Control Technology
Lecture 1

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Outlines

- Preleminaries
  - 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 (JMCMS)
  - Reviewer (ASTES)
- Publications: 25 Research Publications

Course Details

- Course Contents

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

Recommended book

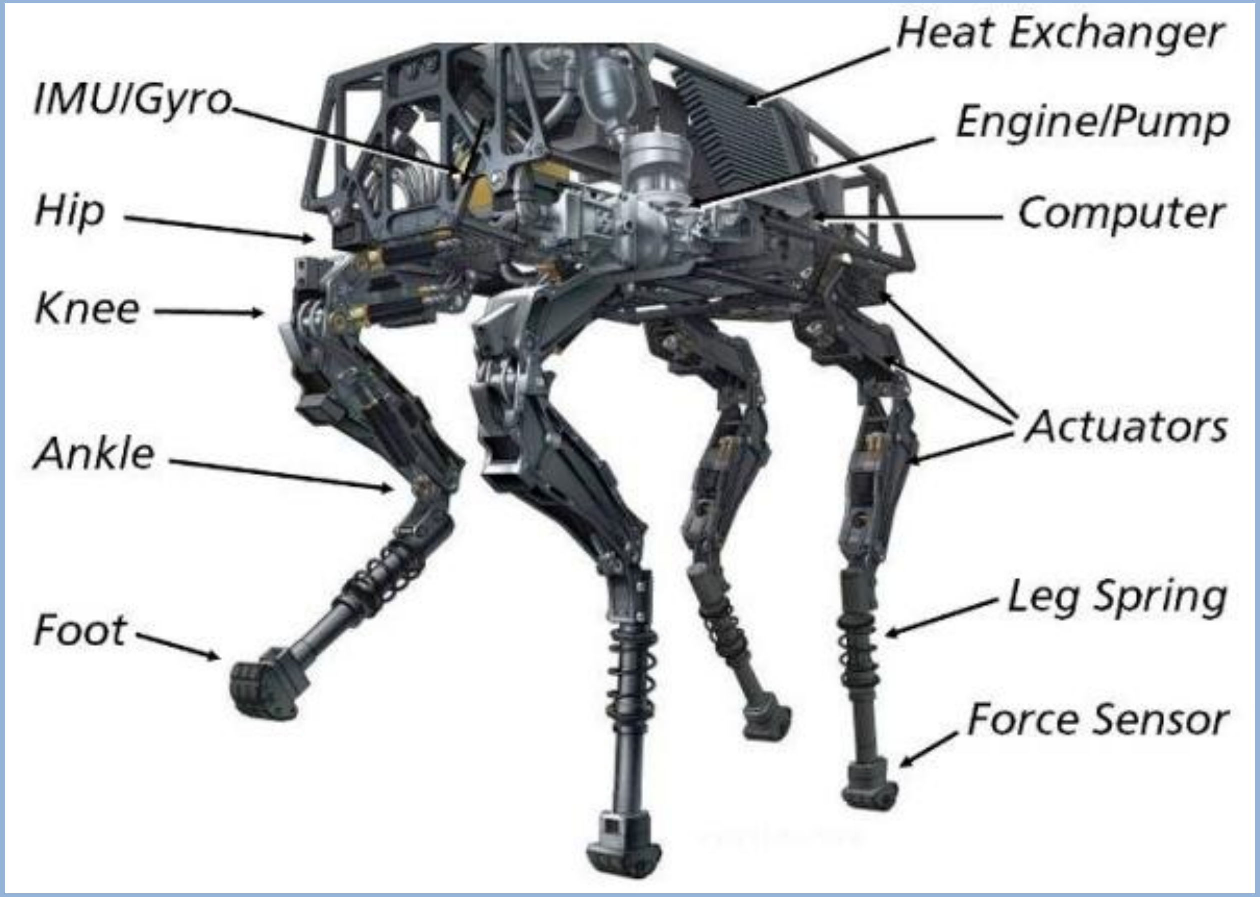
- **Text book:**
- **Design** of Feedback Control Systems by Steffani, Savant, Shahian and Hostetler
- **Reference Book**:
- Modern Control Engineering by Katsushiko, Ogata
- Modern Control Systems by R. C.Dorf and R. H. Bishop

Course outline

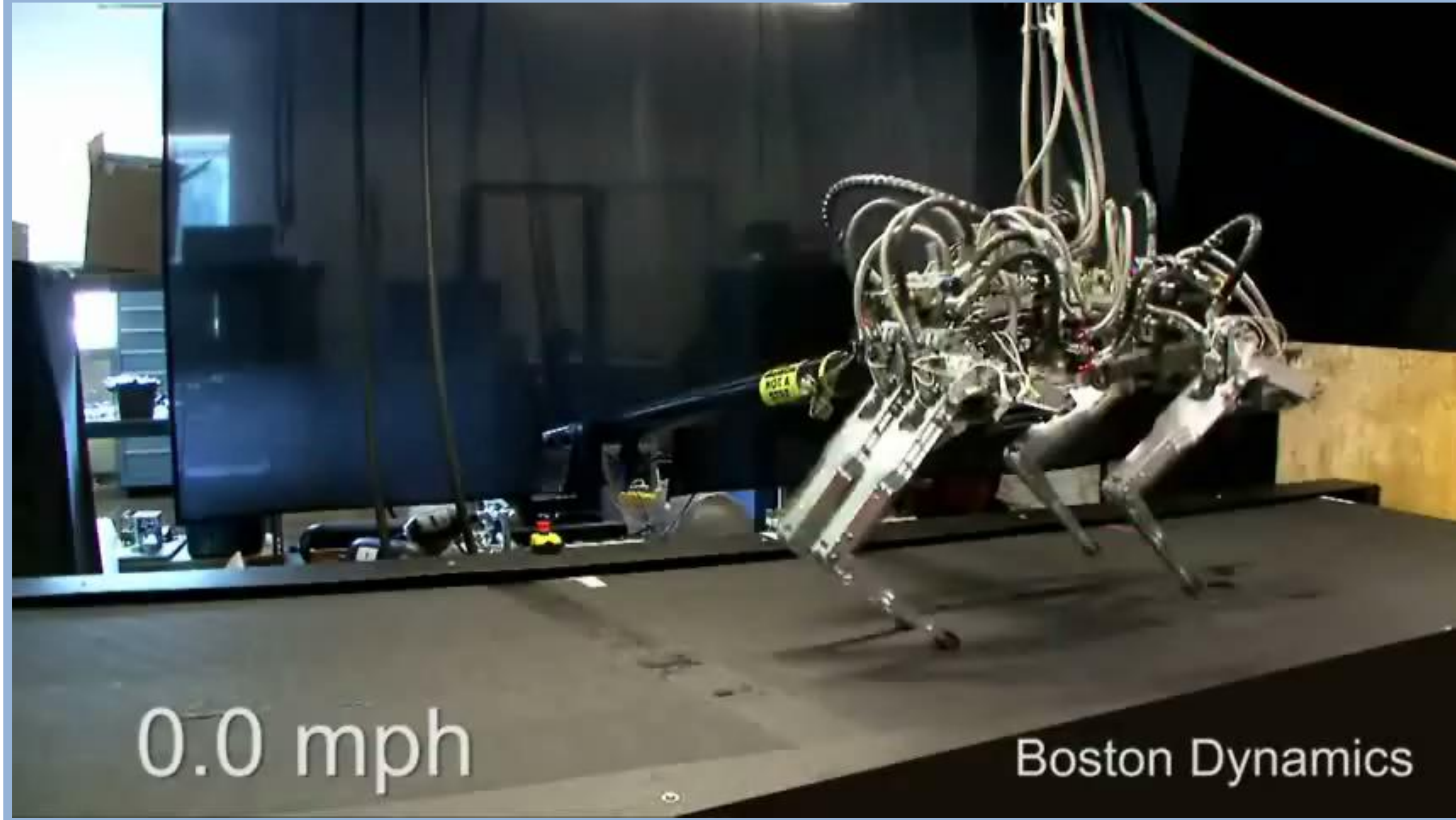
- Topic 1 : Open and closed-loop systems, Block diagrams
- Topic 2: Modeling of Electrical, Mechanical and Biological system
- Topic 3: Performance criteria, steady state error of second order system
- Topic 4: s plane system stability analysis
- Topic 5: Signal flow graphs and block diagram reduction
- 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??

