Control System

Background

In recent years, concept of automatic control has achieved a very important position in advancement of modem science. Automatic control systems have played an important role in the advancement and improvement of engineering skills.

Practically, every activity in our day to day life is influenced by some sort of control system. Concept of control systems also plays an important role in the working of space vehicles, satellites, guided missiles etc. Such control systems are now integral part of the modem industrialization, industrial processes and home appliances. Control systems are found in number of practical applications like computerized control systems, transportation systems, power systems, temperature limiting systems, robotics etc.

Hence for an engineer it is absolutely necessary to get familiar with the analysis and designing methods of such control systems.

Definition

To understand the meaning of the word control system, first we will define the word system and then we will try to define the word control system.

System: *A system is a combination or an arrangement of different physical components which act together as an entire unit to achieve certain objective.*

Every physical object is actually a system. A classroom is a good example of physical system. A room along with the combination of benches, blackboard, fans, lighting arrangement etc. can be called a classroom which acts as an elementary system. Another example of a system is a lamp. A lamp made up of glass, filament is a physical system. Similarly, a kite made up of paper and sticks is an example of a physical system.

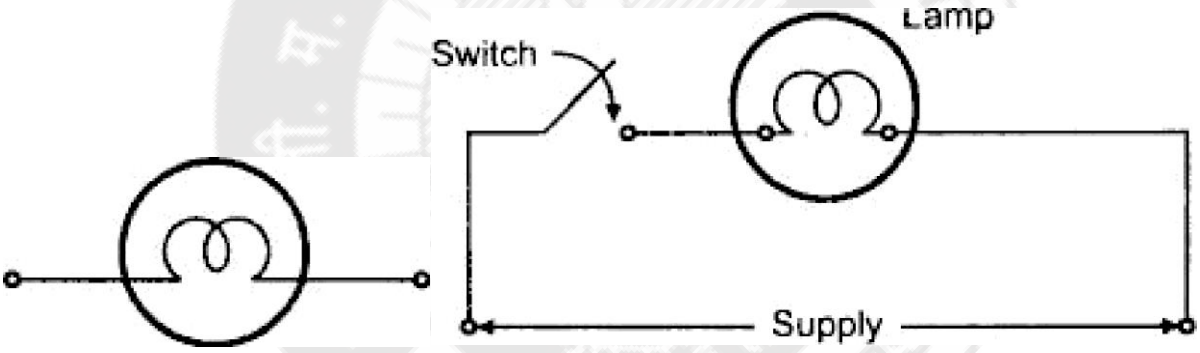
Similarly, system can be of any type i.e. physical, ecological, biological etc.

In such system, output or part of the output is fedback to the input for comparison with the reference input applied to it.

Control systems: *To control means to regulate, to direct or to command. Hence a control system is an arrangement of different physical elements connected in such a manner so as to regulate, direct or command itself or some other system.*

For example, if in a classroom, professor is delivering his lecture, the combination becomes a control system as; he tries to regulate, direct or command the students in order to achieve the objective which is to impart good knowledge to the students. Similarly, if lamp is switched ON or OFF using a switch, the entire system can be called a control system.

The concept of physical system and a control system is shown in fig.(a) and fig (b).



(a) Physical system ***(b)Control system***

In short, a control system is in the broadest sense, an interconnection of the physical components to provide a desired function, involving some kind of controlling action in it.

Plant: The portion of a system which is to be controlled or regulated is called the plant or the process.

Controller: The element of the system itself or external to the system which controls the plant or the process is called controller.

For each system, there must be an excitation and system accept it as an input. And for analyzing the behavior of system for such input, it is necessary to define the output of a system.

Input: It is an applied signal or an excitation signal applied to a control system from an external energy source in order to produce a specified output.

Output: It is the particular sign of interest or the actual response obtained from a control system when input is applied to it.

Disturbance: It is a signal which tends to adversely affect the value of the output of a system. If such a disturbance is generated within the system itself, it is called an internal disturbance. The disturbance generated outside the system, acting as an extra input to the system in addition to the normal input, affecting the output adversely is called an external disturbance.

The input variable is generally referred to as the **Reference Input** and output is generally referred as the **Controlled signal**.

Cause and effect relationship between input and output for a plant can be shown in fig.

Classifications of Control Systems

1.*Natural Control Systems*: The biological systems, systems inside human being are of natural type.

