Automatic Control Systems

Lecture-1
Introduction

Dr. Yehia EL Mashad
TA: Eng. Ahmed Abdelalim

Automatic control theory

A Course

used for analyzing and designing automatic control systems

Brief history of automatic control (I)

- 1868 First article of control ‘on governor’s’ –by Maxwell
- 1877 Routh stability criterion
- 1892 Liapunov stability condition
- 1895 Hurwitz stability condition
- 1932 Nyquist
- 1945 Bode
- 1947 Nichols
- 1948 Root locus
- 1949 Wiener optimal control research
- 1955 Kalman filter and controlbility observability analysis
- 1956 Artificial Intelligence

Brief history of automatic control (II)

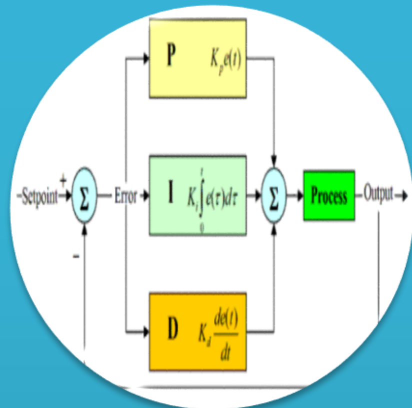
- 1957 Bellman optimal and adaptive control
- 1962 Pontryagin optimal control
- 1965 Fuzzy set
- 1972 Vidyasagar multi-variable optimal control and Robust control
- 1981 Doyle Robust control theory
- 1990 Neuro-Fuzzy

21 century — information age, cybernetics(control theory), system approach and information theory , three science theory (supports) in 21 century.

Control system analysis and design

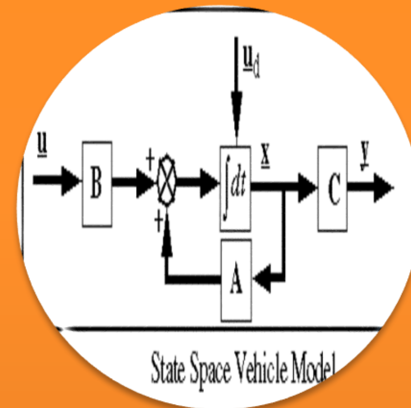
- **Step1: Modeling**
  - By physical laws
  - By identification methods
- **Step2: Analysis**
  - Stability, controllability and observability
- **Step3: Control law design**
  - Classical, modern and post-modern control
- **Step4: Analysis**
- **Step5: Simulation**
  - Matlab, Fortran, simulink etc….
- **Step6: Implement**

Course Outline



Classical Control

- System Modelling
  - Transfer Function
  - Block Diagrams
  - Signal Flow Graphs
- System Analysis
  - Time Domain Analysis (Test Signals)
  - Frequency Domain Analysis
    - Bode Plots
    - Nyquist Plots
    - Nichol’s Chart



Modern Control

- State Space Modelling
- Eigenvalue Analysis
- Observability and Controllability
- Solution of State Equations (state Transition Matrix)
- State Space to Transfer Function
- Transfer Function to State Space
  - Direct Decomposition of Transfer Function
  - Cascade Decomposition of Transfer Function
  - Parallel Decomposition of Transfer Function

Text Books

1. Modern Control Engineering, (5th Edition)   By: Katsuhiko Ogata.
   University of Minnesota
2. Control Systems Engineering, (6th Edition),   By: Norman S. Nise.
   Electrical and Computer   Engineering Department
   at California State Polytechnic University

Prerequisites

- For Classical Control Theory
  - Differential Equations
  - Laplace Transform
  - Basic Physics
  - Ordinary and Semi-logarithimic graph papers
- For Modern Control theory above &
  - Linear Algebra
  - Matrices

Practical Sessions

- Practicals are divided into two sessions
  - Software Based
    - Matlab
    - Simulink
    - Control System Toolbox
  - Hardware Based (Instrument & Control Lab)
    - Modular Servo System

Marks Distribution

- ❑ Total Marks = 100
- ❑ Mid Term Exam = 20
  - Attendance & Tutorials = 10 marks
  - Lab Work =10 marks
  - Mini Project = 20 marks
- ❑ Final Exam Marks = 40

What is Control System?

- A system Controlling the operation of another system.
- A system that can regulate itself and another system.
- A control System is a device, or set of devices to manage, command, direct or regulate the behaviour of other device(s) or system(s).

Definitions

System – An interconnection of elements and devices for a desired purpose.

Control System – An interconnection of components forming a system configuration that will provide a desired response.

Process – The device, plant, or system under control. The input and output relationship represents the cause-and-effect relationship of the process.

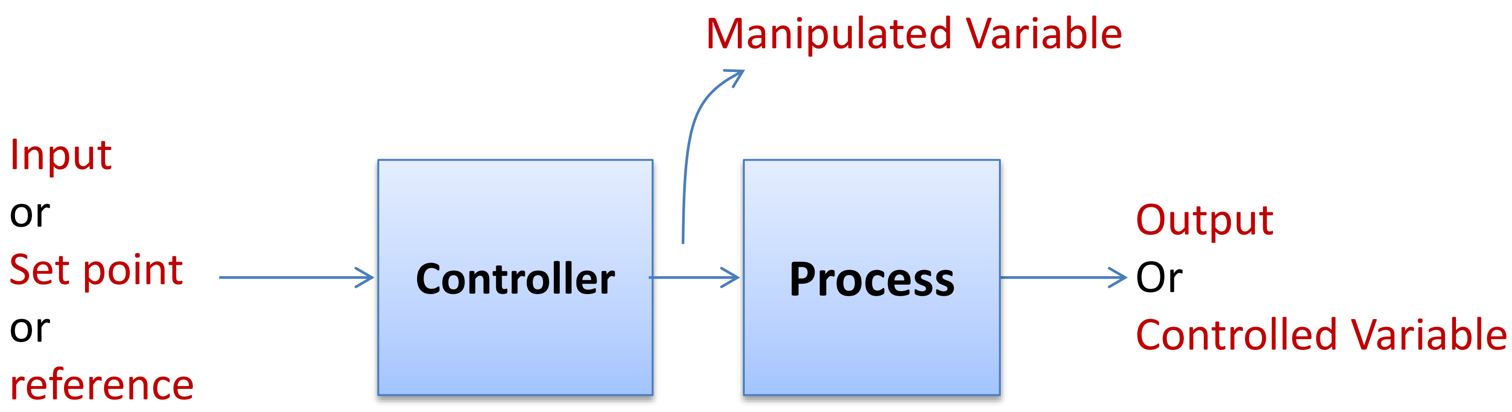
Definitions

Controlled Variable– It is the quantity or condition that is measured and Controlled. Normally *controlled variable* is the output of the control system.

Manipulated Variable– It is the quantity of the condition that is varied by the controller so as to affect the value of *controlled variable*.

Control – Control means measuring the value of *controlled variable* of the system and applying the *manipulated variable* to the system to correct or limit the deviation of the measured value from a desired value.

Definitions



Disturbances– A disturbance is a signal that tends to adversely affect the value of the system. It is an unwanted input of the system.

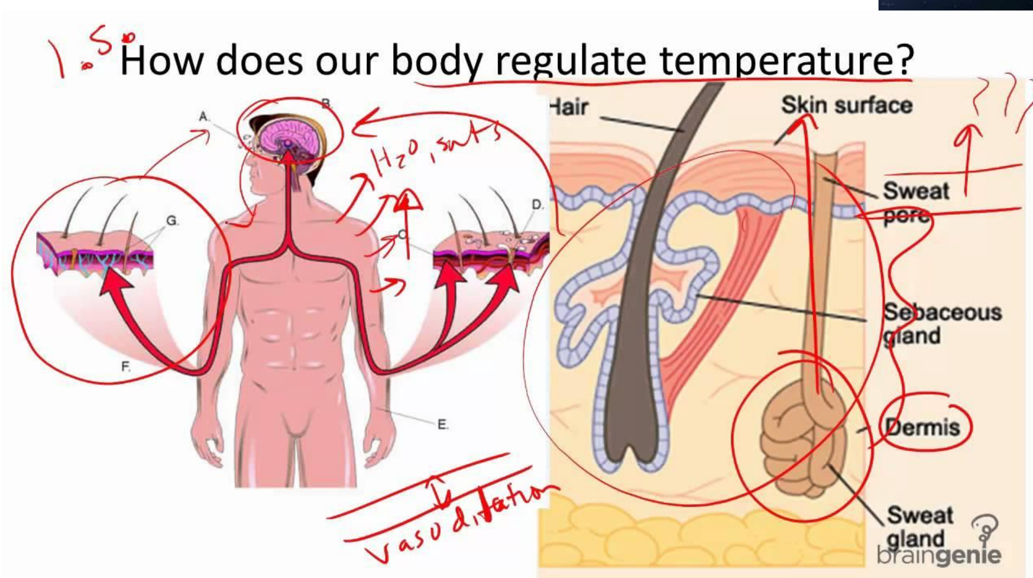
- If a disturbance is generated within the system, it is called *internal disturbance*. While an *external disturbance* is generated outside the system.

Types of Control System

- Natural Control System
  - Universe
  - Human Body
- Manmade Control System
  - Vehicles
  - Aeroplanes

