Control Systems

By

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CONTROL SYSTEMS

Course objectives:

- To understand the different ways of system representations such as Transfer function representation and state space representations and to assess the system dynamic response
- To assess the system performance using time domain analysis and methods for improving it

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Course objectives:

- To assess the system performance using frequency domain analysis and techniques for improving the performance

- To design various controllers and compensators to improve system performance

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Course Outcomes: At the end of this course, students will demonstrate the ability to

- Understand the modeling of linear-time-invariant systems using transfer function and state space representations.
- Understand the concept of stability and its assessment for linear-time invariant systems.
- Design simple feedback controllers

CONTROL SYSTEMS Syllabus

UNIT - I

- **Introduction to Control Problem: Industrial Control examples. Mathematical models of physical systems.**
- Control hardware and their models.
- Transfer function models of linear time-invariant systems.
- Feedback Control: Open-Loop and Closed-loop systems.
- Benefits of Feedback.
- Block diagram algebra.

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UNIT - II

- **Time Response Analysis of Standard Test Signals:**
- Time response of first and second order systems for standard test inputs.
- Application of initial and final value theorem.
- Design specifications for second order systems based on the time-response.
- Concept of Stability.
- Routh-Hurwitz Criteria.
- Relative Stability analysis.
- Root-Locus technique. Construction of Root-loci.

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UNIT - III

- **Frequency-Response Analysis:**
- Relationship between time and frequency response, Polar plots, Bode plots.
- Nyquist stability criterion.
- Relative stability using Nyquist criterion - gain and phase margin. Closed-loop frequency response..

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UNT - IV

- **Introduction to Controller Design:**
- Stability, steady-state accuracy, transient accuracy, disturbance rejection, insensitivity and robustness of control systems.
- Root-loci method of feedback controller design.

Design specifications in frequency-domain.

- Frequency-domain methods of design.
- Application of Proportional, Integral and Derivative Controllers, Lead and Lag compensation in designs. Analog and Digital implementation of controllers.

UNIT - V

- **State Variable Analysis and Concepts of State Variables:**
- State space model.
- Diagonalization of State Matrix. Solution of state equations. Eigen values and Stability Analysis.
- Concept of controllability and observability.
- Pole-placement by state feedback.
- Discrete-time systems. Difference Equations.
- State-space models of linear discrete-time systems. Stability of linear discrete-time systems

CONTROL SYSTEMS

TEXT BOOKS:

1. M. Gopal, “Control Systems: Principles and Design”, McGraw Hill Education, 1997.
2. B. C. Kuo, “Automatic Control System”, Prentice Hall, 1995.

REFERENCE BOOKS:

1. K. Ogata, “Modern Control Engineering”, Prentice Hall, 1991.
1. I. J. Nagrath and M. Gopal, “Control Systems Engineering”, New Age International, 2009.

Introduction to Control Systems

History

- **18th Century** James Watt's centrifugal governor for the speed control of a steam engine.

- **1920s** Minorsky worked on automatic controllers for steering ships.
- **1930s** Nyquist developed a method for analyzing the stability of controlled systems

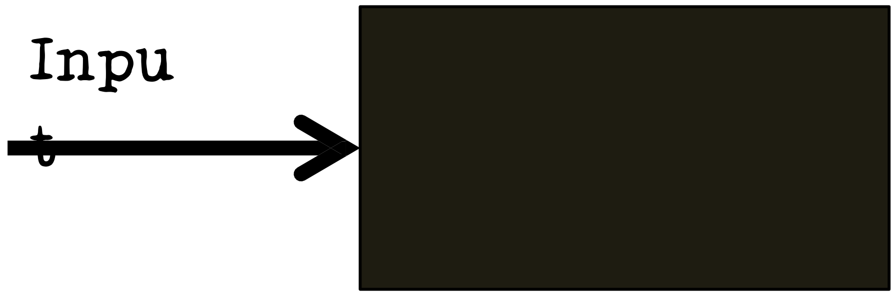
- **1940s** Frequency response methods made it possible to design linear closed loop control
- **1950s** Root-locus method due to Evans was fully developed
- **1960s** State space methods, optimal control, adaptive control
- **1980s** Learning controls are begun to investigated and developed.

History

- **Present** and on-going research fields. Recent application of modern control theory includes

Non-engineering systems such as biological, biomedical, economic and socio-economic systems

Input

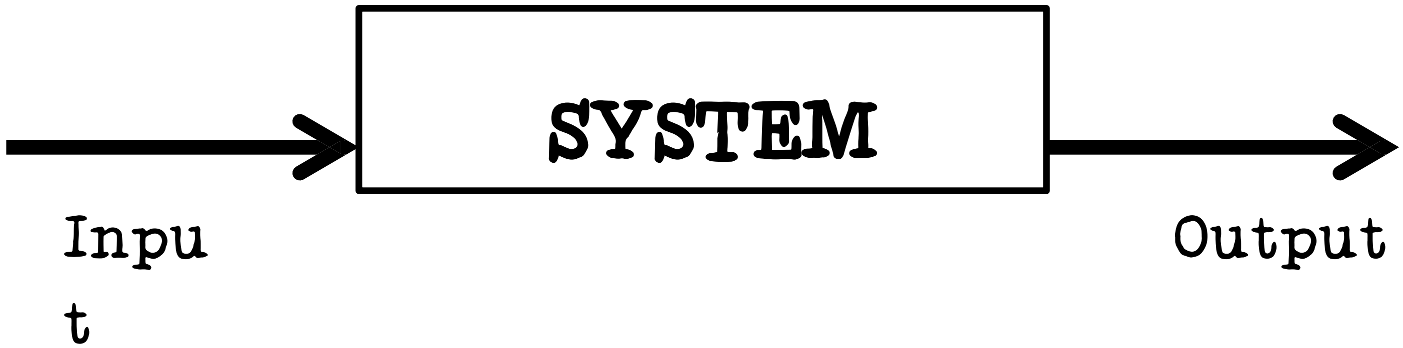


- The stimulus or excitation applied to a control system from an external source in order to produce the output is called input

Output

- The actual response obtained from a system is called output.