Example1: The perspiration system inside the human being is a good example of natural control system. This system activates the secretion glands, secreting sweat and regulates the temperature of human body.

2.Manmade Control Systems: The various systems, we are using in our day to day life are designed and manufactured by human beings. Such systems like vehicles, switches, various controllers etc. are called manmade control systems.

Example 2: An automobile system with gears, accelerator, braking system is a good example of manmade control system.

3.Combinational Control Systems: Combinational control system is one, having combination of natural and manmade together i.e. driver driving a vehicle.

4.Time Varying and Time-Invariant Systems: Time varying control systems are those in which parameters of the systems are varying with time. It is not dependent on whether input and output are functions of time or not.

For example, space vehicle whose mass decreases with time as it leaves earth. The mass is a parameter of space vehicle system. As against this, if even though the inputs and outputs are functions of time but the parameters of system are independent of time, which are not varying with time and are constants, then system is said to be time invariant system. Different electrical networks consisting of the elements as resistances, inductances and capacitances are time invariant systems as the values of the elements of such system are constant and not the functions of time.

5.Linear and Nonlinear Systems: A control system is said to be linear if it satisfies following properties.

a) The principle of superposition is applicable to the system; this means the response to several inputs can be obtained by considering one input at a time and then algebraically adding the individual results.

Mathematically principle of superposition is expressed by two properties:

i.) *Additive Property* which says that x and y belonging to the domain of the function f then we have,

$$\mathbf{f(x+y) = f(x) + f(y)}$$

ii.) Homogenous Property which says that any x belonging to the domain of the function f and for any scalar constants α we have,

$$\mathbf{f(\alpha x) = \alpha\, f(x)}$$

Real Time Example: A resistive network shown in fig.(a) is a linear system. The fig.(b) shows the relationship between the input (V_{in}) and the output (I).

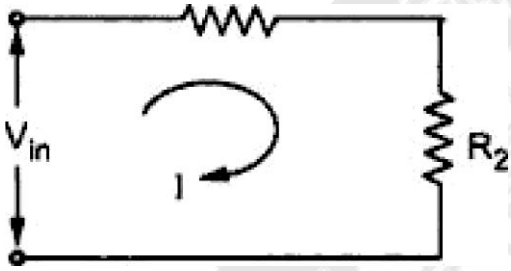


fig.(a) linear system

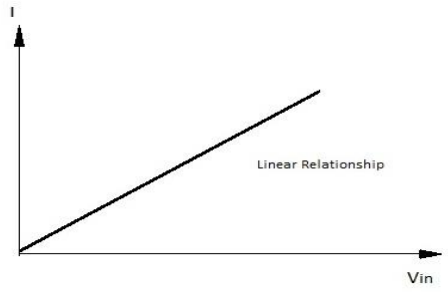


fig.(b) Response of a system

A control system is said to be non-linear if,

a. It does not satisfy the principle of superposition.

b. The equations describing the systems are non-linear in nature.

The functions $f(x)=x^2$ is non-linear because

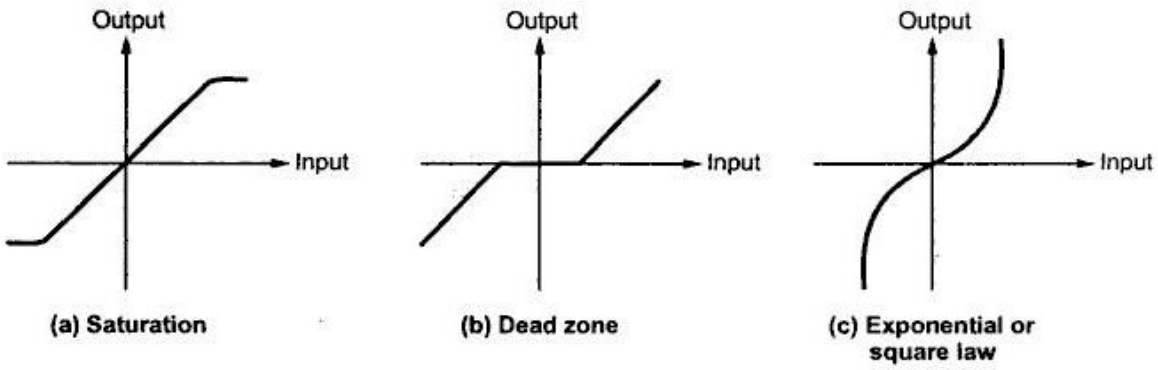
$$\mathbf{f(x_1+x_2) = (x_1+x_2)^2 \neq (x_1)^2 + (x_2)^2}$$

$$\mathbf{\text{and } f(\alpha x) = (\alpha x)^2 \neq \alpha x^2, \text{ where } \alpha = \text{constant}}$$

The equations of nonlinear system involve such nonlinear functions.

c. The output does not vary linearly for nonlinear systems.

