

# TI-RSLK

Texas Instruments Robotics System Learning Kit



TEXAS INSTRUMENTS



# Module 17

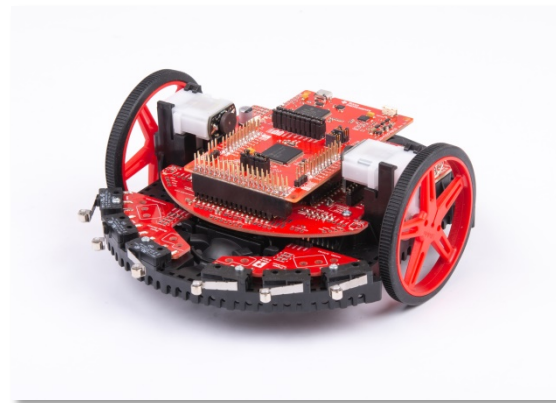
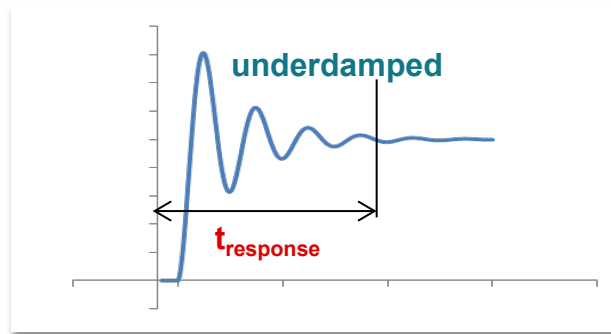
Lecture: Control Systems



# 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

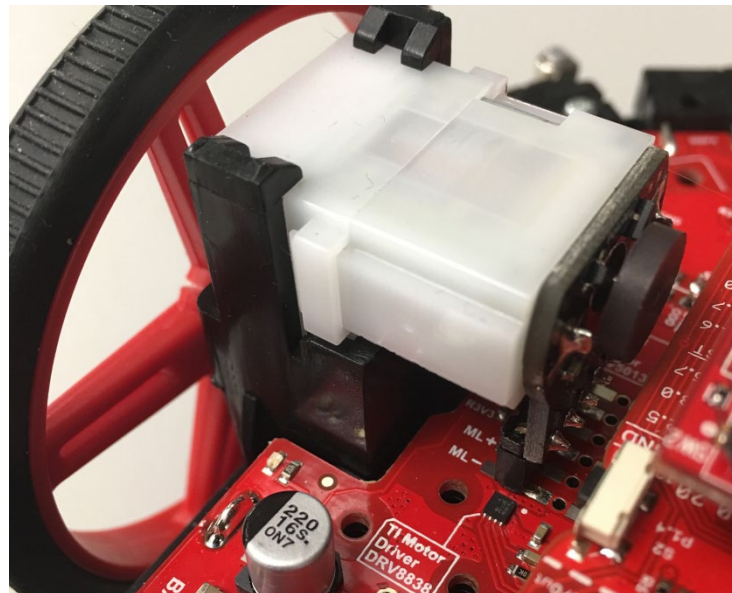




# Introduction to Control Systems

**Microcomputers are widely employed in control systems:**

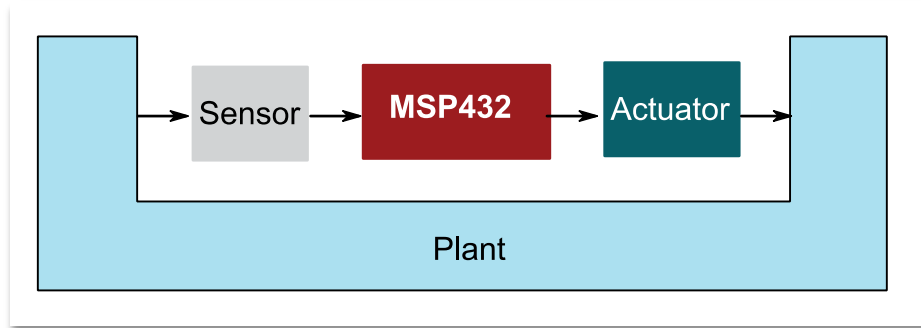
- Automotive
  - Automatic breaking systems,
  - Ignition systems
  - Fuel systems
- Household appliances
- Industrial robots
- Medical devices