“System”



- A system is an arrangement of or a combination of different physical components connected or related in such a manner so as to form an entire unit to attain a certain objective.

Combining above definitions

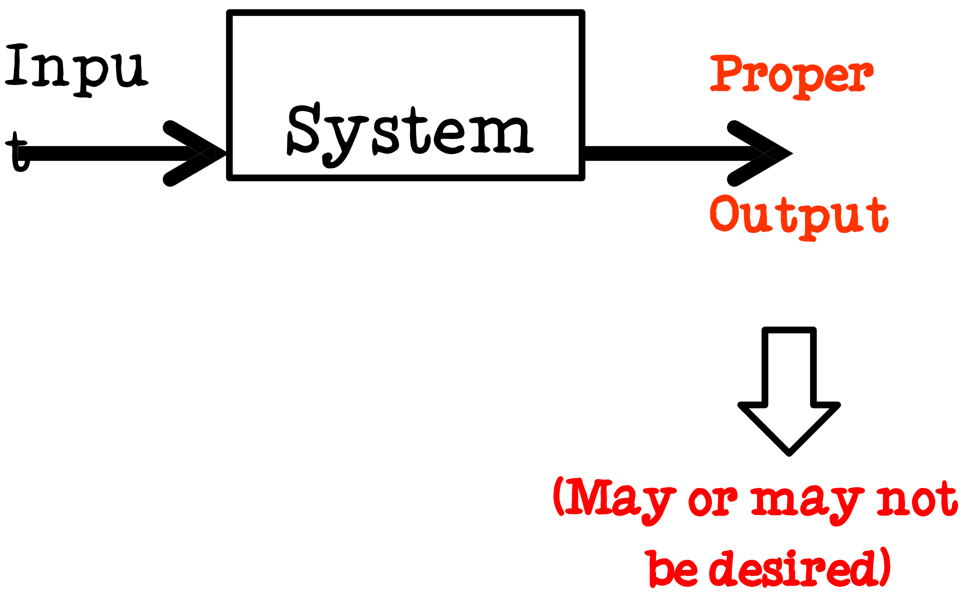
System + Control = Control System

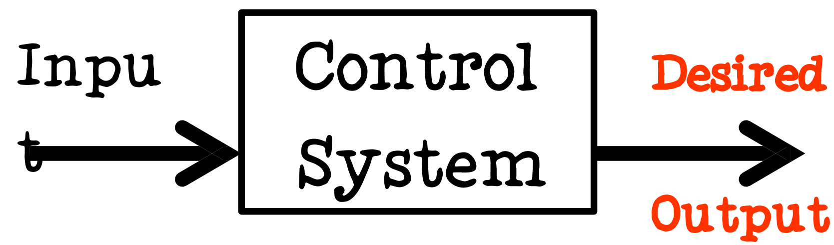
- It means to regulate, direct or command a system so that the desired objective can be attained

Control System

- It is an arrangement of different physical elements connected in such a manner so as to regulate, direct or command itself to achieve a certain objective.

Difference between System and Control System





Difference between System and Control System

An example :

Fan

Input: 230V/50Hz AC Supply → Fan (System) → Air Flow: Output

A Fan: Can't Say System

- A Fan without blades cannot be a "SYSTEM" Because it cannot provide a desired/proper output i.e. airflow

Input Output

230V/50Hz

AC Supply

No Airflow

(No Proper/ Desired Output)

A Fan: Can be a System

- A Fan with blades but without regulator can be a "SYSTEM"

  Because it can provide a **proper output** i.e. airflow

- But it cannot be a "Control System" Because it cannot

  provide desired output i.e. controlled airflow

Input Output

230V/50Hz

AC Supply

Airflo
w
(Proper Output)

A Fan: Can be a Control System

- A Fan with blades and with regulator can be a "CONTROL SYSTEM" Because it can provide a **Desired output.**

  i.e. Controlled airflow

Input

230V/50Hz

AC Supply

Control Element

Output

Controlled Airflow

(Desired Output)

Classification of control system

- **Natural control system:** the system inside a human being or biological system

- **Man-made control system:** : control system that are designed and developed by man. Example an automobile, Air craft, AC washing machine etc,

  Manual control: Example driver driving a car, Fan, Light etc

  Automatic control: AC, Servo Voltage stabilizer, Automatic washing machine, etc

- **Combinational control system:** this control system is a combination of natural and manmade

Classification of control system

Continuous Time or Discrete time Control Systems :

- If the signals in all parts of a control system are continuous functions of time, the system is continuous time feedback control system.
(e.g. speed control of motor by tacho-generator)

- If one or more system variables of a control system are know at a certain discrete time ,the system is discrete time control system
(e.g. computer system)Microprocessor/ Micro control based control System

Classification of control system

- Linear Control or Non-Linear Control Systems:

If a system obeys superposition principle the system is said to be a linear system.

- If it does not obey superposition principle is said to be a non-linear system.