The various nonlinearities practically present in the systems are represented in the given fig.



Non-Linearities

6. Continuous Time and Discrete Time Control Systems: In a continuous time, control system all system variables are the functions of a continuous time variable t. In discrete time systems one or more system variables are known only at certain discrete intervals of time. They are not continuously dependent on the time. Microprocessor or computer-based systems use such discrete time signals. The reasons for using such signals in digital controllers are,

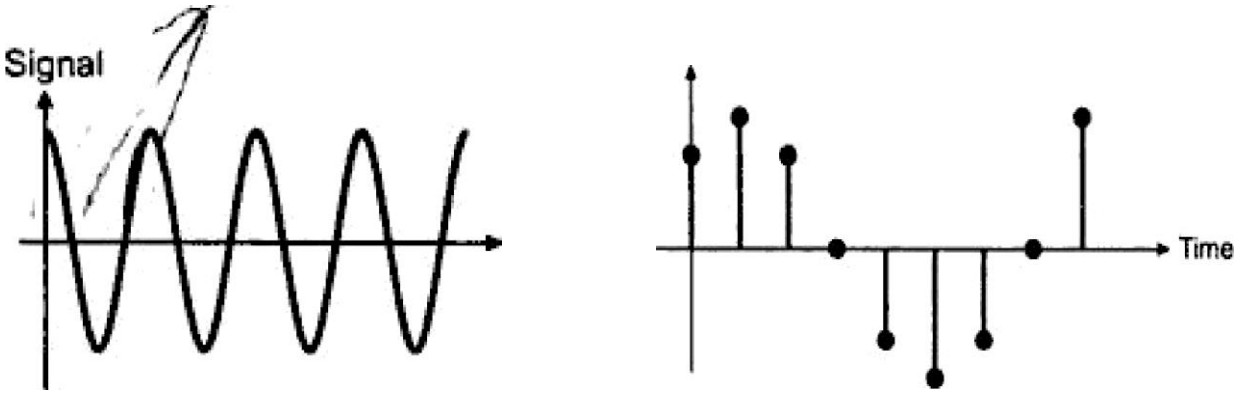
1) Such signals are less sensitive to noise.

2)Time sharing of one equipment to other channels is possible.

3) Advantages from point of view of size, speed, memory, flexibility etc.

The systems using such digital controllers or sampled signals are called sampled data systems.

Continuous time systems use the signals as shown in the fig.(a) which are continuous with time while discrete system uses the signals as shown and fig.(b).



(a) Continuous signal *(b) Discrete signal*

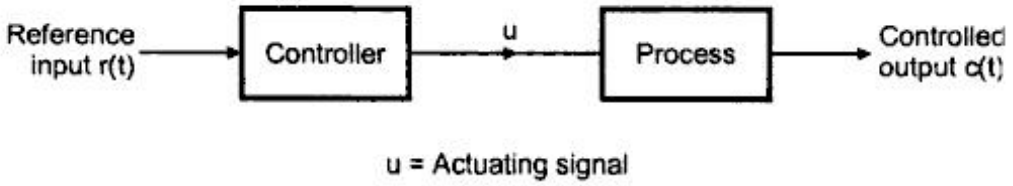
7.Deterministic and Stochastic Control Systems: A control system is said to be deterministic when its response to input as well as behaviour to external disturbances is predictable and repeatable. If such response is unpredictable, system is said to be stochastic in nature.

8.Lumped parameter and distributed parameter control systems: Control system that can be described by ordinary differential equations is called lumped parameter control systems. For example, electrical networks with different parameters as resistance, inductance, etc. are lumped parameter systems. Control systems that can be described by partial differential equations are called distributed parameter control systems. For example, transmission line having its parameter resistance and inductance totally distributed along it.

