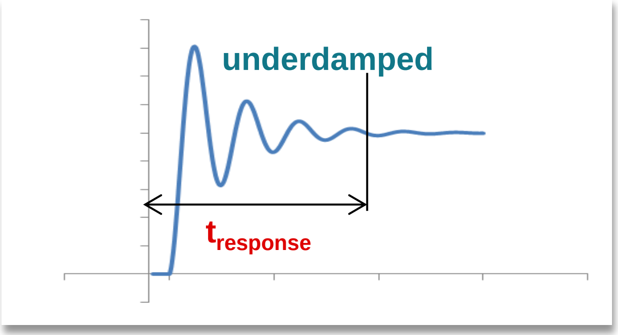
Module 17

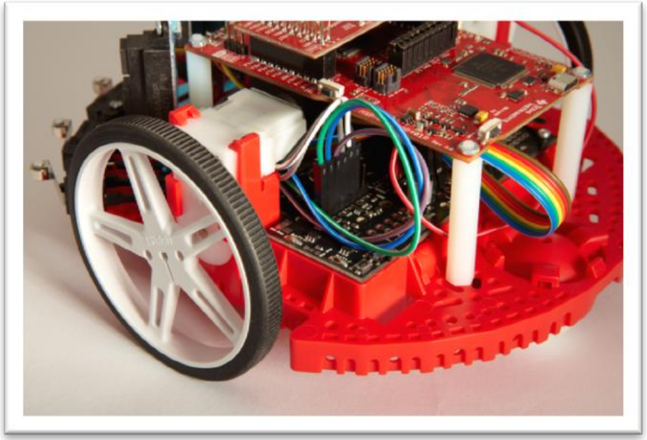
Lecture: Control Systems

Control Systems

You will learn in this module

- Introduction to control
  - Inputs
  - Control equations
  - Outputs
- DC motor control
  - Tuning
- Controller Performance
  - Stability
  - Accuracy
  - Time constant

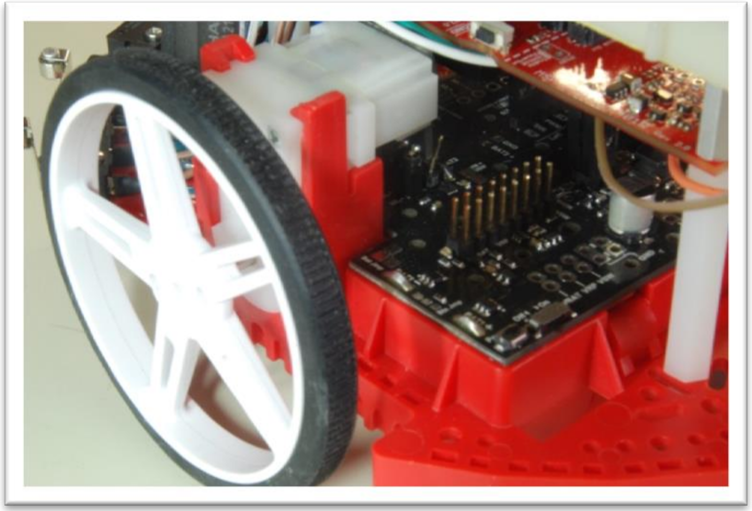




Introduction to Control Systems

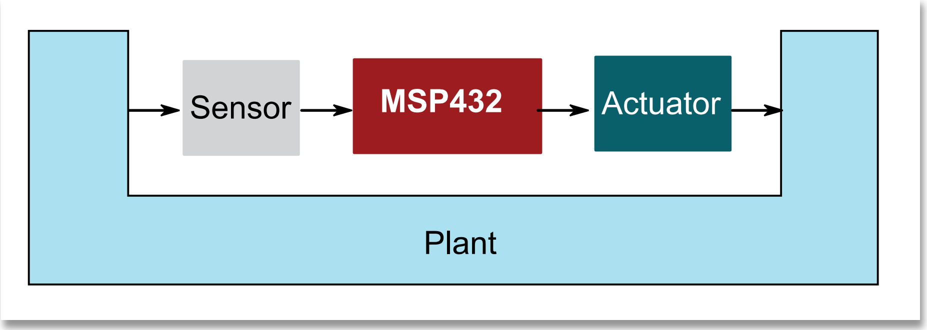
Microcomputers are widely employed in control systems:

- Automotive
  - Automatic breaking systems,
  - Ignition systems
  - Fuel systems
- Household appliances
- Industrial robots
- Medical devices

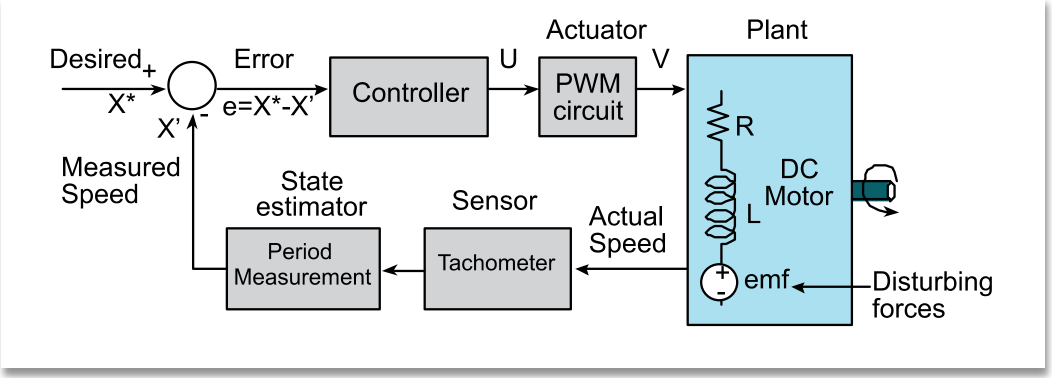


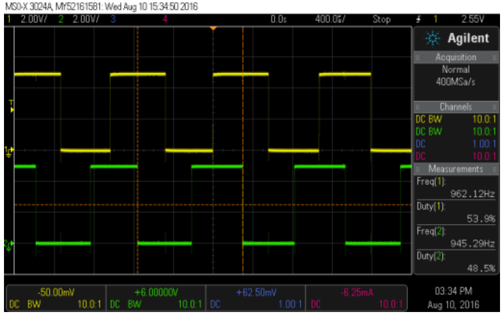
Control System Strategy

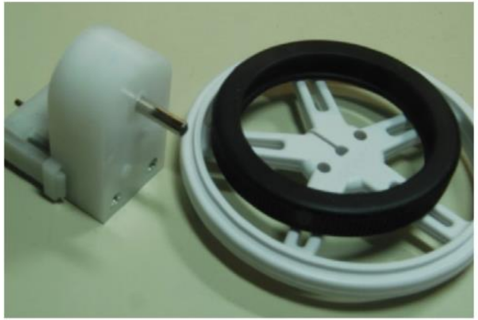
- Plant is a system that is intended to control
- Collect information concerning the plant – data acquisition system (DAS)
- Compare with desired performance
- Generate outputs to bring plant closer to desired performance



Control Theory



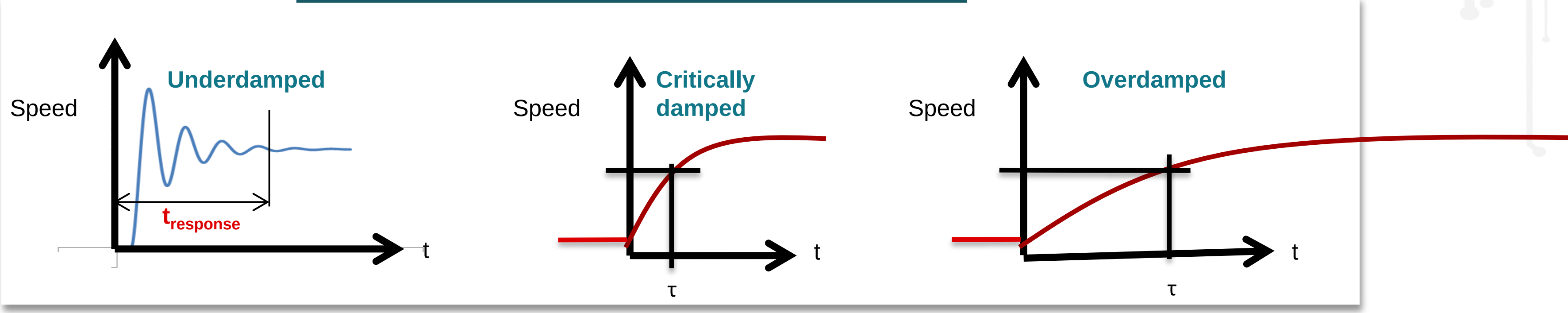




Performance Metrics

- Accuracy = steady-state controller error
  - Average difference between desired and actual
- Time constant = transient response
  - How quickly the system responds to change
- Stability = Standard deviation of controller error
  - System output changes smoothly – without oscillation or unlimited excursions

