Control Systems

6th sem, ECE

Syllabus (SECTION-A):

Introduction: History of automatic control, servomechanism, regulating systems, open loop , closed loop control systems, feedback, effect of feedback, linear and non linear control systems, block diagrams, Examples: speed control system, robot control system., temperature controls system traffic control system , business control systems etc. (06hours)

Modeling: Differential equations of physical systems, electrical, mechanical, translational, rational, gear systems, thermal systems. Electrical, mechanical analogies, Laplace transforms, transfer function. Block diagram algebra, signal flow graphs, characteristic equation, Control system components: Error detectors potentiometer, synchros, stepper motor, ac and dc techo-generators. (07hours)

Time Domain Analysis: Typical test input signals, Transient response of the first order, second order system, Time domain specifications Dominant closed loop poles of higher order systems, Steady state error and error coefficients. (04hours)

Stability: Concepts of absolute and relative stability pole zero location, Routh-Hurwitz criteria. (02hours)

Root Locus Technique: Introduction, Root Locus Concept, Construction Root Loci, Stability analysis. (04hours)

Syllabus (SECTION-B):

Frequency Response: Introduction, Bode diagram, polar plots, log magnitude vs. phase plot, nyquist stability criterion, stability analysis, relative stability, Gain margin & Phase margin close loop frequency response. (04hours)

Introduction To Design: Necessity of compensation, lag and lead compensation, design of PID Controller. (05hours)

State Space Analysis: Concept of State, state variable and state vector, state space modeling of continuous time and discrete time systems, solution of state equation, concepts of controllability and observability, pole-placement design. (09hours)

Recommended Books:

TEXT BOOKS

1. Control Systems Engineering by I.J. Nagrath and M. Gopal.
2. Linear Control Systems by B S Manke.

RECOMMENDED BOOKS

1. Design of feedback Control Systems by R. T. Stefani et al.
2. Modern Control Engineering by K. Ogata.
3. Problems and Solutions of Control Systems: With Essential Theory by A K Jairath.

What is Control System?

- **Control:**
  - Control can be defined as to regulate, direct or command something (here a system) so as that desired objective is attained.
  - Making a system to behave as desired, as we want as per the requirements.
- **System:**
  - Entity to which inputs are given & outputs are obtained.
  - Arrangement/combination of different physical components connected or related in such a manner so as to form an entire unit to attain a certain objective.

Control system:

- A control system can be defined as output quantity is being controlled by the variation in input quantity.
- Any quantity of interest in machines, mechanism or other equipment is maintained or altered in accordance with a desired manner.
- Useful in automation i.e. making the manual operations semi-automatic or fully automatic by studying and analyzing them, by using various mathematical tools.

Requirement of a good control systems:

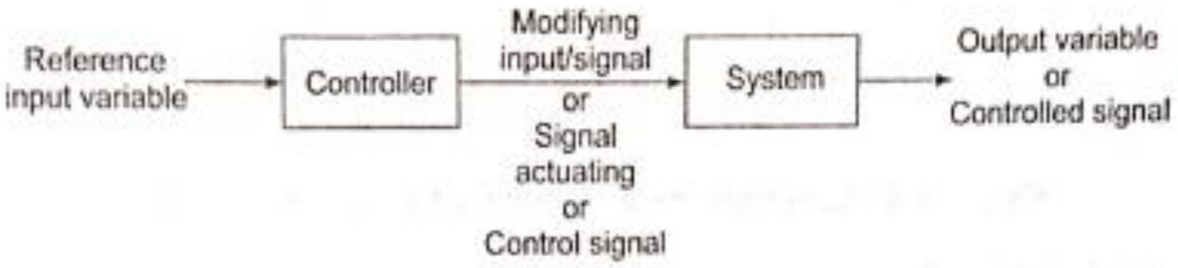
- **Accuracy:** Must be high. Can be improved by using feedback element/closed loop. .
- **Sensitivity:** The changes in output occur due to environmental or parametric changes. Hence system must be insensitive to such parameters but sensitive to input.
- **Noise:** It is the unwanted signal. Hence must be insensitive to the unwanted noise signal.
- **Stability:** It must be bounded input bounded output. Stable for all the variations.
- **Speed:** High speed so that the output is fast as possible.
- **Simplicity:** Must not be complicated. Must be easy to understand and everyone should get a clear concept.
- **Flexible:** It must be flexible and must operate and respond on every input.
- **Economical:** It must be cost effective.

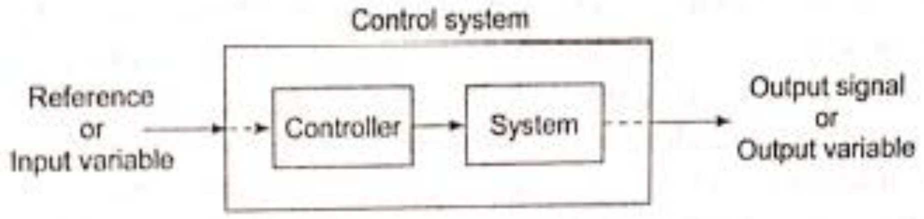
Significance of the Control Systems:

- **Whenever a system is needed to be made automatic**, control system is needed.
- Knowledge about control systems can make it easy to make any operations which are **manual into semi-automatic or fully automatic according to the requirements.**
- **Human intervention is reduced** which used to lead to errors.
- Using concepts of control systems, we can easily **increase the efficiency of the system** and **increase the accuracy of the system.**
- It **can be evaluated frequently to ensure that the processes are** where they need to be and are **functioning properly and efficiently and effectively.**
- **Examples of this in our day-to-day life:** traffic signals, washing machine, oven, toaster, fan, hand drier, AC, perspiration, tea/coffee maker, automatic electric iron, voltage stabilizer, driving a car, etc.