Cont…

- Time-varying and time invariant control system
- Lumped and distributed control system
- SISO and MIMO control system
- Optimal control
- Adaptive control system
- Closed loop and open loop control system

Classification of Control System

Classification of Control System

(Depending on control action)

Manual Control

Open Loop

Closed Loop

Control System

Automatic Control

Open Loop

Closed Loop

Control System

Classification of Control System

Classification of Control System

(Depending on control action)

Open Loop Control System

- Manual
- automatic

Closed Loop Control System

- Manual
- automatic

Open Loop Control System

Definition:

"A system in which the control action is totally independent of the output of the system is called as open loop system"

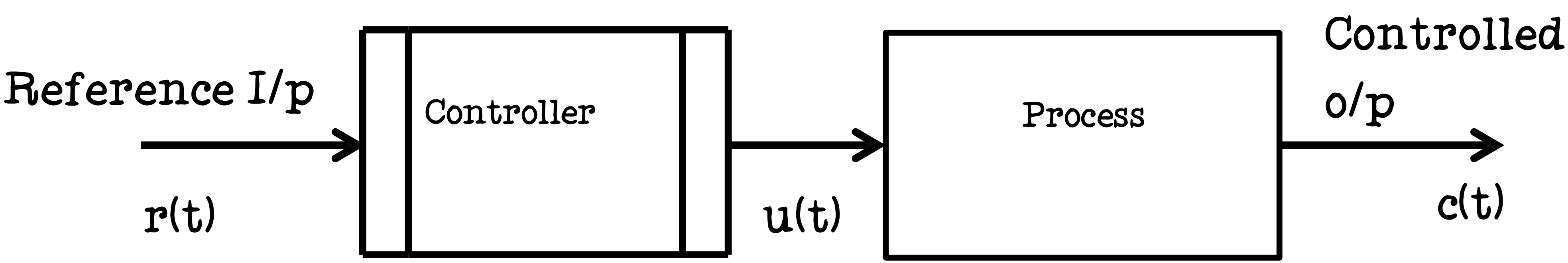


Fig. Block Diagram of Open loop Control System

Open Loop Control Systems

- A system in which the output has no effect on the control action is known as an open loop control system. For a given input the system produces a certain output

- A traffic control system is a good example of an open loop system. The signals change according to a preset time and are not affected by the density of traffic on any road.

Examples of Open Loop Control Systems

We use open loop control systems in many applications of our day to day life. Some of the systems designed based on the concept of open loop control systems.

- Automatic washing machine.
- Electric hand drier.
- Time-based Bread toaster.
- Automatic coffee Vending Machine.
- TV remote control.
- Door lock system.

OLCS Examples

- **Electric hand drier** - Hot air (output) comes out as long as you keep your hand under the machine, irrespective of how much your hand is dried.

OLCS Examples

- **Automatic washing machine**

  This machine runs according to the pre-set time irrespective of washing is completed or not.

OLCS Examples

Bread toaster

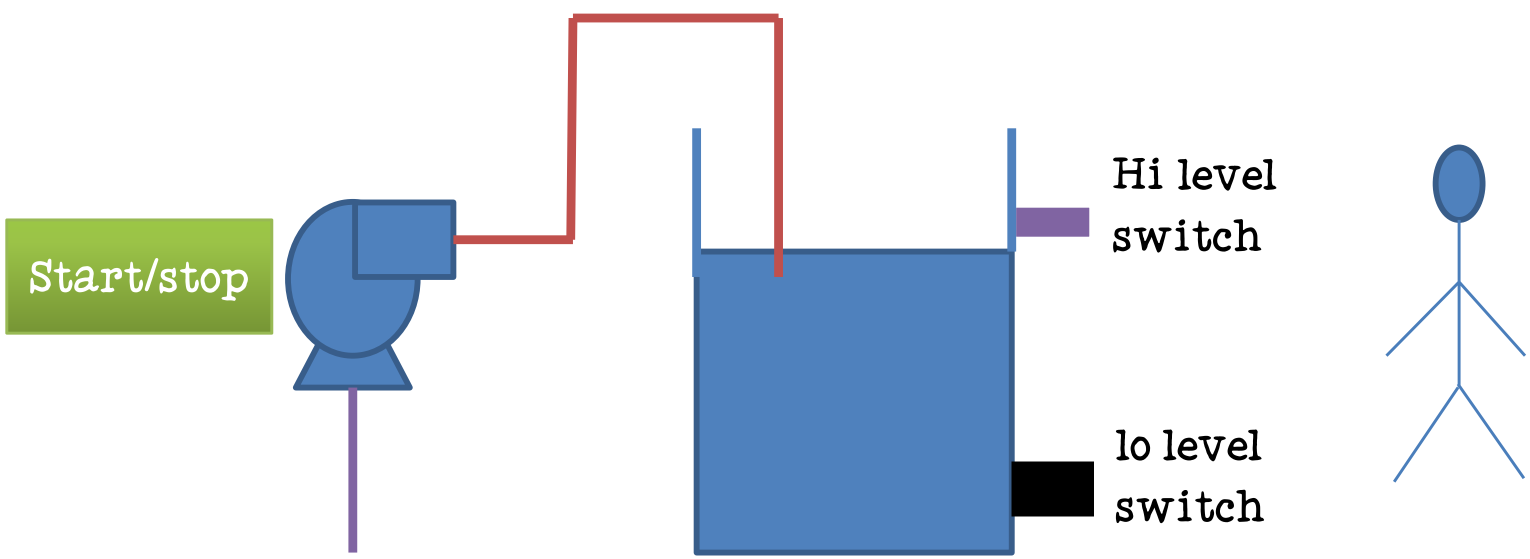
This machine runs as per adjusted time irrespective of toasting is completed or not.

OLCS Examples

- **Automatic tea/coffee Vending Machine** - These machines also function for pre adjusted time only.

Tank level control

An example of a manual open loop control system. In open loop control system when we start the pump it will continue fill the fluid in the tank but at a time tank will overflow still pump will not stop.



Tank level control example :

In open loop control we have no feedback that what is going on in process. We have to manually control the pump by putting a man at near the tank. He will see that if the high level switch glow then he will stop the pump and if lo level will glow then he will start the pump.

OLCS Examples

- **Light switch** - lamps glow whenever light switch is on irrespective of light is required or not.

- **Volume on stereo system** - Volume is adjusted manually irrespective of output volume level.

Advantages of OLCS

- Simple in construction and design.
- Economical.
- Easy to maintain.
- Generally stable.
- Convenient to use as output is difficult to measure.

Disadvantages of OLCS

- They are unreliable
- They are inaccurate
- Any change in output cannot be corrected automatically.