9.Single input Single output (SISO) and Multiple input Multiple output (MIMO): A system having only one input and one output is called single input single output system. For example, a position control system has only one input (desired position) and one output (actual output position), Some systems may have multiple type of inputs and multiple outputs, these are called multiple input multiple output systems.

10.Open loop and Closed loop system:

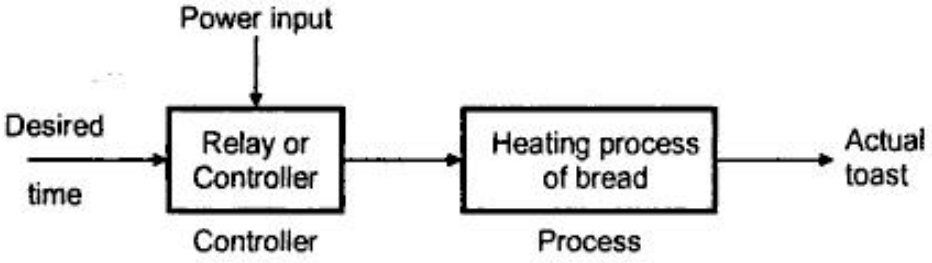
Open Loop Systems: A system in which output is dependent on input but controlling action or input is totally independent of the output or changes in output of the system, is called an Open Loop System. It can be represented as



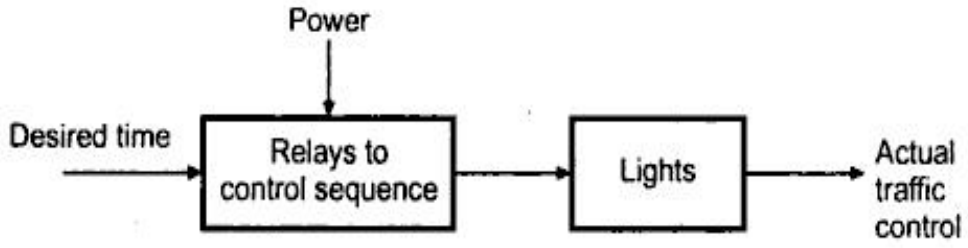
Reference input [r(t)] is applied to the controller which generates the actuating signal (u) required to control the process which is to be controlled. Process is giving out the necessary desired controlled output c(t).

Real Time Applications Open Loop Systems

1) ***Automatic Toaster System:*** In this system, the quality of toast depends upon the time for which the toast is heated. Depending on the time setting, bread is simply heated. The toast quality is to be judged by the user and has no effect on the inputs.



2) ***Traffic Light Controller:*** A traffic flow control system used on roads is time dependent. The traffic on the road becomes mobile or stationary depending on the duration and sequence of lamp glow. The sequence and duration are controlled by relays which are predetermined and not dependent on the rush on the road.



3) ***Automatic Door Opening and Closing System****:* In this system, photo sensitive devices are used. When a person interrupts a light, photo device generates actuating signal which opens the door for specific time. When person passes through the door, light becomes, continuous closing the door. The opening and closing of the door is the output which has nothing to do with the inputs, hence an open loop system,

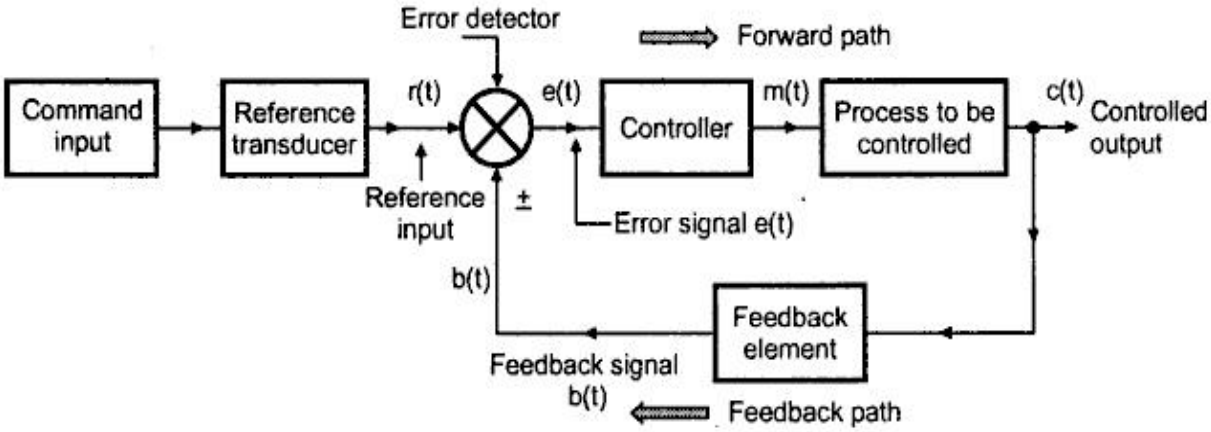
The room heater, fan regulator, automatic coffee server, electric lift, theatre lamp dimmer, automatic dimmer are examples of open loop systems.