Control System

- **Plant:** Set of various machine components or parts functioning together to perform a particular operation.
- **Process:** It is a logical series/continuing operation, giving a total plant operation.
- **Systems are taken to be the same as process or plant in context of their operations involving the control.**
- The plant itself can involve some kind of processes.
- Example: A chemical plant involves heating, cooling, filtering and precipitation process.
- **Control:**
- Corrective action (regulate, direct or command) taken on the plant by external means as to get the desired output from it.
- If the control action is taken by a human being, then control is called **manual control**.
- If the control action is taken by a gadget or device, then control is called **automatic control.**
- **Controller:** Agent (device/human) that offers the ccontrol action on the plant.

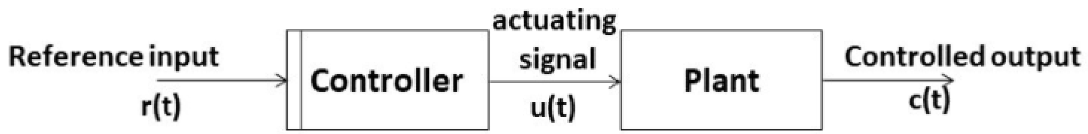


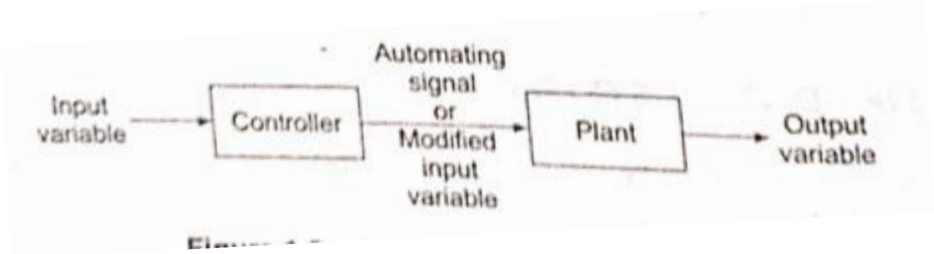


Depending on degree of automation/ presence of human being as a part of a control system:

- **Manually controlled c**ontrol system.
  - It has an operator as the controller.
  - Control action is regulated through human intervention.
  - Examples: operation of lathe machines in mechanical workshops, human-operated stage lighting control system, etc.
- **Semi-Automatic controlled** control system.
  - Involves both human beings and a device/gadget as a part of the controller.
  - Examples: present-day cars where driver controls the steering and the temperature control is separately performed by thermostatic devices, semi-automatic washing machines, microwave ovens, etc.
- **Automatic controll**ed control system.
  - Do not require any human intervention for their operation and control purposes.
  - Examples: pilot-less light aircrafts used in defence, metro rails in Korea, CNC (computerized numerically coded) lathe machines, etc.

Depending on configuration/presence of feedback:



