



# Control Technology Lecture 1

Engr. Muhammad Aamir Aman  
Lecturer  
Department of Electrical Engineering



# Outlines

- Preliminaries
  - My Intro.
  - Course Contents
  
- Control Systems ABC
  - Introduction
  - Examples
  - Terminologies



# My Intro

## ➤ Academics:

- ❑ MS – Power and Energy Engineering (INU)
- ❑ BSc – Electrical Engineering (INU)

## ➤ Professional Experience:

- ❑ Editorial Board Member (SCIREA)
- ❑ Reviewer (JMCMMS)
- ❑ Reviewer (ASTES)

## ➤ Publications: 25 Research Publications



# Course Details

- Course Contents
  
- Assignments & quizzes
  - Research Paper
    - Selection
    - Reading
    - Writing (Summarizing)
    - Presenting



# Recommended book

- **Text book:**
- **Design of Feedback Control Systems by Steffani, Savant, Shahian and Hostetler**
- **Reference Book:**
- **Modern Control Engineering by Katsushiko, Ogata**
- **Modern Control Systems by R. C. Dorf and R. H. Bishop**



# Course outline

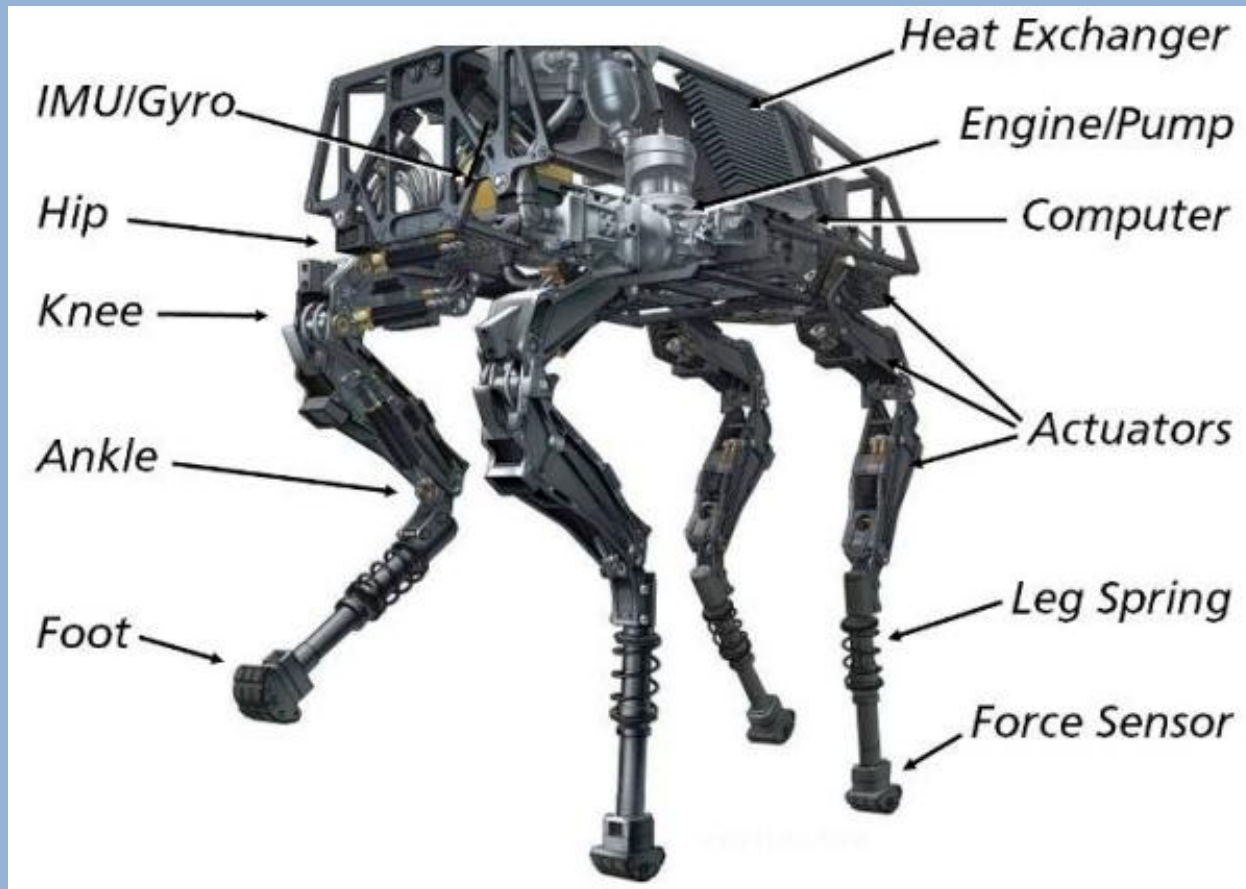
- Topic 1 : Open and closed-loop systems, Block diagrams
- Topic 2: Modeling of Electrical, Mechanical and Biological system
- Topic 3: Performance criteria, steady state error of second order system
- Topic 4: s plane system stability analysis
- Topic 5: Signal flow graphs and block diagram reduction
- Topic 6: State equations and state space methods
- Topic 7: RH criteria
- Topic 8: Analysis and design with the root loci method
- Topic 9: Frequency domain analysis
- Topic 10: Bode plots ,gain and phase margin
- Topic 11: Nichols charts
- Topic 12: Phase portraits
- Topic 13: Compensation techniques
- Topic 1 4 PI,PD,PID controller
- Topic 15 workshop MATLAB/Simulink for Control Engineers
- Topic 16 Simulation and Controller design using Matlab for inverted pendulum
- Topic 17 Presentation and Evolution of Semester research project



# WHY CONTROL SYSTEMS??



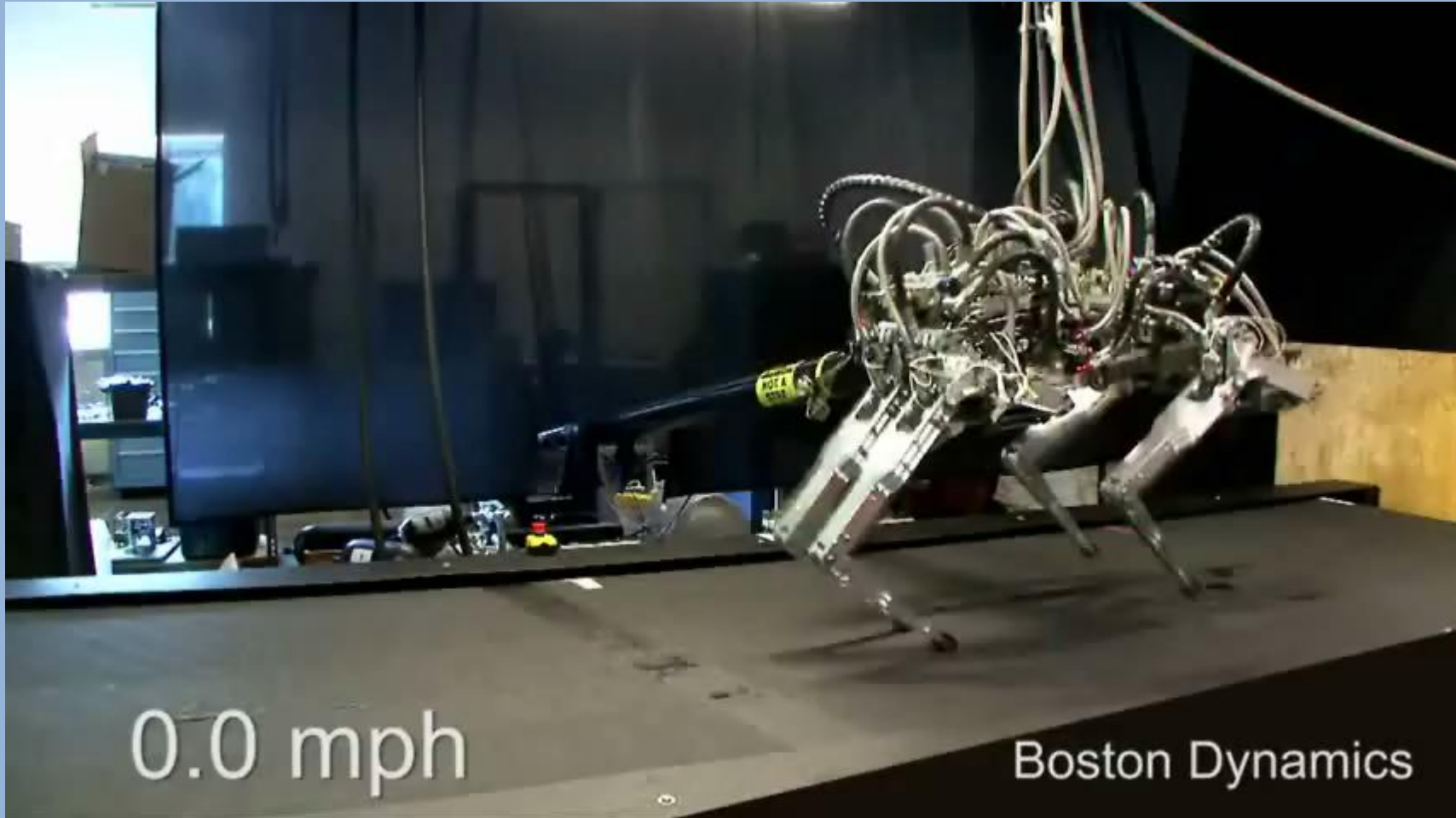
# Big Dog – Quadruple Robot







# World Fastest Robot

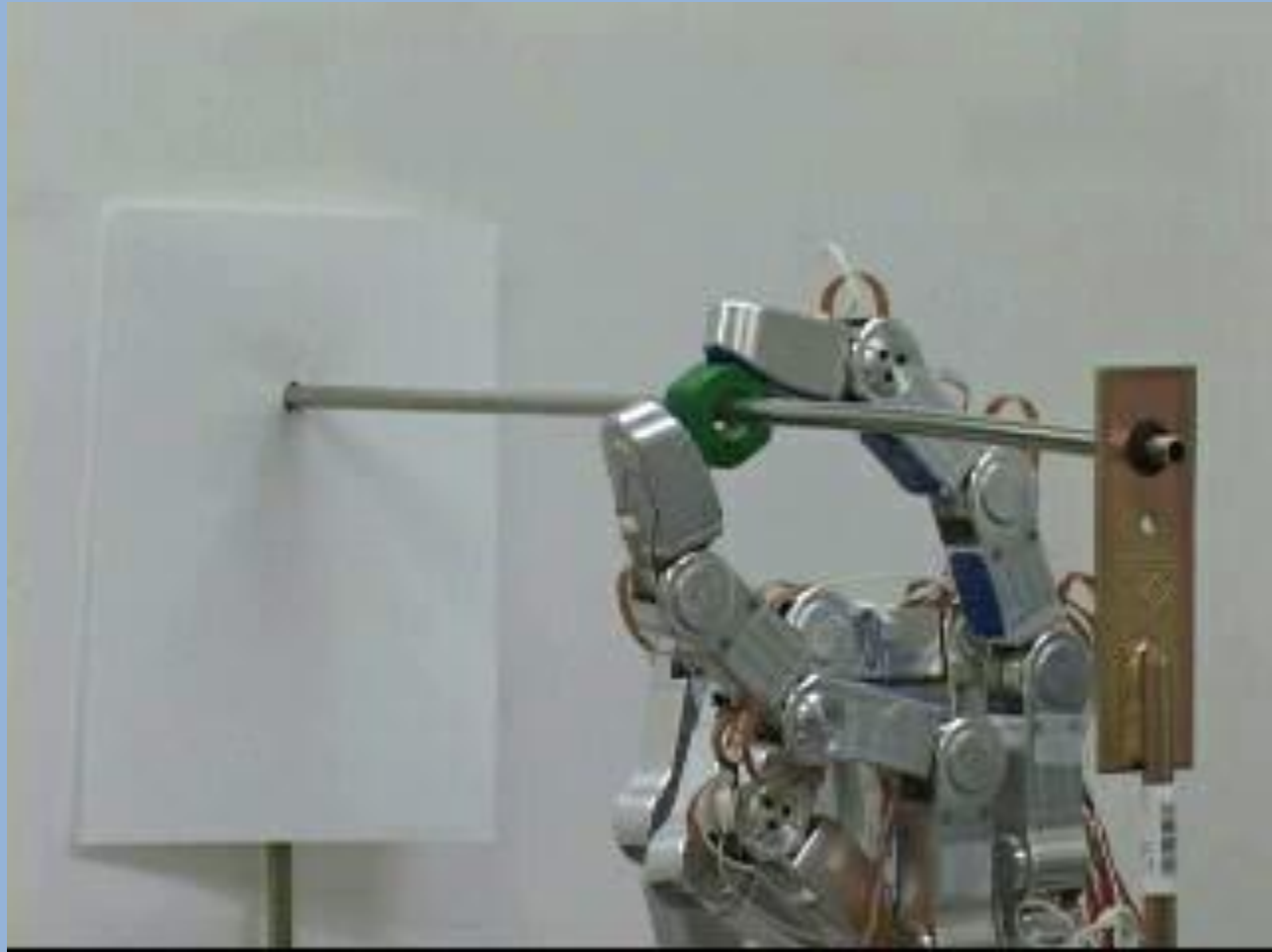


0.0 mph

Boston Dynamics



# A Robotic Hand





# Introduction

## ➤ What is Control?

- **Control** (steering) of a vehicle movement (proj., vel.)
- **Control** of an electrical furnace (temp.)
- **Control** of the medicine dosage in a given therapy
- **Control** of a production process (material processing)
- **Control** of a manufacturing process (assembly)