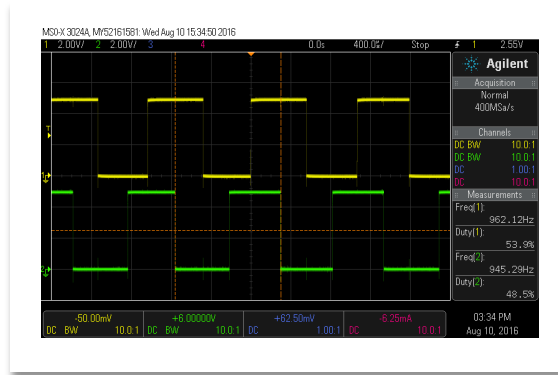
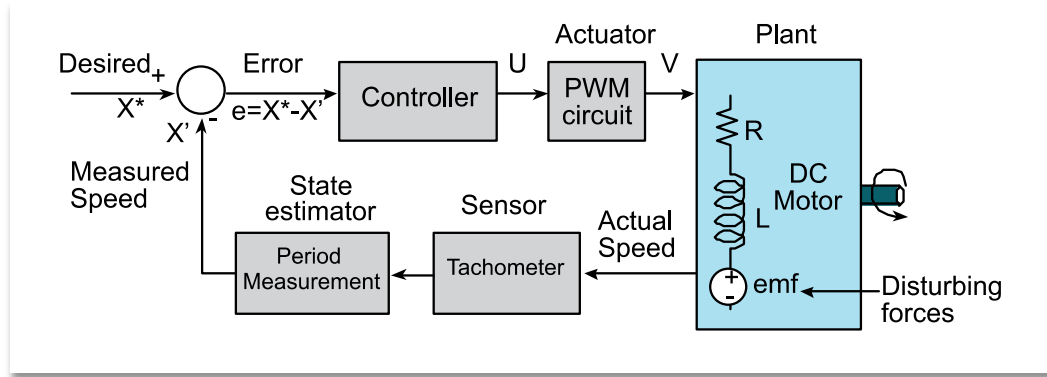
# Control System Strategy

- 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

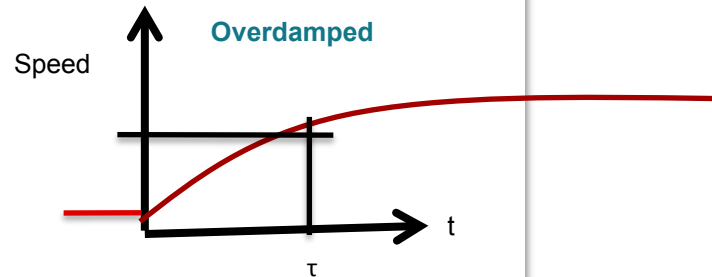
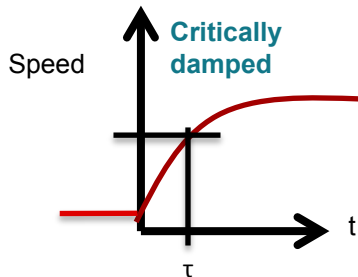
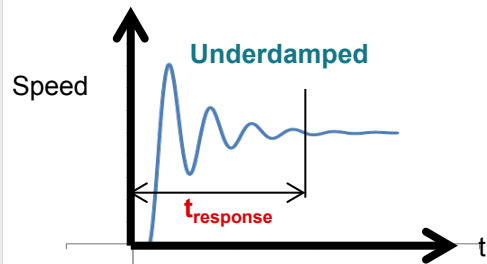