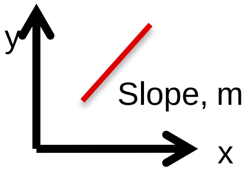
Response to change in setpoint, or change in load



Motor Model

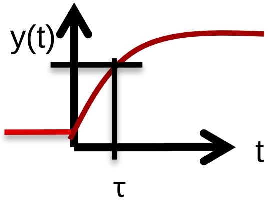
Duty cycle, x(t) → **Motor** → Speed y(t)

Linear model
- Gain, m
- Time constant, τ



Duty cycle, X(s) → **Motor** → Speed Y(s)

$$H(s) = \frac{Y(s)}{X(s)} = \frac{m}{1+s\tau}$$

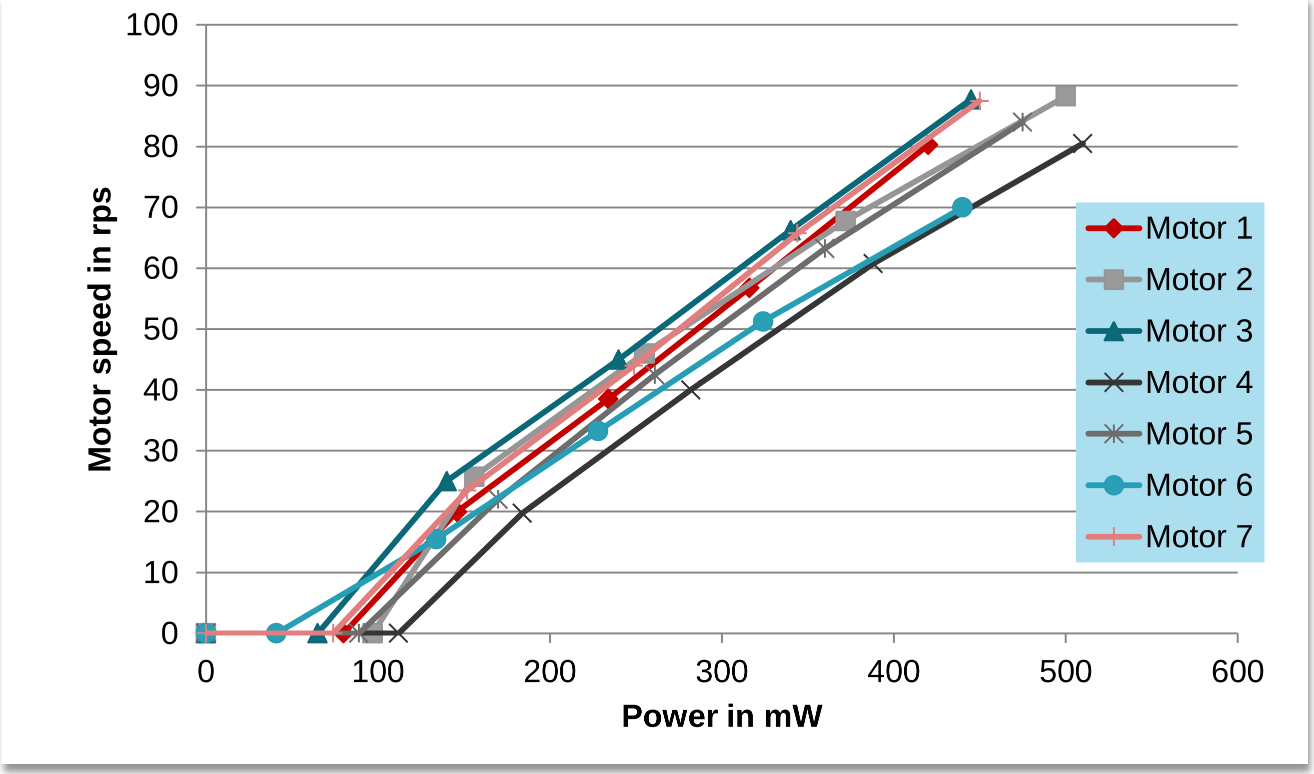


$$y(t) = S_0 + \Delta S\, e^{-t/\tau}$$

Motors are not linear