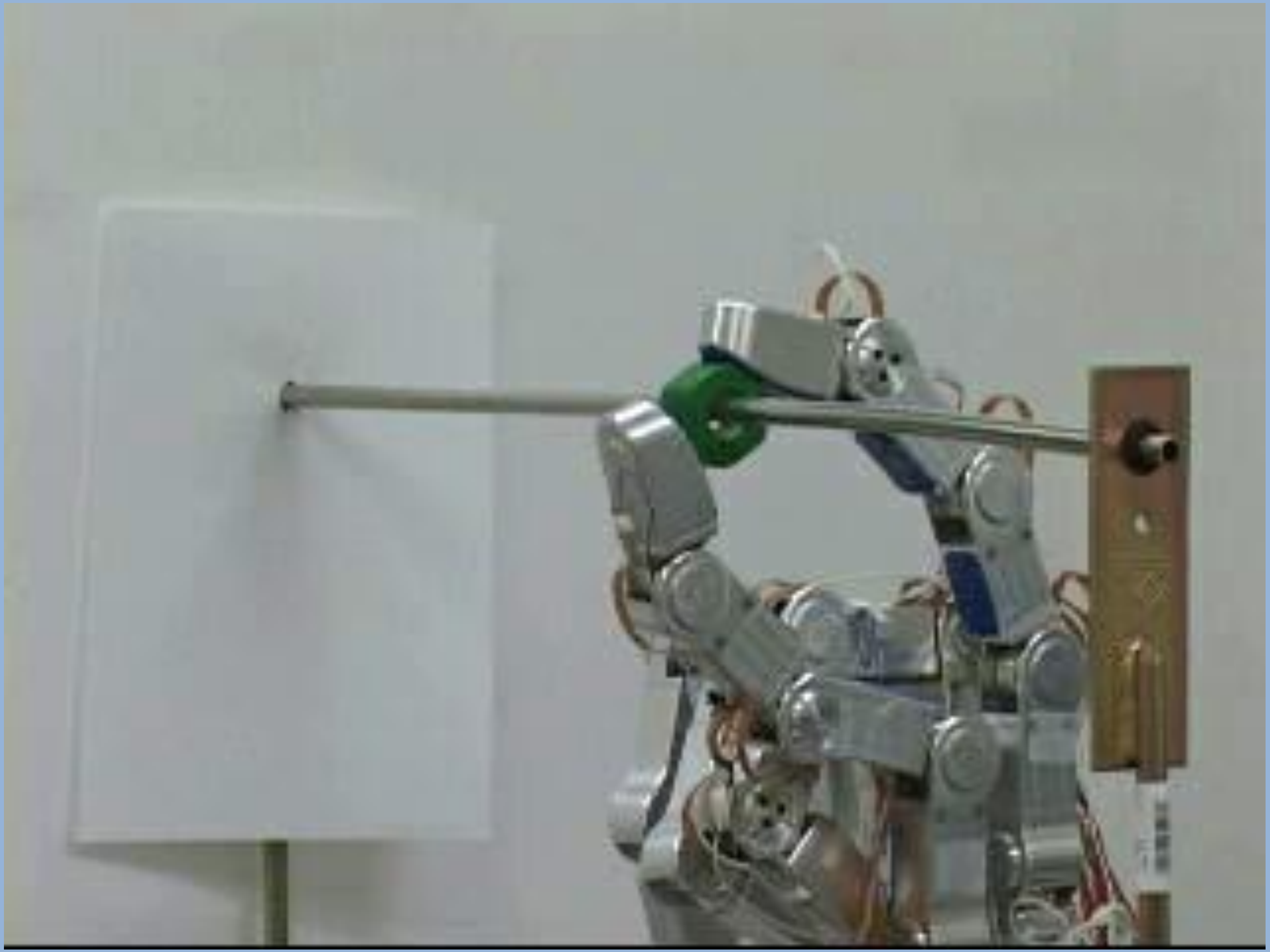
Big Dog – Quadruple Robot



World Fastest Robot



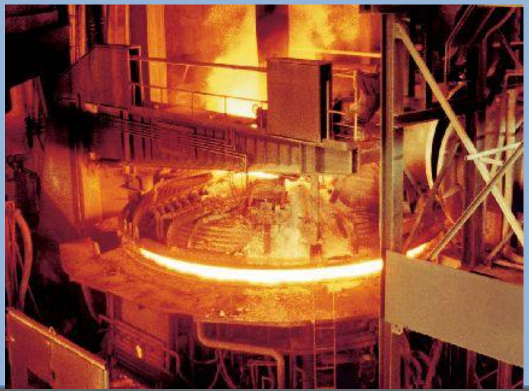
A Robotic Hand



Introduction

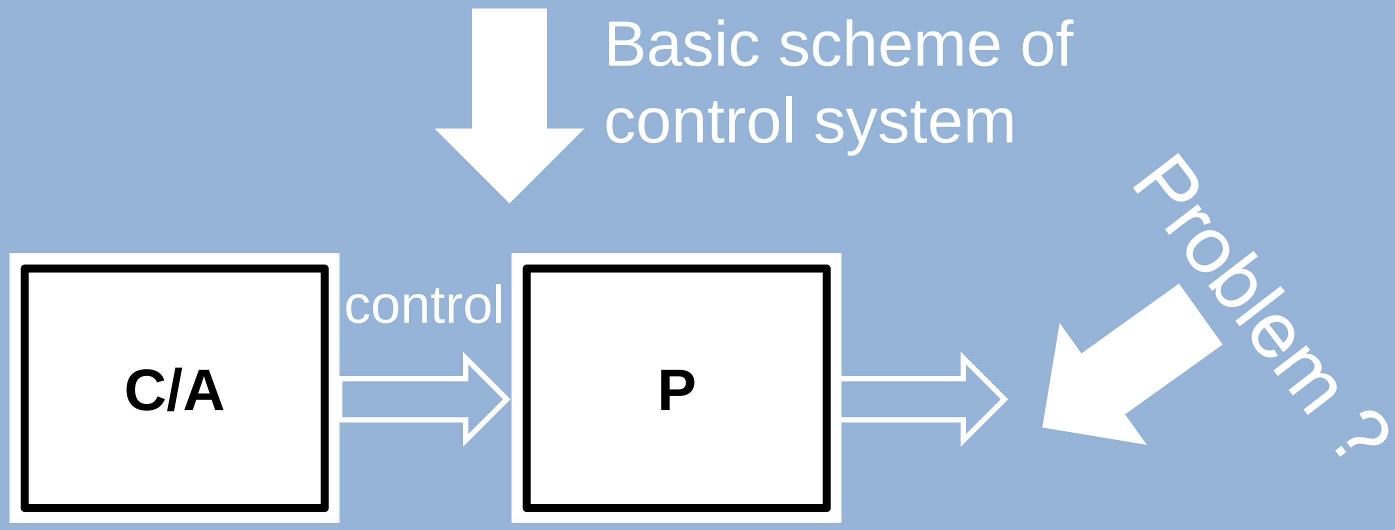
- What is Control?
  - **Control** (steering) of a vehicle movement (proj., vel.)
  - **Control** of an electrical furnace (temp.)
  - **Control** of the medicine dosage in a given therapy
  - **Control** of a production process (material processing)
  - **Control** of a manufacturing process (assembly)

Any thing common ??



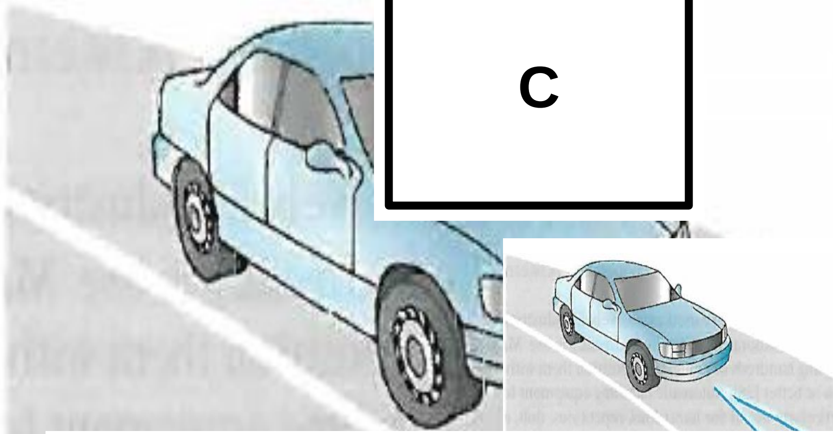
Introduction

- 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



C

A

P

Control
commands

Control

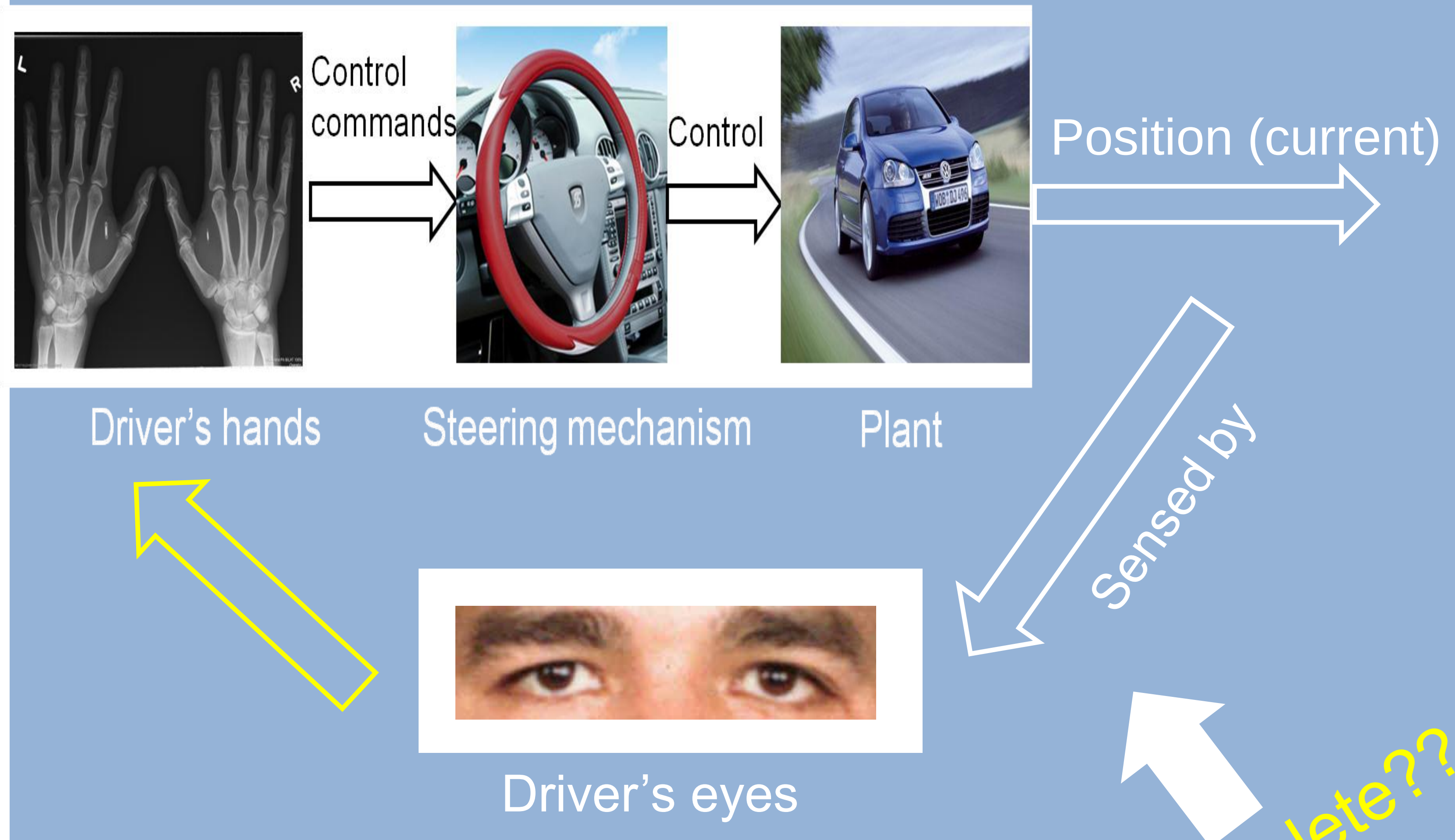
of travel

hands

Steering mechanism

Plant

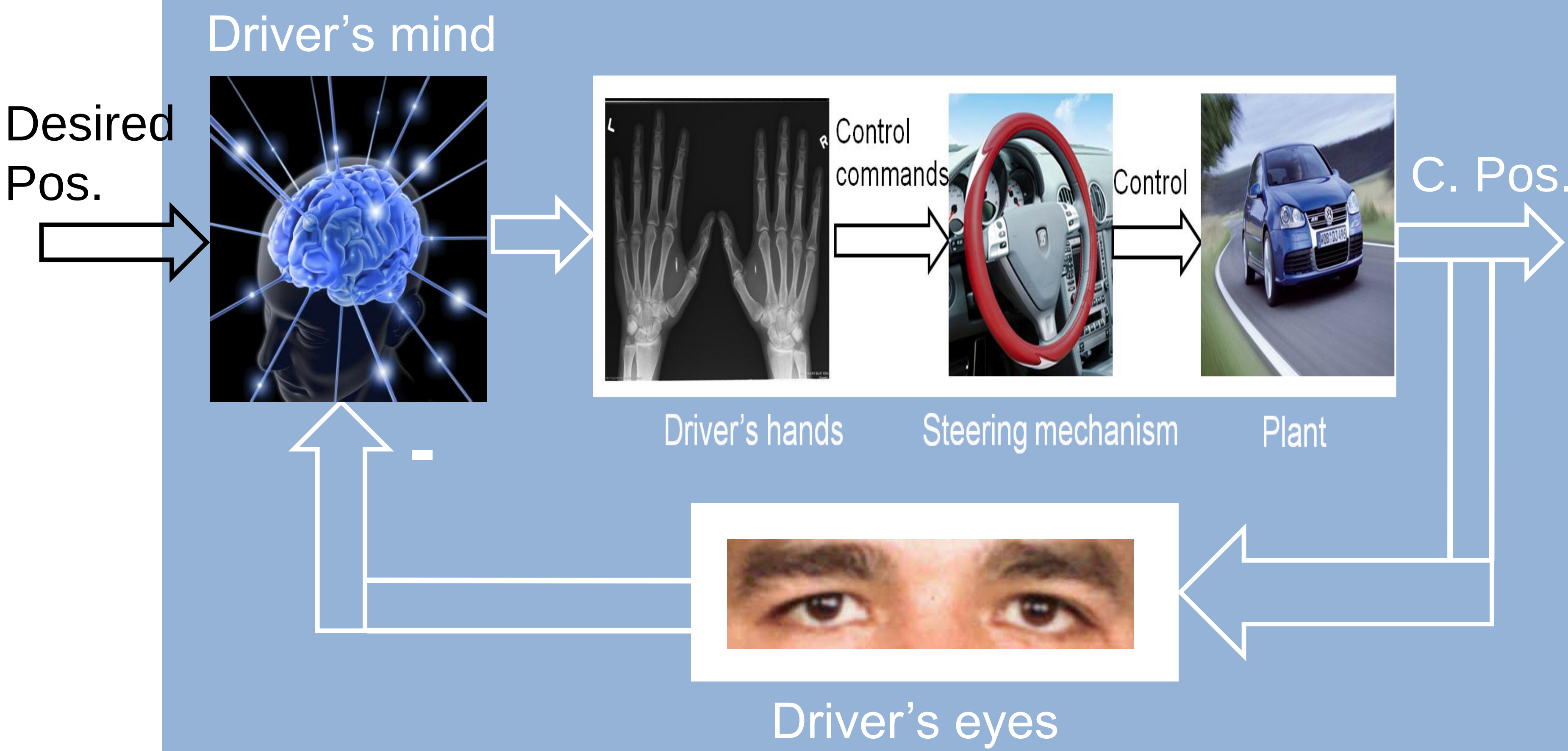
Example 1 – Car Steering



More better scheme with Feedback

Complete??