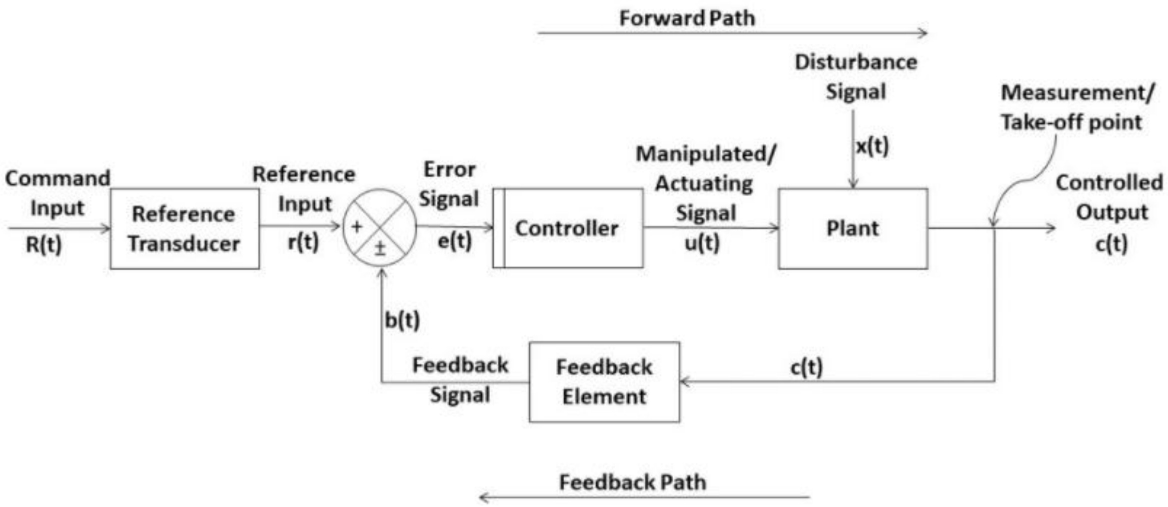


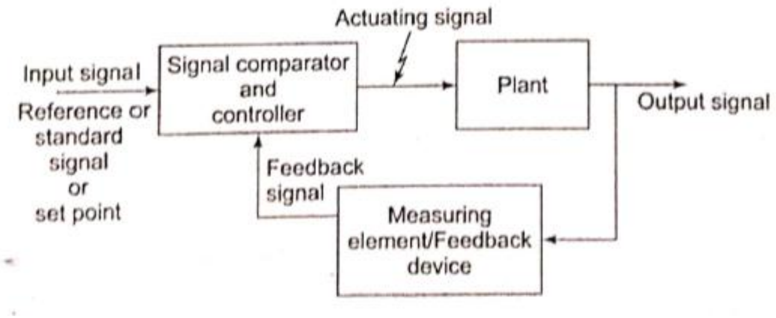
Open loop control system/Non-feedback control system:

The systems whose control action is free from the output.

The output depends only on the input. There is no

feedback in the system.





Closed loop control system/Feedback control system:

The systems depend on the control action of the output.

Feedback devices are sensors, transducers, display devices, etc.

Open-loop	Closed-loop
System whose control action is free from output.	System depends on the control action of the output.
Non-feedback system.	Feedback system.
Components: controller and controlled process.	Components: controller, amplifier, controlled process and feedback elements.
Construction is simple.	Construction is complex.
Accuracy depends on the calibration.	Accurate because of feedback.
Stable.	Less stable and sometimes may be unstable.
No feedback, hence no effect on gain.	Feedback is present, hence gain is reduced.
Response is fast.	Response is slow.
Non-reliable.	Reliable.
System is affected by the disturbance.	System is not that much affected by the disturbance.
Optimization is not possible.	Optimization is possible.
Less costly.	More costly.
Examples: automatic washing machine, traffic lights, TV remote, immersion rod, hand drier, etc.	Examples: AC, temperature control system, pressure control system, speed control system, missile launchers, etc.

Based on change of plant parameters / time dependencies:

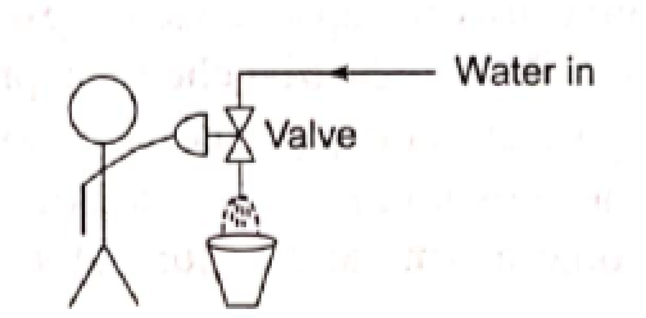
- **Time-varying control system.**
  - Parameters of the control systems vary with respect to time.
  - The output signal depends upon the time of application of the input.
  - Example: Automobile control system where mass decreases with time as the fuel is consumed during its movement, environment system, economic system of a country, etc.
- **Time-Invariant control system.**
  - Parameters of the control systems do not vary with respect to time (constant-coefficient control systems).
  - Response of such control systems is independent of the time at which the input is applied.
  - Example: Systems described by differential equations with constant coefficients, spring, mass & damper system, etc.

Based on plant output behaviour

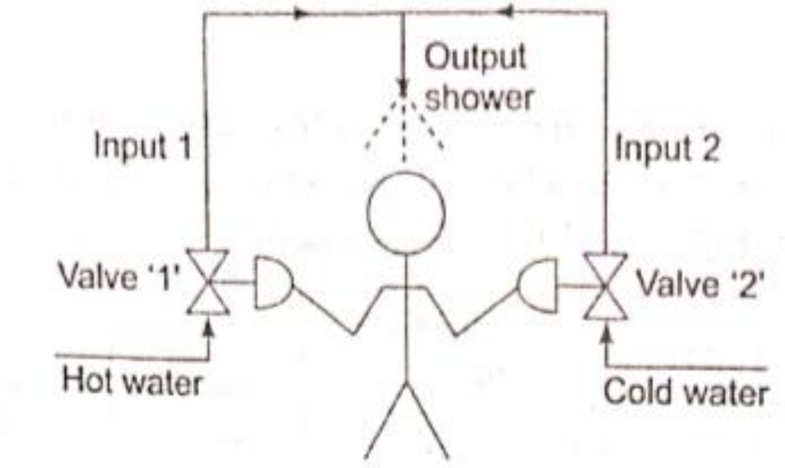
- **Linear Control Systems.**
  - Input-output relationships are represented by linear differential equations.
  - Follows the principles of superposition/additivity and proportionality/homogeneity.
  - **Homogeneity:** A system is said to be homogeneous, if we multiply input with some constant A then the output will also be multiplied by the same value of constant (i.e. A).
  - **Additivity:** Suppose we have a system S and we are giving the input to this system as a1 for the first time and we are getting the output as b1 corresponding to input a1. On the second time we are giving input a2 and correspond to this we are getting the output as b2. Now suppose this time we are giving input as a summation of the previous inputs (i.e. a1 + a2) and corresponding to this input suppose we are getting the output as (b1 + b2) then we can say that system S is following the property of additivity.
  - Example: Purely resistive network (v = iR) with a constant DC source.
- **Non-Linear Control Systems.**
  - Principles of superposition and proportionality are not obeyed. Non-linear effects are saturation, Electronic distortion like clipping.
  - **Mostly real time systems are non-linear**. So **piecewise linear approximation** is used to linearize for small variation of parameters and then controlled.