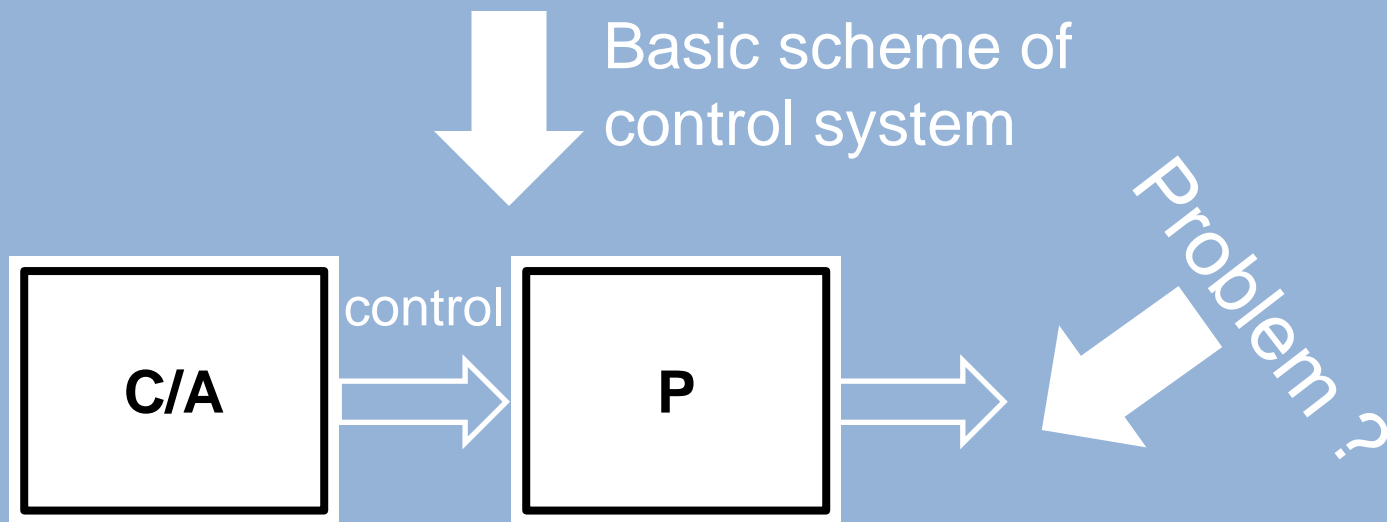
Any thing common ??





# Introduction

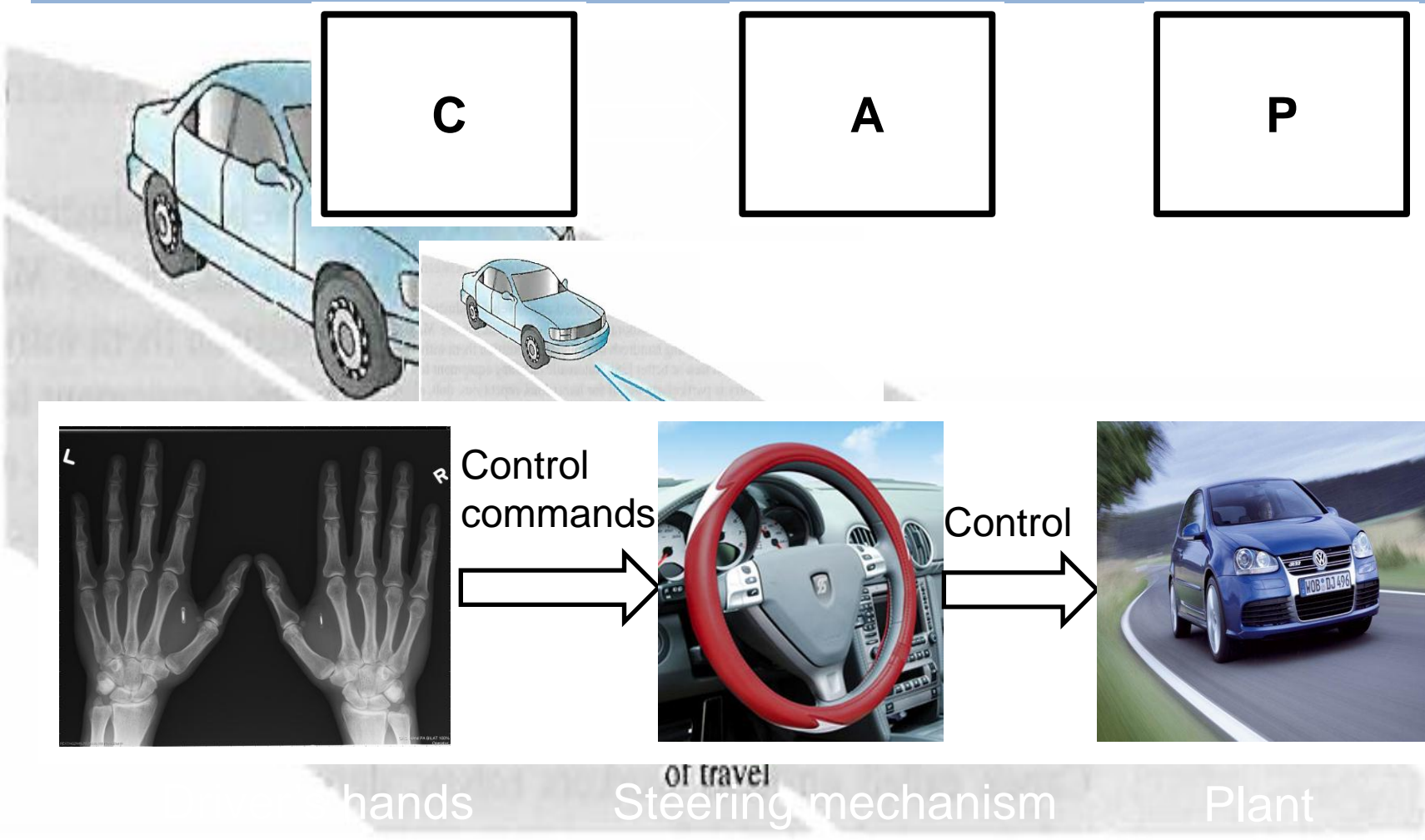
- Subject (Controller &/or Actuator)
- Object (Plant/Process)
- Control parameter



The interconnection of these two or three basic parts defines a control system



# Example 1 – Car Steering





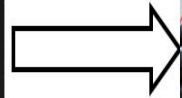


# Example 1 – Car Steering



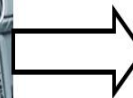
Driver's hands

Control commands



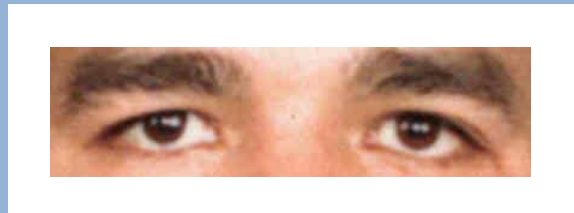
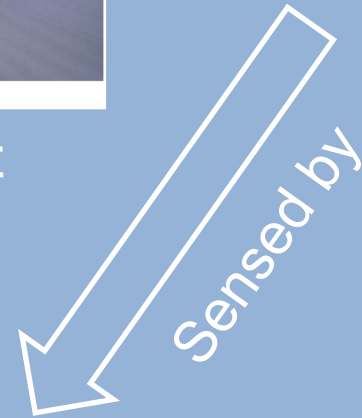
Steering mechanism

Control

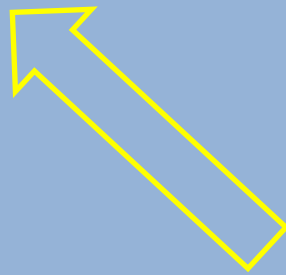


Plant

Position (current)



Driver's eyes



More better scheme with Feedback

Complete???



# Example 1 – Car Steering

Driver's mind

Desired  
Pos.



Control  
commands



Control



C. Pos.

Driver's hands

Steering mechanism

Plant



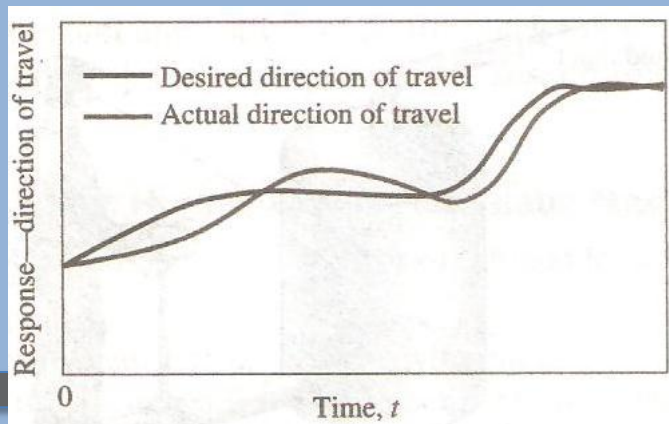
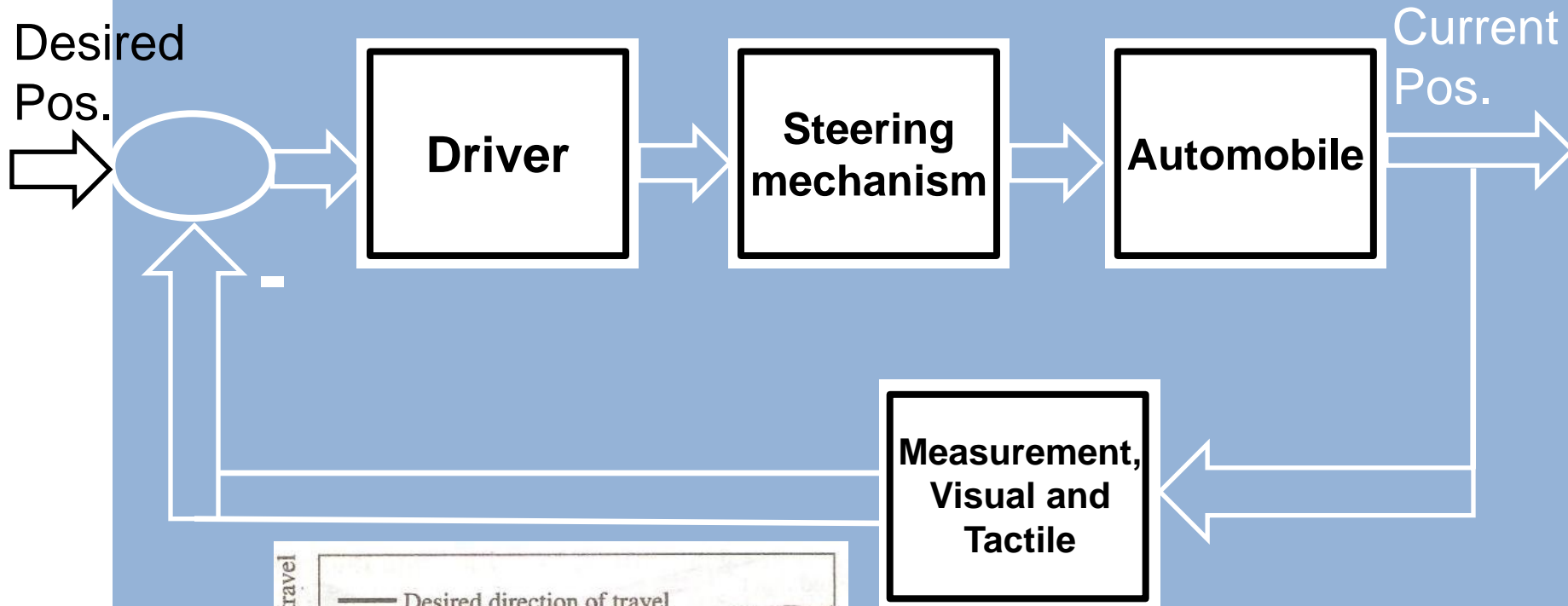
Driver's eyes

More better scheme (Closed loop control system)