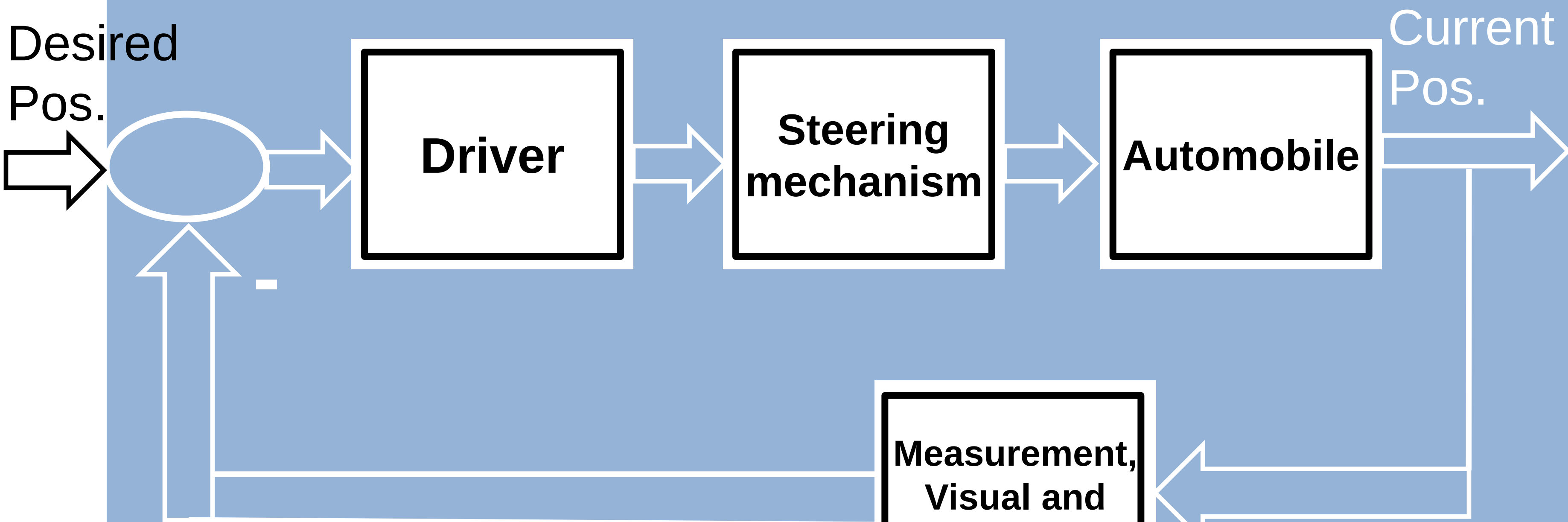
Example 1 – Car Steering

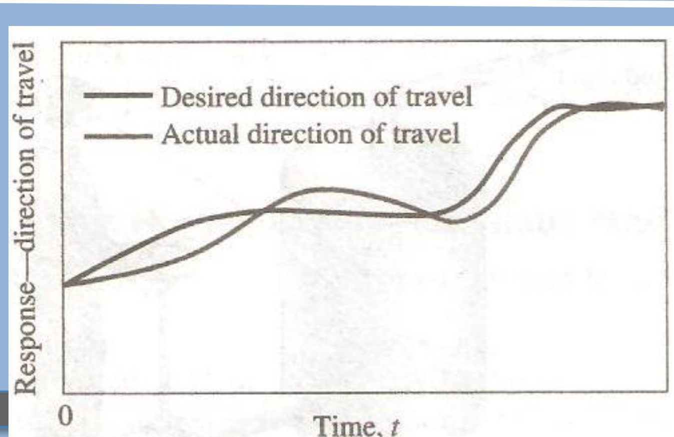


More better scheme (Closed loop control system)