Based on number of inputs and outputs

- A plant may have single or multiple inputs and outputs (**SISO, MISO, SIMO, MIMO).**
- The increasing number of system/plant inputs and outputs increases the complexity of the system and its control requirements.



A person filling up a pail of water. When the pail gets full, the human controller makes the water pipeline tap valve fully closed. (SISO)



Two-input control by a human controller for regulating a single output, i.e. a shower. (MISO)

Based on number of inputs and outputs

- Examples for MIMO - powerplant, etc.
- Temperature and Humidity control of a room:
    - To control the temperature you need the heating element (one input) and to control the humidity you need water sprayer (second input).
    - The input variables are - the heating power and water sprayer
    - The output variables are the - temperature and humidty

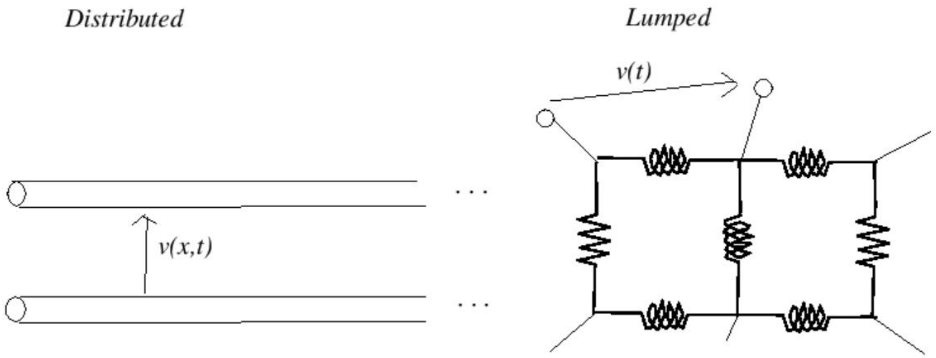
- Example for SIMO - antenna technology for wireless communications (multiple antennas are used at the destination or receiver), wireless local area networks (WLANs), mobile communications, etc.

Based on signal parameters

- **Continuous Control Systems:**
  - All system parameters are functions of continuous time ‘t’.
  - Examples are speed control, positioning control, torque control, voltage control, etc.

- **Discrete Control Systems:**
  - The data/parameters are not available continuous but at sampled intervals.
  - The sampled intervals are further classified into two categories.
  - **Sampled data control systems:**
    - The signal here is pulse data. It is less susceptible to the noise.
  - **Digital data control systems:**
    - The signal here is digital data (binary). The digital computer or a controller is used.

Based on distribution of parameters over structure of contro



- **Lumped Parameter Systems**
  - The elements are assumed to be concentrated at a point (function of the time only).
  - Analysis of such type of system is very easy which includes ordinary differential equations (ODE).
  - Example: spring mass damper system, electrical networks, etc.
- **Distributed Parameter Systems**
  - The elements are assumed to be distributed uniformly along the length (depend on both time and location).
  - Analysis of such type of system is slightly difficult which includes partial differential equations (PDE).
  - Example: transmission lines, etc.

Depending on control learning capabilities (able to control human capabilities)

- **Adaptive control system.**
  - Possess the ability of adaptation.
  - Identify dynamic characteristics of plant & then decide modifications to be made in actuating signal (controller output).
  - Act of ‘self-redesign’ or ‘self-organization’ so as to compensate for the unpredictable changes in the plant (erratic changes in the conditions of the environment or its structure).
  - Control system becomes reliable and versatile.
  - Examples: spacecraft control systems, ecological systems.
- **Learning control system.**
  - Possess the ability to learn.
  - Recognizes the similar features and patterns of a circumstance/situation and use their past learned experiences in an optimal fashion to generate the output.
  - Designed using AI techniques like artificial neural networks, expert systems, etc.

Depending on control learning capabilities (able to control human capabilities)

- **Self-regulating control system.**
  - Possess both adaptation and learning capabilities.
  - Example: human being.

- **Optimal control system.**
  - Control systems are designed to optimize certain performance indices of the system.
  - Trade-off between the parameters.
  - Mostly, modern day control systems work on optimization algorithms and after certain conditions of optima are fulfilled, the output at the controller is available.
  - Example: maximizing the profit and increasing the fuel efficiency of a car, etc.

Depending on main purpose of the system:

- **Process control system (pH level, temp, pressure flow, humidity, etc).**
- **Speed control system.**
- **Traffic control system**
- **Production control system.**
- **Economy control system.**
- **Quality control system.**
- **Robot arm control system.**

Servo control systems

- **A feedback control system for controlling the mechanical signals from a process such as position, velocity or acceleration.**
- Control systems where the **reference or input varies continuously** and the control system operates seen as the **output follows the input.**
- Also called **'Follower System'** or a **'Servomechanism'.**
- Examples:
    - Most of mechanical actuators in mechanical processes require control/automation use servo systems. CNC (computerized numerically coded) machines, where machine tools are operated as per the programmed instructions.
    - Solar power panel tracks the sun continously for optimum power generation.
    - Robot hand control, printers, aircraft automatic landing system, etc.