# Example 1 – Car Steering

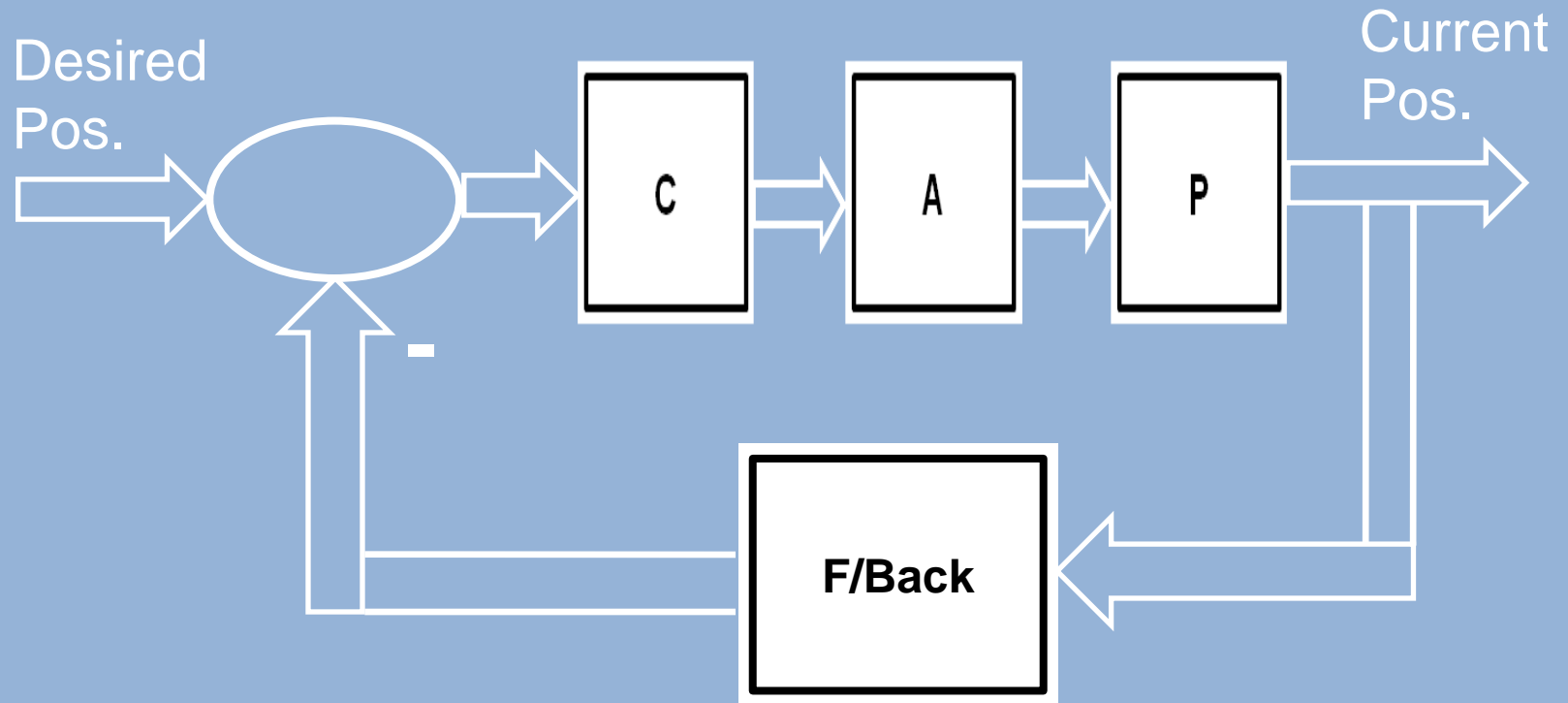
## ➤ Block Diagram of Car Steering Control







# Block Diagram of Closed Loop C/System



Closed Loop Position Control



# Example 1 – Car Steering (Open Loop)

Driver's mind

Desired Pos.