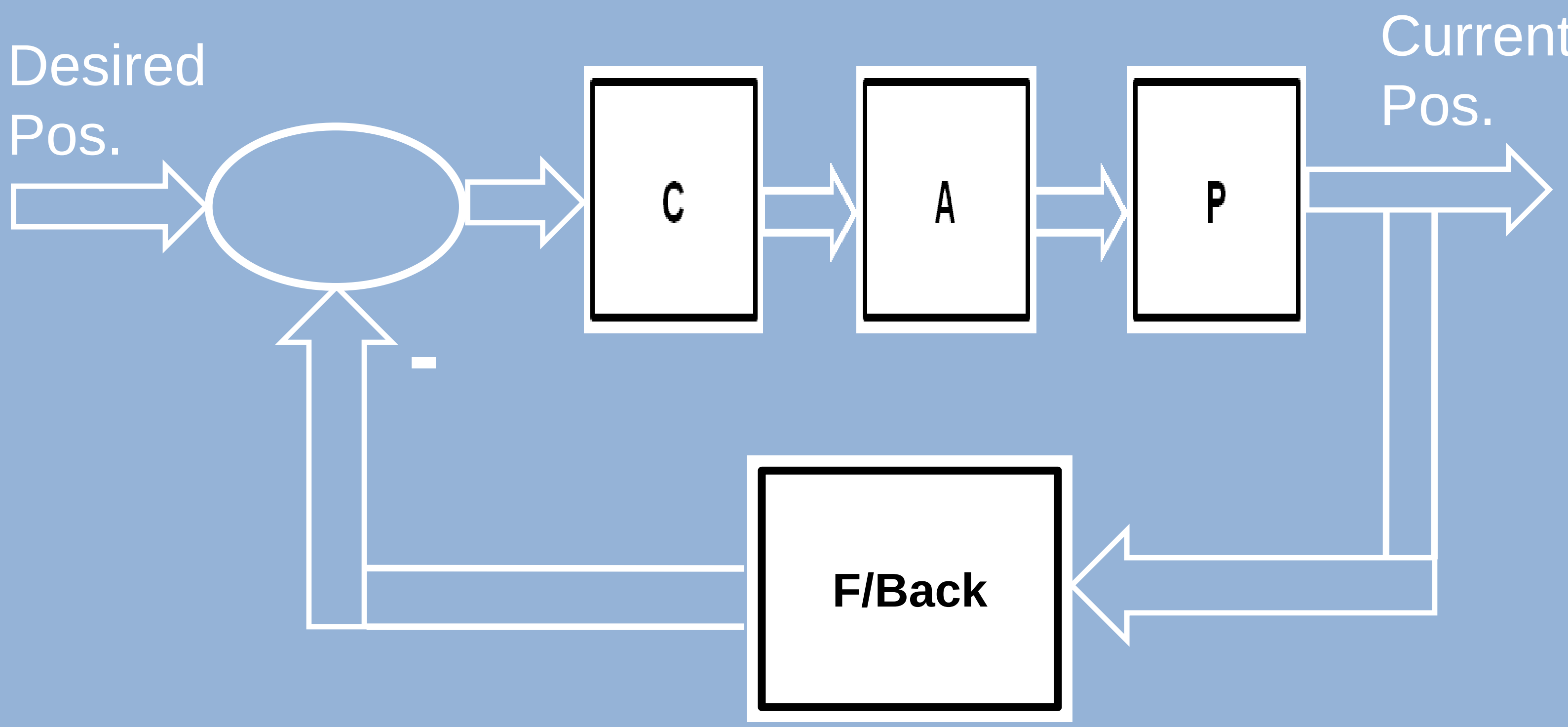
Example 1 – Car Steering

- Block Diagram of Car Steering Control



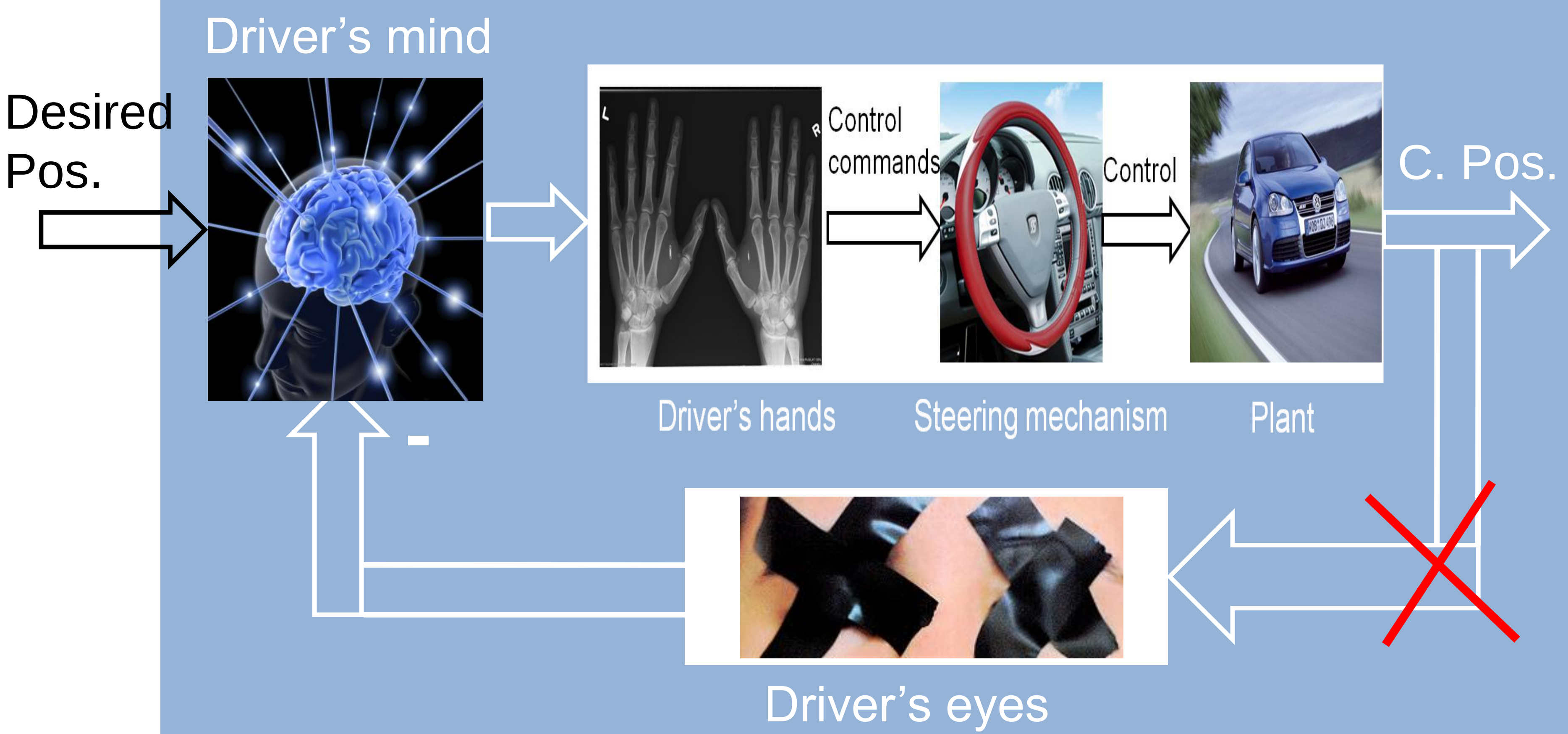


Block Diagram of Closed Loop C/System



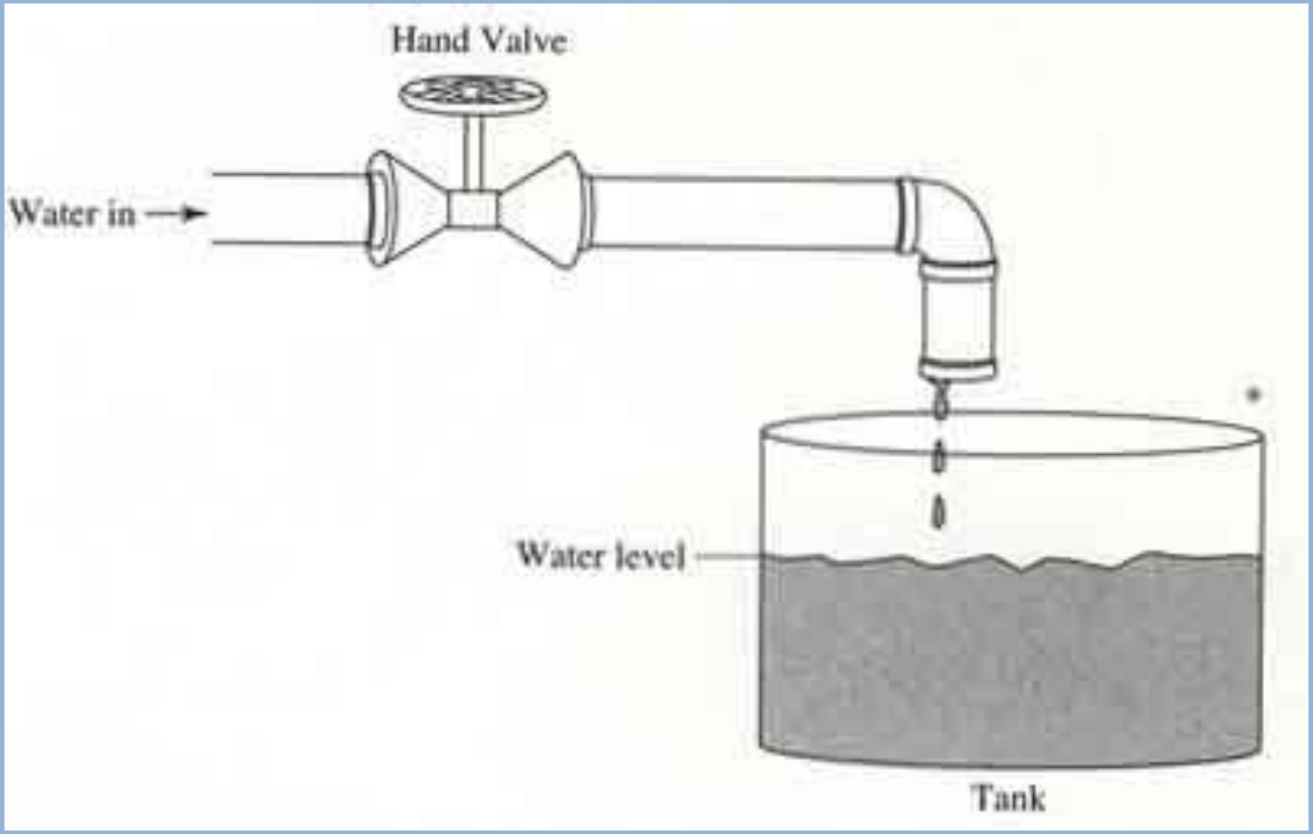
Closed Loop Position Control

Example 1 – Car Steering (Open Loop)



Example 2

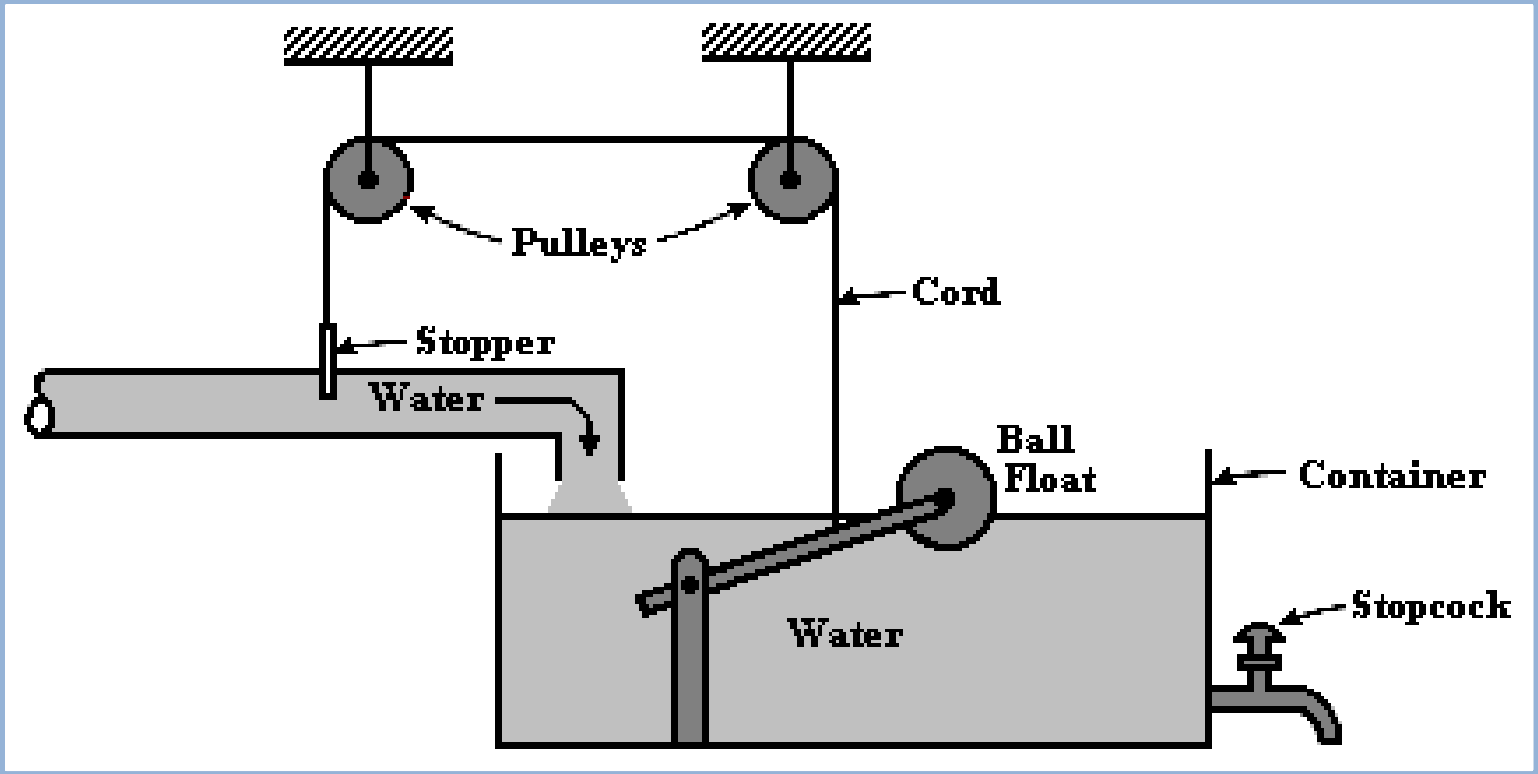
- Water Level Control System (Open Loop)



Assuming no visual F/back

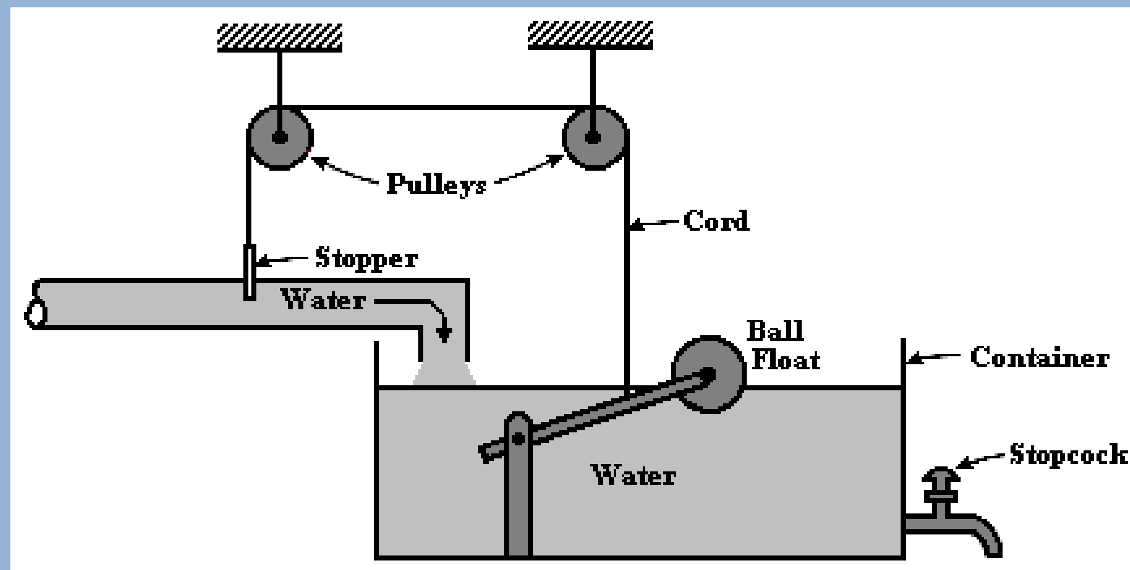
Example 2

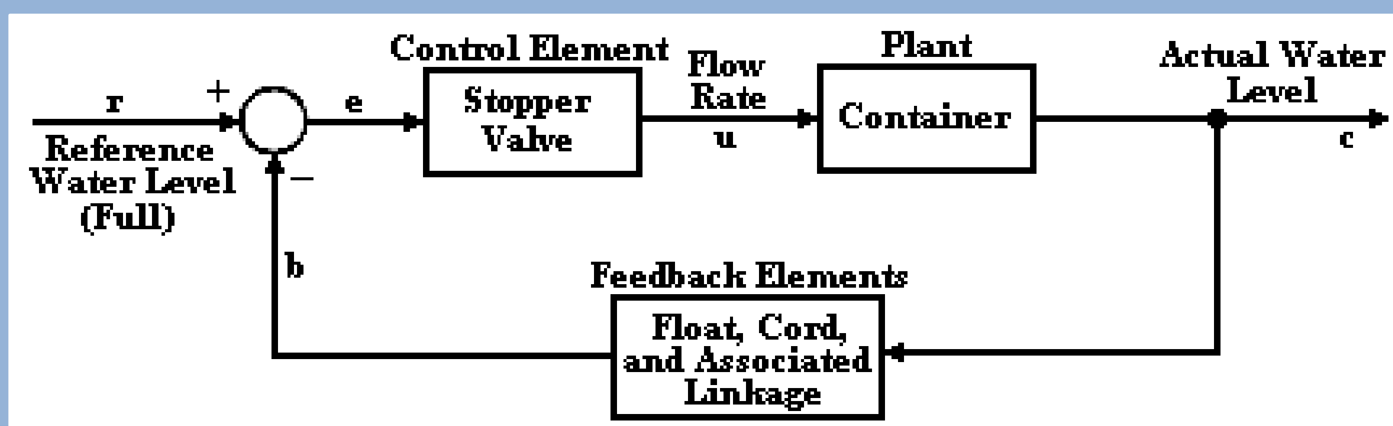
- Water Level Control System (Closed Loop)