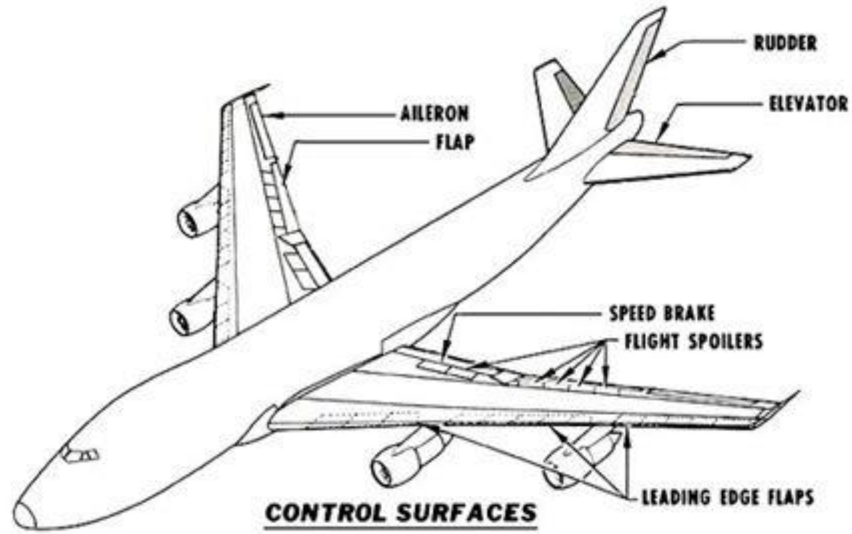
Types of Control System

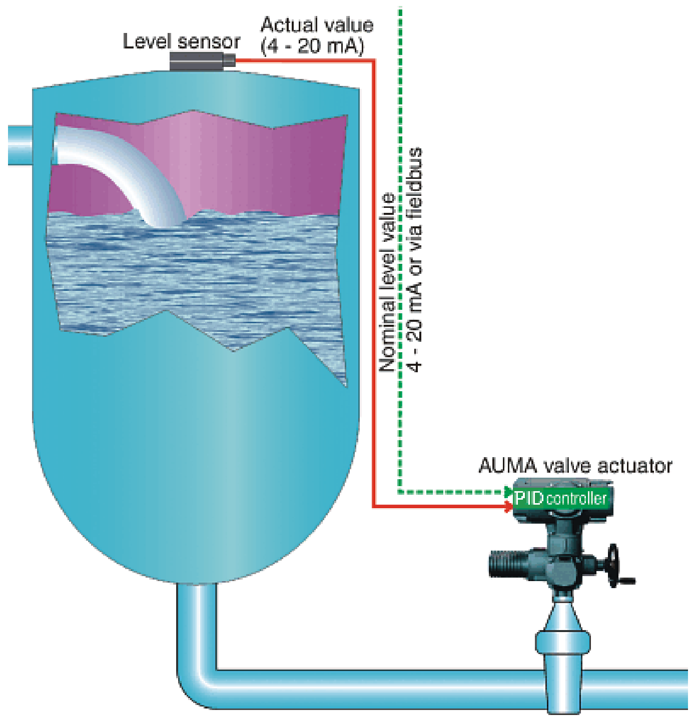
- Natural Control System
  - Universe
  - Human Body



Types of Control System

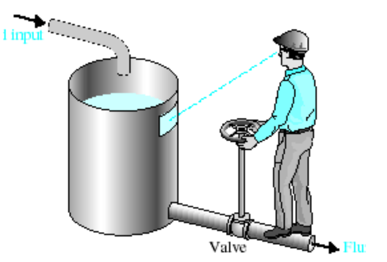
- Manmade Control System
  - Aeroplanes
  - Chemical Process





Types of Control System

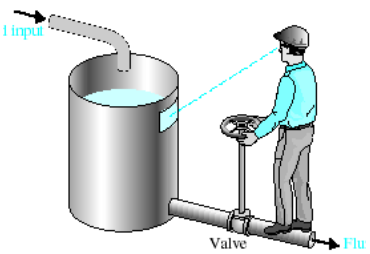
- Manual Control Systems
  - Room Temperature regulation Via Electric Fan
  - Water Level Control



- Automatic Control System
  - Room Temperature regulation Via A.C
  - Human Body Temperature Control

Types of Control System

- Manual Control Systems
  - Room Temperature regulation Via Electric Fan
  - Water Level Control



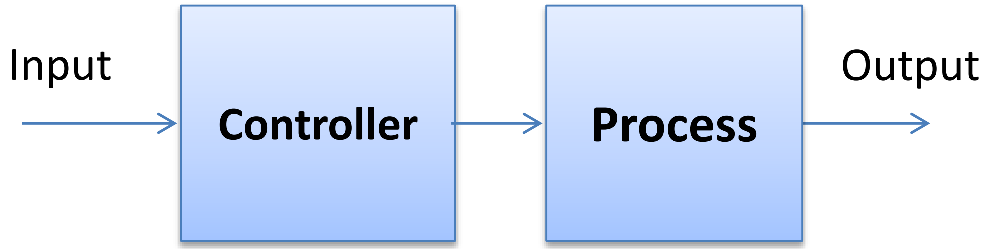
- Automatic Control System
  - Home Water Heating Systems
  - Room Temperature regulation Via A.C
  - Human Body Temperature Control

Types of Control System

Open-Loop Control Systems

Open-Loop Control Systems utilize a controller or control actuator to obtain the desired response.

- Output has no effect on the control action.
- In other words output is neither measured nor fed back.



Open-loop control system (without feedback).

Examples:- Washing Machine, Toaster, Electric Fan

Control Systems:

a. Open loop simple-not expensive-not accurate

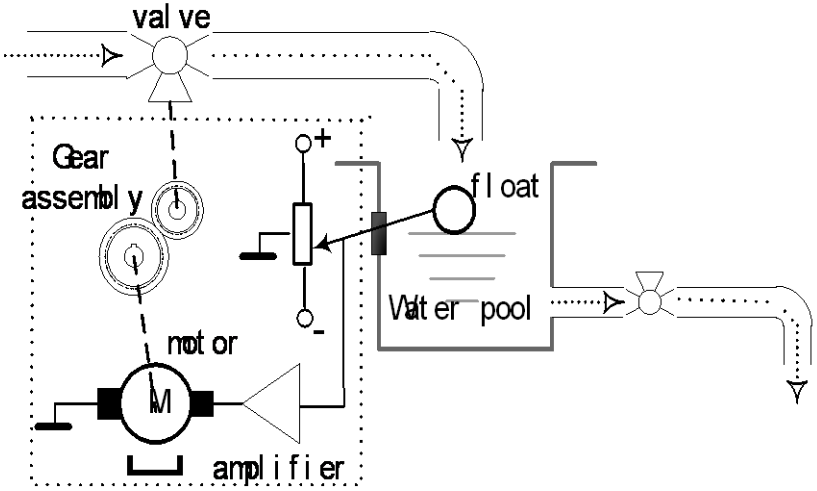
b. Closed loop: feed back

1.**Regulators** output=constant despite any unwanted disturbance

2. **Follow up-Servo** output=input

Examples

1) A water-level control system



*** Operating principle……**

*** Feedback control…… Measurement-Comparison - Correction**

Another example of the water-level control

* Operating principle……

* Feedback control……

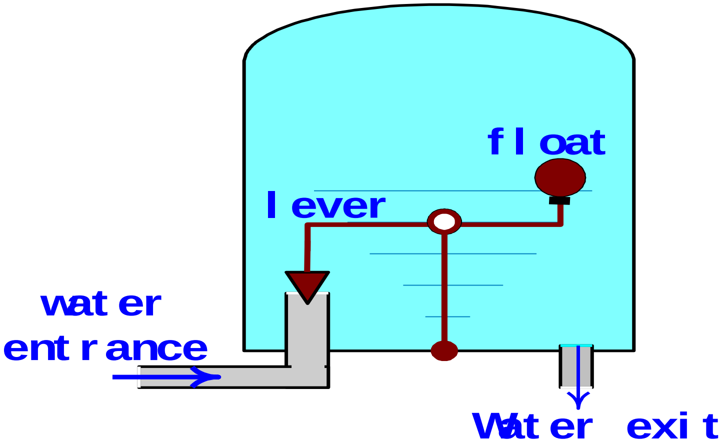


Figure 1.2

2) A temperature Control system

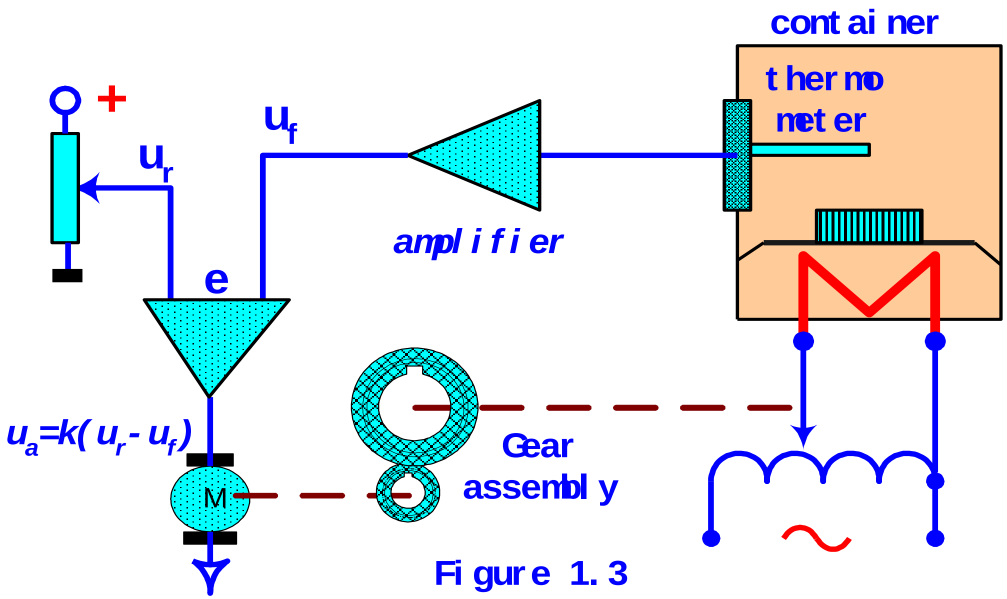


Figure 1.3

* Operating principle…

* Feedback control(error)…

3) A DC-Motor control system

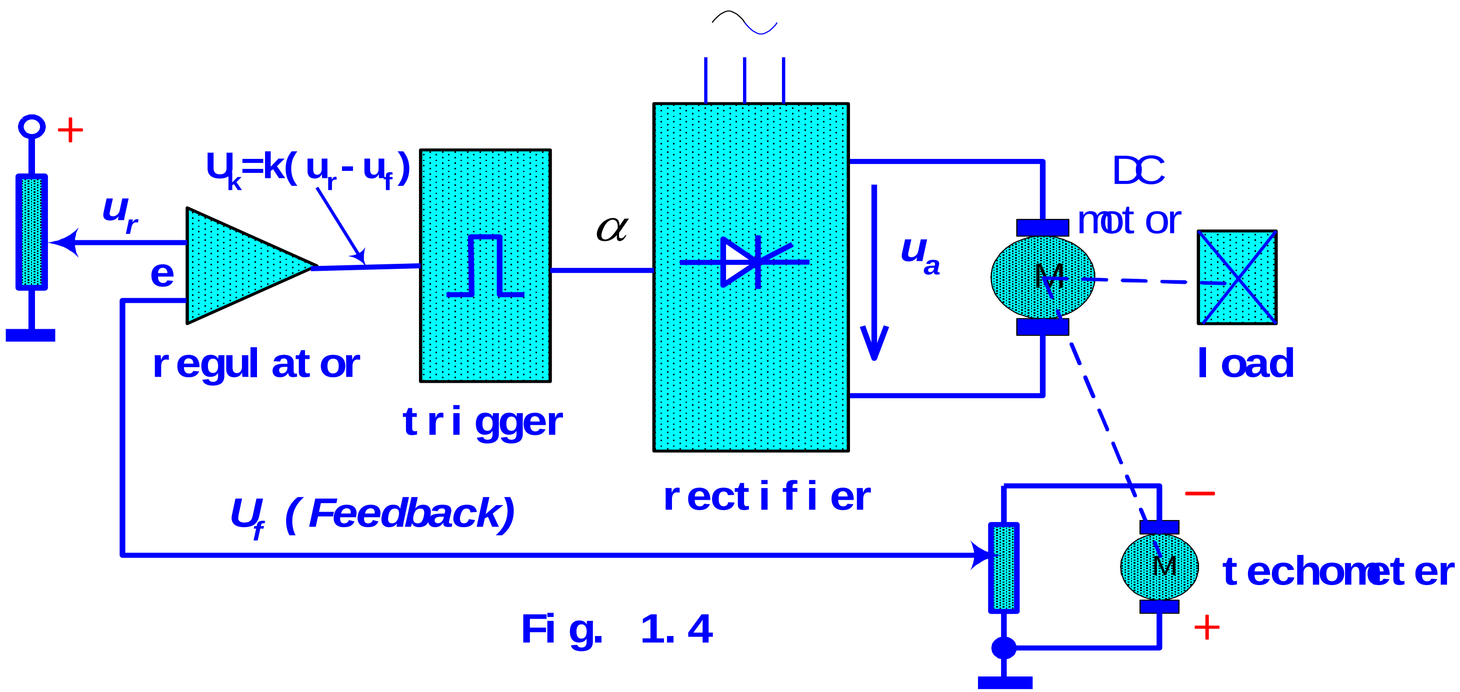
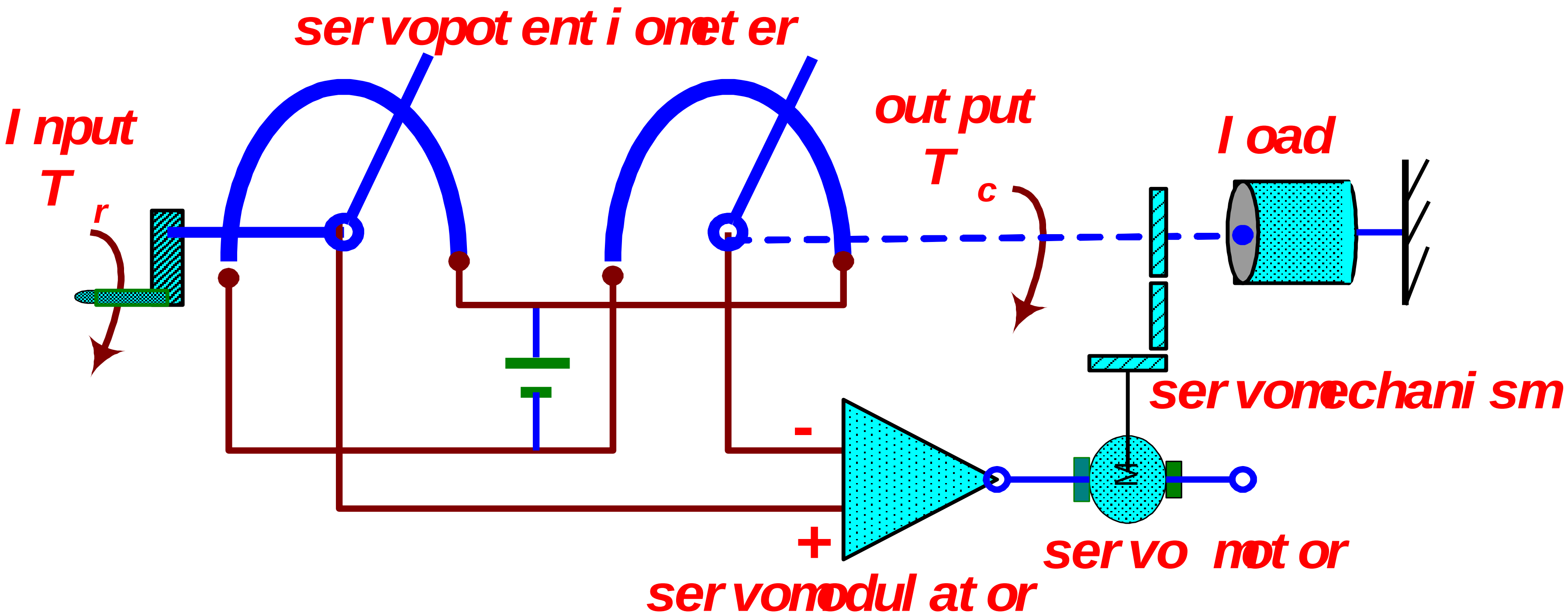


Fig. 1.4

* Principle…

* Feedback control(error)…

4) A servo (following) control system



* principle……

* feedback(error)……

5) A feedback control system model of the family planning

(similar to the social, economic, and political realm(sphere or field))

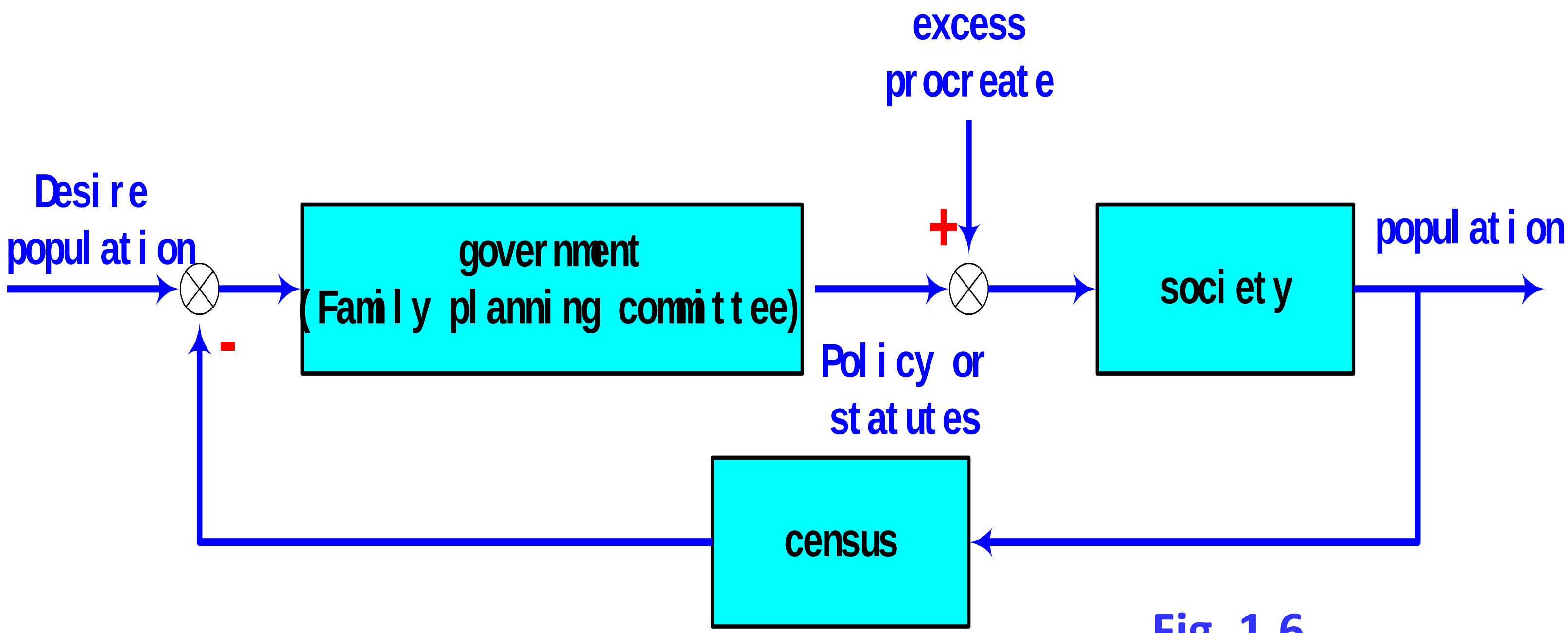


Fig. 1.6

* principle……

* feedback(error)……

Types of Control System

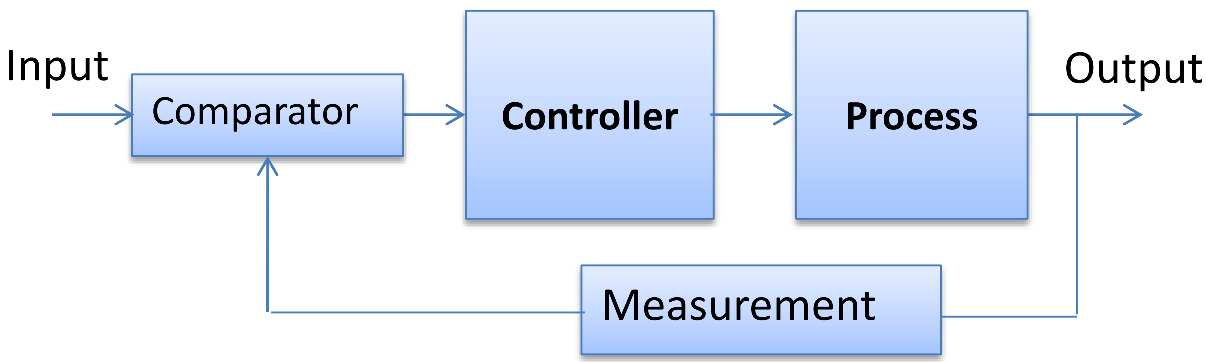
Open-Loop Control Systems

- Since in open loop control systems reference input is not compared with measured output, for each reference input there is fixed operating condition.
- Therefore, the accuracy of the system depends on calibration.
- The performance of open loop system is severely affected by the presence of disturbances, or variation in operating/ environmental conditions.

Types of Control System

Closed-Loop Control Systems

Closed-Loop Control Systems utilizes feedback to compare the actual output to the desired output response.

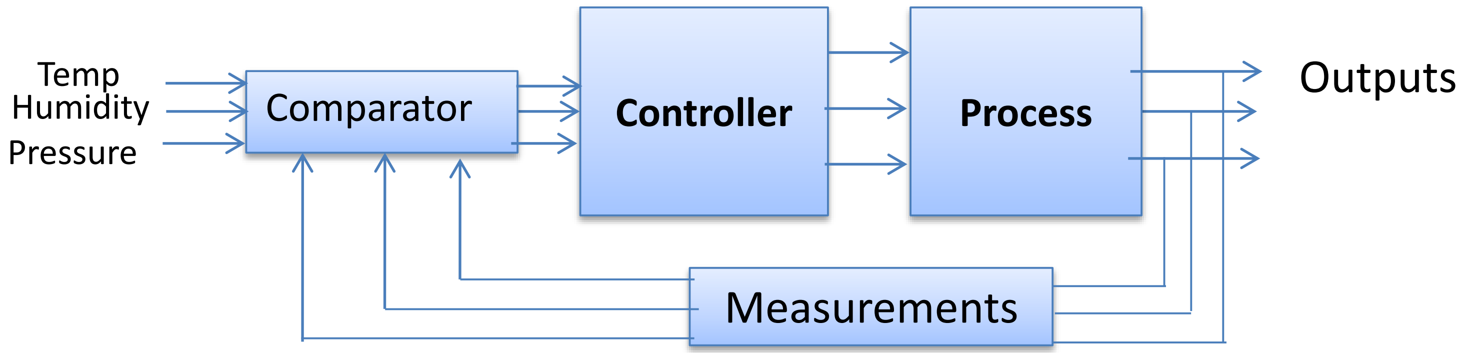


Closed-loop feedback control system (with feedback).