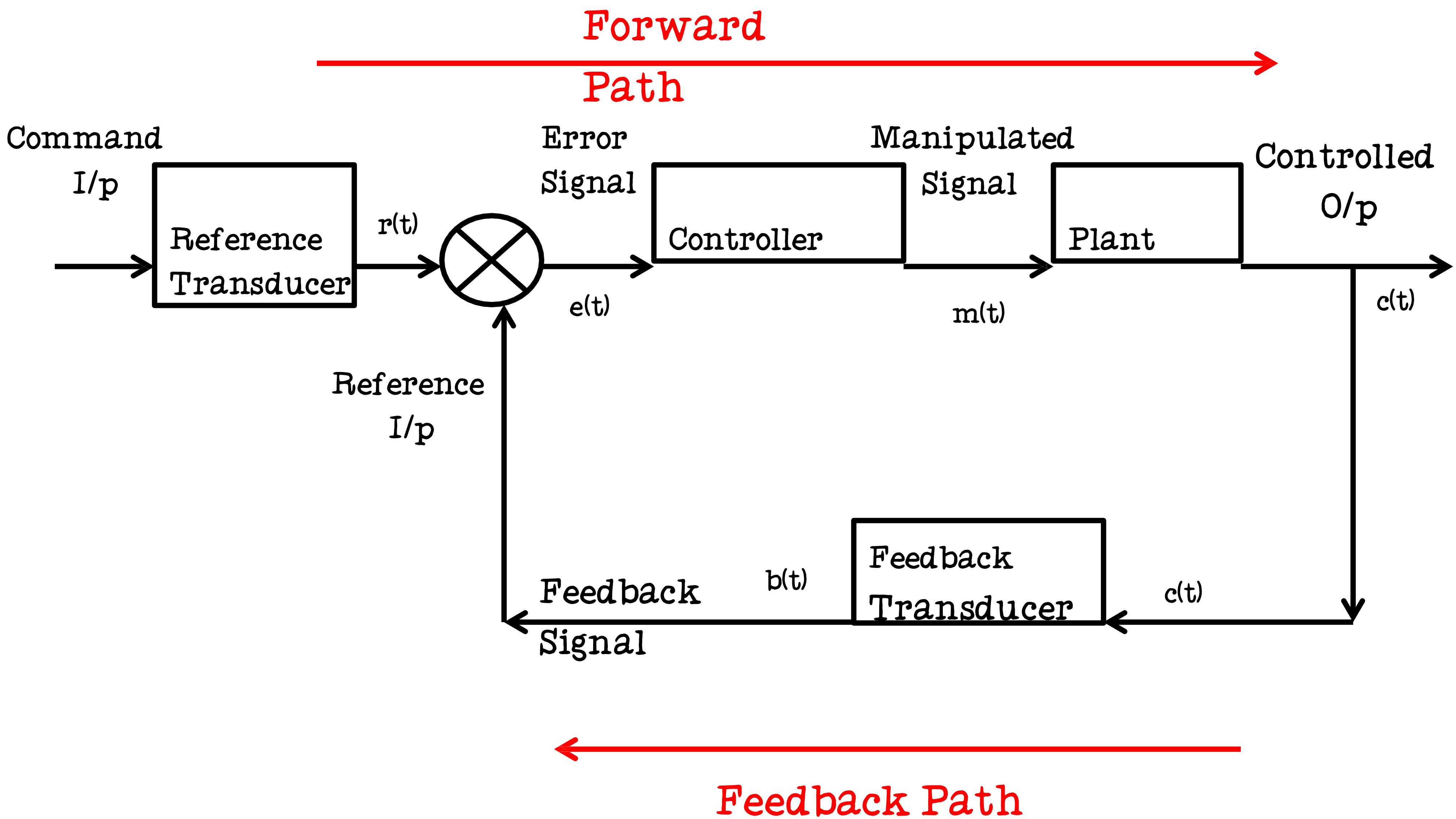
If there are any disturbances, the out put changes and there is no adjustment of the input to bring back the output to the original value.

Closed Loop System

Definition:

- A systemin which the control action is some how dependent on the output is called as closed loop system
- Input is control by output or input is dependant on output
- Negative Feed back is used

Block Diagram of CLCS



Basic Components of Closed Loop Control System

- Plant
- Feedback
- Controller
- Error detector

Plant:

The portion of a system which is to be controlled or regulated is called as plant or process. It is a unit where actual processing is performed and if we observe in the above figure, the input of the plant is the controlled signal generated by a controller. A plant performs necessary actions on a controlled system and produces the desired output.

Feedback:

It is a controlled action in which the output is sampled and a proportional signal is given to the input for automatic correction of any changes in the desired output.

The output is given as feedback to the input for correction i.e. information about output is given to input for correcting the changes in output due to disturbances. The feedback signal is fed to the error detector. Negative feedback is preferred as it results in better stability and accuracy. The other disturbance signals are rejected.

Controller:

the element of a system within itself or external to the system which controls the plant is called as a controller. The error signal will be a weak signal and so it has to be amplified and then modified for better control action.

In most of the systems, the controller itself amplifies the error signal and integrates or differentiates to generate a control signal. An amplifier is used to amplify the error signals and the controller modifies the error signal.