Friction affects everything

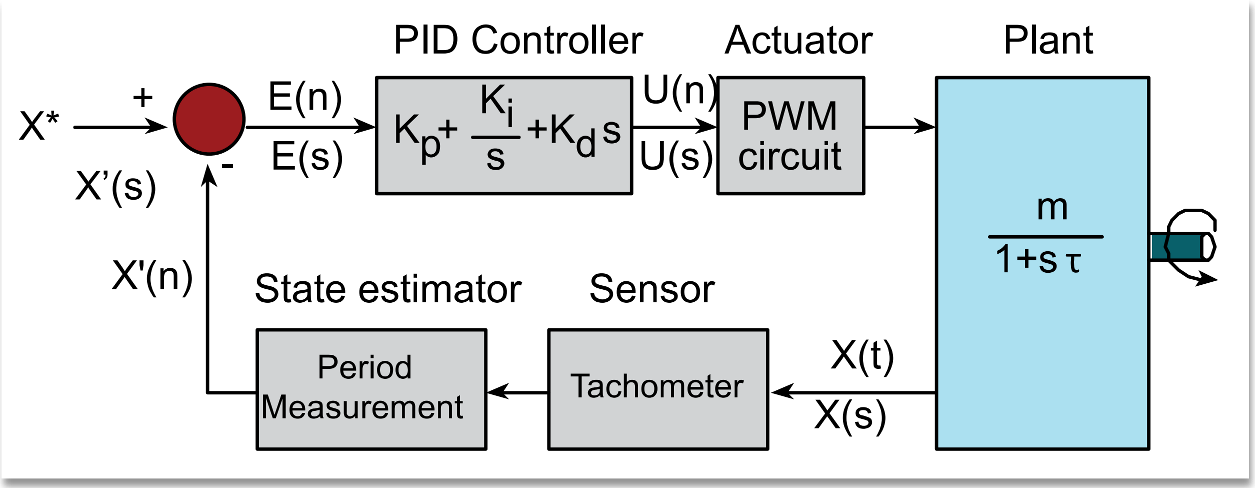
Motivation for a Control System

Motors are not linear
Friction affects everything

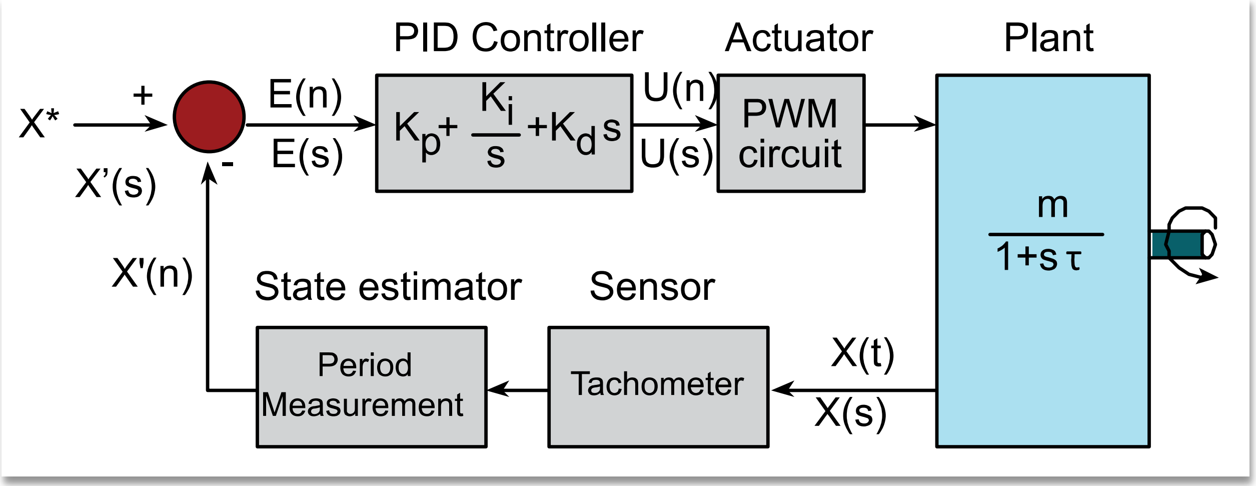


Power = Voltage*Current*DutyCycle

PID Control


PID Controller
Actuator
Plant
X*
+
E(n)
E(s)
Kp+ Ki/s +Kd s
U(n)
U(s)
PWM circuit
-
X'(s)
m
1+s τ
X'(n)
State estimator
Sensor
Period Measurement
Tachometer
X(t)
X(s)