Closed Loop Systems: A system in which the input is somehow dependent on the output or changes in the output is called closed loop systems. To have dependencies of input on the output, such systems uses the feedback property.

Feedback Property: It is the property of the system by which it permits the output to be compared with the reference input to generate the error signal based on which the appropriate controlling action can be decided.

In such systems, output or the part of output is fedback to the input for comparison with reference input applied to it.

Closed loop systems can be represented as-



The various signals used here are,

r(t) = reference input

e(t) = Error signal

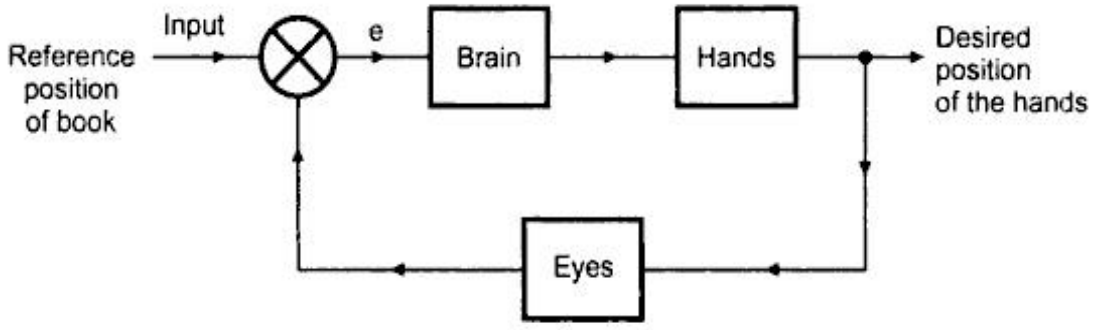
c(t) = Controlled output

m(t) = Manipulated signal

b(t) = Feedback signal

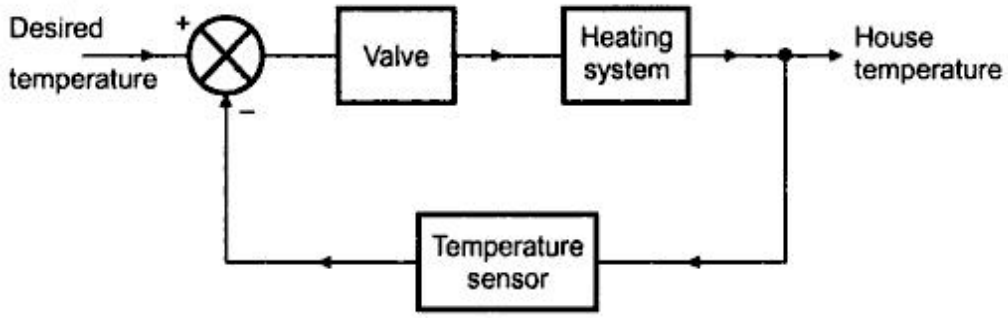
<u>Real Time Applications of Closed Loop Systems</u>

1) **Human Being:** The best example is the human being. If a person wants to reach for a book on the table, closed loop system can be represented as in fig.



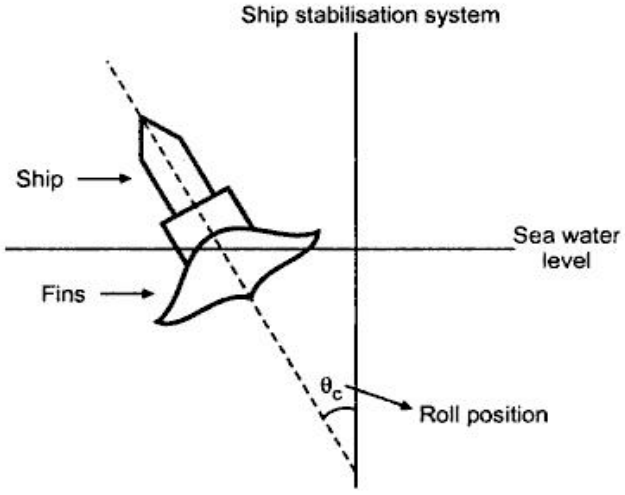
Position of the book is given as the reference. Feedback signal from eyes, compares the actual position of the hands with reference position. Error signal is given to brain. Brain manipulates this error and gives signal to the hands. This process continues till the position of the hands get achieved appropriately.