Error Detector:

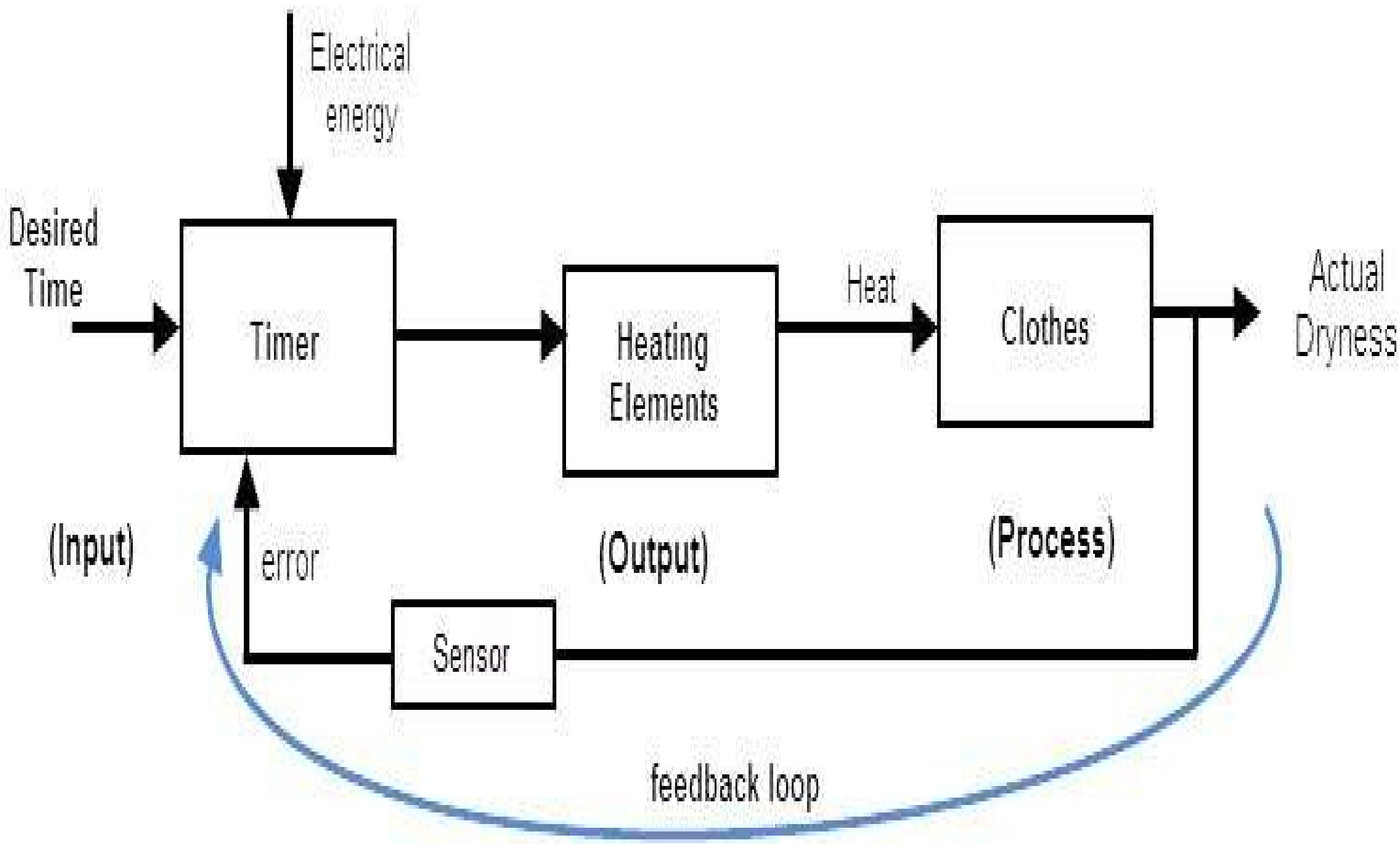
The function of error detector is to compare the reference input with the feedback signal. It produces an error signal which is a difference of two inputs which are reference signal and a feedback signal. The error signal is fed to the controller for necessary controlled action. This error signal is used to correct the output if there is a deviation from the desired value.

Closed loop control system

- A system which maintains a prescribed relationship between the controlled variable and the input signal.
- The output or the controlled variable is measured and compared with the reference input and an error signal is generated.
- This is the activating signal to the controller which, by its action, tries to reduce the error.
- Thus the controlled variable is continuously feedback and compared with the input signal If the error is reduced to zero, the output is the desired output and is equal to the reference input