PID Control



E = X*- X'

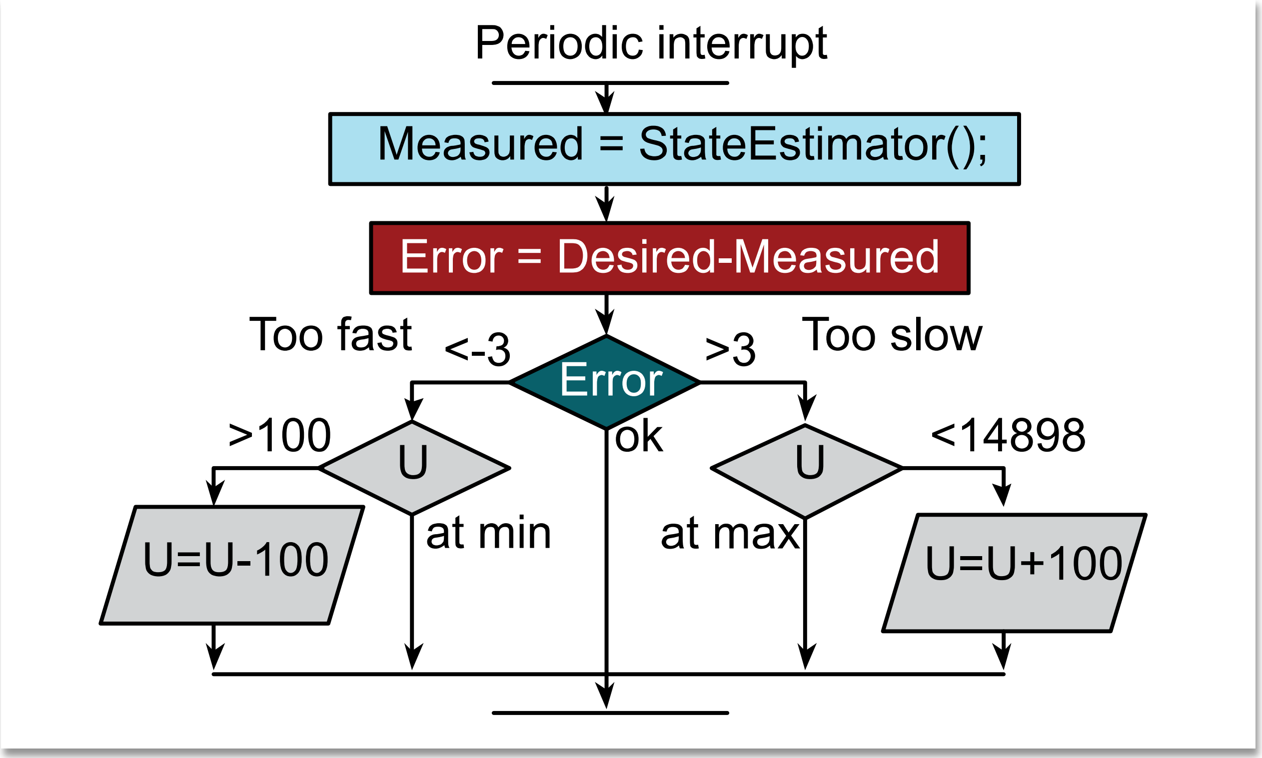
$$G(s) = K_p + K_d s + \frac{K_i}{s}$$

$$\frac{X(s)}{X^*(s)} = \frac{G(s)H(s)}{1 + G(s)H(s)}$$

$$H(s) = \frac{m}{1 + \tau s}$$

U = duty cycle to motor

Incremental Control of Motor Speed



General Approach to PID

$$U(t) = K_p E(t) + \int_0^t K_i E(\tau) d\tau + K_d \frac{dE(t)}{dt}$$

Run controller every Δt

- Proportional $U_p = K_p E$
- Integral $U_i = U_i + K_i E \Delta t$
- Derivative $U_d = K_d (E(n) - E(n-1))/\Delta t$
- PID $U = U_p + U_i + U_d$
- Run ten times faster than motor τ
- Run slower or equal to sensor sampling rate