Control commands



Control



C. Pos.

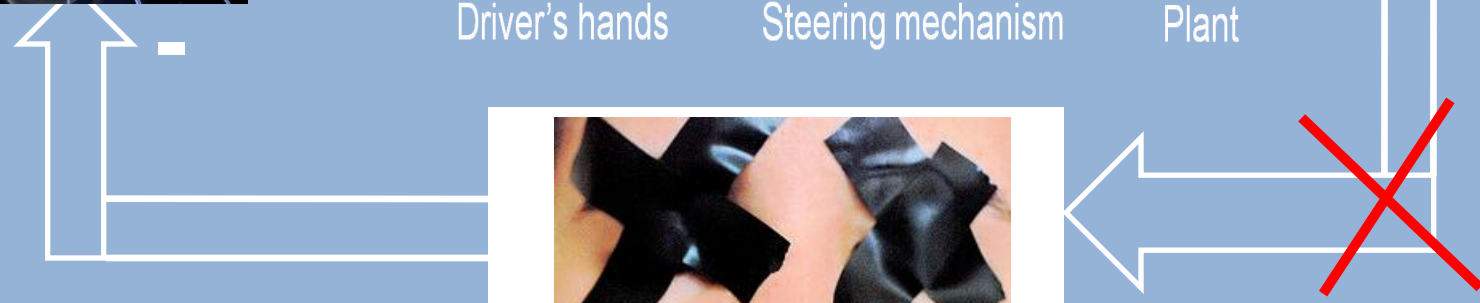
Driver's hands

Steering mechanism

Plant



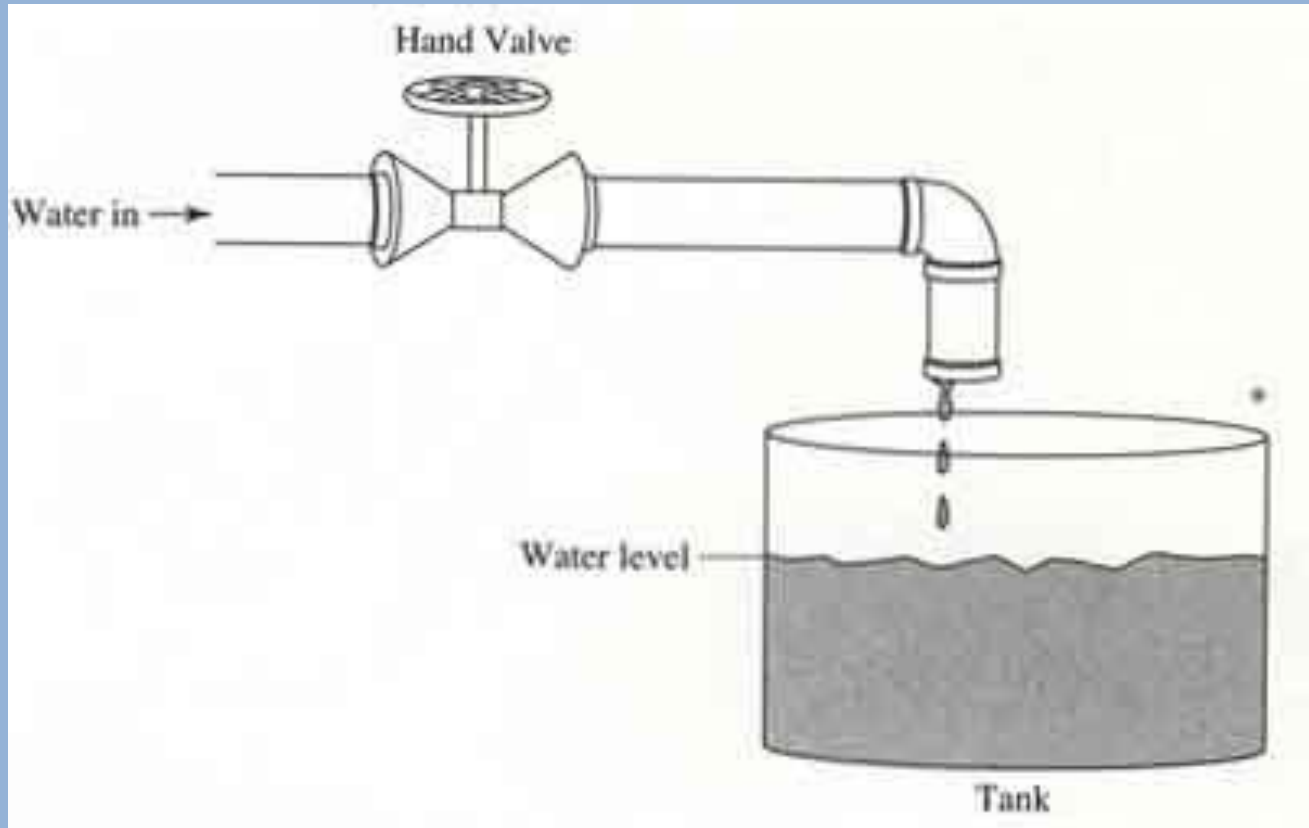
Driver's eyes





# Example 2

## ➤ Water Level Control System (Open Loop)

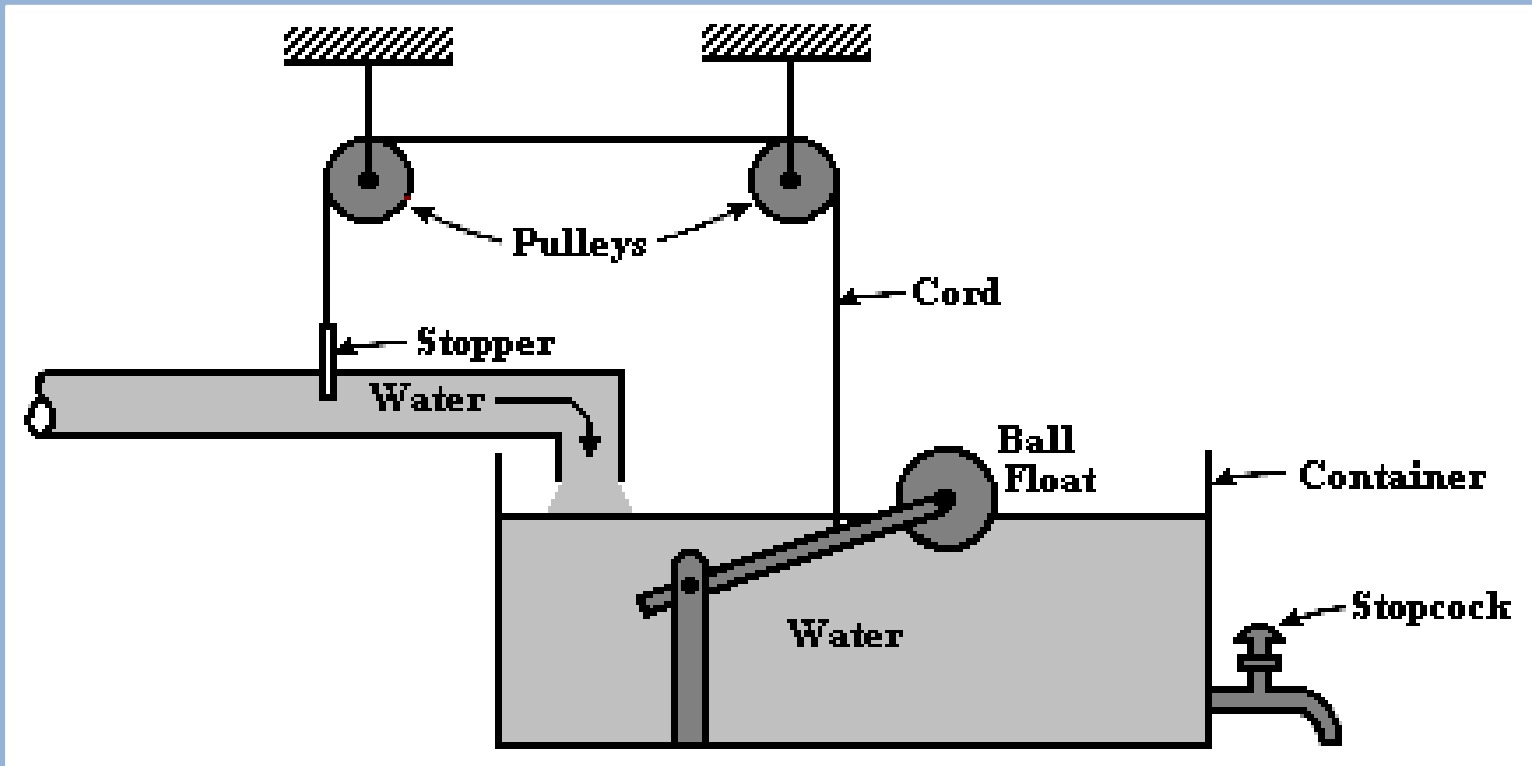


Assuming no visual F/back



## Example 2

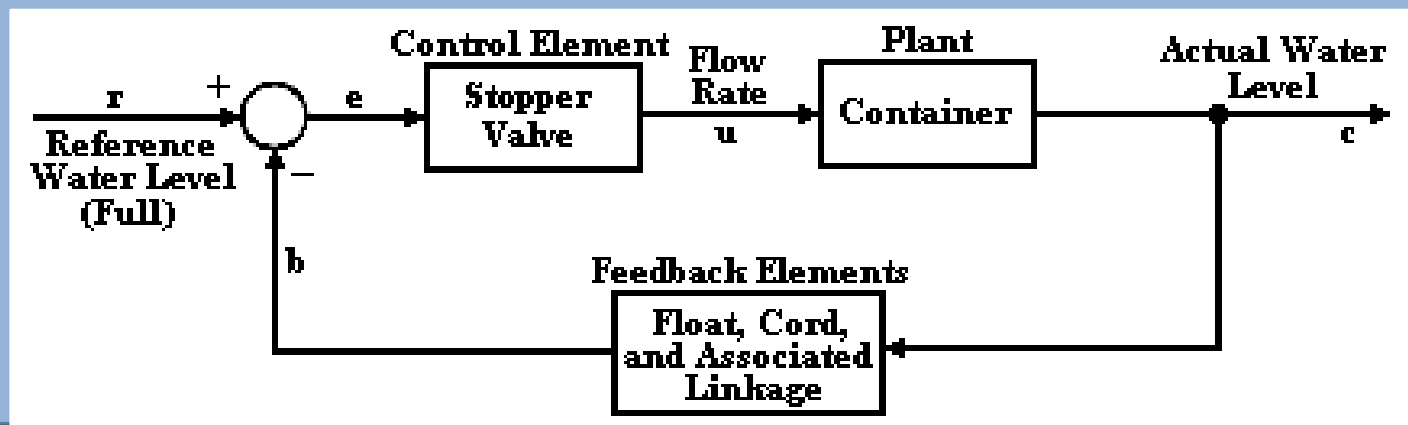
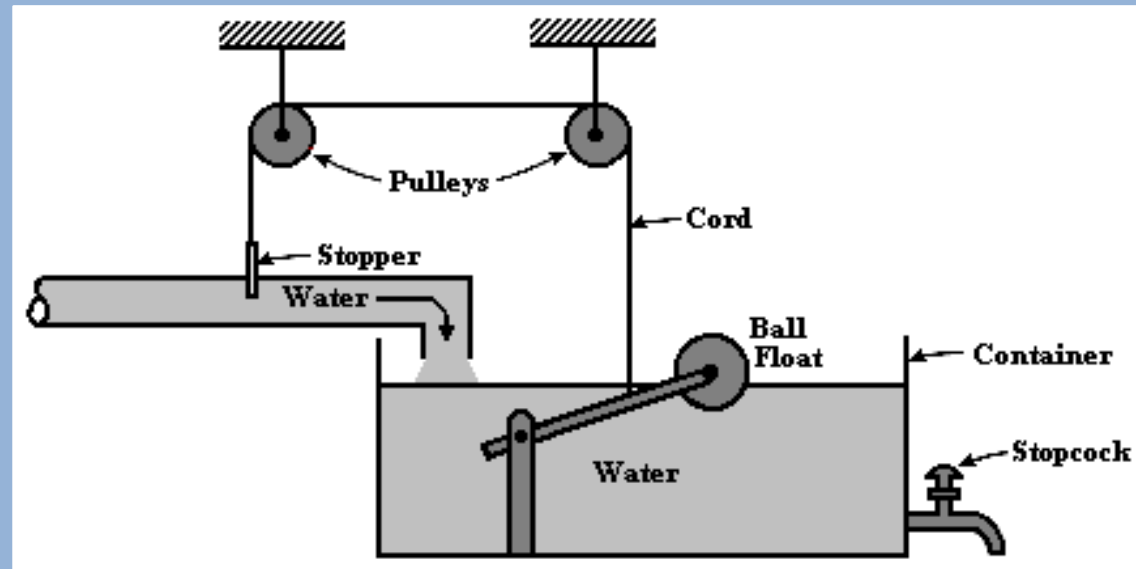
- Water Level Control System (Closed Loop)





# Example 2

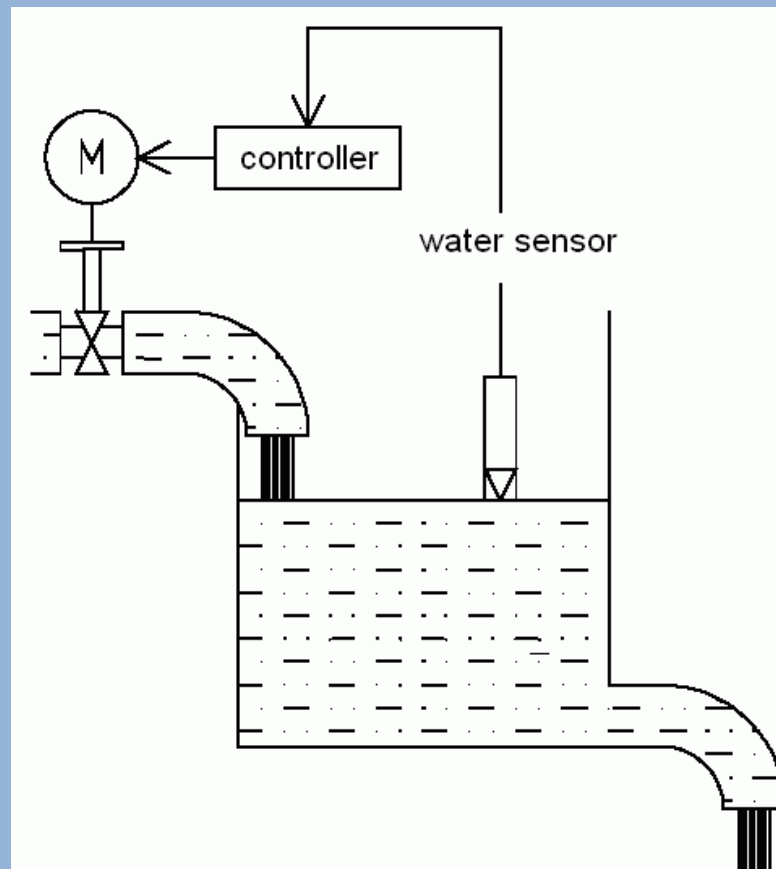
## ➤ Water Level Control System (Closed Loop)





# Example 2

- Water Level Control System (Closed Loop)  
(2nd Implementation)

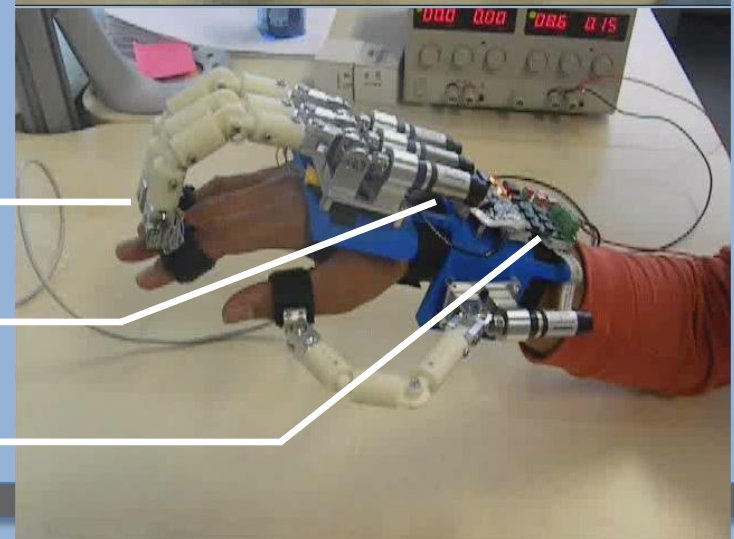
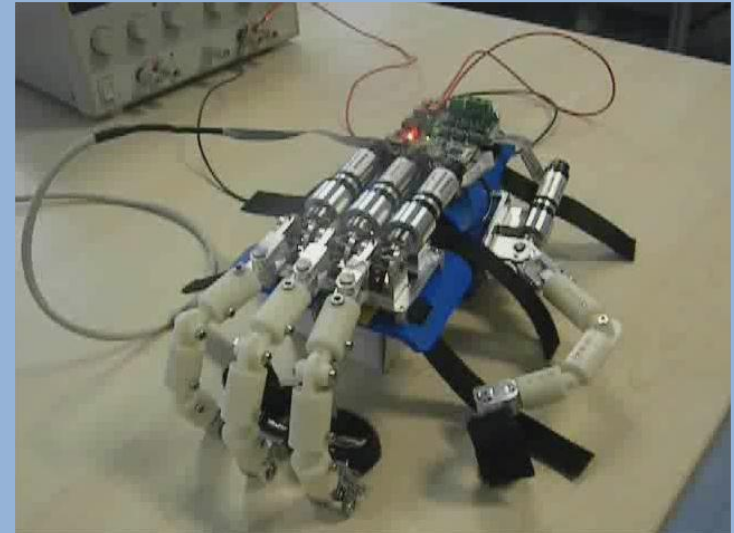
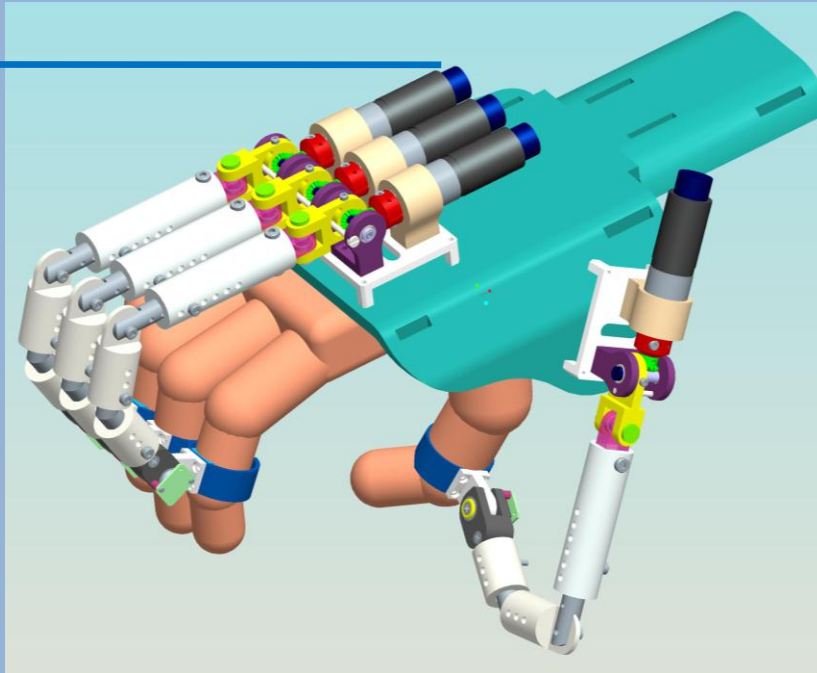