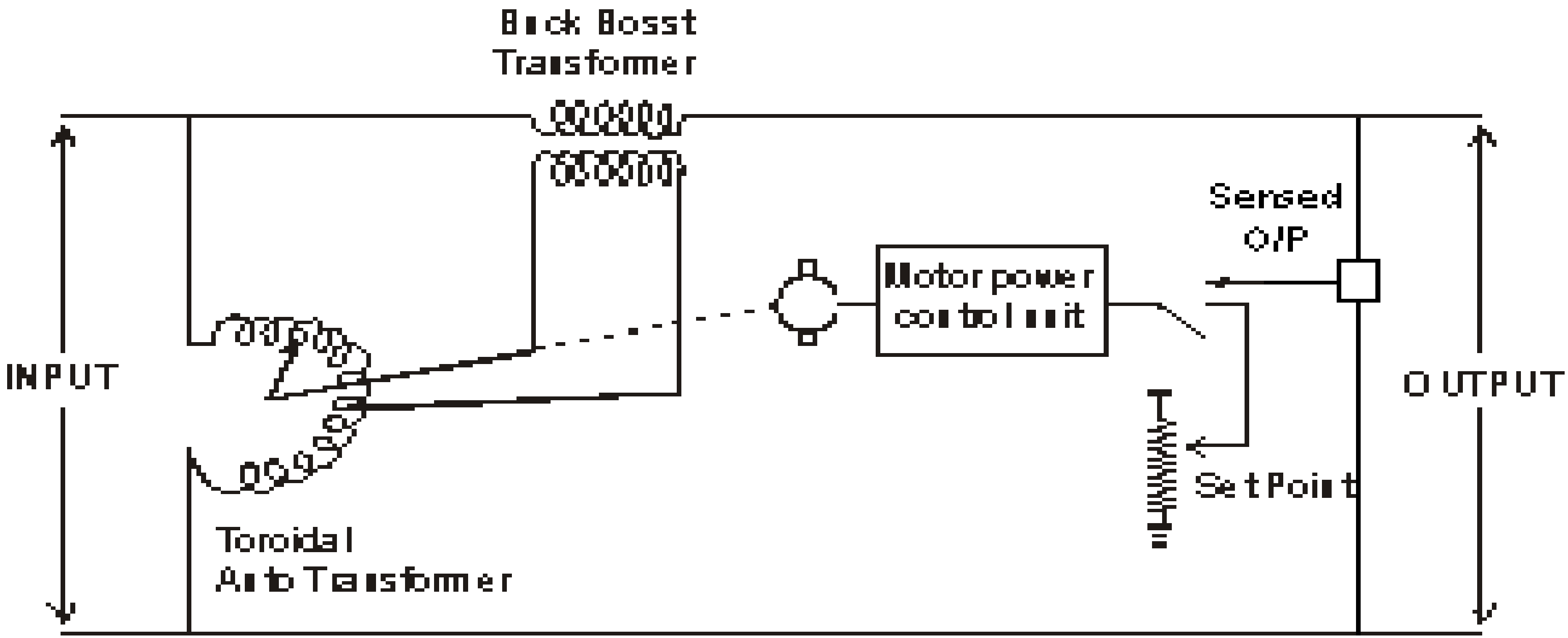
CLCS Examples

- **Automatic Electric Iron-** Heating elements are controlled by output temperature of the iron.



CLCS Examples

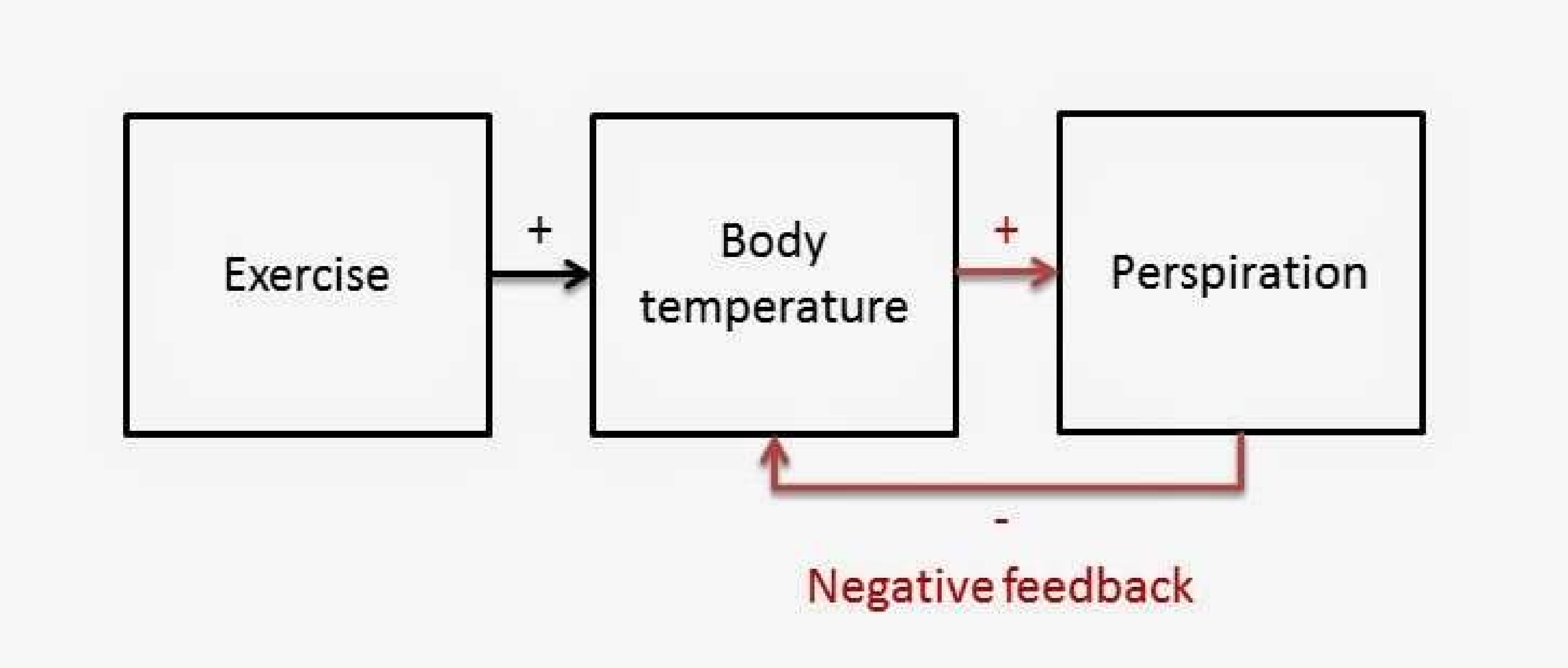
- **Servo voltage stabilizer** - Voltage controller operates depending upon output voltage of the system.