Regulators/Automatic Regulating System

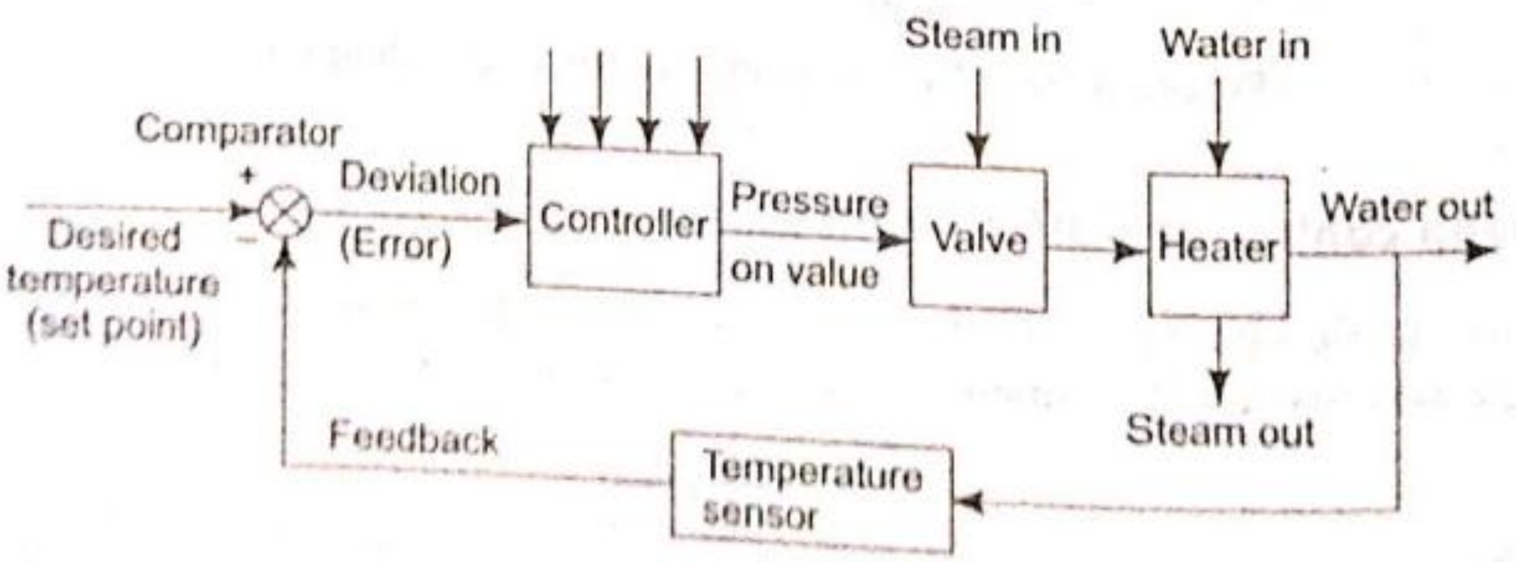
- **A feedback control system** where the **set point (reference input) or the desired output (controlled signal) is either constant or slowly varying with respect to time** and in which the primary task is to **maintain the actual output at the desired value in the presence of disturbances.**
- Examples:
  - Applications involving voltage control,
  - room temperature control,
  - process pressure,
  - temperature control, etc.

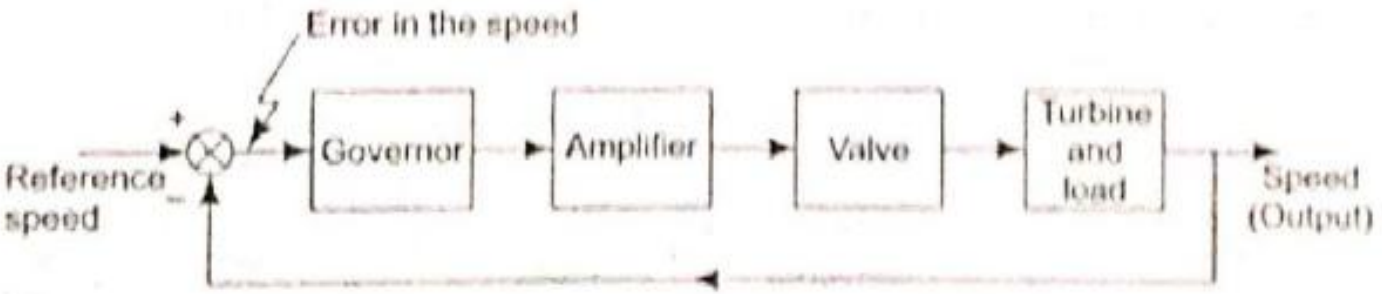
Process Control Systems

- Feedback control systems which **regulate the process outputs or variables** such as pH level, temperature, pressure flow, humidity, distribution, batch reaction, etc.

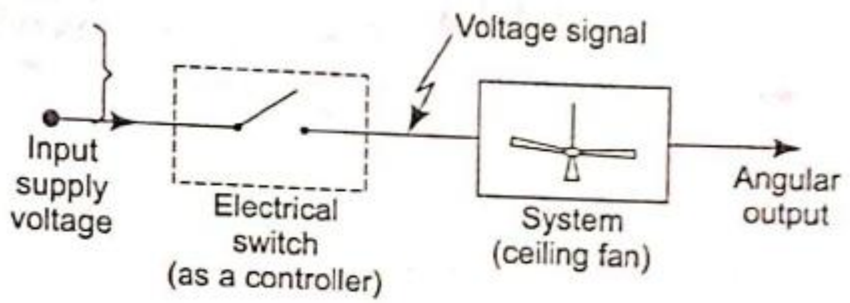
- Obtaining a process and then study its dynamic behavior are a must before designing such control systems.