# Performance Metrics

- 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



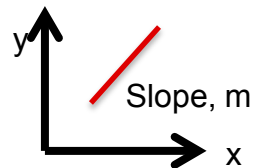


# Motor Model

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

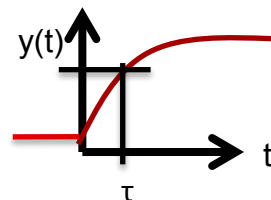
Linear model

- Gain,  $m$
- Time constant,  $\tau$



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

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



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

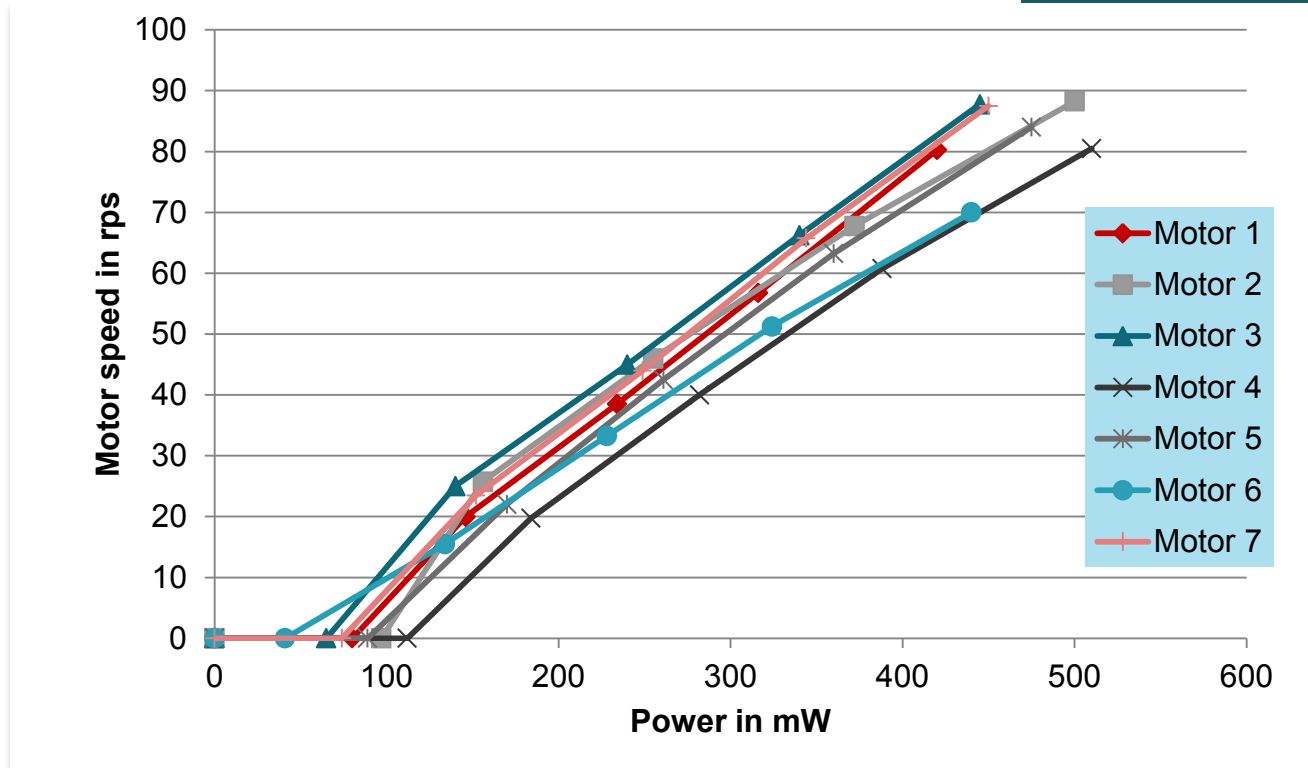
Motors are not linear  
Friction affects everything





# Motivation for a Control System

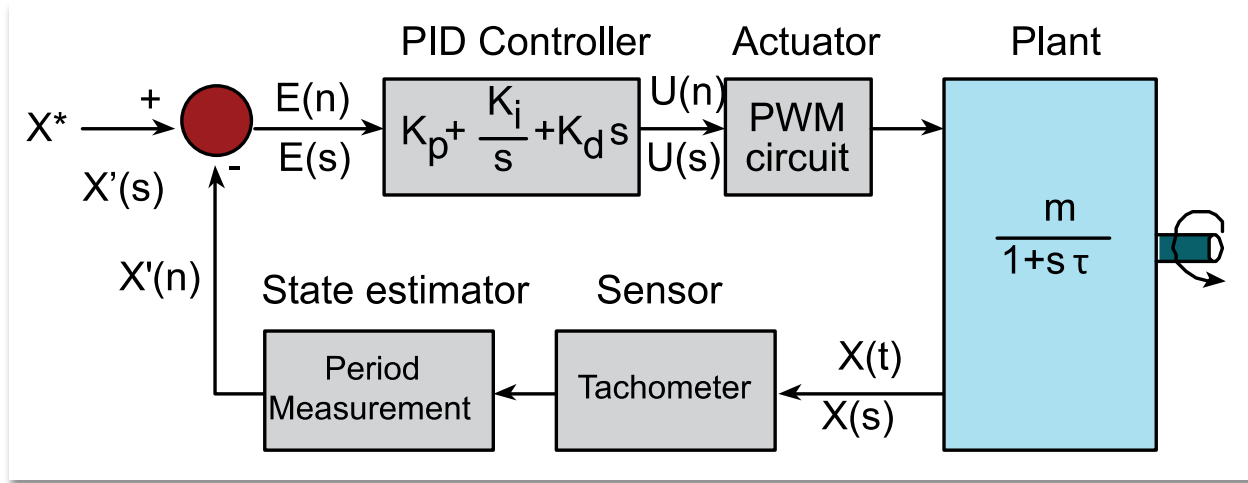
Motors are not linear  
Friction affects everything