# Example 3

## ➤ Hand Exoskeleton Robotic System

Sensor



Plant

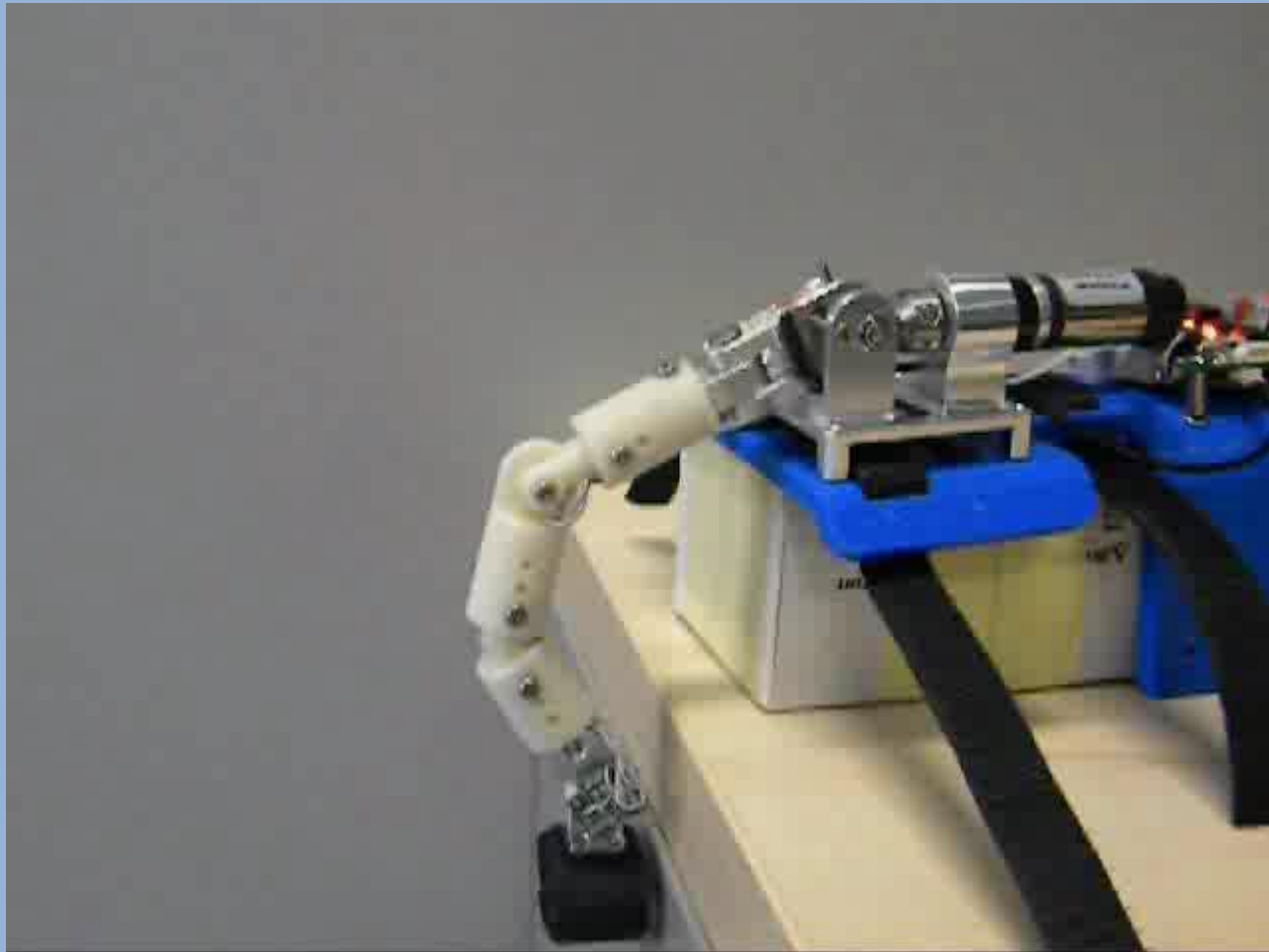
Actuator

Controller



# Example 3

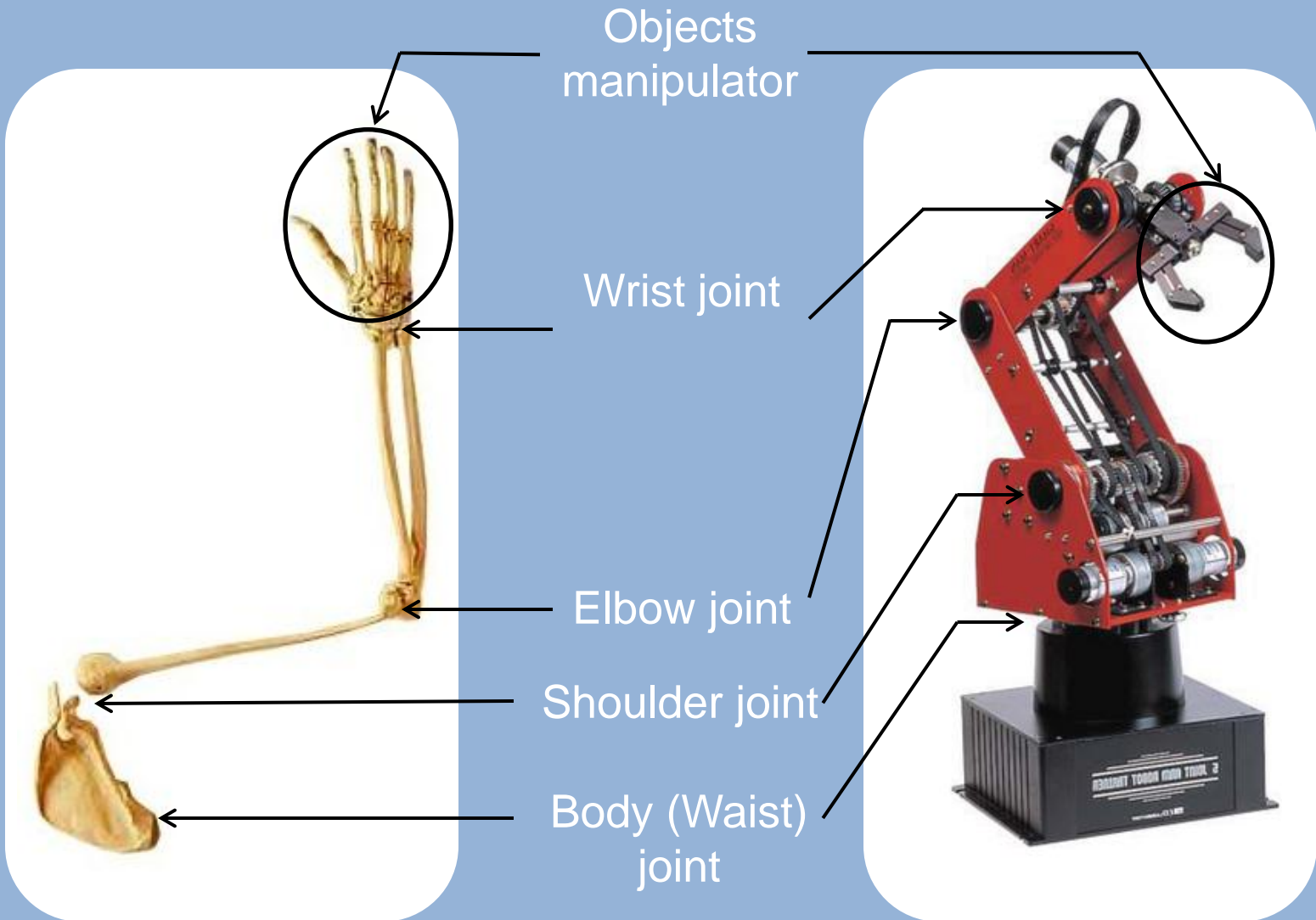
- Hand Exoskeleton Robotic System Control







# Example 4: Robotic Arm

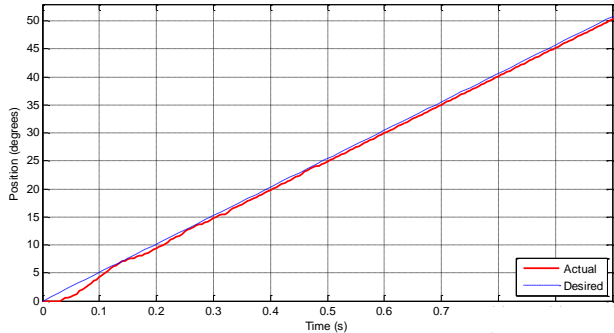




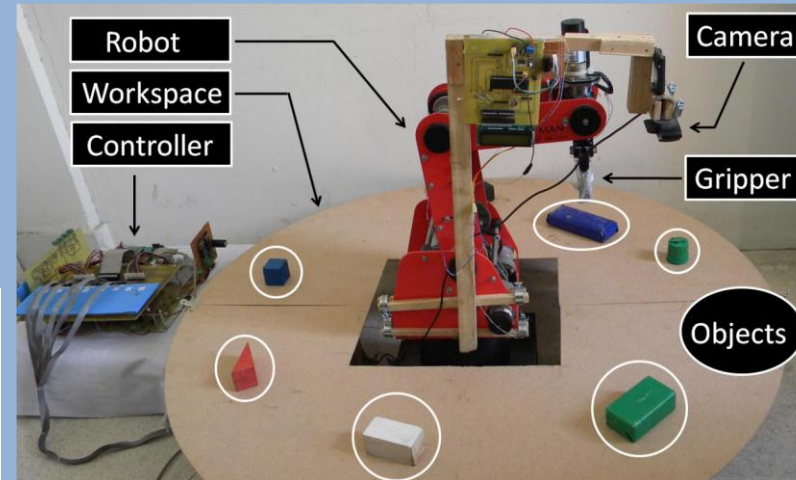
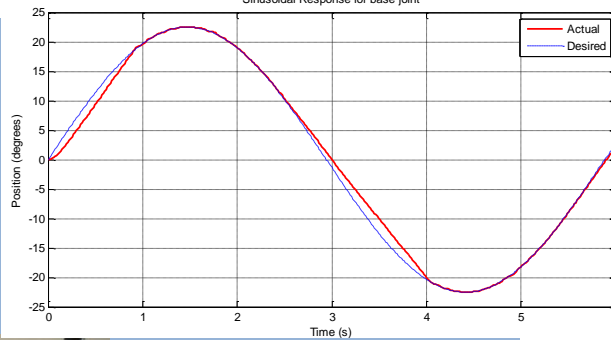
# Example 4

## ➤ Task Accomplishment Using Robotic Arm

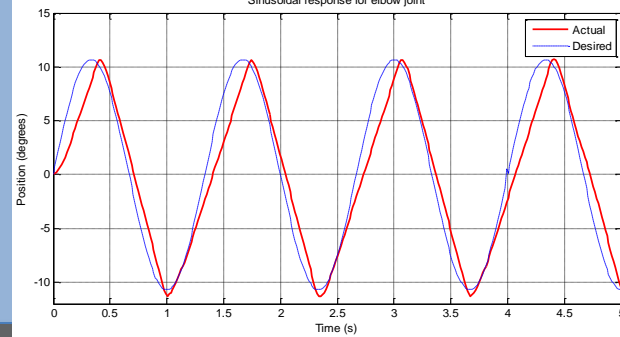
Ramp response for wrist joint (roll)



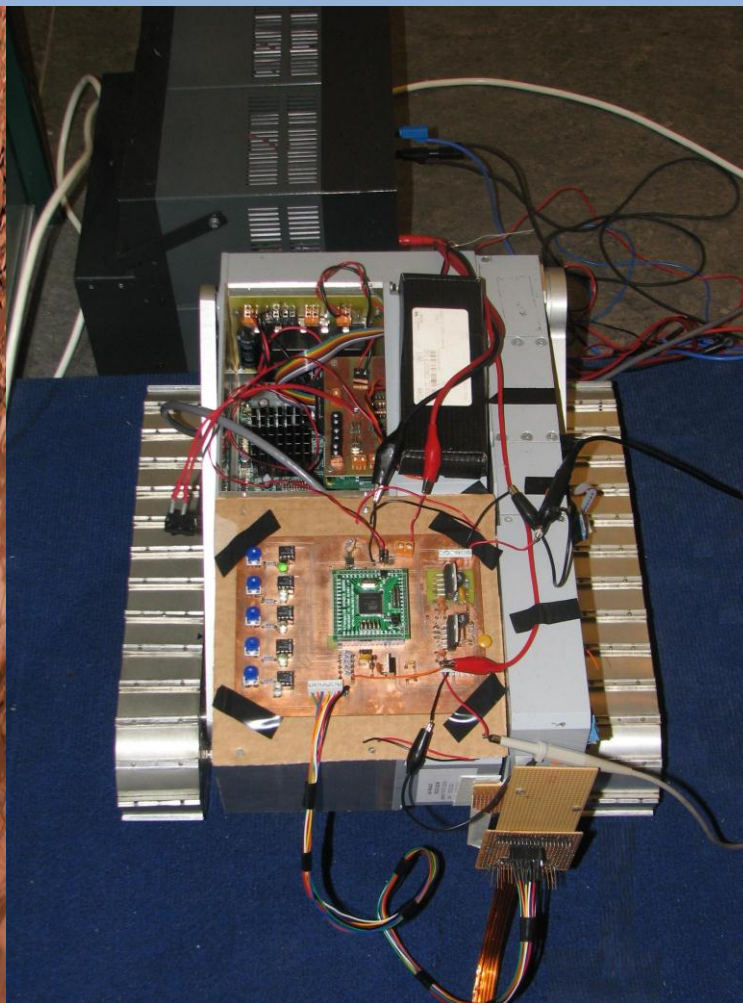
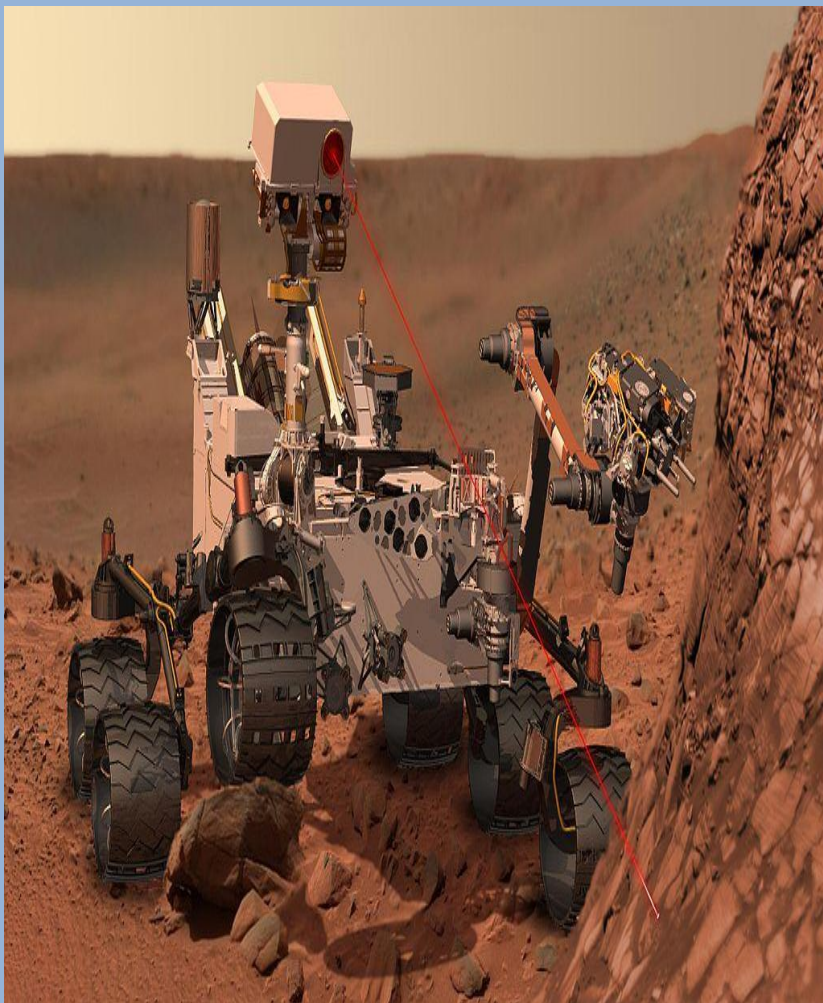
Sinusoidal Response for base joint