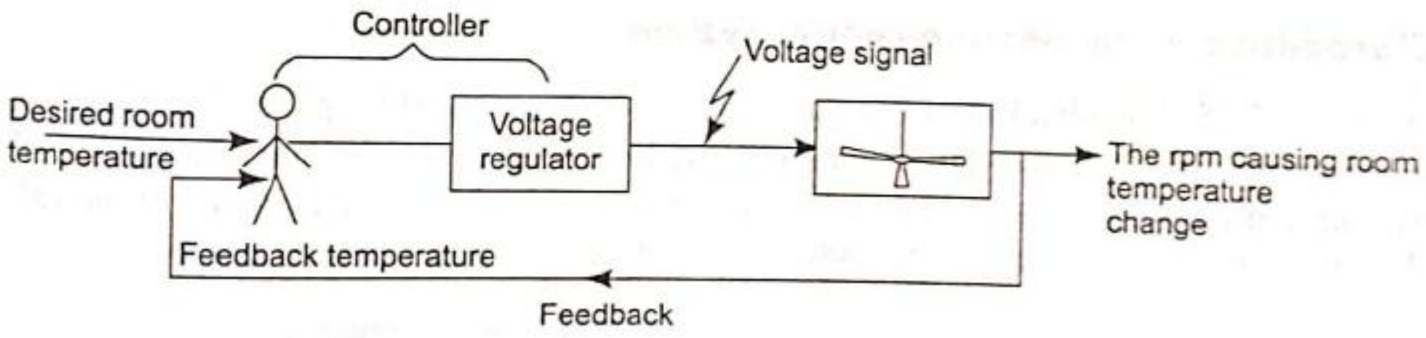
Steam turbine speed & water heating CS

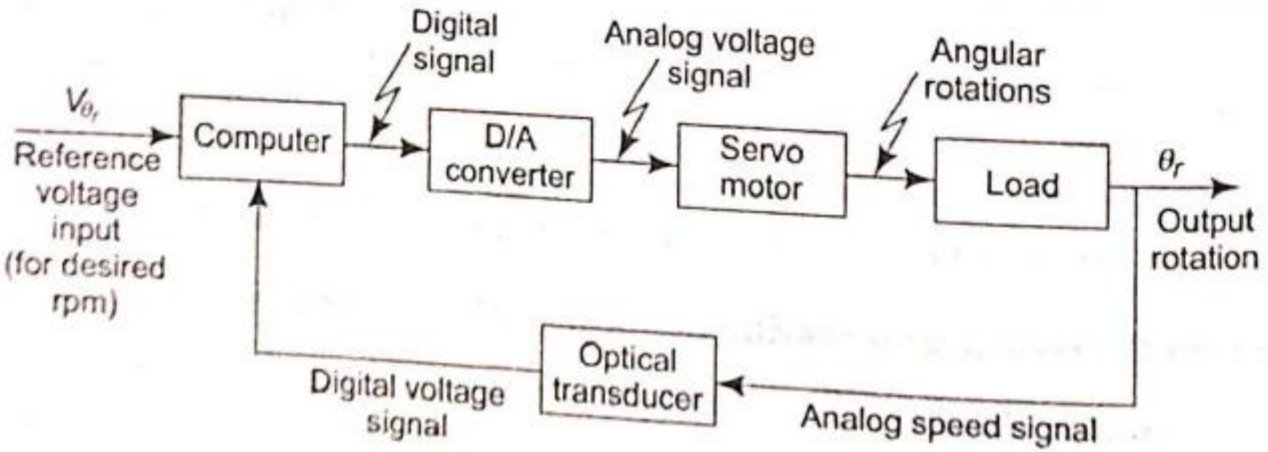




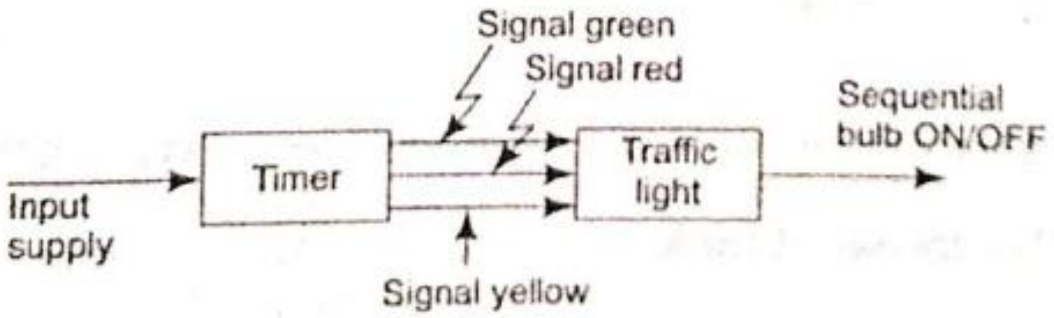
Ceiling fan CS & computer-based servomechanism