$$\text{Power} = \text{Voltage} * \text{Current} * \text{DutyCycle}$$

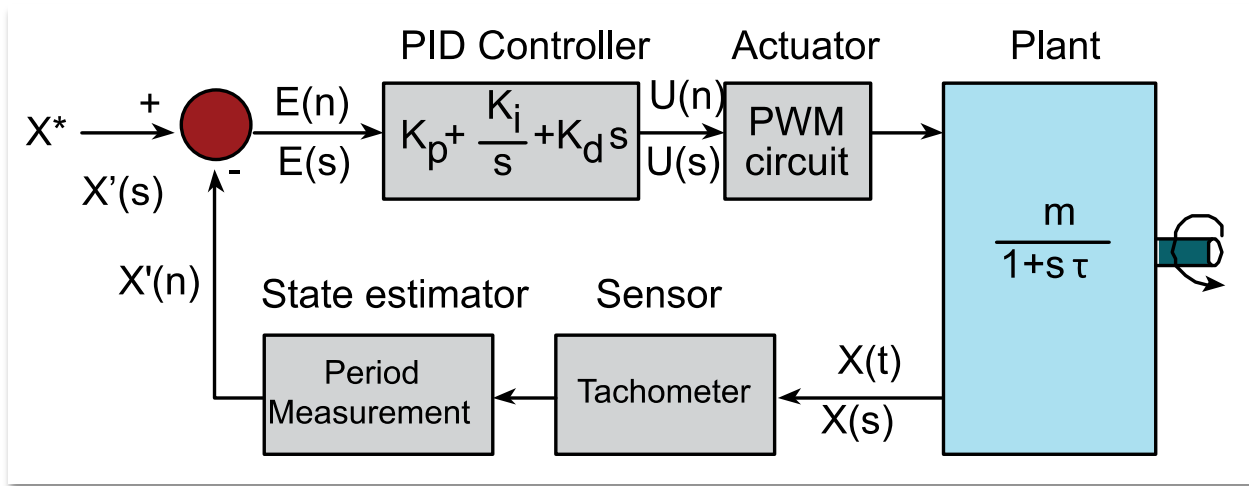


# PID Control





# PID Control



$$E = X^* - X'$$

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

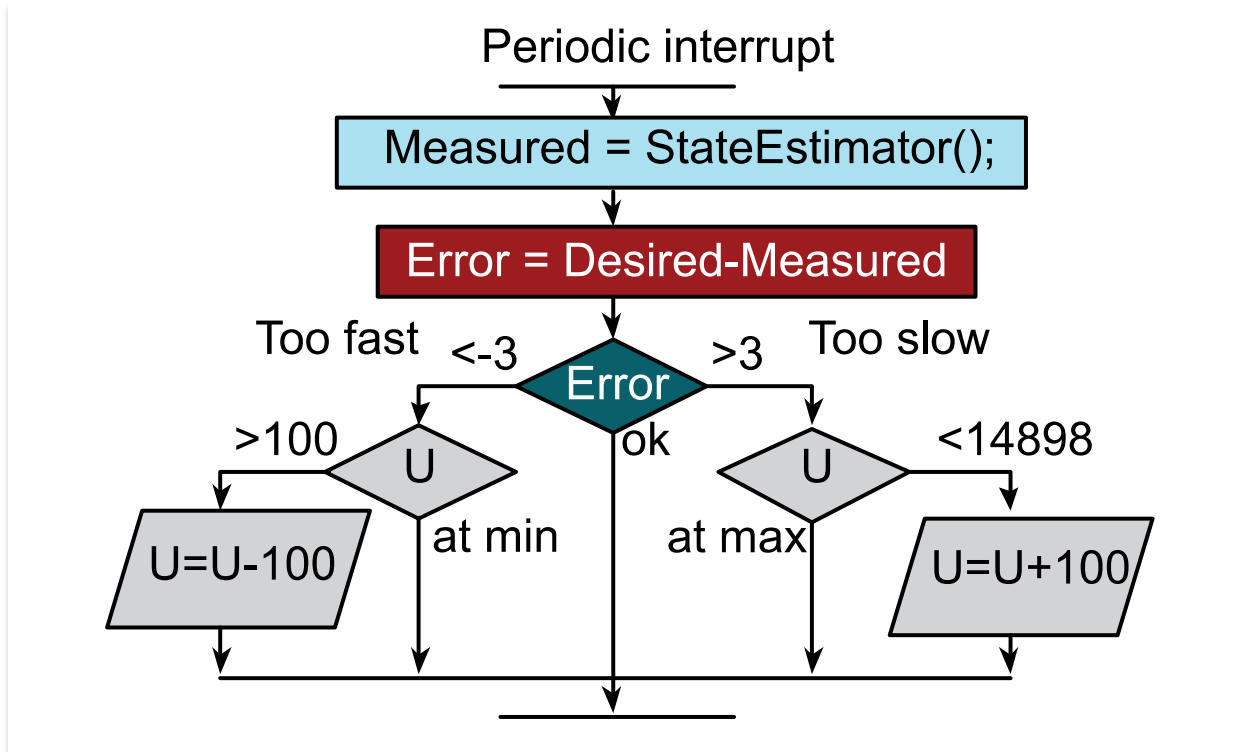
$$\frac{X(s)}{X^*(s)} = \frac{G(s)H(s)}{1 + G(s)H(s)}$$