Examples:- Refrigerator, Iron

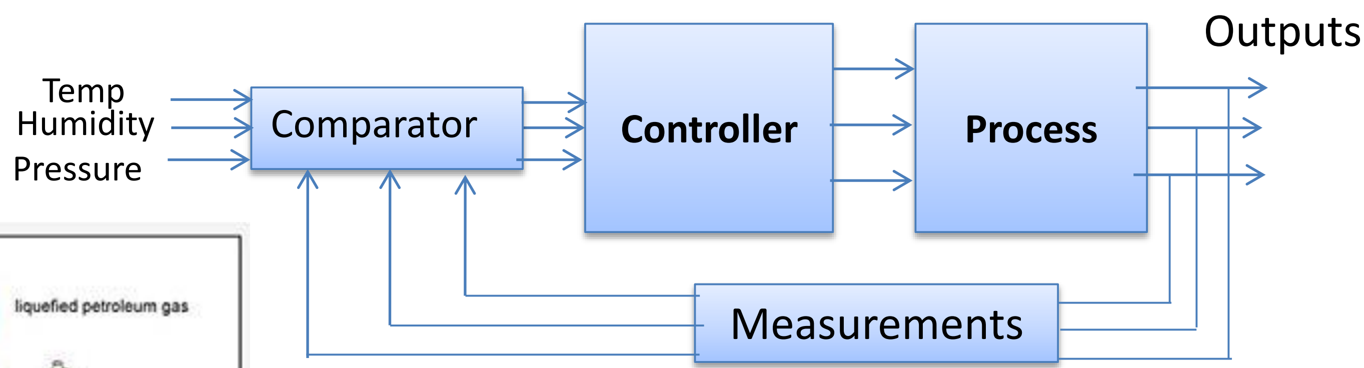
Types of Control System

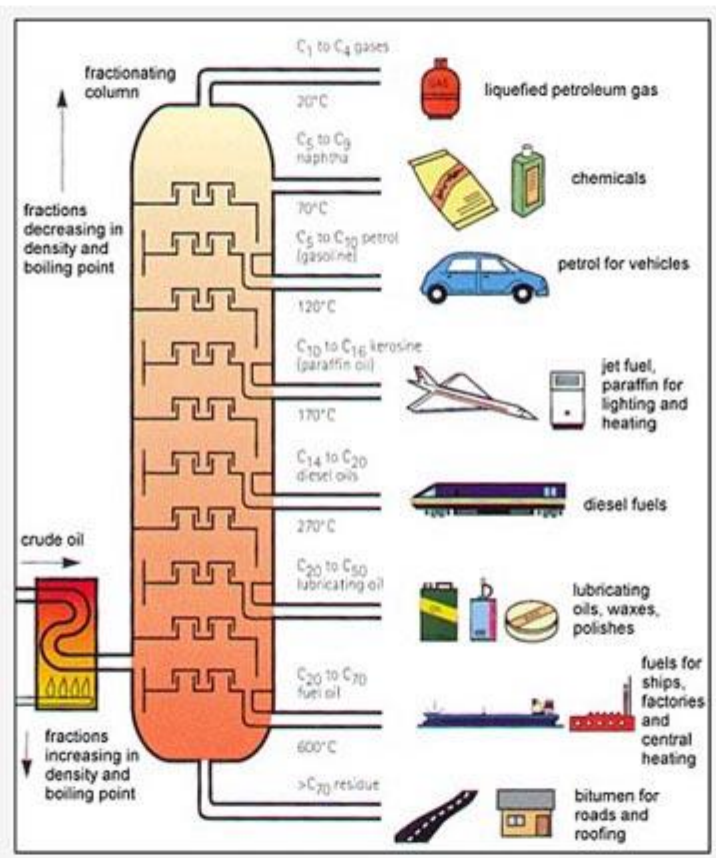
Multivariable Control System



Types of Control System

Multivariable Control System

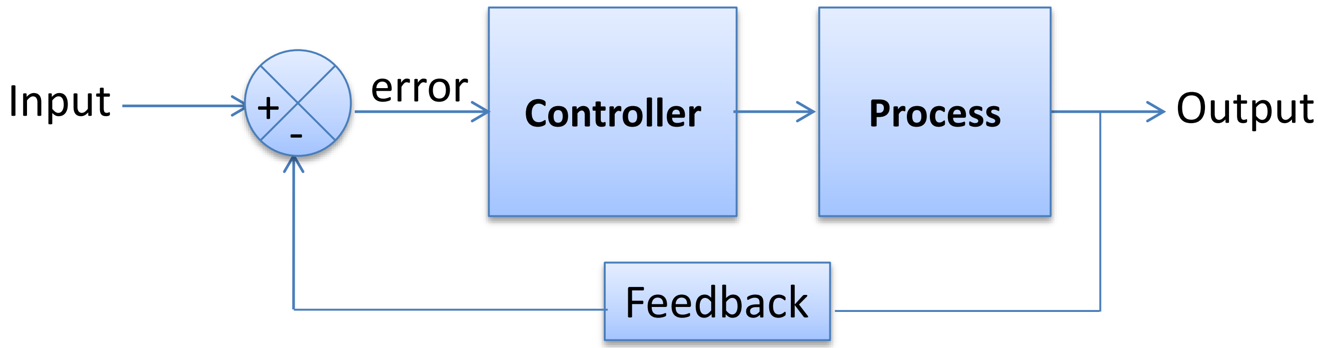




Types of Control System

Feedback Control System

- A system that maintains a prescribed relationship between the output and some reference input by comparing them and using the difference (i.e. error) as a means of control is called a feedback control system.

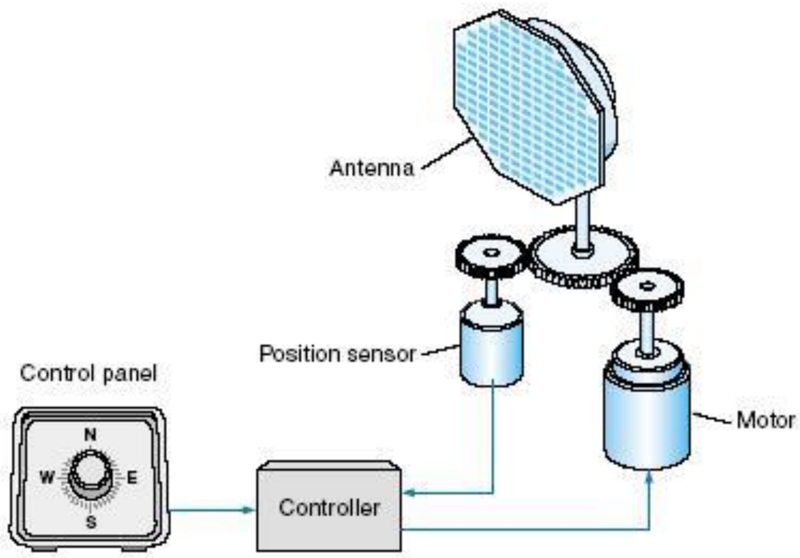


- Feedback can be positive or negative.

Types of Control System

Servo System

- A Servo System (or servomechanism) is a feedback control system in which the output is some mechanical position, velocity or acceleration.



Antenna Positioning System

Modular Servo System (MS150)

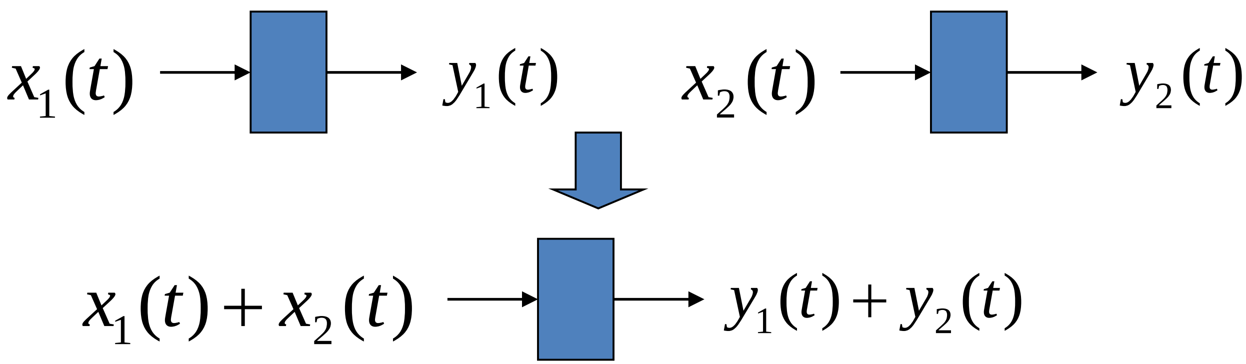
Some examples of linear system

- Electrical circuits with constant values of circuit passive elements
- Linear OPA circuits
- Mechanical system with constant values of k,m,b etc
- Heartbeat dynamic
- Eye movement
- Commercial aircraft

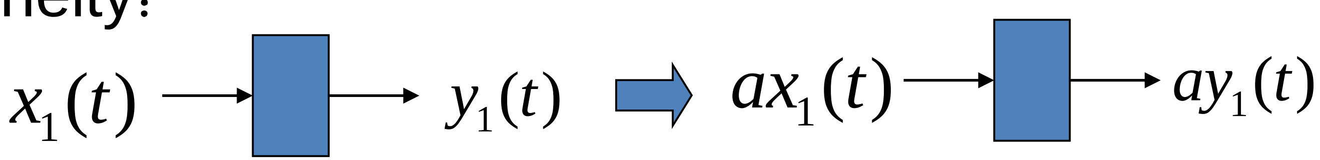
Linear system

A system is said to be linear in terms of the system input x(t) and the system output y(t) if it satisfies the following two properties of superposition and homogeneity.