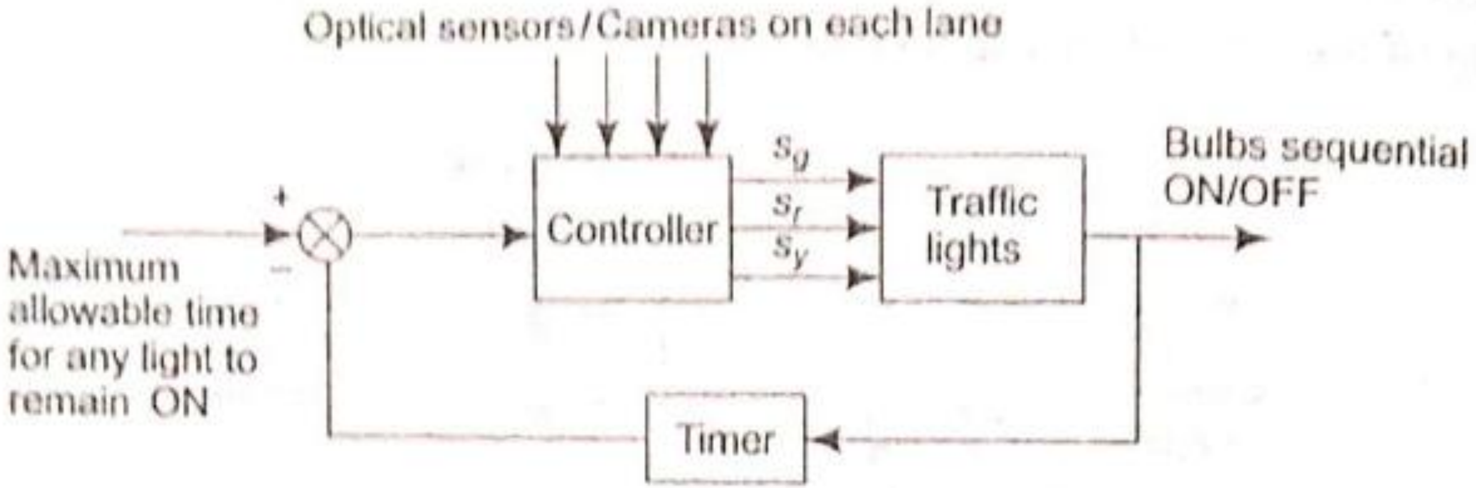




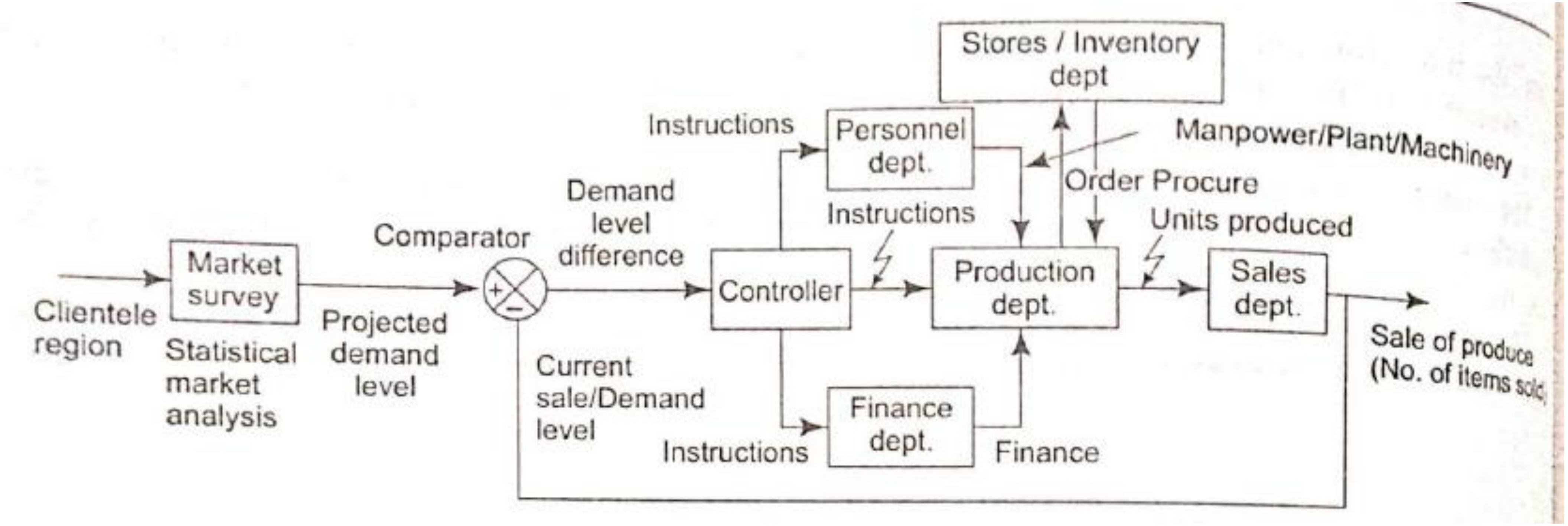


Traffic control system

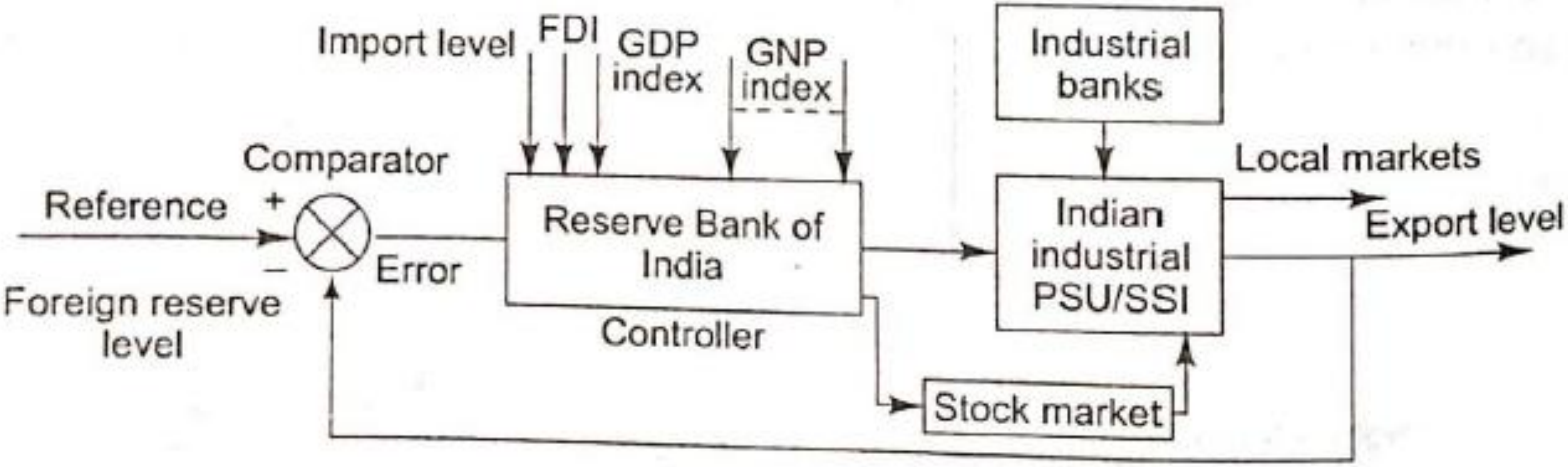