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

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  $\Delta t$

- 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  $\tau$
- 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

$$\pi = 314159/100000$$

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

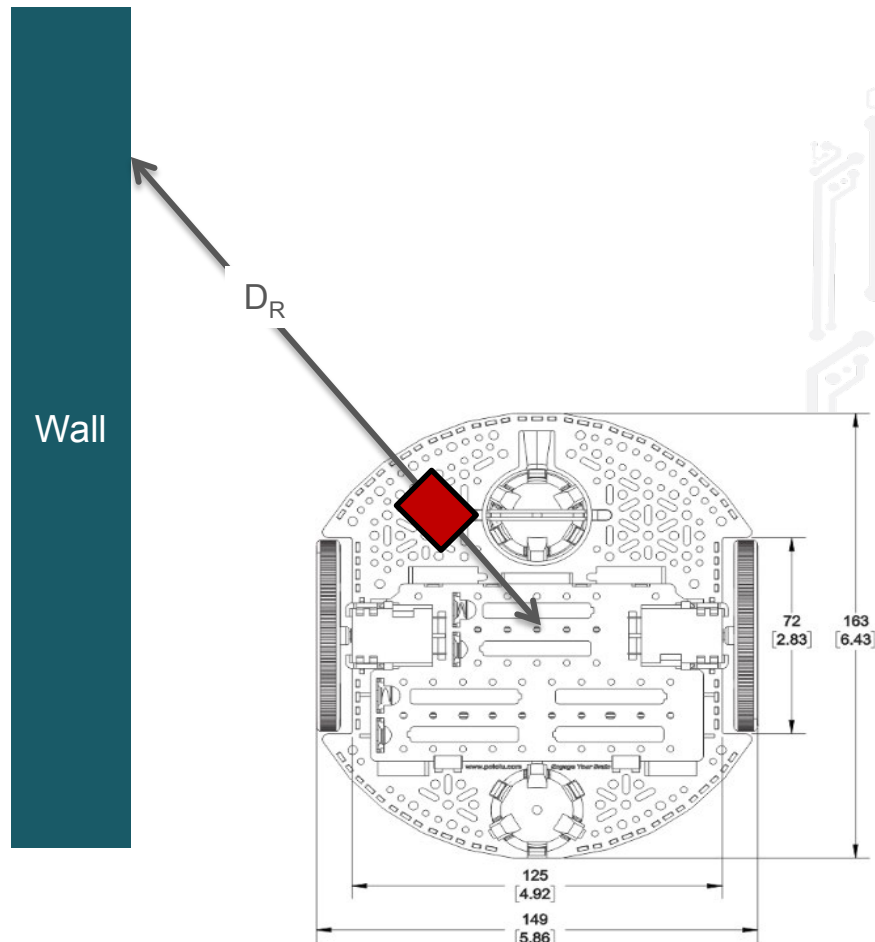


# Proportional Controller

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

- Error  $E = 250\text{mm} - D_R$
- Proportional  $U_L = 5000 - 8 * E$
- Proportional  $U_R = 5000 + 8 * E$   
 $2000 \leq U_L \leq 7000$   
 $2000 \leq U_R \leq 7000$
- Controller period  $\Delta t \leq \tau / 10$
- Run slower or equal to sensor sampling rate

Run controller every  $\Delta t$   
5000 is expected output





# Integral Controller

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

Run controller every  $\Delta t$

- Error  $E = X^* - X'$
- Integral  $U = U + K_i E \Delta t$
- Antireset windup  $2 \leq U \leq 14998$
  
- Controller period  $\Delta t \leq \tau / 10$
- 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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