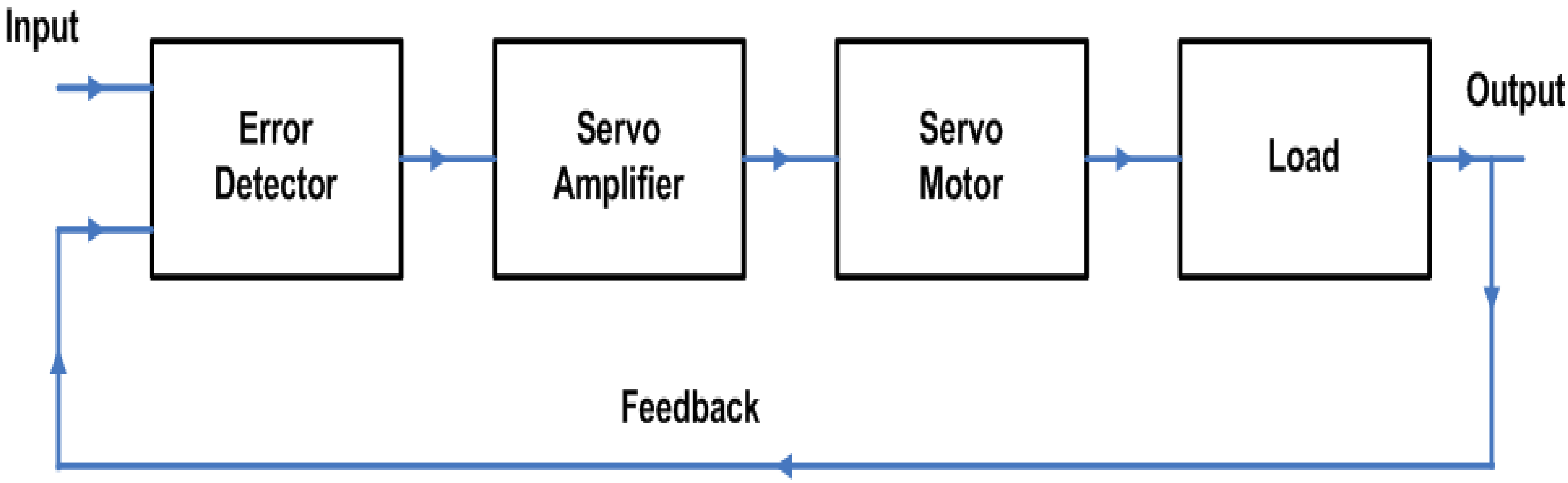
Servo Voltage Stabilizer

CLCS Examples

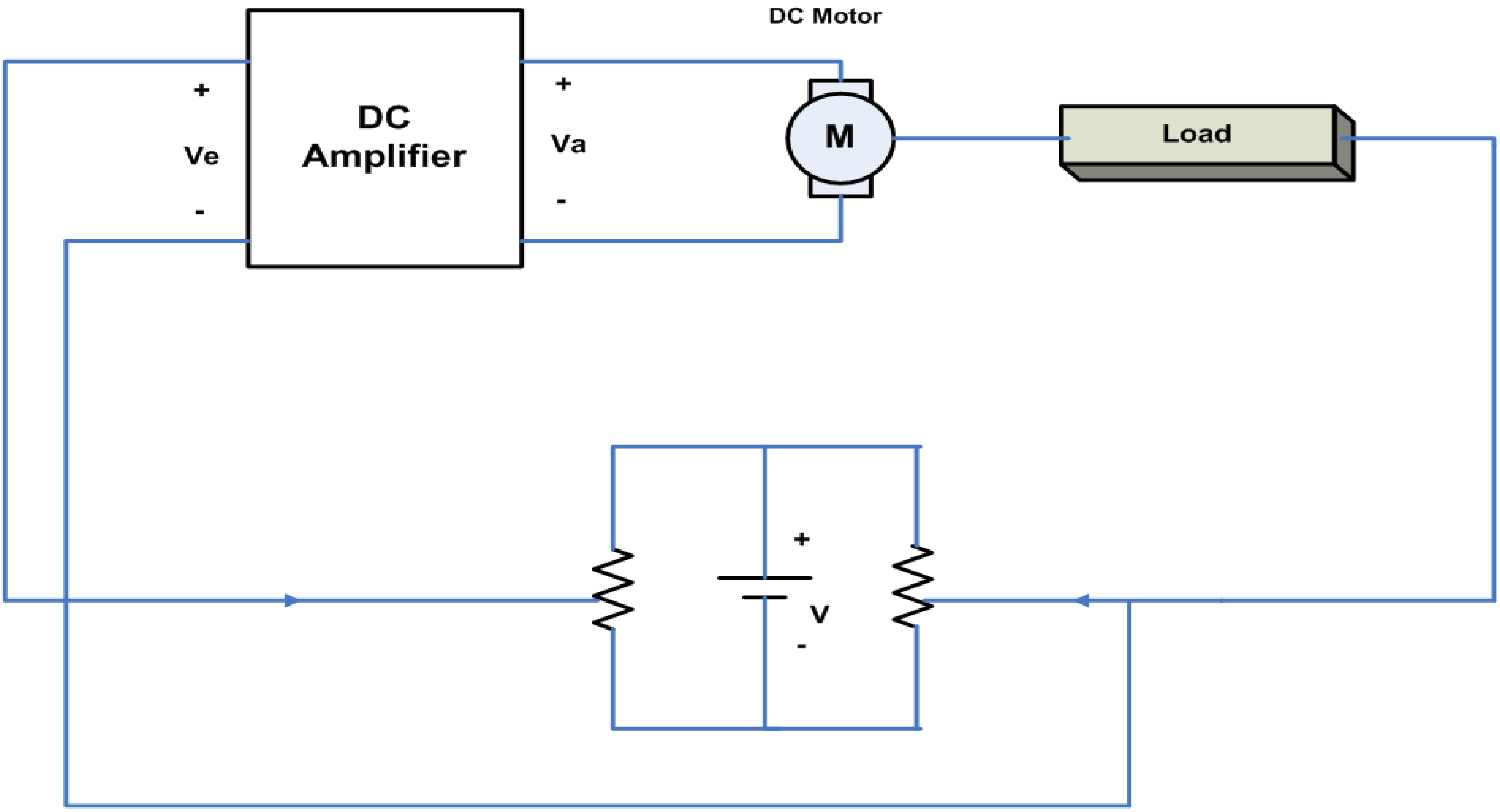
- **Perspiratio n**



General block diagram of Servo System



DC Servo System



Advantages of CLCS

- Closed loop control systems are more accurate even in the presence of non-linearity.
- Highly accurate as any error arising is corrected due to presence of feedback signal.
- Bandwidth range is large.
- Facilitates automation.
- The sensitivity of system may be made small to make system more stable.
- This system is less affected by noise.

Disadvantages of CLCS

- They are costlier.
- They are complicated to design.
- Required more maintenance.
- Feedback leads to oscillatory response.
- Overall gain is reduced due to presence of feedback.
- Stability is the major problem and more care is needed to design a stable closed loop system.