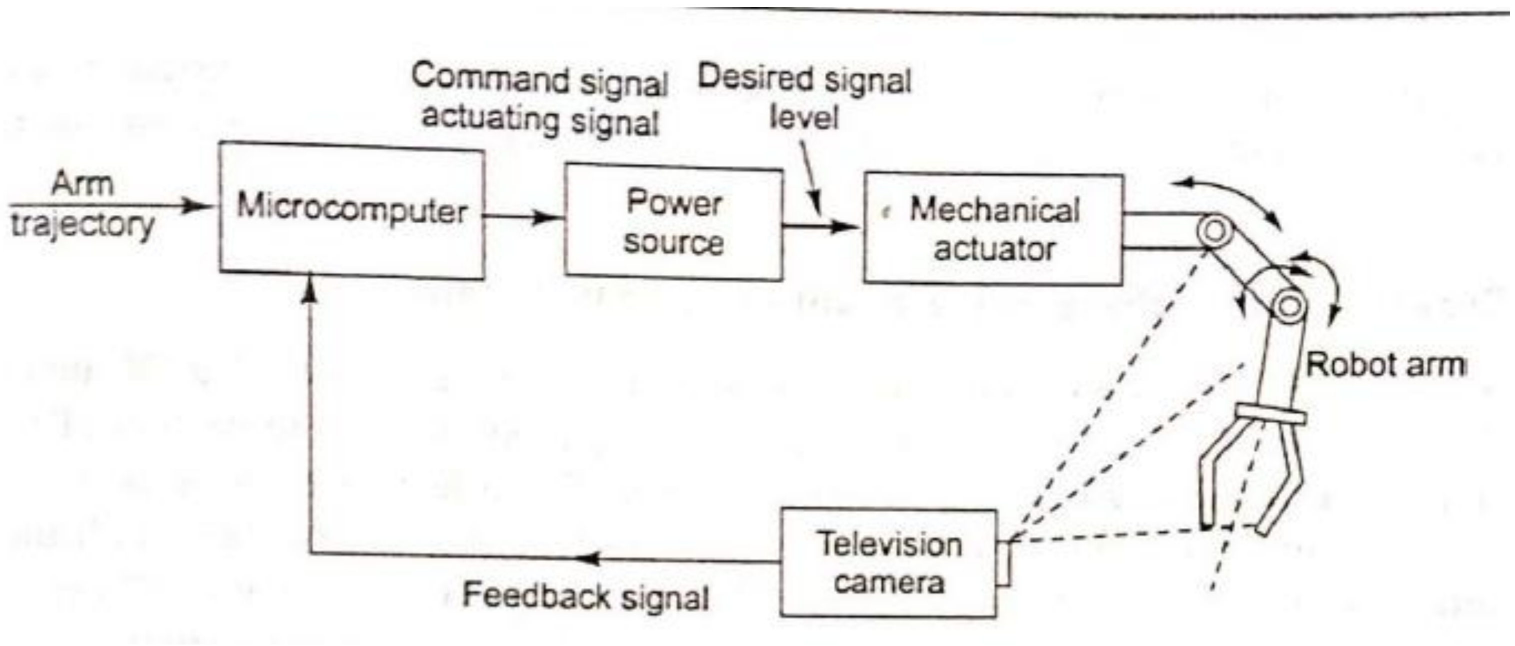
Production control system.



Economy control system.



Robot arm control system.



Quality control system.