Fixed-point math

- What is a fixed-point number
  - value = integer*constant
  - constant has units, dimensional analysis
- Why do we use fixed-point numbers
  - Express non-integer values
  - Faster than floating point
  - Less expensive microcontroller
- How do we use fixed-point numbers
  - Range is small and known
  - Convert to integer math, divide last

$\pi = 314159/100000$

$U = 0.123*e \rightarrow U = (2015*e)/16384$

Proportional Controller

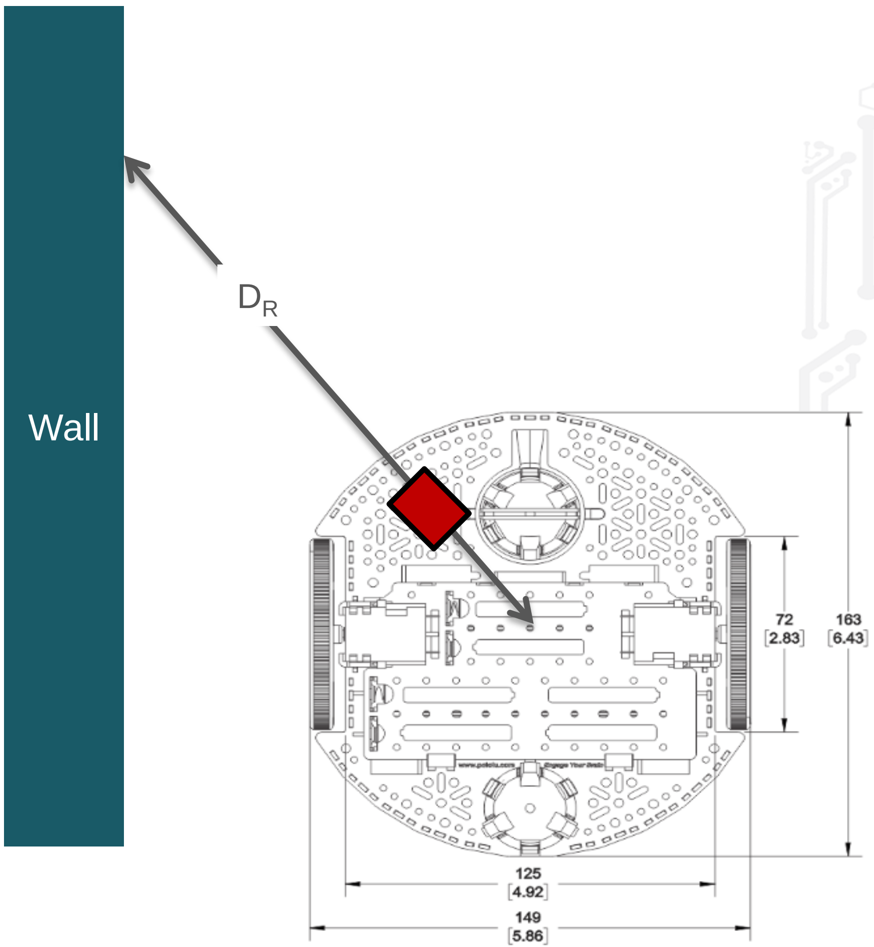
$$U(t) = K_0 + K_p E(t)$$

- Error $E = 250\text{mm} - D_R$
- Proportional $U_L = 5000 - 8*E$
- Proportional $U_R = 5000 + 8*E$

  $2000 \le U_L \le 7000$

  $2000 \le U_R \le 7000$
- Controller period $\Delta t \le \tau / 10$
- Run slower or equal to sensor sampling rate

Run controller every Δt
5000 is expected output



Integral Controller

$$U(t) = \int_0^t K_i E(\tau) d\tau$$

Run controller every Δt

- Error — $E = X^* - X'$
- Integral — $U = U + K_i E \Delta t$
- Antireset windup — $2 \le U \le 14998$

- Controller period — $\Delta t \le \tau / 10$
- Run slower or equal to sensor sampling rate

Summary

Strategy of Proportional Control

- Get the direction correct
- If responsiveness is too slow, increase gain
- If over reacts, decrease gain

Strategy of Integral Control

- Add a lot to U if e is positive large
- Subtract a lot from U if e is negative large
- Add a little to U if e is positive small
- Subtract a little from U if e is negative small
- Leave U constant if e is zero

Advice

- Controller only as good as its sensor
- Observe everything “What was it thinking?”
- Change one parameter at a time
- Choose stability over responsiveness

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