Superposition：



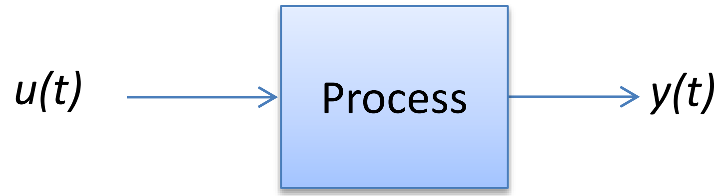
Homogeneity：



Types of Control System

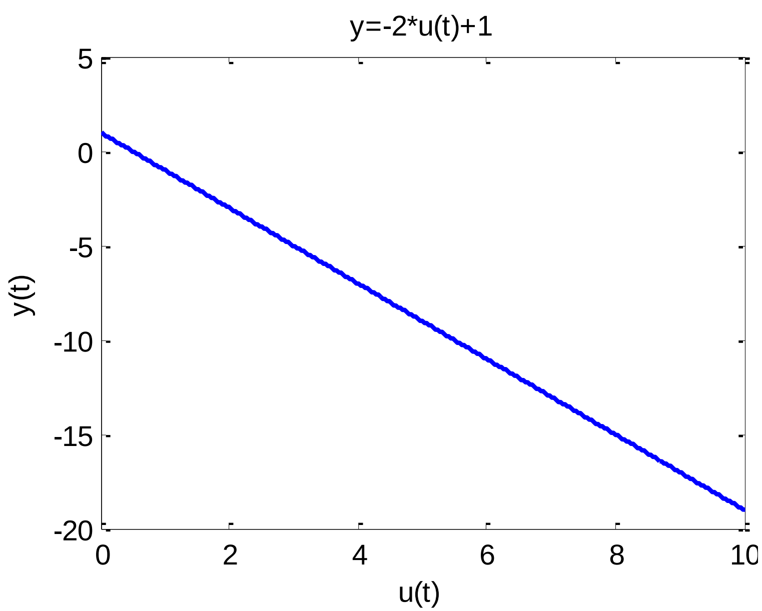
Linear Vs Nonlinear Control System

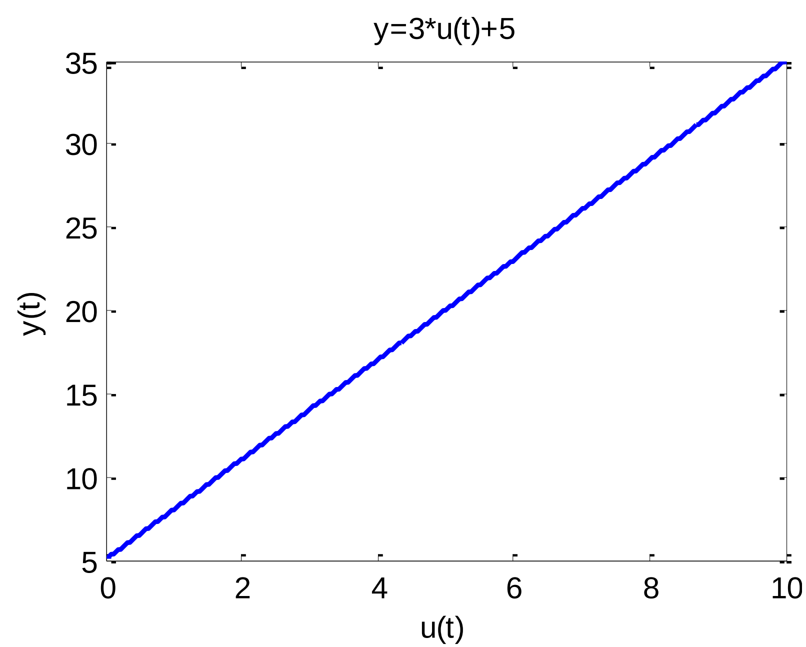
- A Control System in which output varies linearly with the input is called a linear control system.



$$y(t) = -2u(t) + 1$$

$$y(t) = 3u(t) + 5$$

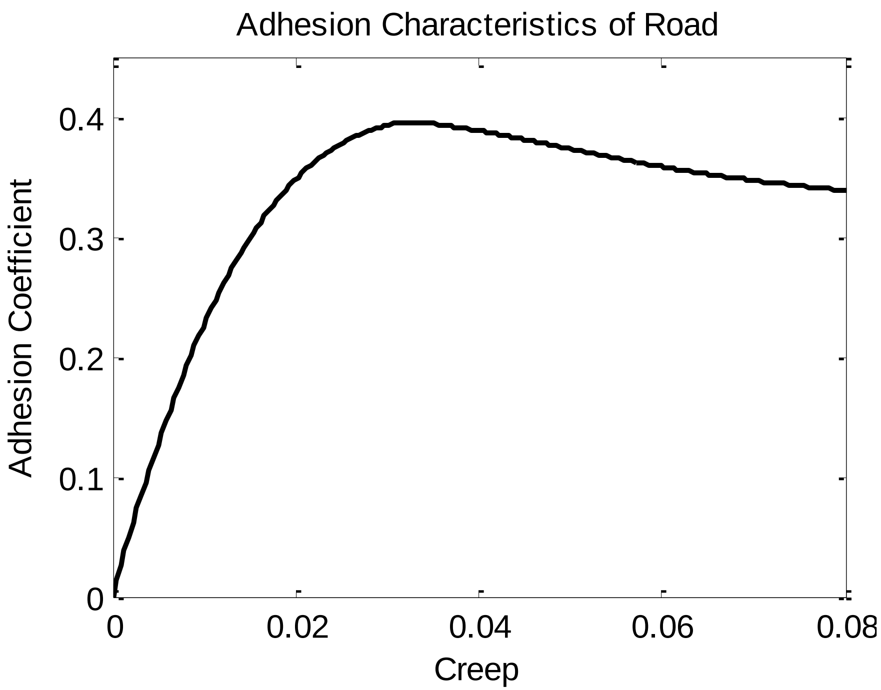




Types of Control System

Linear Vs Nonlinear Control System

- When the input and output has nonlinear relationship the system is said to be nonlinear.



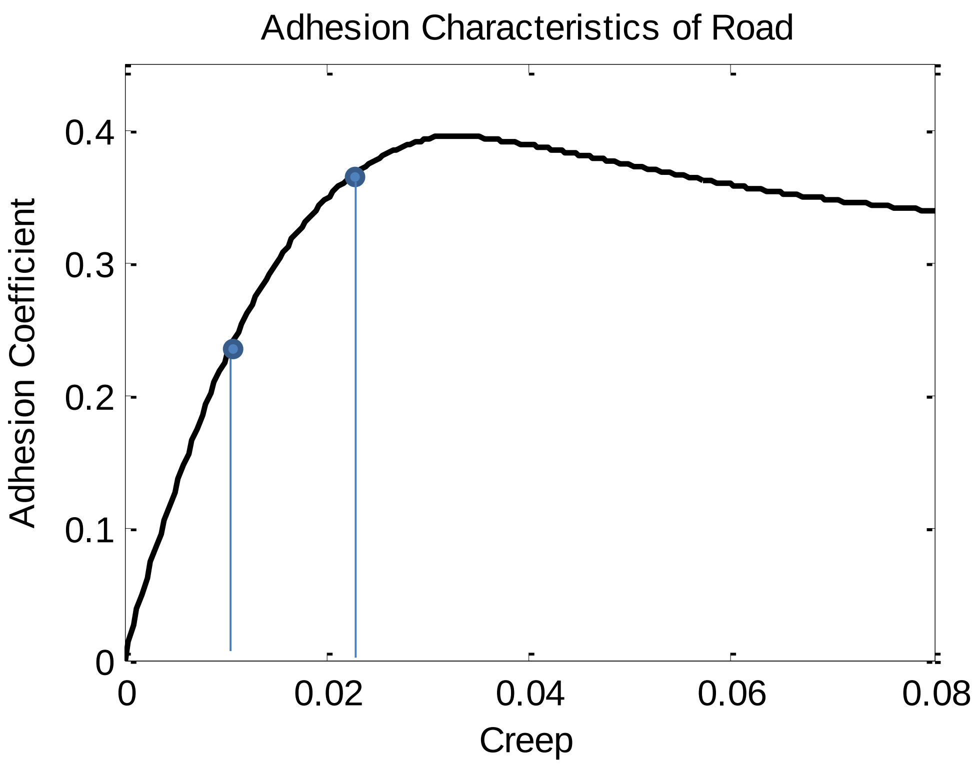
Types of Control System

Linear Vs Nonlinear Control System

- Linear control System Does not exist in practice.

- Linear control systems are idealized models fabricated by the analyst purely for the simplicity of analysis and design.

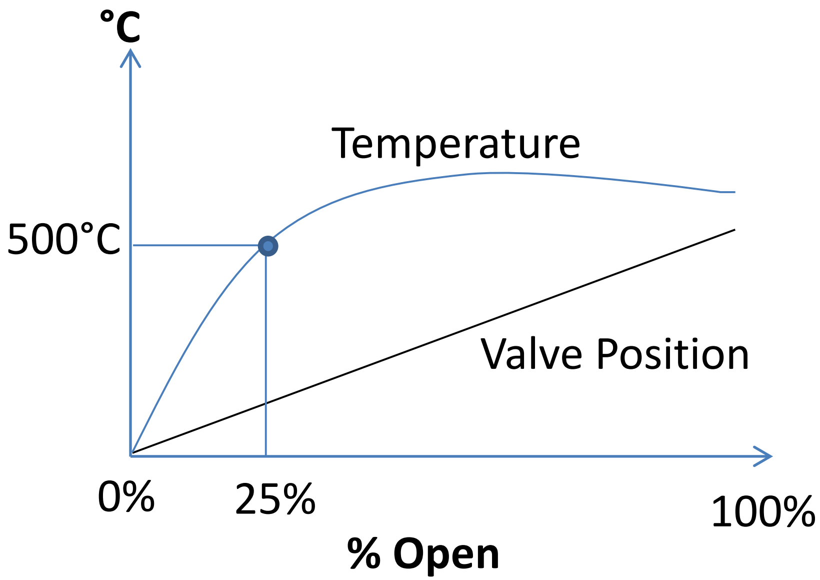
- When the magnitude of signals in a control system are limited to range in which system components exhibit linear characteristics the system is essentially linear.



Types of Control System

Linear Vs Nonlinear Control System

- Temperature control of petroleum product in a distillation column.