Sinusoidal response for elbow joint



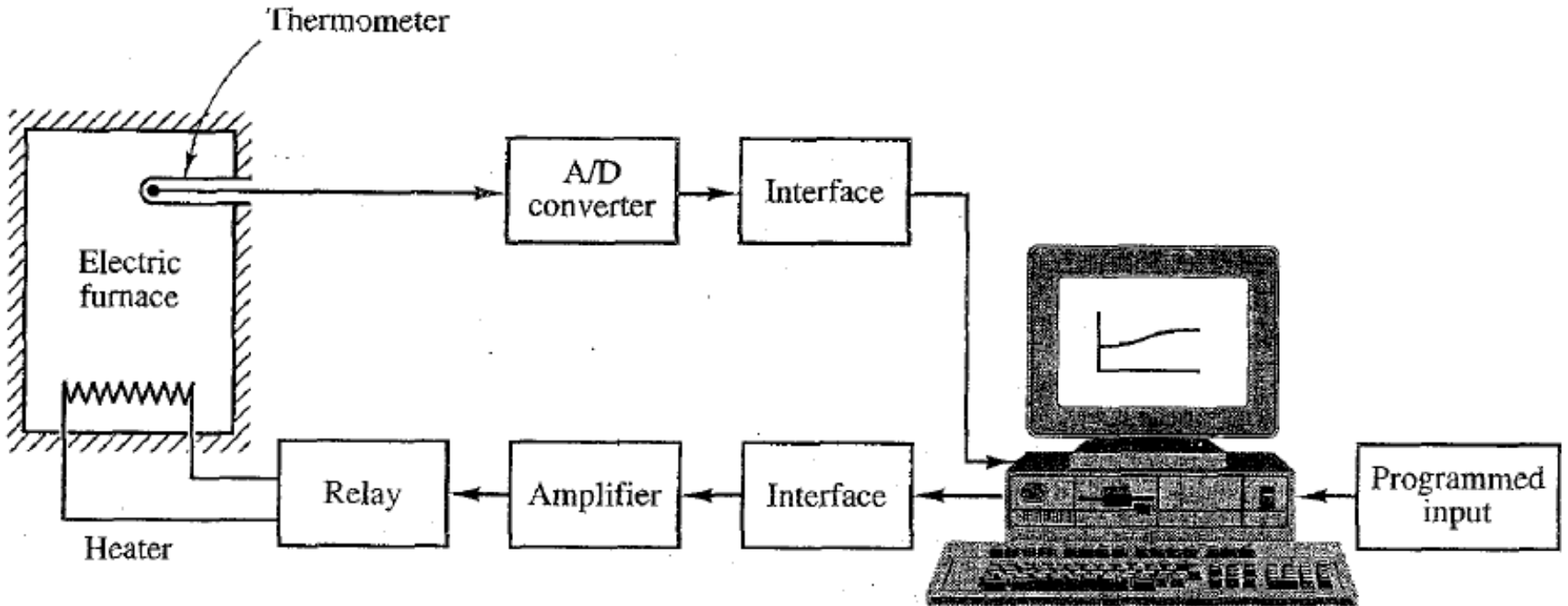
# Example 5: Mars Rover





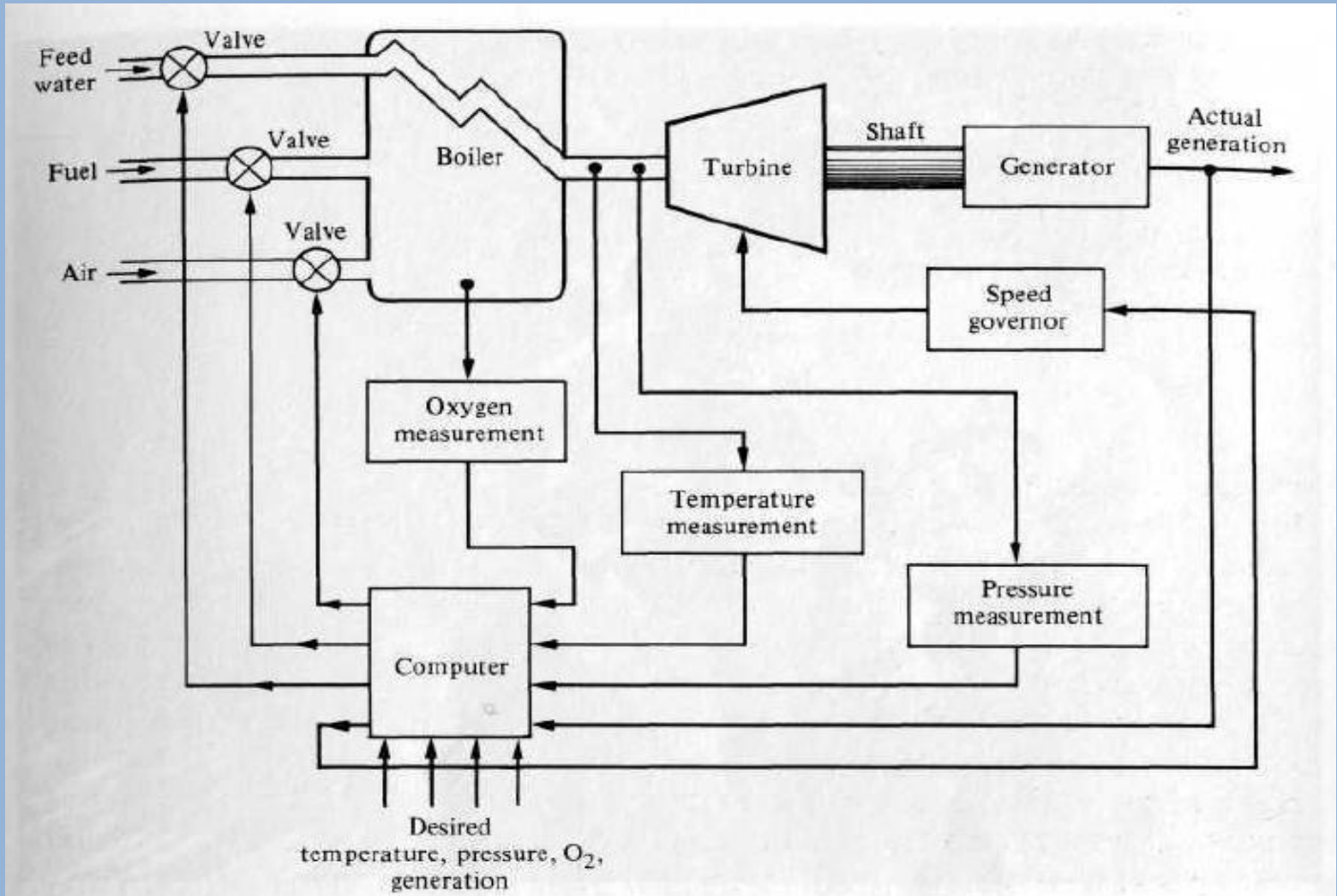


# Example 6: Temperature Control System





# Example 7: Boiler-Generator C/System





# Open Loop Control Systems

## ➤ Description

- Open -> No Loop (means no sensory feedback)
- Preferred whenever fixed relationship b/w I/p & O/p
- Usually used where events can be handled on time basis
- Accuracy not so critical

## ➤ Examples:

- Washing machine (not measure des. o/p - cleanliness)
- Hand drier
- Traffic signals





# Open Loop Control Systems

## ➤ Advantages

- Simple construction
- Ease of maintenance
- Less expensive than a corresponding c/loop system (less no. of components)
- Convenient when O/p is hard/expensive to measure
- They are less prone to stability issues



## ➤ Disadvantages

- Less accurate
- Disturbances can change desired o/p (worst case)
- Recalibration often required (to ensure the required o/p quality)



# Closed Loop Control Systems

## ➤ Description

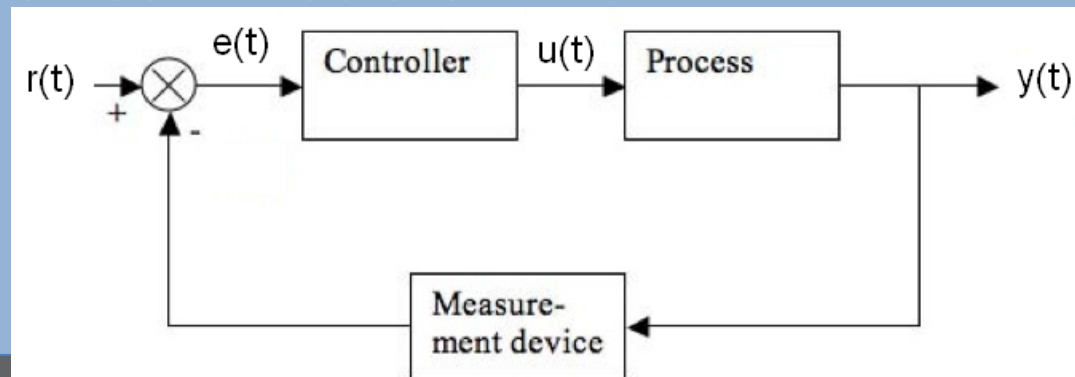
- Having a sensory feedback -> Closed loop
- Working principle
- Definition of terms
  - Error signal, Actuating signal, Controlled O/p
- Also called as “Feedback control systems”

## ➤ Examples

- 7 examples presented in Lecture

## ➤ Advantages

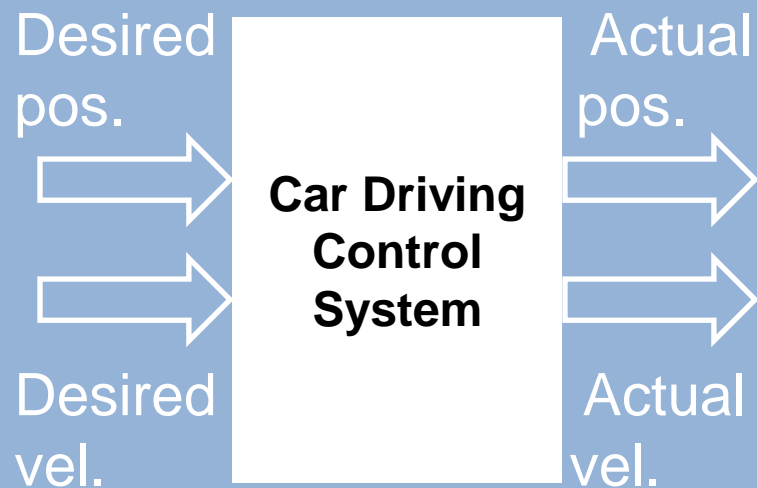
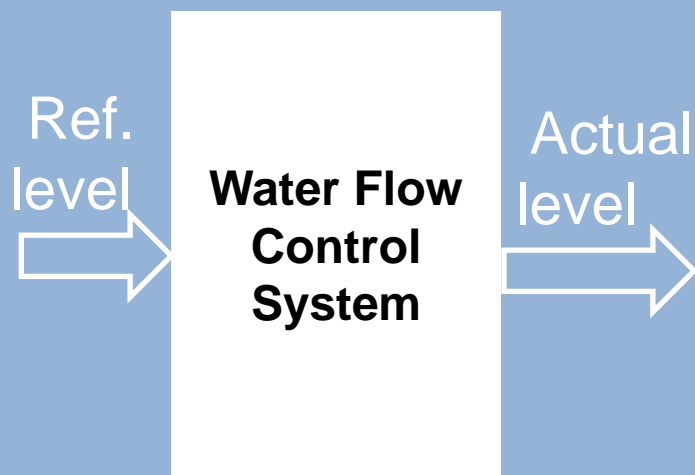
## ➤ Disadvantages