Example 2

- Water Level Control System (Closed Loop)

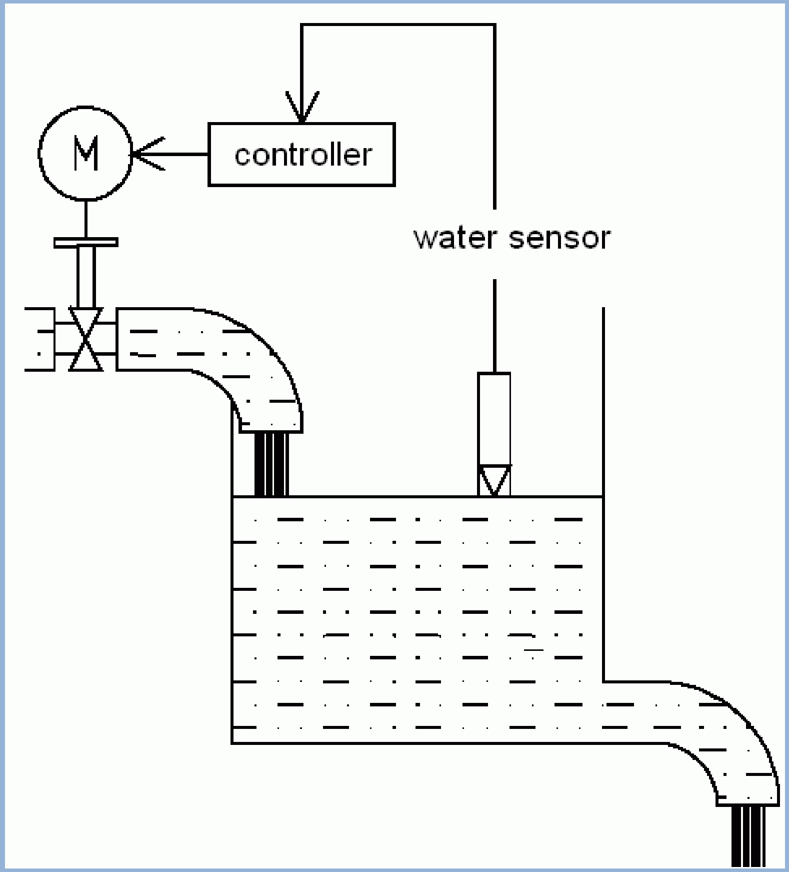




Example 2

- Water Level Control System (Closed Loop)

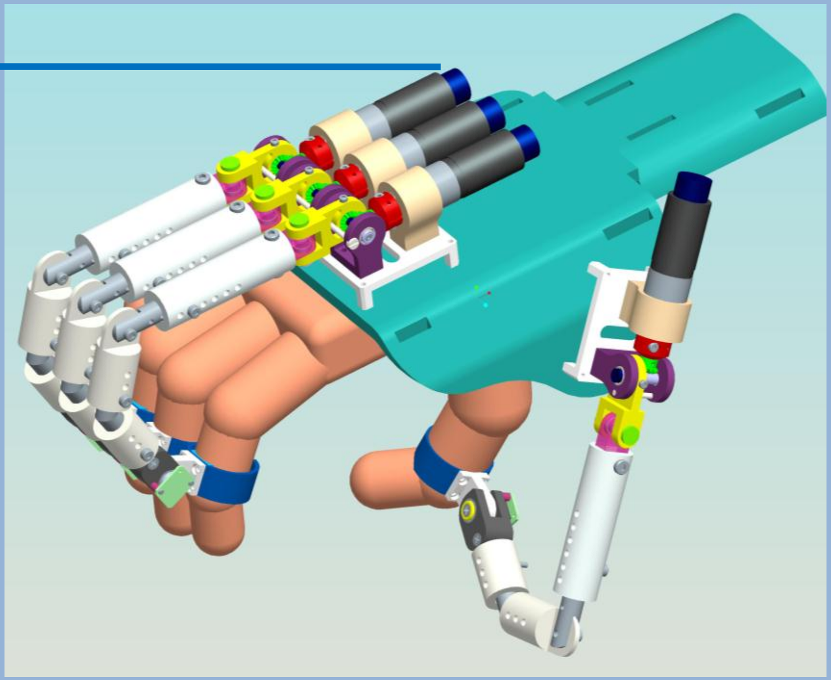
(2nd Implementation)

