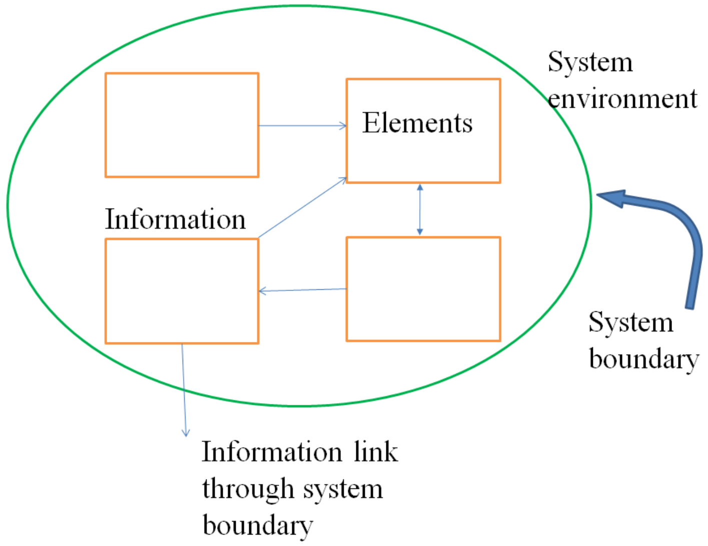
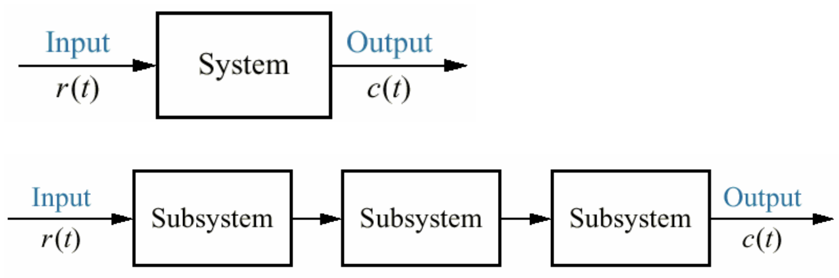
Lecture 01: Introduction to control system Engineering

System:

A system is a collection of components which interact with each other and with the environment (by information or energy links) from which the system is separated by a notational boundary.



Systems include physical, biological, organizational, and other entities, and combinations thereof, which can be represented through a common mathematical symbolism. The study of feedback control systems is essentially a study of an important aspect of systems engineering and its application.



$r(t)$: Reference input

$c(t)$: Controlled variable

Input:

- The input is the stimulus, excitation or command applied to a control system.
- Typically from external energy source, usually in order to produce a specified response from the control system.

Output:

- The output is the actual response obtained from a control system.
- It may or may not be equal to specified response implied by the input.

Control Engineering:

Control engineering or Control systems engineering is based on the foundations of feedback theory and linear system analysis, and it integrates the concepts of network theory and communication theory.

It is the engineering discipline that applies control theory to design systems with predictable behaviors. The practice uses sensors to measure the output performance of the device being controlled (often a vehicle) and those measurements can be used to give feedback to the input actuators that can make corrections toward desired performance. When a device is designed to perform without the need of human inputs for correction it is called automatic control (such as cruise control for regulating a car's speed). Multi-disciplinary in nature, control systems engineering activities focus on implementation of control systems mainly derived by mathematical modeling of systems of a diverse range.

Why control is important (for production process / in plant)?

(1) Safety: Prevent injury to plant personnel, protect the environment by preventing emission and minimizing waste and prevent damage to the process equipment.
(2) Maintain product quality (composition, purity, color, etc.) on a continuous basis and with minimum cost.
(3) Maintain plant production rate at minimum cost.
So, we can say that the reasons for automation of process plants are to provide safety and at same time maintain desired product quality, high plant throughput, and reduce demand on human labor.

Control system:

A control system is a system capable of *monitoring* and *regulating* the operation of a process or a plant. The study of control system is essentially a study of an important aspect of systems engineering and its applications.

A control system consists of subsystems and processes (or plants) assembled for the purpose of controlling the outputs of the process. For example, a furnace produces heat as a result of the flow of fuel. In this process, flow of fuel in the ***input***, and heat to be controlled is the ***output***.

There are two common classes of control systems, with many variations and combinations: logic or sequential controls, and feedback or linear controls. There is also fuzzy logic, which attempts to combine some of the design simplicity of logic with the utility of linear control. Some devices or systems are inherently not controllable.

Controls are classified with respect to:

- technique involved to perform control (*i.e*. human/machines): **manual/automatic control**
- Time dependence of output variable (*i.e*. constant/changing): **regulator/servo,** (also known as regulating/tracking control)
- fundamental structure of the control (*i.e*. the information used for computing the control)**: Open-loop/feedback control,** (also known as open-loop/closed-loop control)

<u>Manual/Automatic Controls - Examples</u>
A system that involves:

- a person controlling a machine is called **manual control**. *<u>Ex</u>: Driving a car*
- machines only is called a **automatic control**. *<u>Ex</u>: Central AC*

<u>Servo/Regulator Controls – Examples</u>
An *automatic* control system designed to:

- follow a changing reference is called **tracking control** or a **servo**. *<u>Ex</u>: Remote control car*
- maintain an output fixed (regardless of the disturbances present) is called a **regulating control** or a **regulator**. *<u>Ex</u>: Cruise control*

Open-Loop Control /Feedback control
<u>The structures are fundamentally different:</u>

- In an **open-loop control**, the system does NOT measure the actual output and there is no correction to make that output conform to the desired output.