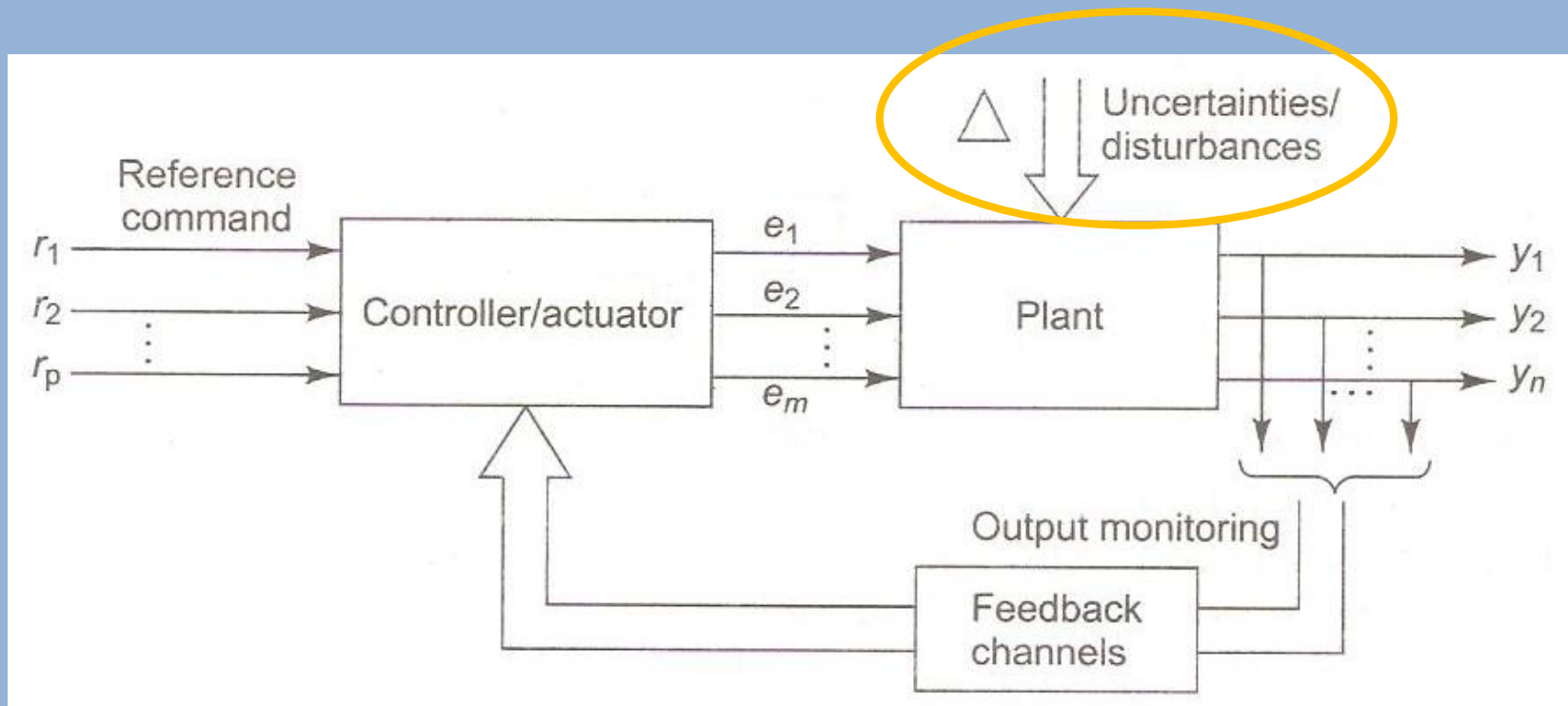
# Control Classification w.r.t. I/Os



- SISO (Single Input Single Output)
- MIMO (Multiple Inputs Multiple Outputs)
- SIMO (Single Input Multiple Outputs)
- MISO (Multiple Inputs Single Output)



# Control Classification w.r.t. I/Os



MIMO System



# Advantages of Control Systems

- Convenience of I/p form
- Compensation of disturbances
- Remote control



# Overall Control System

- Sensors provide the eyes and actuators provides the muscle. C/system combines them

- ❖ **Better Sensors**

Provide better *Vision*



- ❖ **Better Actuators**

Provide better *Muscles*



- ❖ **Better Control**

Provides better performance by combining *sensors* and *actuators* in more intelligent ways





# Control System Integration

- Success in control engineering needs to examine the following issues:
  - Objectives
  - Plant
  - Sensors
  - Actuators
  - Computing
  - Architectures and interfacing
  - Algorithms
  - Accounting for disturbances and uncertainty
  - Communications



# Applications of Control Systems

- Robotics
- Manufacturing
- Biotechnology
- Power systems
- Process control
- Transportation
- Motion control
- Network control
- Flight control & navigation
- Consumer electronics



▪ ...



# Applications of Control Systems

Application	(Millions of dollars)*				
	1972	1973	1976	1980	1990
Motor controls (speed, position)	90.3	100.5	112	150	250
Numerical controls	43.4	47.3	76	100	170
Thickness controls (steel, paper)	45.4	57.8	99	180	240
Process controls (oil, chemical)	318.5	357.2	449	700	2000
Pollution monitoring and control	14.0	17.0	26	75	300
Nuclear reactor control	9.3	11.1	19	25	60

\*U.S. market estimates for several control system applications. The examples given in parentheses are not all-inclusive of the applications.





# LAPLACE TRANSFORM (LT)

*Laplace*







# Online Resource: Khan Academy

Khan Academy - Service Pack 3 Internet Explorer

http://www.khanacademy.org/

File Edit View Favorites Tools Help

startnow Search with Bing Search Shopping Games Travel MSN Amazon eBay Facebook Twitter

Khan Academy SEARCH

Favorites Google Suggested Sites Free Hotmail Web Slice Gallery

Khan Academy

Find: laplace Previous Next Options 17 matches

**Jump to playlist: Math Science Humanities & Other Test Prep Talks and Interviews**

## Differential Equations

Topics covered in a first year course in differential equations. Need to understand basic differentiation and integration from Calculus playlist before starting here.

<a href="#">What is a differential equation</a>	<a href="#">2nd Order Linear Homogeneous Differential Equations 4</a>	<a href="#">Laplace Transform 6</a>
<a href="#">Separable Differential Equations</a>	<a href="#">Complex roots of the characteristic equations 1</a>	<a href="#">Laplace Transform to solve an equation</a>
<a href="#">Separable differential equations 2</a>	<a href="#">Complex roots of the characteristic equations 2</a>	<a href="#">Laplace Transform solves an equation 2</a>
<a href="#">Exact Equations Intuition 1 (proofy)</a>	<a href="#">Complex roots of the characteristic equations 3</a>	<a href="#">More Laplace Transform tools</a>
<a href="#">Exact Equations Intuition 2 (proofy)</a>	<a href="#">Repeated roots of the characteristic equation</a>	<a href="#">Using the Laplace Transform to solve a nonhomogenous eq</a>
<a href="#">Exact Equations Example 1</a>	<a href="#">Repeated roots of the characteristic equations part 2</a>	<a href="#">Laplace Transform of : <math>L\{t\}</math></a>
<a href="#">Exact Equations Example 2</a>	<a href="#">Undetermined Coefficients 1</a>	<a href="#">Laplace Transform of <math>t^n</math>: <math>L\{t^n\}</math></a>
<a href="#">Exact Equations Example 3</a>	<a href="#">Undetermined Coefficients 2</a>	<a href="#">Laplace Transform of the Unit Step Function</a>
<a href="#">Integrating factors 1</a>	<a href="#">Undetermined Coefficients 3</a>	<a href="#">Inverse Laplace Examples</a>
<a href="#">Integrating factors 2</a>	<a href="#">Undetermined Coefficients 4</a>	<a href="#">Laplace/Step Function Differential Equation</a>
<a href="#">First order homogenous equations</a>	<a href="#">Laplace Transform 1</a>	<a href="#">Dirac Delta Function</a>
<a href="#">First order homogenous equations 2</a>	<a href="#">Laplace Transform 2</a>	<a href="#">Laplace Transform of the Dirac Delta Function</a>
<a href="#">2nd Order Linear Homogeneous Differential Equations 1</a>	<a href="#">Laplace Transform 3 (<math>L\{\sin(at)\}</math>)</a>	<a href="#">Introduction to the Convolution</a>
<a href="#">2nd Order Linear Homogeneous Differential Equations 2</a>	<a href="#">Laplace Transform 4</a>	<a href="#">The Convolution and the Laplace Transform</a>
<a href="#">2nd Order Linear Homogeneous Differential Equations 3</a>	<a href="#">Laplace Transform 5</a>	<a href="#">Using the Convolution Theorem to Solve an Initial Value Prob</a>



# Transforms

## Fourier

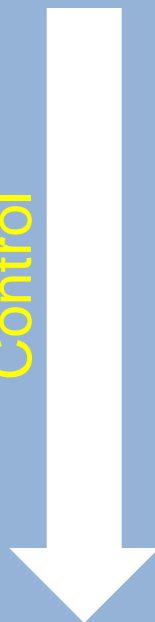
Comm. Theory &  
Field theory



Signal spectrum  
& Filters

## Laplace

Cct. Theory &  
Control



Continuous linear  
differential eqs.

## Z

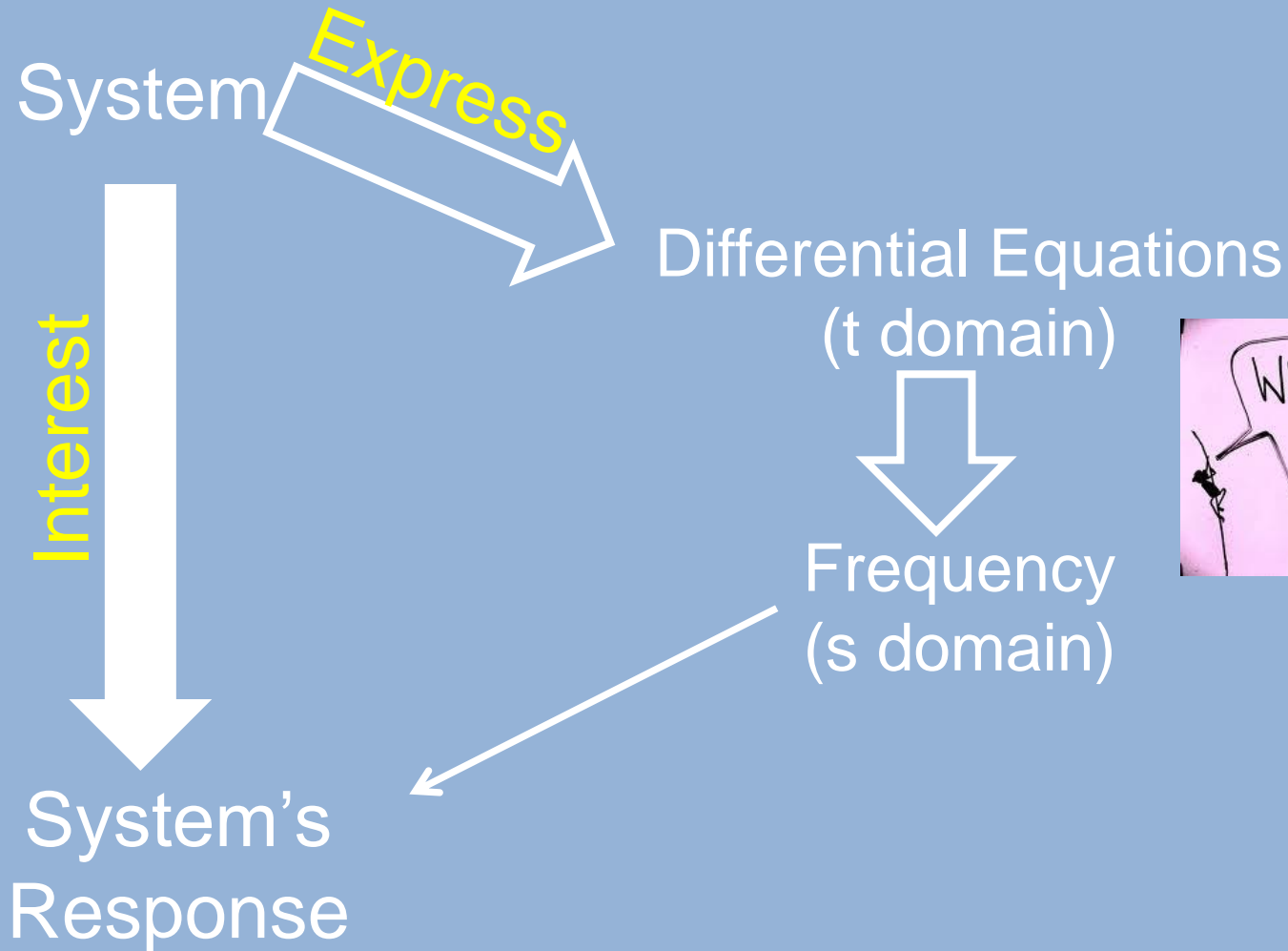
Control Systems



Discrete systems  
& difference eqs.