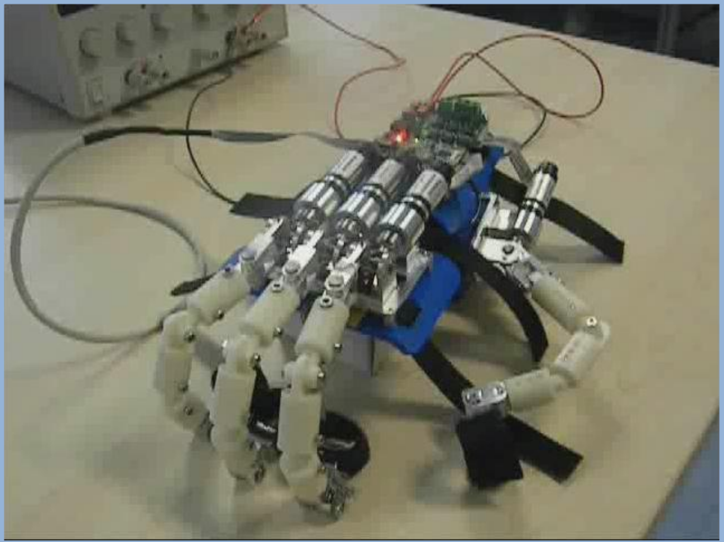


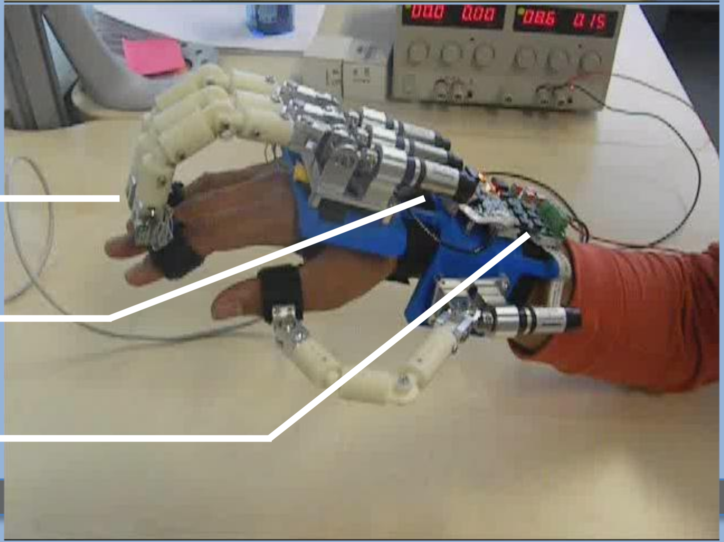
Example 3

- Hand Exoskeleton Robotic System

Sensor







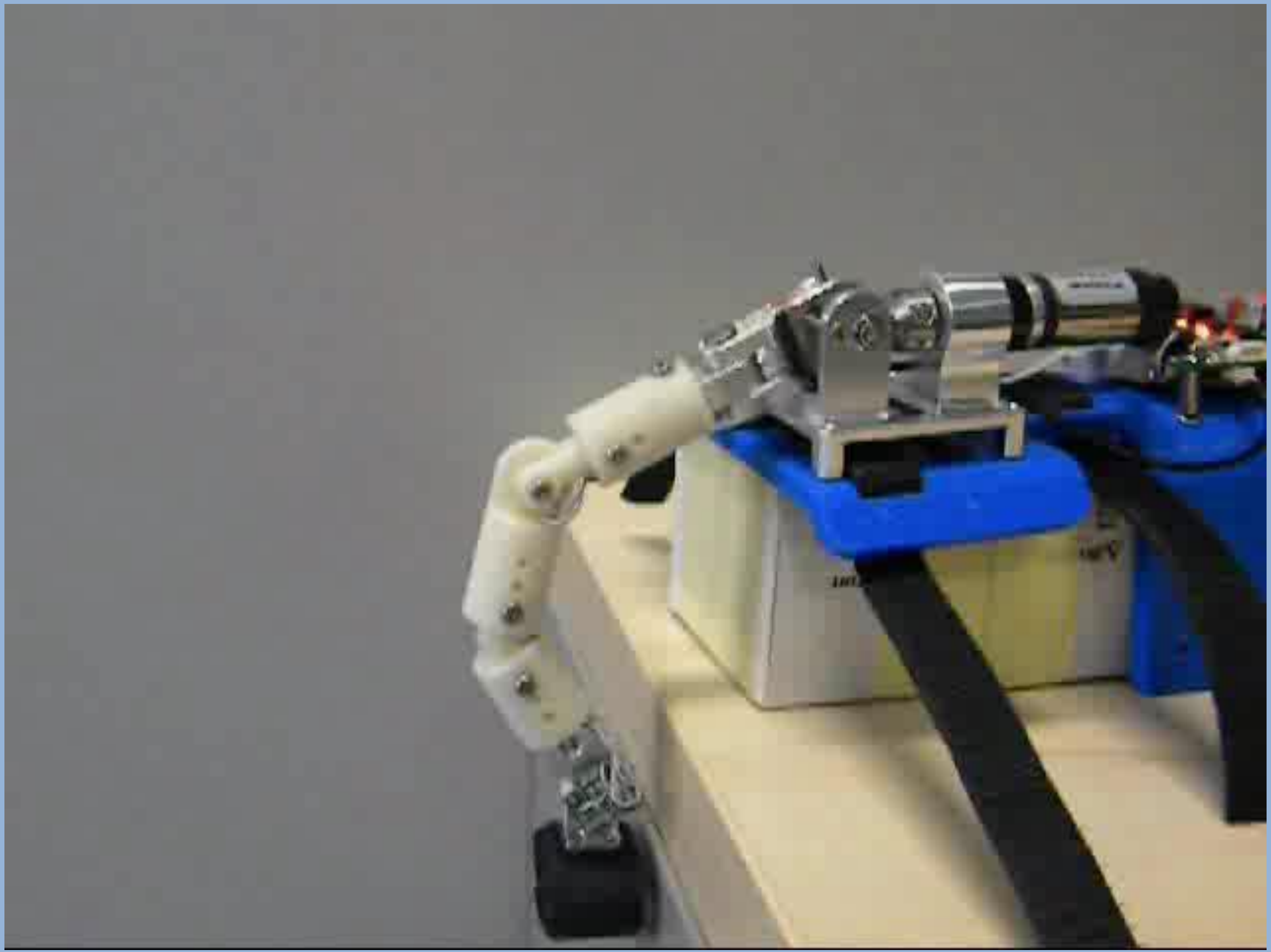
Plant

Actuator

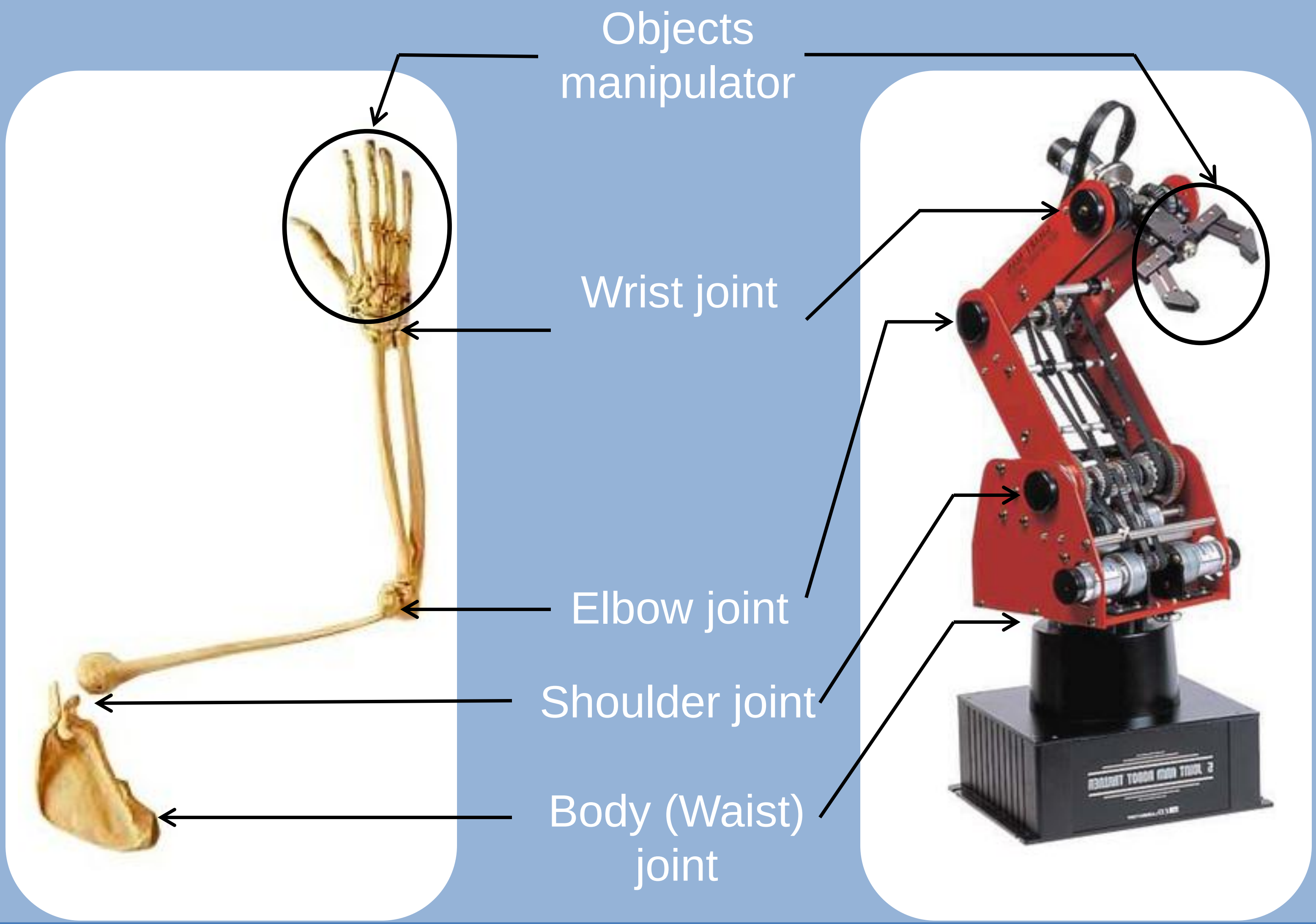
Controller

Example 3

- Hand Exoskeleton Robotic System Control

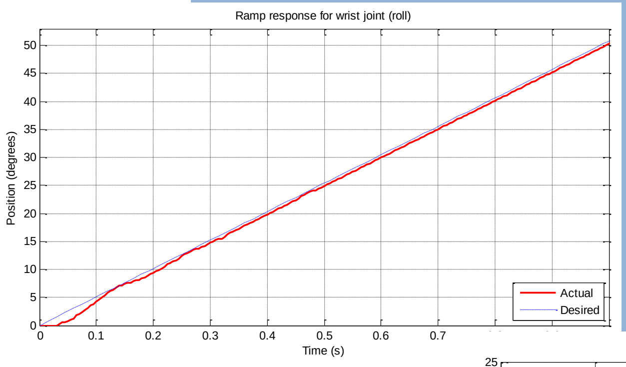


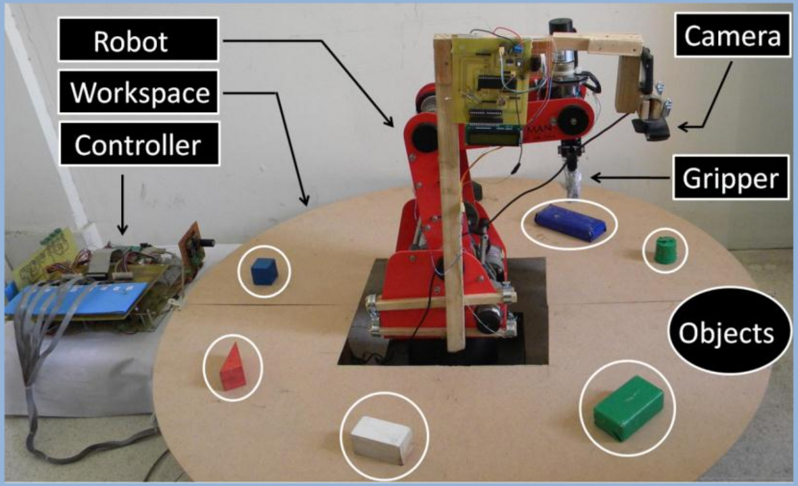
Example 4: Robotic Arm

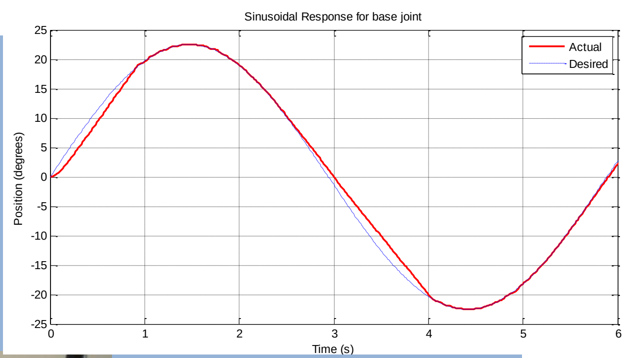


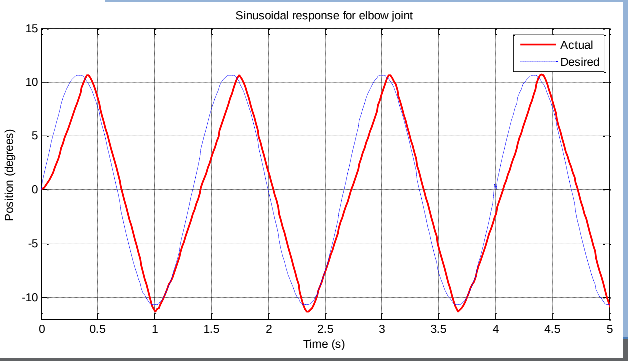
Example 4

- ➢ Task Accomplishment Using Robotic Arm

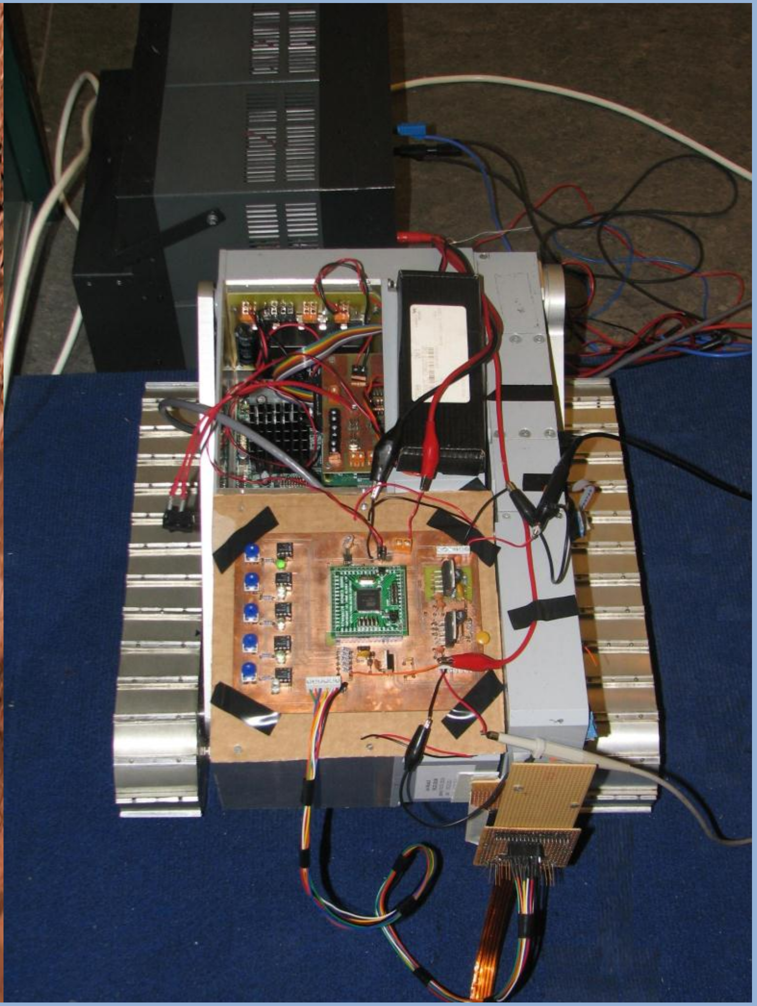




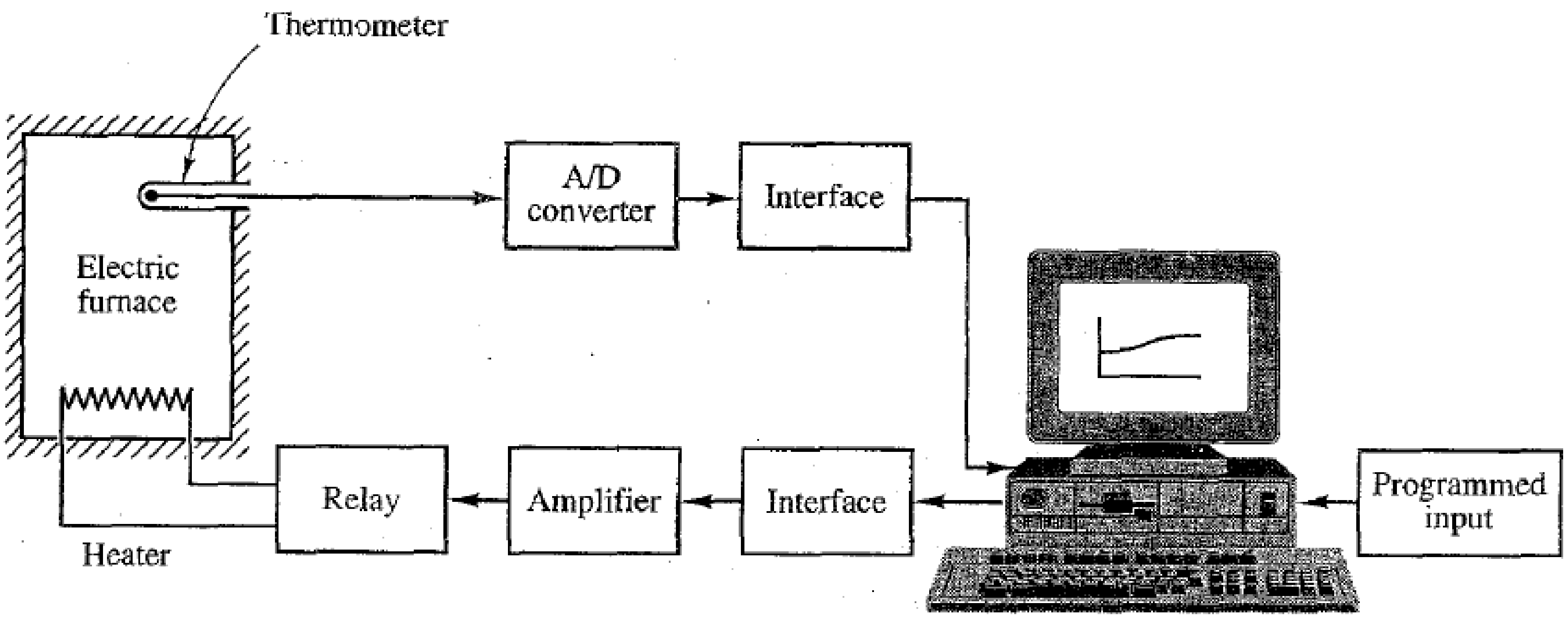




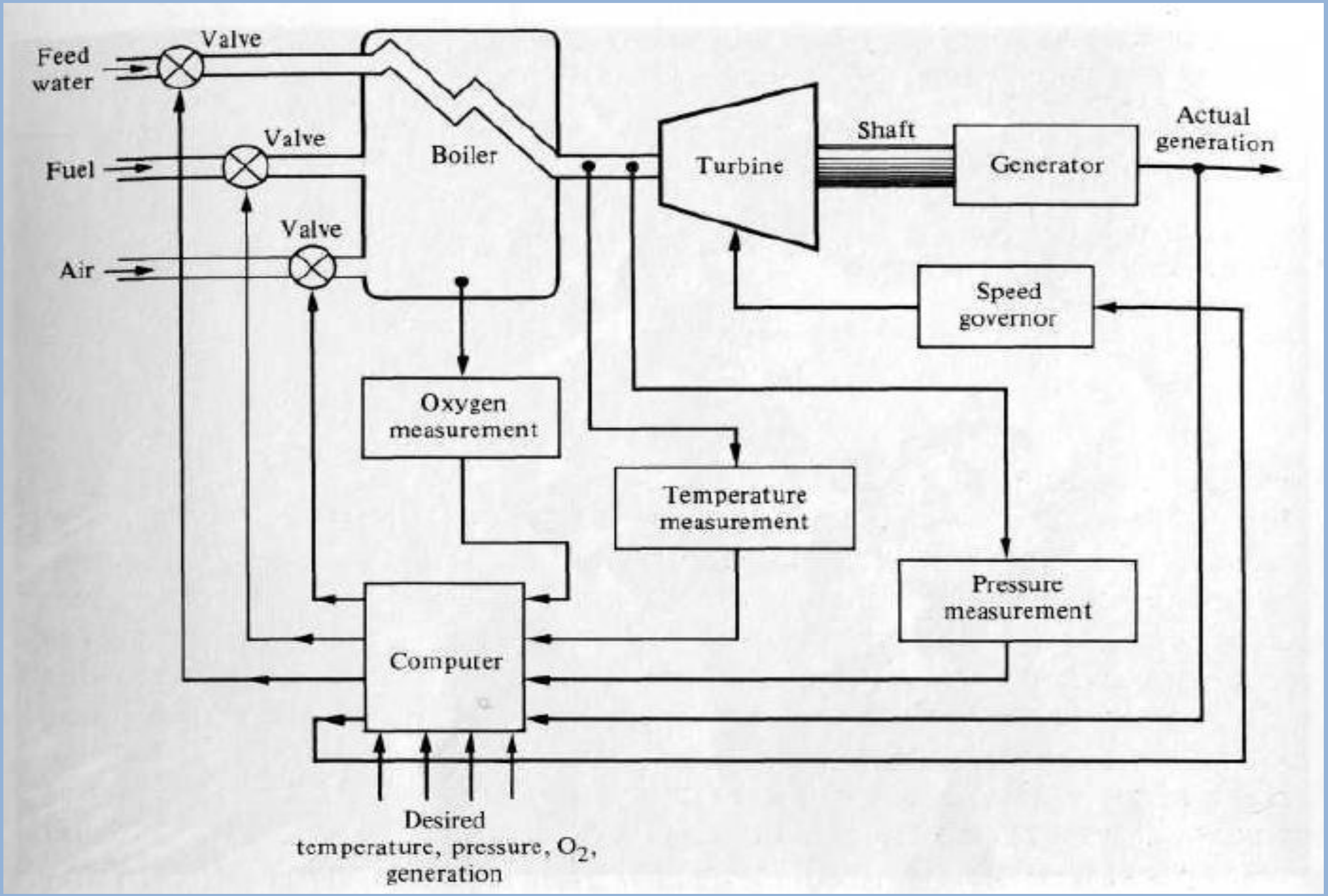
Example 5: Mars Rover



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 handeled on time basis
  - Accuracy not so critical
- Examples:
  - Washing machine (not measure des. o/p - cleanliness)
  - Hand drier
  - Traffic signals

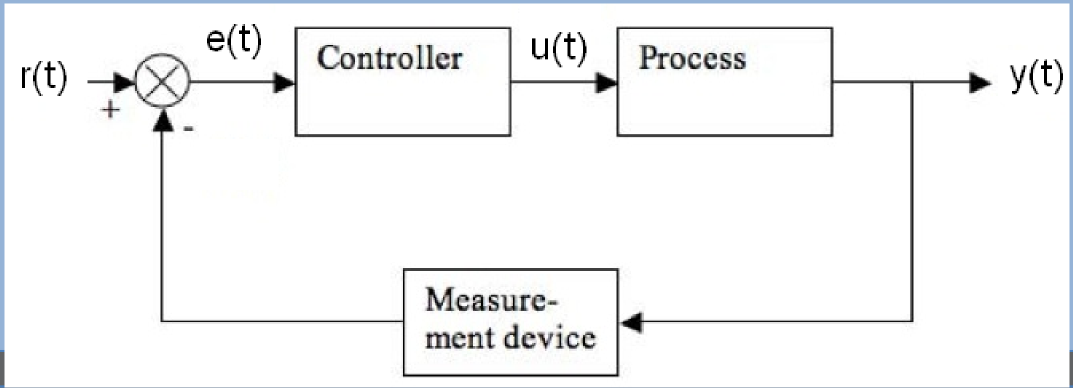


Open Loop Control Systems

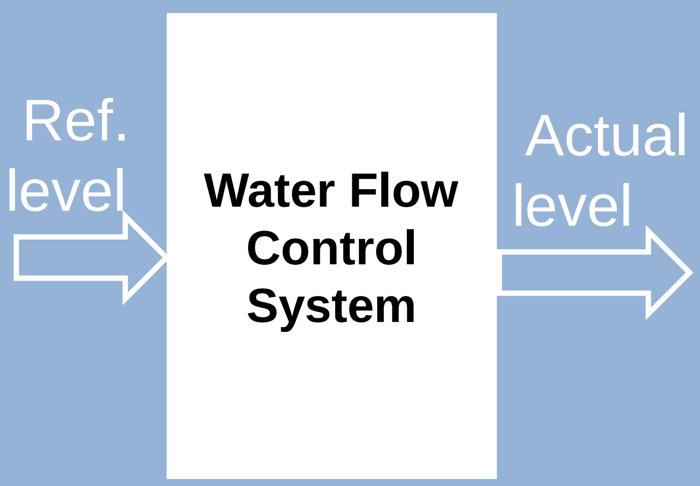
- Advantages
  - Simple construction
  - Ease of maintenance
  - Less expensive than a corresponding c/loop system (less no. of components)
  - Convenient when O/p is hard/expensive to measure
  - They are less prone to stability issues
- Disadvantages
  - Less accurate
  - Disturbances can change desired o/p (worst case)
  - Recalibration often required (to ensure the required o/p quality)

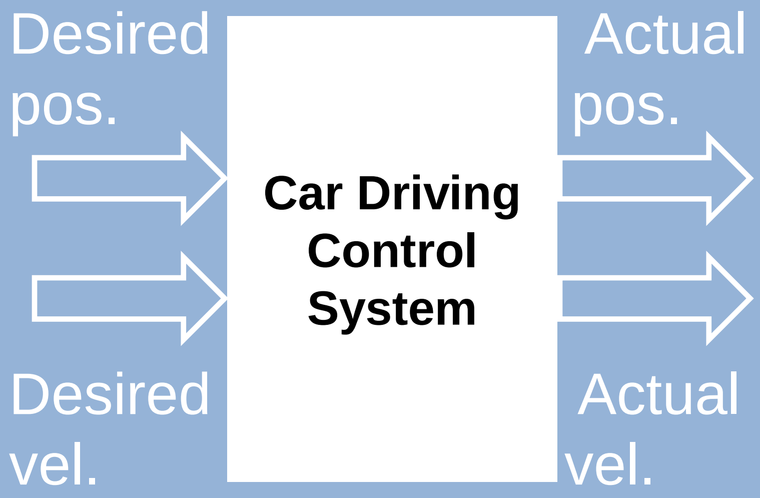
Closed Loop Control Systems

- 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



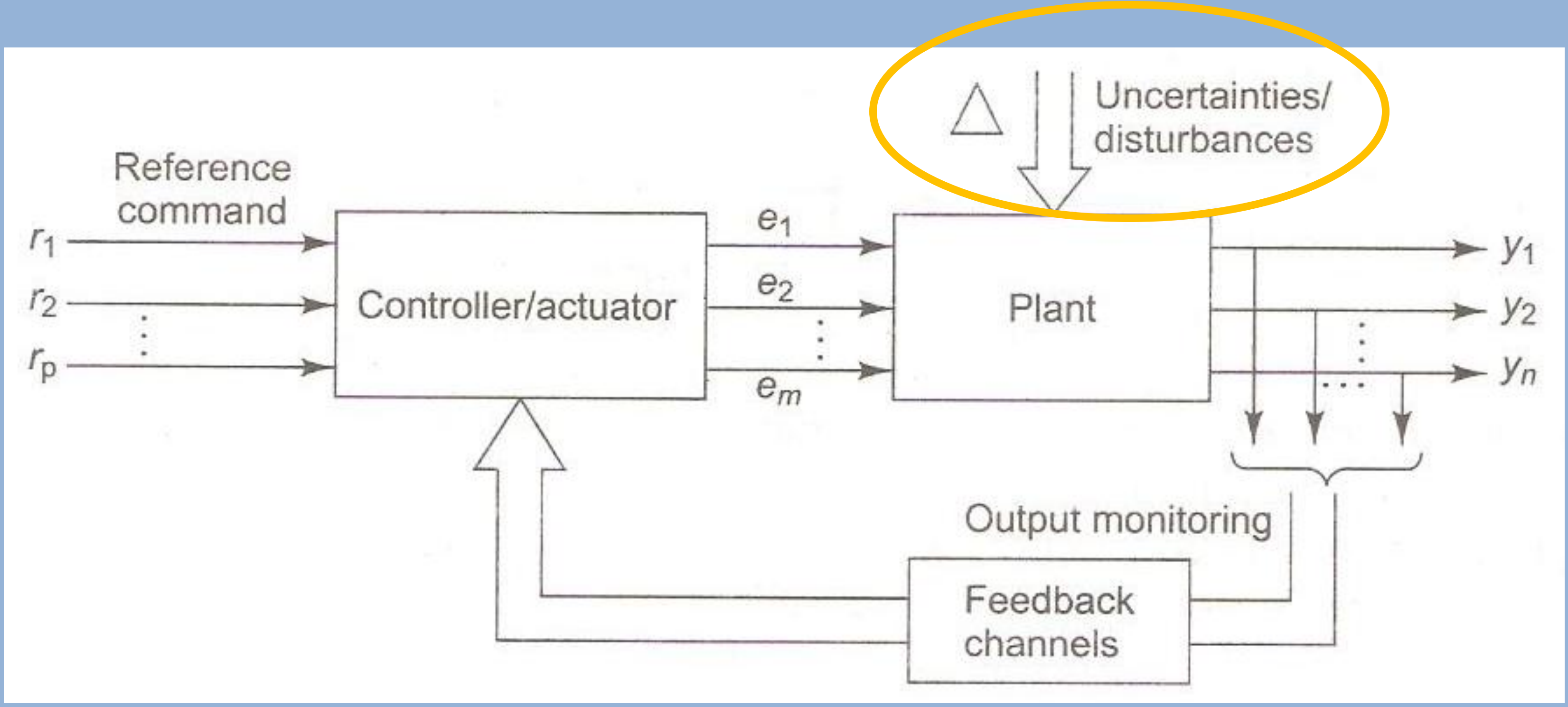
Control Classification w.r.t. I/Os





- 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
- ...