Types of Control System

Time invariant vs Time variant

- When the characteristics of the system do not depend upon time itself then the system is said to time invariant control system.

$$y(t) = -2u(t) + 1$$

- Time varying control system is a system in which one or more parameters vary with time.

$$y(t) = 2u(t) - 3t$$

Types of Control System

Lumped parameter vs Distributed Parameter

- Control system that can be described by ordinary differential equations are lumped-parameter control systems.

$$M\frac{d^2x}{dt^2} = C\frac{dx}{dt} + kx$$

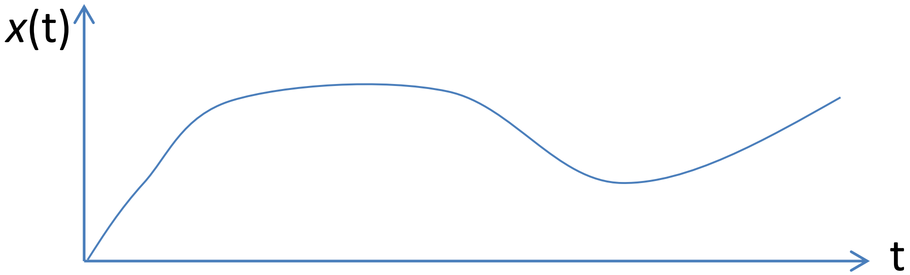
- Whereas the distributed parameter control systems are described by partial differential equations.

$$f_1\frac{\partial x}{dy} + f_2\frac{\partial x}{dz} = g\frac{\partial^2 x}{dz^2}$$

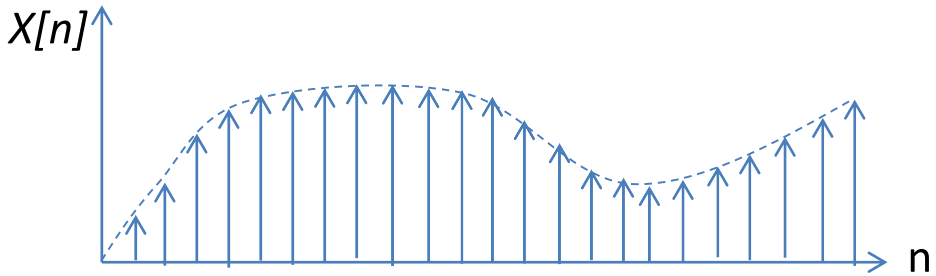
Types of Control System

Continuous Data Vs Discrete Data System

- In continuous data control system all system variables are function of a continuous time t.



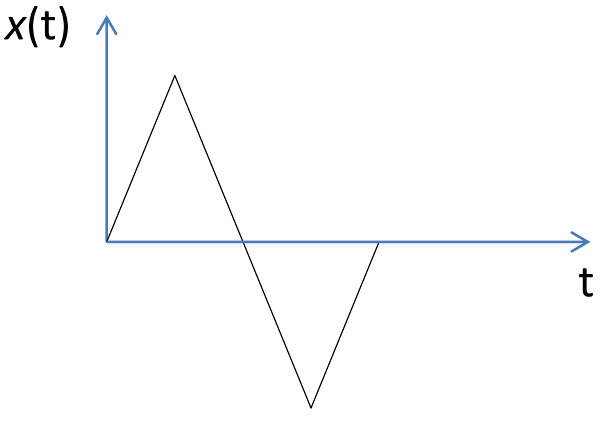
- A discrete time control system involves one or more variables that are known only at discrete time intervals.

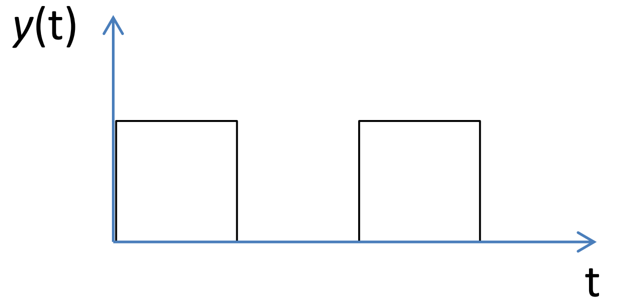


Types of Control System

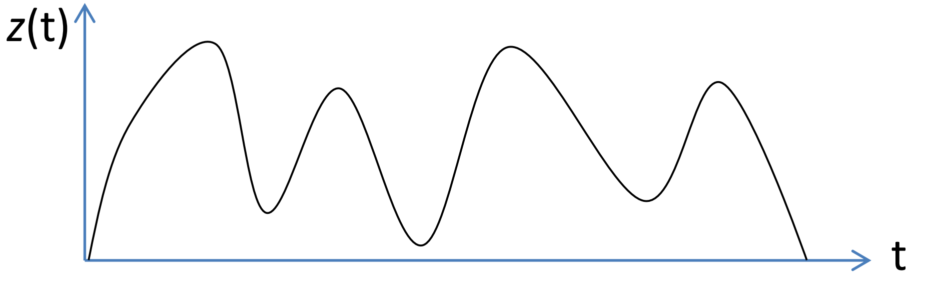
Deterministic vs Stochastic Control System

- A control System is deterministic if the response to input is predictable and repeatable.





- If not, the control system is a stochastic control system



Types of Control System

Adaptive Control System

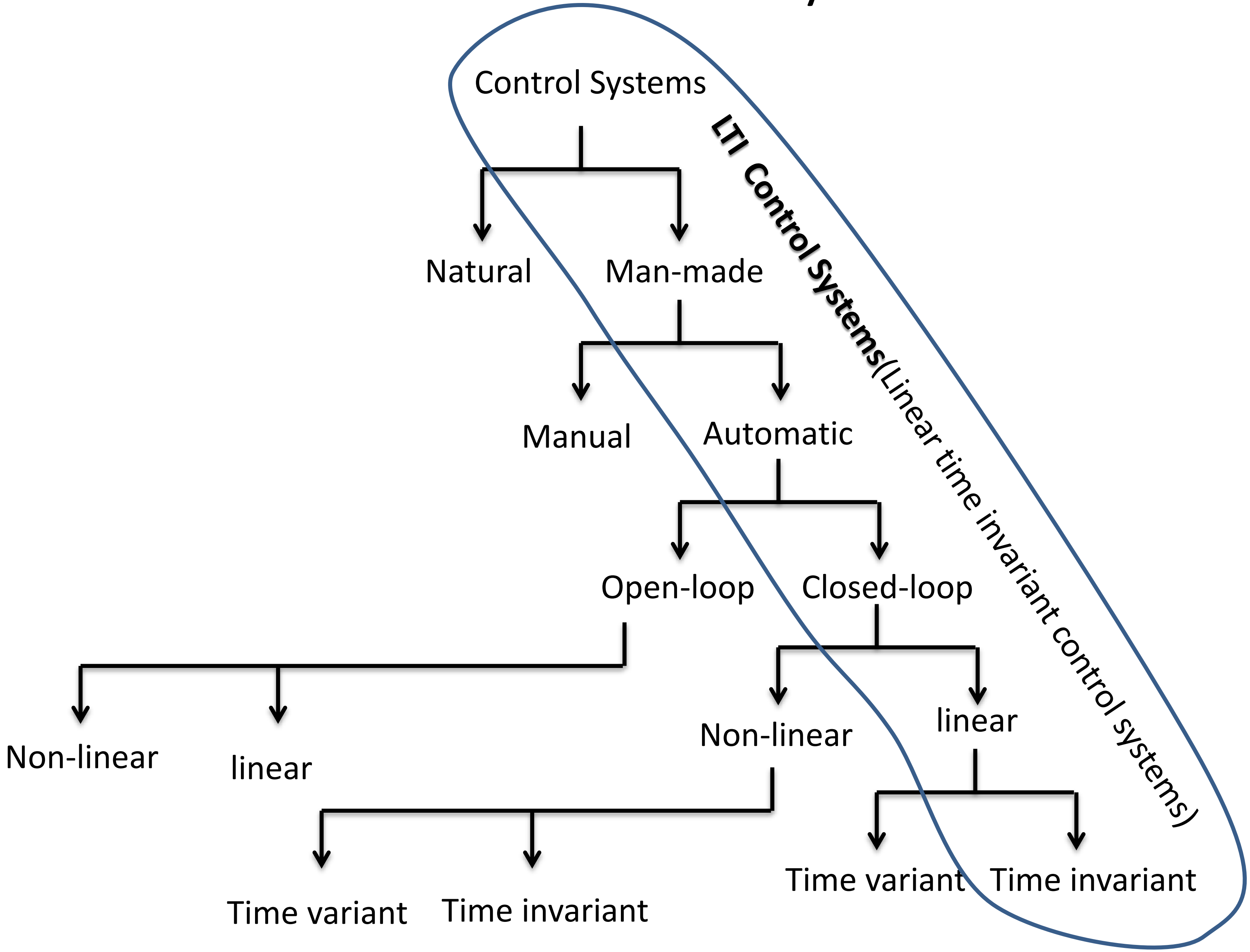
- The dynamic characteristics of most control systems are not constant for several reasons.
- The effect of small changes on the system parameters is attenuated in a feedback control system.
- An adaptive control system is required when the changes in the system parameters are significant.

Types of Control System

Learning Control System

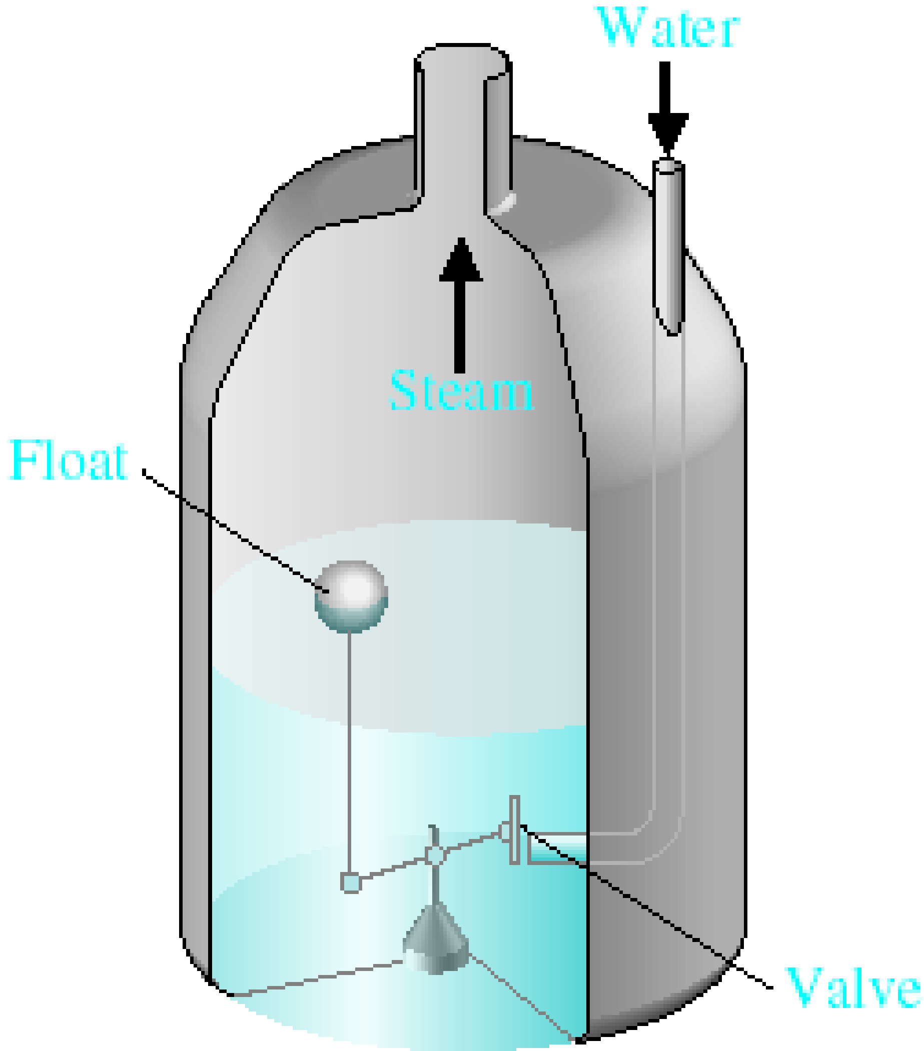
- A control system that can learn from the environment it is operating is called a learning control system.