Difference Between OLCS & CLCS

Open Loop Control System	Closed Loop Control System
1. The open loop systems simple & economical.	1. The are closed loop systems are complex and costlier
2. They consume less power.	2. They consume more power.
3. The OL systems are easier to construct because of less number of components required.	3. The CL systems are not easy to construct because of more number of components required.
4. The open loop systems are inaccurate & unreliable	4. The closed loop are system s more accurate & reliable.

Difference Between OLCS & CLCS

Open Loop Control System	Closed Loop Control System
5. Stability is not a major problem in OL control systems. Generally OL systems are stable.	5. Stability is a major problem in closed loop systems & more care is needed to design a stable closed loop system.
6. Small bandwidth.	6. Large bandwidth.
7.Feedback element is absent.	7.Feedback element is present.
8.Output measurement is not necessary.	8.Output measurement is necessary.

Difference Between OLCS & CLCS

Open Loop Control System	Closed Loop Control System
9. The changes in the output due to external disturbances are not corrected automatically. So they are more sensitive to noise and other disturbances.	9.The changes in the output due to external disturbances are corrected automatically. So they are less sensitive to noise and other disturbances.
10. Examples: Coffee Maker, Automatic Toaster, Hand Drier.	10. Examples: Guided Missile, Temp control of oven, Servo voltage stabilizer.

Classification of Control System

Classification of Control System

- Linear Control System
- Non-linear Control System

Linear Control System

- When an input X1 produces an output Y1 & an input X2 produces an output Y2, then any combination X_1 X_2 should produce an output Y_1 Y_2. In such case system is linear. Therefore, linear systems are those where the principles of superposition and proportionality are obeyed.

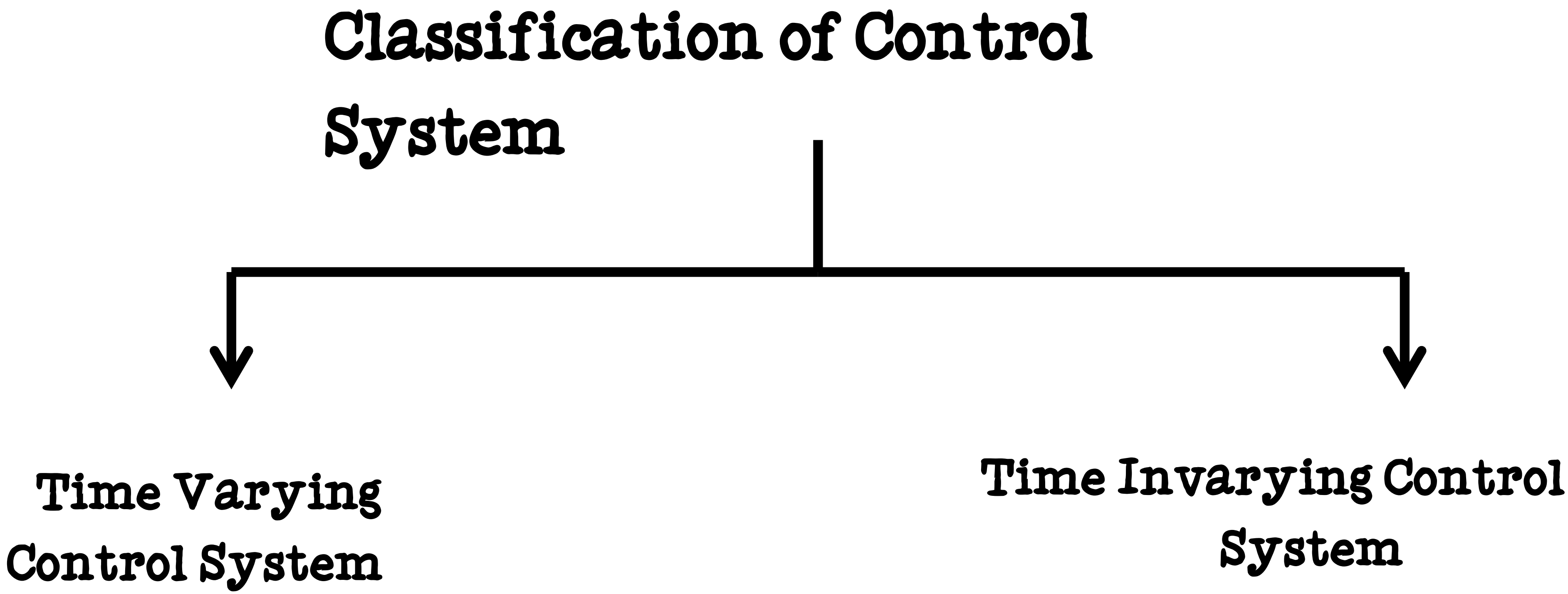
Non-linear Control System

- Non-linear systems do not obey law of superposition.
- The stability of non-linear systems depends on root location as well as initial conditions & type of input.
- Non-linear systems exhibit self sustained oscillations of fixed frequency.

Difference Between Linear & Non-linear System

Linear System	Non-linear System
1. Obey superposition.	1. Do not obey superposition
2. Can be analyzed by standard test signals	2. Cannot be analyzed by standard test signals
3. Stability depends only on root location	3. Stability depends on root locations, initial conditions & type of input
4. Do not exhibit limit cycles	4. Exhibits limit cycles
5. Do not exhibit hysteresis/ jump resonance	5. Exhibits hysteresis/ jump resonance
6. Can be analyzed by Laplace transform, z- transform	6. Cannot be analyzed by Laplace transform, z- transform

Classification of Control System



Time varying/In-varying Control System

- Systems whose parameters vary with time are called

  time varying control systems.

- When parameters do not vary with time are called

  Time Invariant control systems.

Time varying/In-varying Control System

- The mass of missile/rocket reduces as fuel is burnt and hence the parameter mass is time varying and the control system is time varying type.

Servo System

- **Definition:**

1. Servo system is defined as automatic feedback control system working on error signals giving the output as mechanical position, velocity or acceleration.
2. Servo system is one type of feedback control system in which control variable is the mechanical load position & its time derivatives like velocity and acceleration.