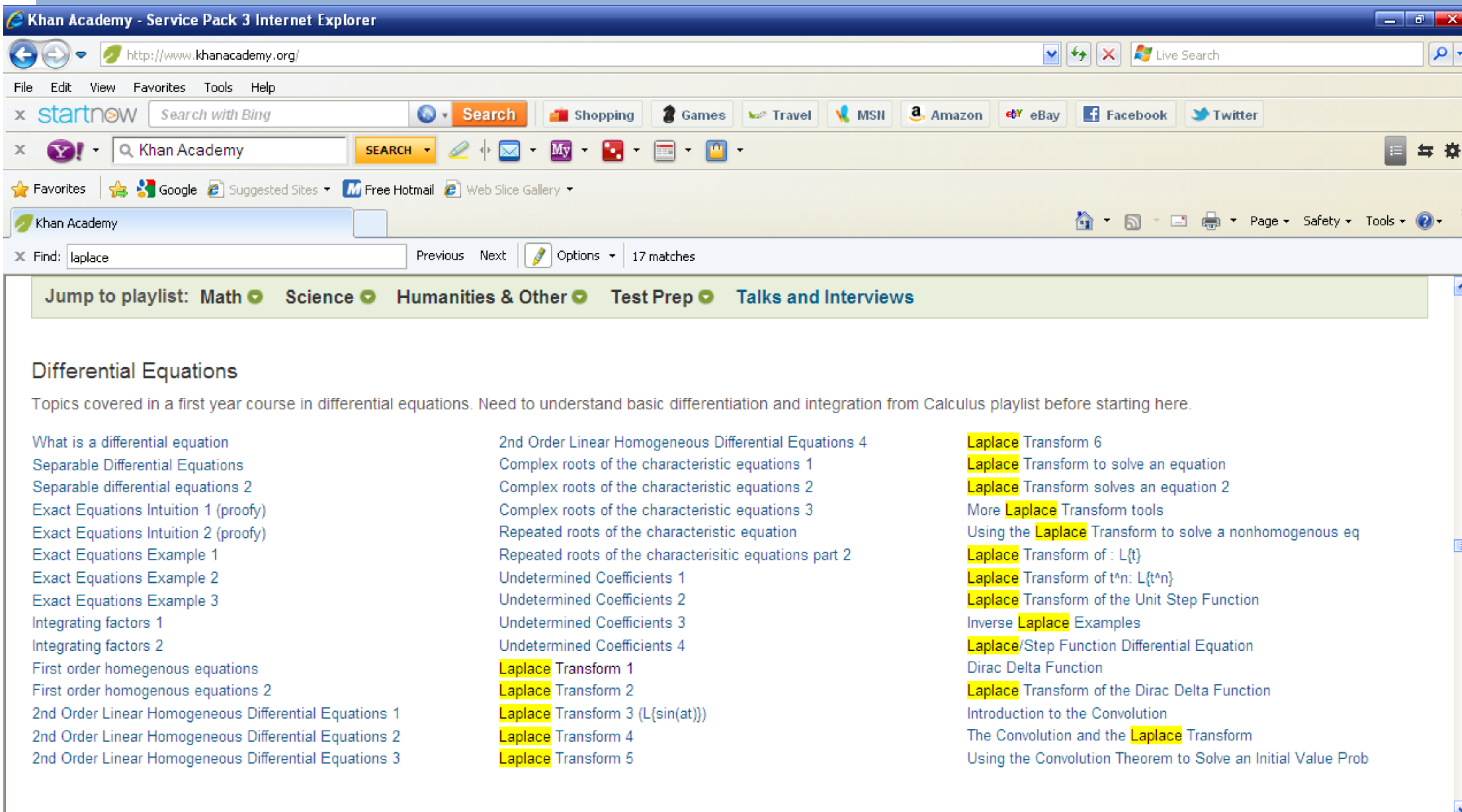
Applications of Control Systems

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)

Online Resource: Khan Academy



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

System

Express

Differential Equations
(t domain)

Frequency
(s domain)

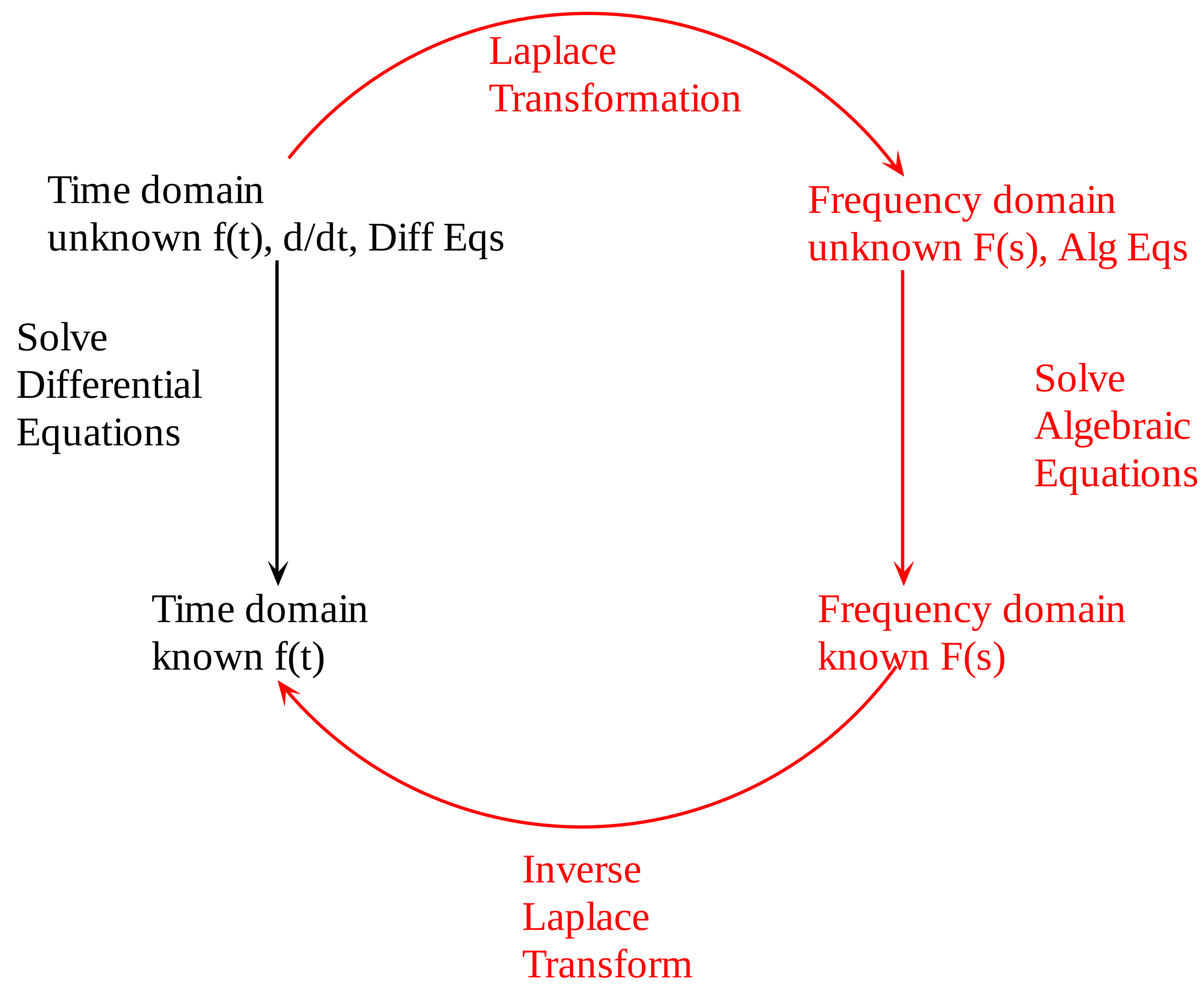
Interest

System's
Response

LT Implementation Cycle

<u>Time Domain</u>		<u>Frequency Domain</u>
Differential equations	Laplace Transform →	Algebraic equations
I/p *e(t)* O/p response *r(t)*	← Inverse Laplace Transform	I/p *E(s)* O/p response *R(s)*

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

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

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

LT Definition

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

$$f(t) \Leftrightarrow F(s)$$

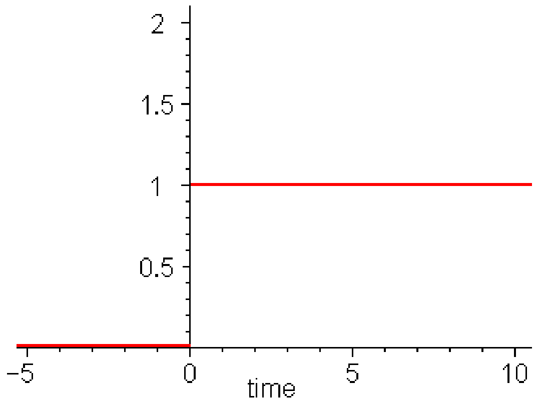
The above is a statement that f(t) and F(s) are transform pairs. What this means is that for each f(t) there is a unique F(s) and for each F(s) there is a unique f(t)

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.



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

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

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

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

MATLAB Commands

- Laplace

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

- Inverse Laplace

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

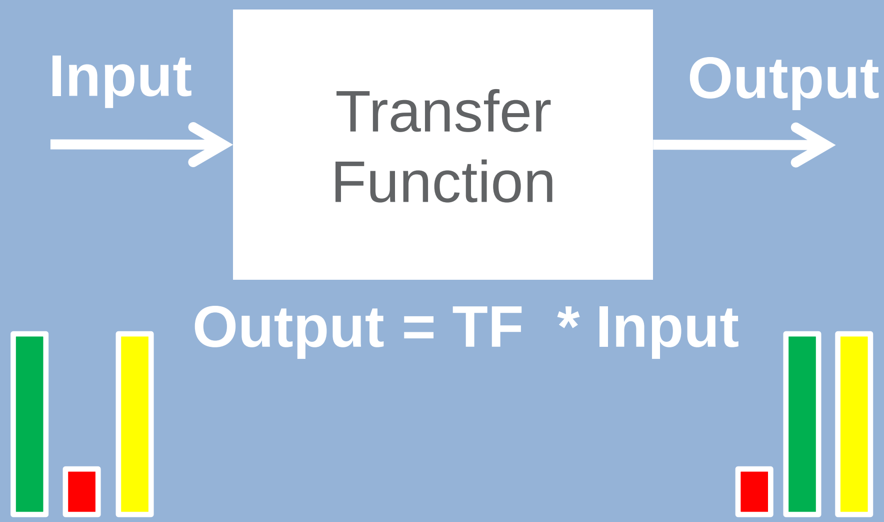
- Transfer Function

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

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

Transfer Function

Transfer functions describe the input-output relationship.



LT Table

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

Thanks