Classification of Control Systems

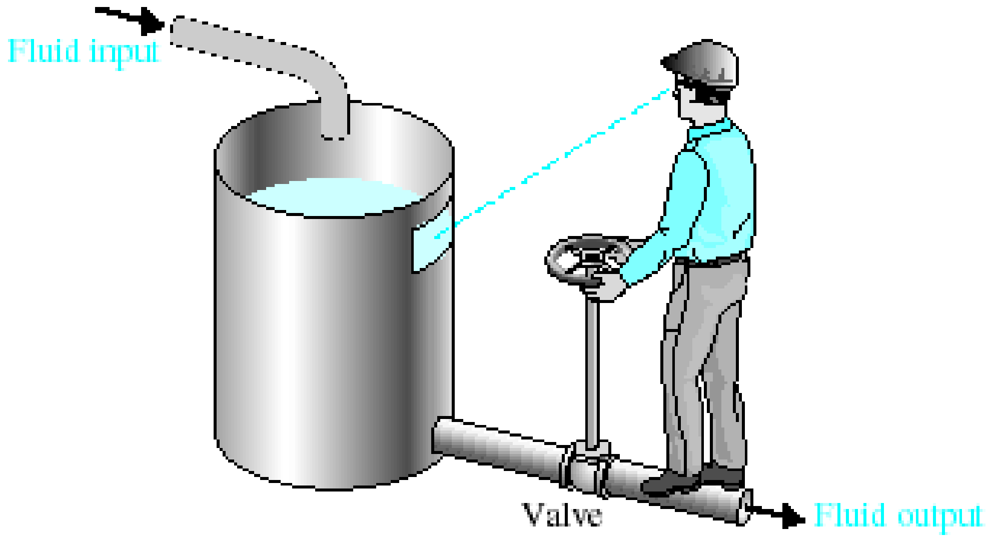


Examples of Control Systems

Water-level float regulator

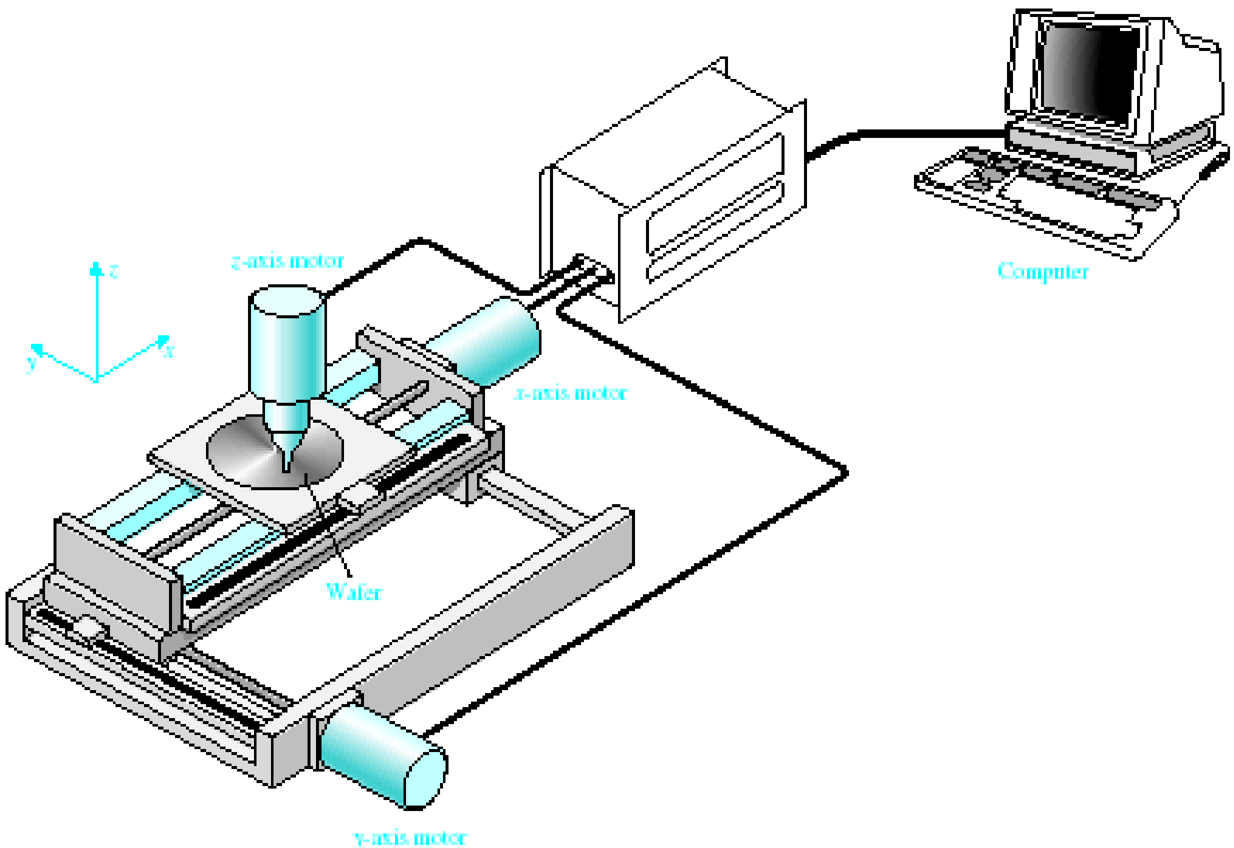


Examples of Control Systems



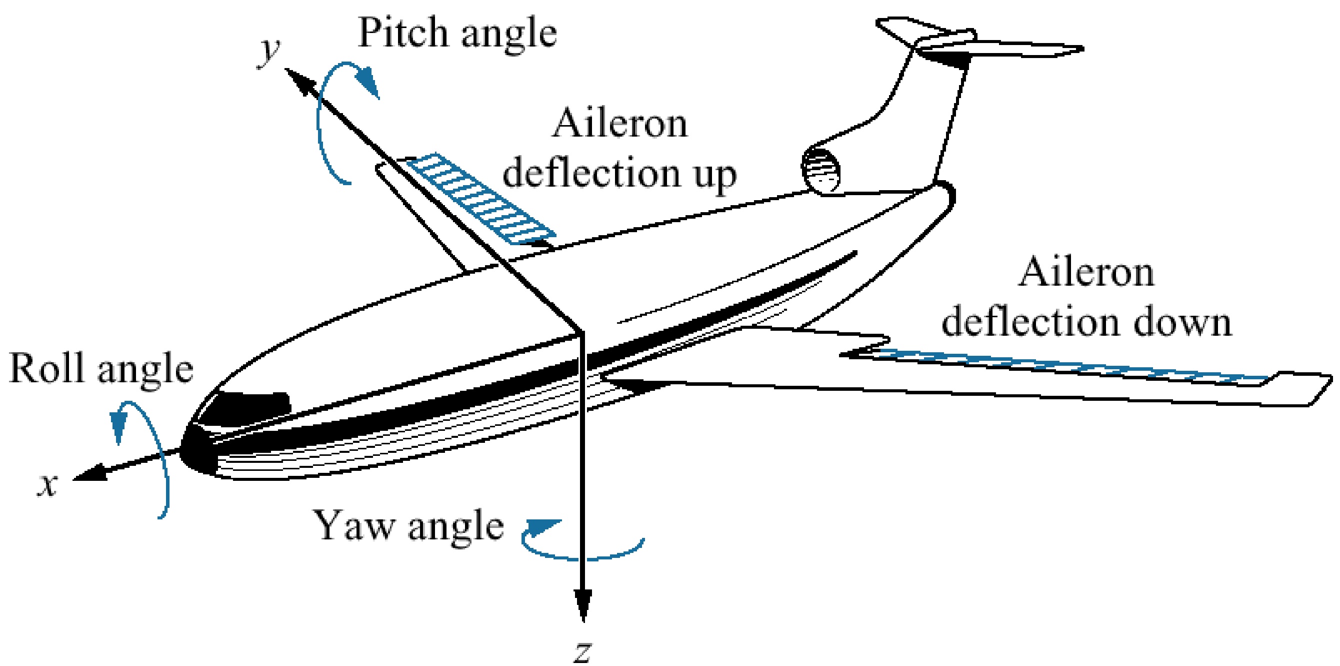
A manual control system for regulating the level of fluid in a tank by adjusting the output valve. The operator views the level of fluid through a port in the side of the tank.

