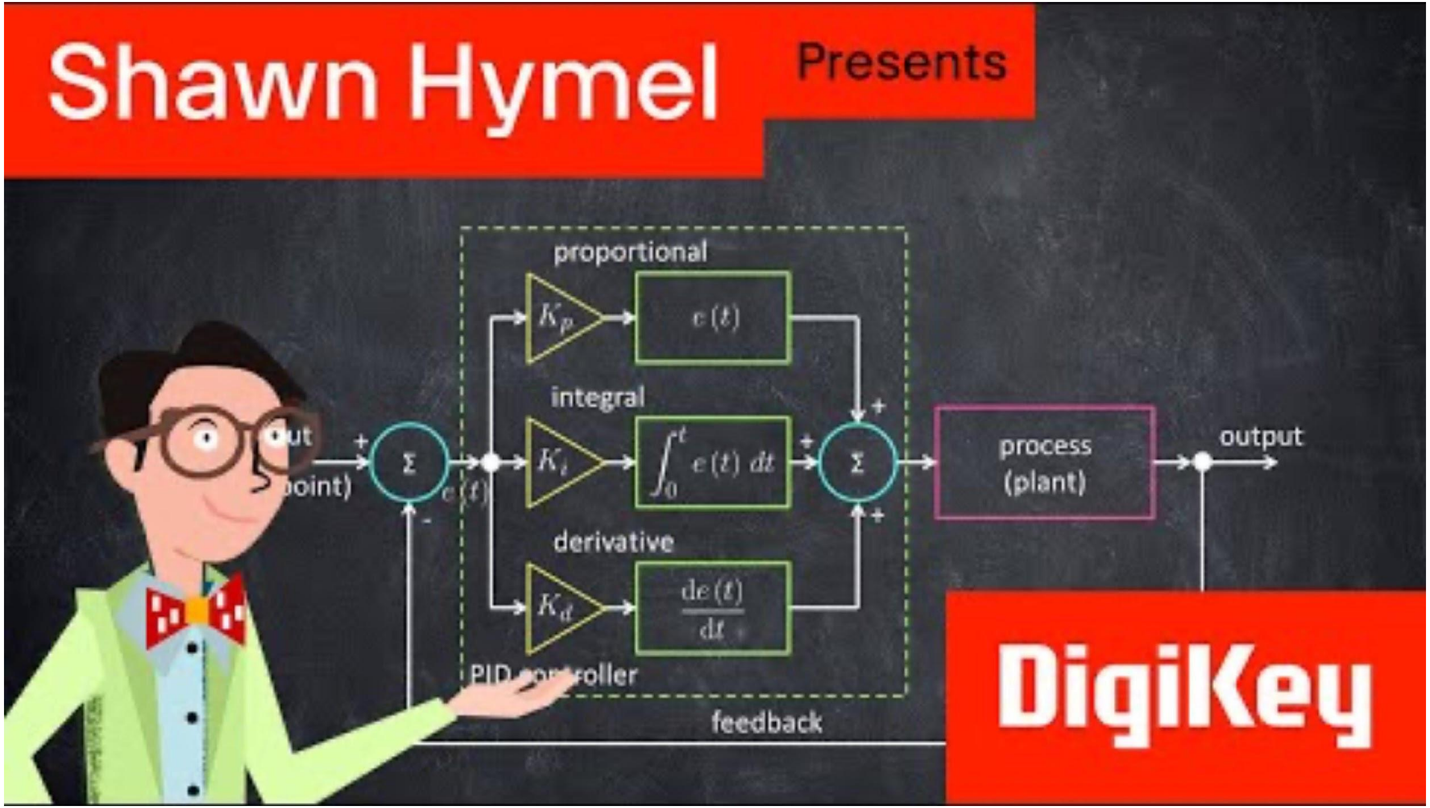
PID Math Demystified

PID Math Demystified

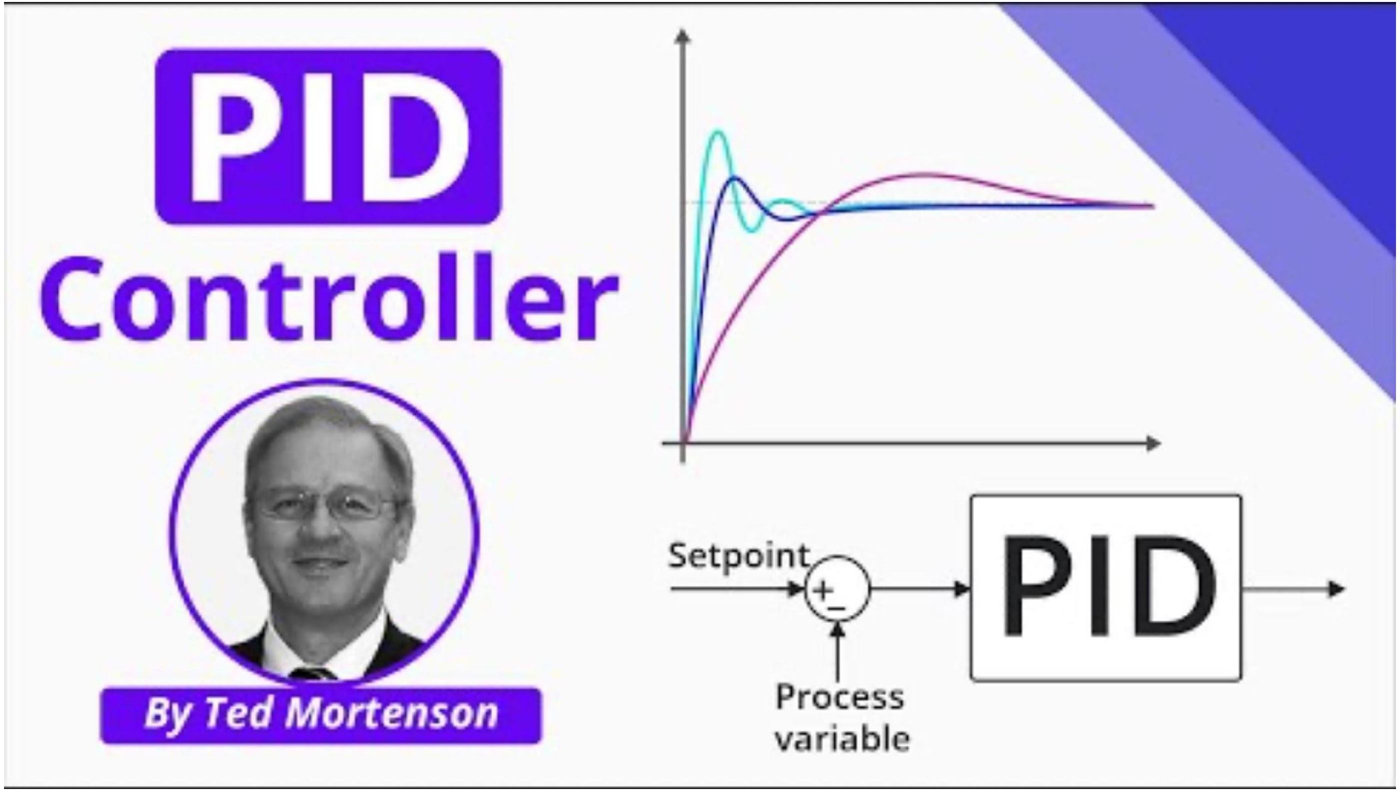


Motor Control Experiment at CCNY Robotics Lab





Shawn Hymel
Presents
proportional
integral
derivative
process
(plant)
output
feedback
DigiKey


PID
Controller
By Ted Mortenson
Setpoint
+
–
Process
variable
PID