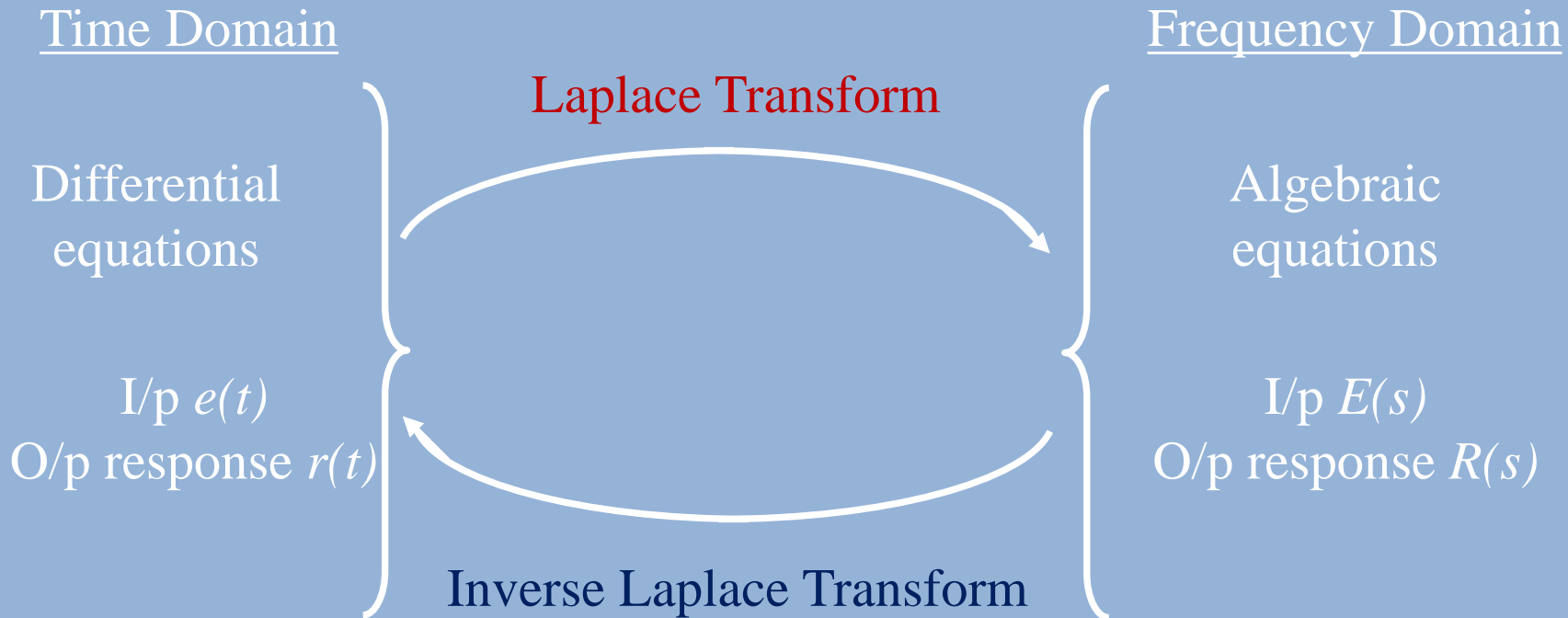


# LT & Control



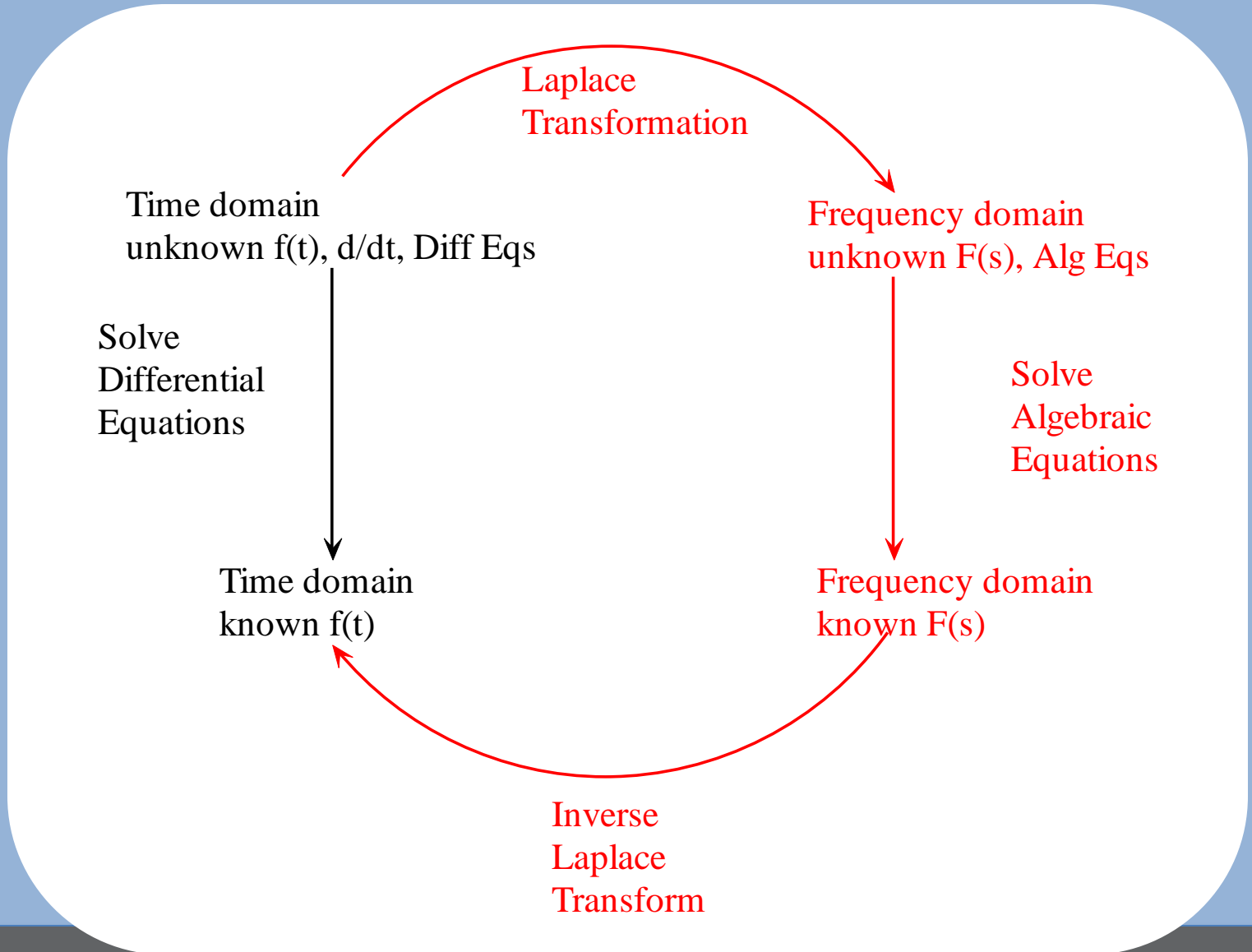


# LT Implementation Cycle





# LT Implementation Cycle





# LT Definition

## ➤ Definition

- Consider a continuous time variable  $f(t)$ ;

$$0 \leq t < \infty$$

The Laplace transform pair associated with  $f(t)$  is defined as

$$\mathbf{L}[f(t)] = \mathbf{F}(s) = \int_0^{\infty} f(t) e^{-st} dt$$

$$\mathbf{L}^{-1}[\mathbf{F}(s)] = f(t) = \frac{1}{2\pi j} \int_{\sigma - j\infty}^{\sigma + j\infty} \mathbf{F}(s) e^{ts} ds$$



# LT Definition

- Lower case  $f$  indicates function of time
- Upper case  $F$  indicates function of  $s$
- Important point:

$$\mathbf{f(t) \Leftrightarrow F(s)}$$

The above is a statement that  $f(t)$  and  $F(s)$  are transform pairs. What this means is that for each  $f(t)$  there is a unique  $F(s)$  and for each  $F(s)$  there is a unique  $f(t)$





# LT Definition

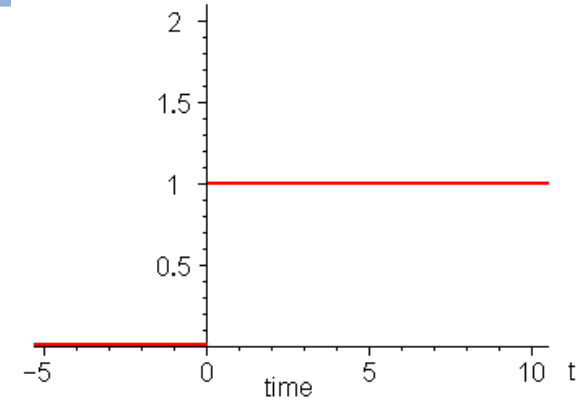
- The Laplace Transform is a function of a complex variable  $s$ . Often  $s$  is separated into its real and imaginary parts

$$s = \sigma + j\omega$$



# Example-I: Simple computation by Def.

$$\mathcal{L}[f(t)] = \int_{t=0}^{t=\infty} f(t) e^{-st} dt$$



$$1(t) = \begin{cases} 0, & t < 0 \\ 1, & t \geq 0 \end{cases}, \quad \mathcal{L}[1(t)] = \int_{t=0}^{t=\infty} 1(t) e^{-st} dt$$

$$\mathcal{L}[1(t)] = \int_{t=0}^{t=\infty} 1(t) e^{-st} dt = \int_{t=0}^{t=\infty} e^{-st} dt$$

$$= \left[ \frac{-1}{s} e^{-st} \right]_{t=0}^{t=\infty} = \frac{-1}{s} \left[ \lim_{t \rightarrow \infty} e^{-st} - 1 \right] = \frac{1}{s}$$



# MATLAB Commands

## ➤ Laplace

```
>>syms t  
>>f = t^4  
  
>>laplace(f)
```

## ➤ Inverse Laplace

```
>>syms s  
>>f = 1/s^2  
>>ilaplace(f) % Inverse laplace
```

$$H(s) = \frac{s + 2}{s^2 + s + 10}$$

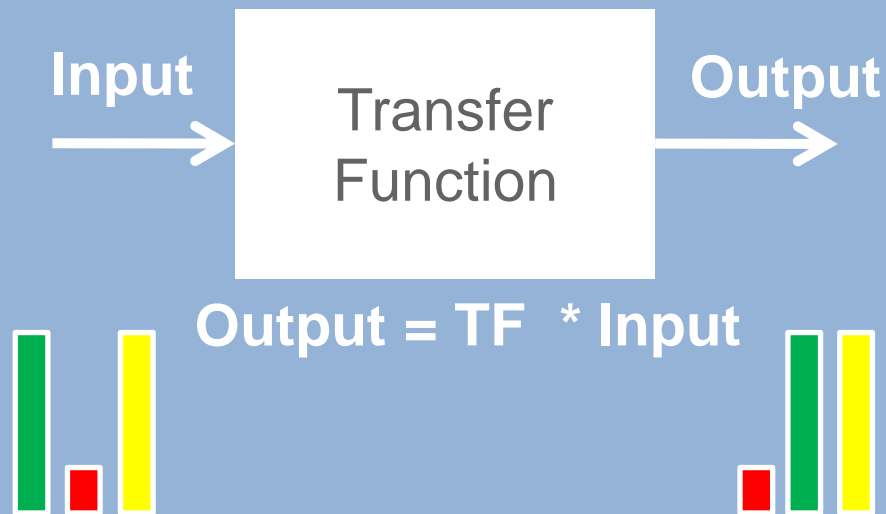
## ➤ Transfer Function

```
sys = tf(num,den) % Transfer function
```



# Transfer Function

Transfer functions describe the input-output relationship.





# LT Table

$f(t)$	$(t \geq 0)$	$\mathcal{L}[f(t)]$	Region of Convergence
1		$\frac{1}{s}$	$\sigma > 0$
$\delta_D(t)$		1	$ \sigma  < \infty$
$t$		$\frac{1}{s^2}$	$\sigma > 0$
$t^n$	$n \in \mathbb{Z}^+$	$\frac{1}{s^{n+1}}$	$\sigma > 0$
$e^{\alpha t}$	$\alpha \in \mathbb{C}$	$\frac{1}{s - \alpha}$	$\sigma > \Re\{\alpha\}$
$te^{\alpha t}$	$\alpha \in \mathbb{C}$	$\frac{1}{(s - \alpha)^2}$	$\sigma > \Re\{\alpha\}$
$\cos(\omega_o t)$		$\frac{s}{s^2 + \omega_o^2}$	$\sigma > 0$
$\sin(\omega_o t)$		$\frac{\omega_o}{s^2 + \omega_o^2}$	$\sigma > 0$
$e^{\alpha t} \sin(\omega_o t + \beta)$		$\frac{(\sin \beta)s + \omega_o^2 \cos \beta - \alpha \sin \beta}{(s - \alpha)^2 + \omega_o^2}$	$\sigma > \Re\{\alpha\}$
$t \sin(\omega_o t)$		$\frac{2\omega_o s}{(s^2 + \omega_o^2)^2}$	$\sigma > 0$
$t \cos(\omega_o t)$		$\frac{s^2 - \omega_o^2}{(s^2 + \omega_o^2)^2}$	$\sigma > 0$
$\mu(t) - \mu(t - \tau)$		$\frac{1 - e^{-s\tau}}{s}$	$ \sigma  < \infty$



THANKS