Examples of Modern Control Systems

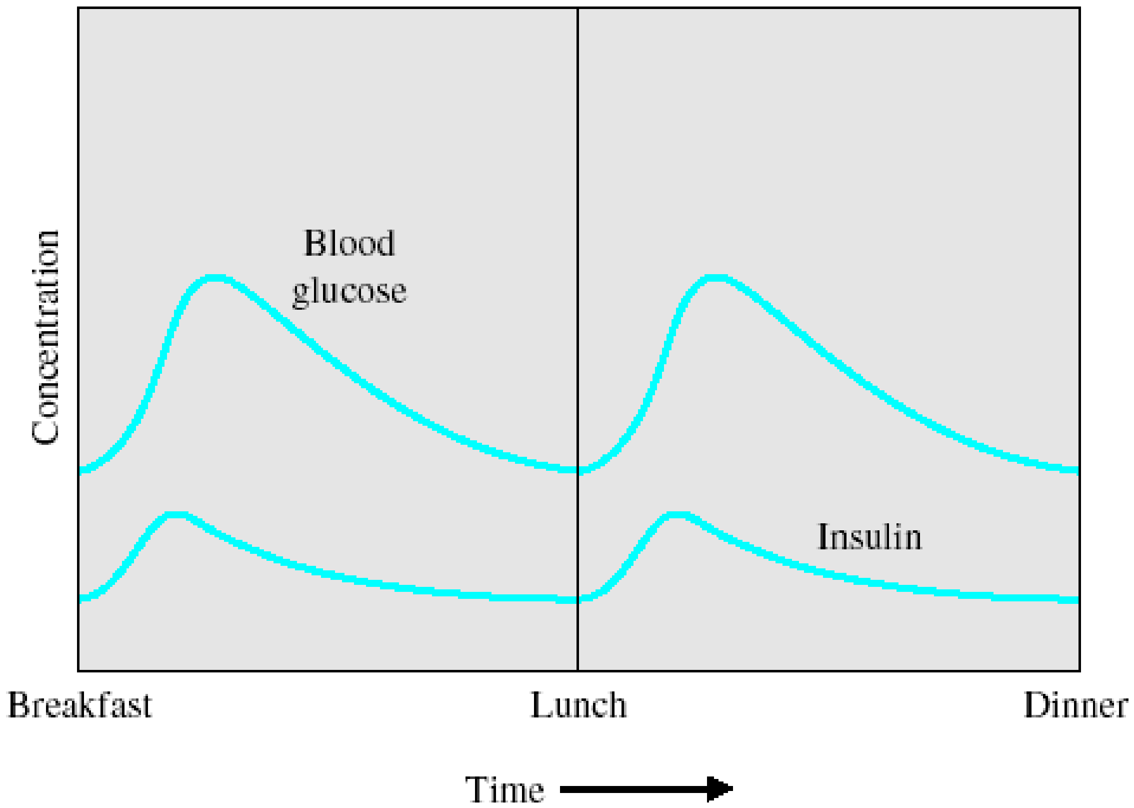


A three-axis control system for inspecting individual semiconductor wafers with a highly sensitive camera.

Examples of Modern Control Systems



Examples of Modern Control Systems



The blood glucose and insulin levels for a healthy person.

System response: *Output signals due to inputs and ICs.*

1. The point of view of Mathematic:

Homogenous solution $y_h(t)$ + Particular solution $y_p(t)$

2. The point of view of Engineer:

Natural response $y_n(t)$ + Forced response $y_f(t)$

3. The point of view of control engineer:

Zero-input response $y_{zi}(t)$ + Zero-state response $y_{zs}(t)$

Transient response — Steady state response

Example: solve the following O.D.E

$$\frac{d^2y(t)}{dt^2}+4\frac{dy(t)}{dt}+3y(t)=e^{-2t}, \quad t\geq 0, \qquad y(0)=1, \quad \frac{dy(0)}{dt}=1$$

(1) Particular solution: $\ell[y_p(t)]=u(t)$

$$\frac{d^2y_p(t)}{dt^2}+4\frac{dy_p(t)}{dt}+3y_p(t)=e^{-2t}$$

$$let \quad y_p(t)=\alpha e^{-2t}$$

$$then \qquad y'_p(t)=-2\alpha e^{-2t} \qquad y''_p(t)=4\alpha e^{-2t}$$

$$\Rightarrow \quad 4\alpha e^{-2t}+4(-2)\alpha e^{-2t}+3\alpha e^{-2t}=e^{-2t}\Rightarrow \quad \alpha=-1$$

$$we \quad have \qquad y_p(t)=-e^{-2t}$$

(2) Homogenous solution: $\ell[y_h(t)] = 0$

$$y_h''(t) + 4y_h'(t) + 3y_h(t) = 0$$

$$\Rightarrow \quad y_h(t) = Ae^{-t} + Be^{-3t}$$

$y(t) = y_p(t) + y_h(t)$ have to satisfy I.C. $y(0) = 1$, $\dfrac{dy(0)}{dt} = 1$

$$y(0) = 1 \Rightarrow \quad y_h(0) + y_p(0) = 1$$

$$\frac{dy(0)}{dt} = 1 \Rightarrow \quad y_h'(0) + y_p'(0) = 1$$

$$\Downarrow$$

$$y_h(t) = \frac{5}{2}e^{-t} - \frac{1}{2}e^{-3t}$$

(3) zero-input response: consider the original differential equation with no input.

$$y''_{zi}(t) + 4y'_{zi}(t) + 3y_{zi}(t) = 0, \qquad t \geq 0$$

$$y_{zi}(0) = 1, \quad y'_{zi}(0) = 1$$

$$\Rightarrow \quad y_{zi}(t) = K_1 e^{-t} + K_2 e^{-3t}, \quad t \geq 0$$

$$y_{zi}(0) = K_1 + K_2$$
$$y'_{zi}(0) = -K_1 - 3K_2$$

$$\Rightarrow \quad K_1 = 2, \quad K_2 = -1$$

$$y_{zi}(t) = 2e^{-t} - e^{-3t}, \quad t \geq 0$$

zero-input response

(4) zero-state response: consider the original differential equation but set all I.C.=0.

$$y''_{zs}(t) + 4y'_{zs}(t) + 3y_{zs}(t) = e^{-2t}, \qquad t \ge 0$$

$$y_{zi}(0) = 0, \quad y'_{zi}(0) = 0$$

$$y_{zs}(t) = C_1 e^{-t} + C_2 e^{-3t} - e^{-2t}$$

$$\Rightarrow \quad y_{zs}(0) = C_1 + C_2 - 1 = 0$$

$$y'_{zs}(0) = -C_1 - 3C_2 + 2 = 0$$

$$\Rightarrow \quad C_1 = \frac{1}{2}, \quad C_2 = \frac{1}{2}$$

$$y_{zs}(t) = \frac{1}{2}e^{-t} + \frac{1}{2}e^{-3t} - e^{-2t}$$

zero-state response

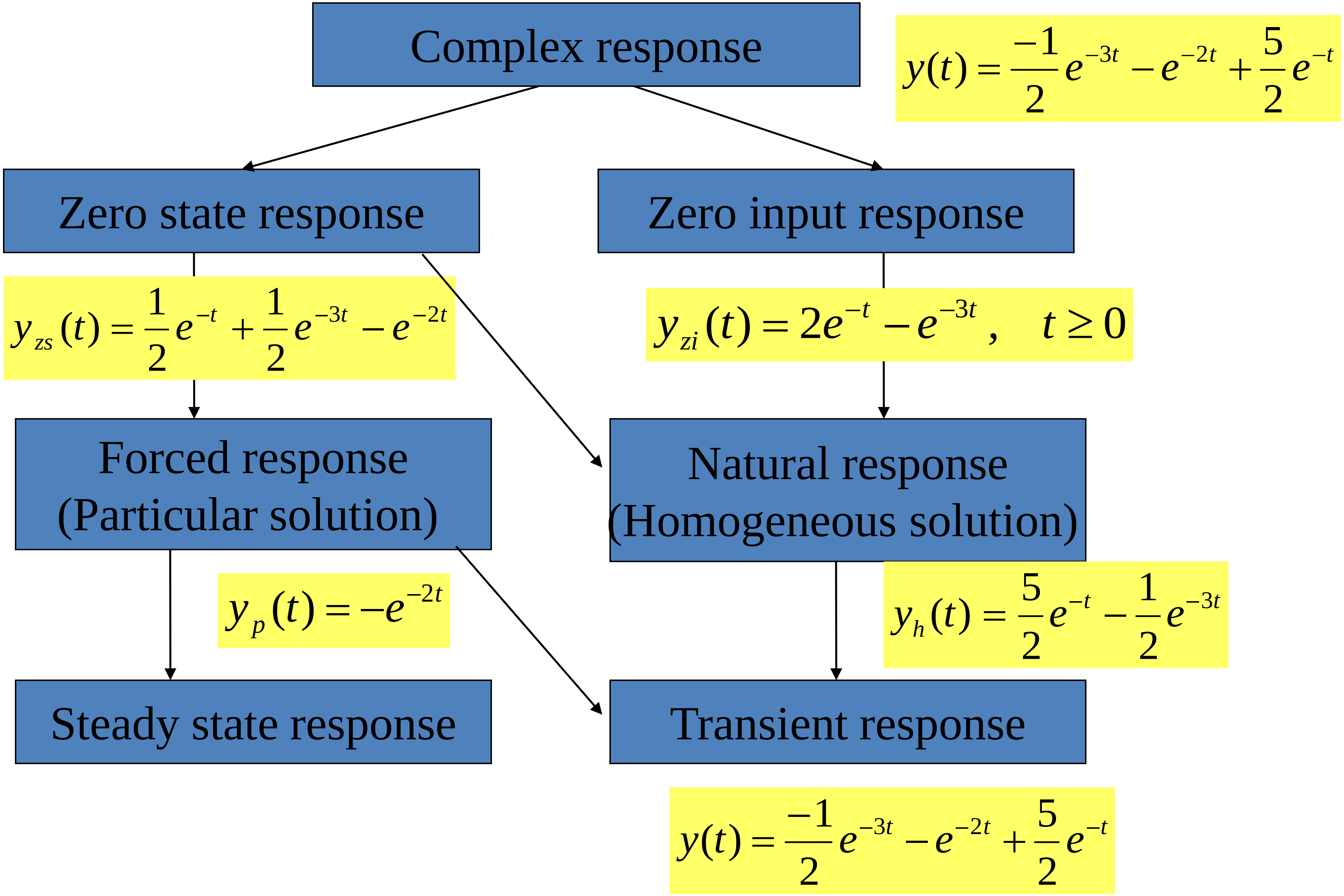
(5) Laplace Method:

$$\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 3y(t) = e^{-2t}, \quad t \geq 0, \qquad y(0) = 1, \quad \frac{dy(0)}{dt} = 1$$

$$s^2Y(s) - sy(0) - y'(0) + 4sY(s) - 4y(0) + 3Y(s) = \frac{1}{s+2}$$

$$Y(s) = \frac{s+5+\dfrac{1}{s+2}}{s^2+4s+3} = \frac{-\dfrac{1}{2}}{s+3} + \frac{-1}{s+2} + \frac{\dfrac{5}{2}}{s+1}$$

$$y(t) = \ell^{-1}[Y(s)] = \frac{-1}{2}e^{-3t} - e^{-2t} + \frac{5}{2}e^{-t}$$


Complex response
$y(t)=\frac{-1}{2}e^{-3t}-e^{-2t}+\frac{5}{2}e^{-t}$
Zero state response
Zero input response
$y_{zs}(t)=\frac{1}{2}e^{-t}+\frac{1}{2}e^{-3t}-e^{-2t}$
$y_{zi}(t)=2e^{-t}-e^{-3t}, \quad t\geq 0$
Forced response
(Particular solution)
Natural response
(Homogeneous solution)
$y_p(t)=-e^{-2t}$
$y_h(t)=\frac{5}{2}e^{-t}-\frac{1}{2}e^{-3t}$
Steady state response
Transient response
$y(t)=\frac{-1}{2}e^{-3t}-e^{-2t}+\frac{5}{2}e^{-t}$