2) **Home Heating System:** In this system, the heating system is operated by a valve. The actual temperature is sensed by a thermal sensor and compared with the desired temperature. The difference between the two, actuates the valve mechanism to change the temperature as per the requirement.

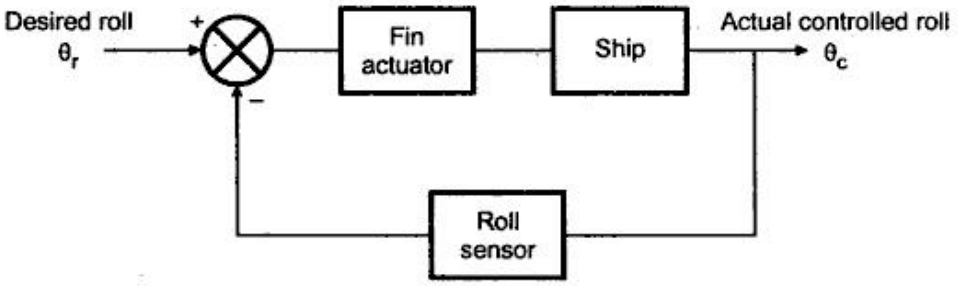


Domestic Heating System

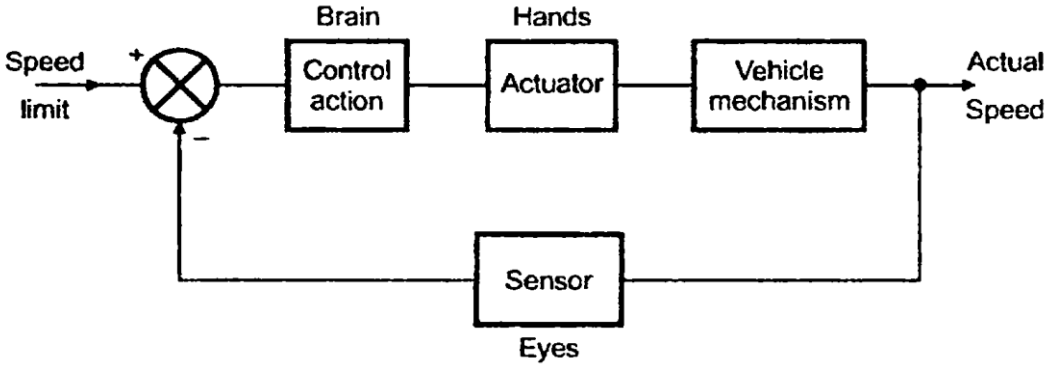
3) **Ship Stabilization System:** In this system, a roll sensor is used as feedback element.



The desired roll position is selected as Θr, while actual roll position is Θc which is compared with Θr, to generate controlling signal. This activates fin actuator in proper way to stabilize the ship.



4) **Manual Speed Control System:** A locomotive operator driving a train is a good example of manual speed control system. The objective is to maintain the speed equal to speed limits set. The entire system is shown in the fig.



Comparison Between Open Loop and Closed Loop Systems

Open Loop	Closed Loop
Any change in output has no effect on the input. Example : Feedback does not exists	Changes in output, affects the input which is possible by use of feedback
Output measurement is not required for operation of system	Output measurement is necessary
Feedback element is absent	Feedback element is present
Error detector is absent	Error detector is necessary
It is inaccurate and unreliable	Highly accurate and reliable
Highly sensitive to the disturbances	Less sensitive to the disturbances
Highly sensitive to the environmental changes	Less sensitive to the environmental changes
Bandwidth is small	Bandwidth is large
Simple to construct and cheap	Complicated to design and hence costly
Generally are stable in nature	Stability is the major consideration while designing
Highly affected by non-linearity	Reduced effect of nonlinearities