- In a **closed loop control** the system includes a sensor to measure the output and uses feedback of the sensed value to influence the control input variable.

Examples of Open-Loop & Feedback Controls

An Electric toaster	A water tank of an ordinary flush toilet
An Electric toaster is an open-loop control. *Since* • The controller is based on the knowledge. • The output is not used in control computation	***A water tank of an ordinary flush toilet*** is a (basic) feedback control, *since* the output is fed back for control computation

Advantage of Control system

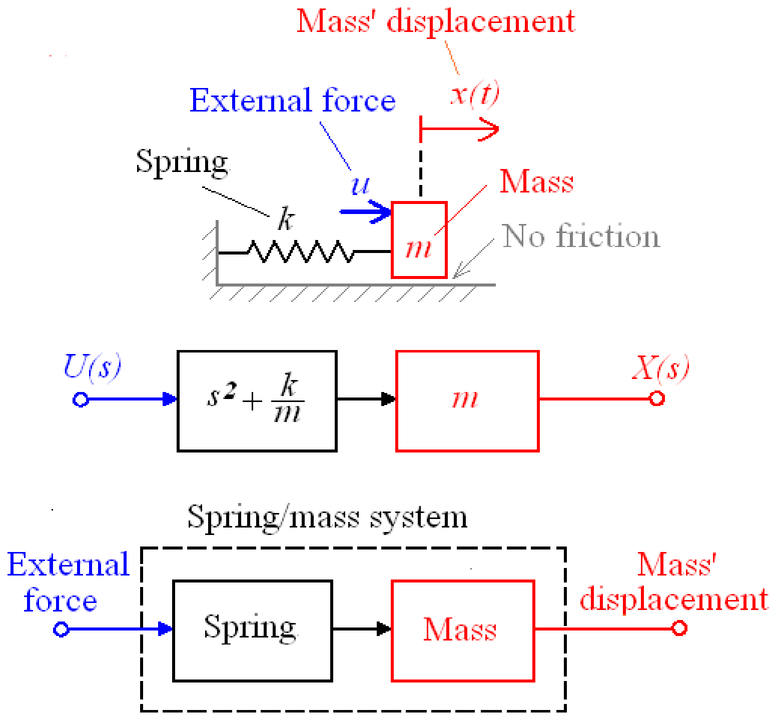
We build control systems for four primary reasons

1. Power amplification
2. Remote control
3. Convenience of input form
4. Compensation of the disturbances

Block Diagram

- It represents the structure of a control system.
- It helps to organize the variables and equations representing the control system.
- It is composed of:
  - boxes, that represents the components of the system including their causality;
  - Lines with arrows that represents the actual dynamic variables, such as *speed*, *pressure*, *velocity*, etc.

Simplest Open-Loop Control Example & Associated Block Diagrams

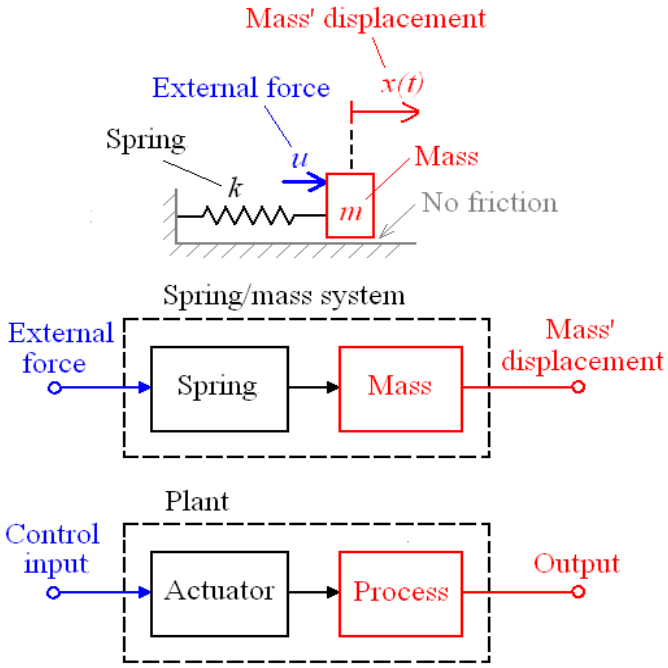


$$u = m\frac{d^2x}{dt^2} + kx \Rightarrow U(s) = (ms^2 + k)X(s)$$

$$U(s) == (s^2 + \frac{k}{m})mX(s)$$

- ***System* = mass + spring**
- ***Control Input*: force *u***
- ***Output*: displacement *x(t)***
- ***Block diagram* (derived using Laplace transforms, more on this later)**
- ***Component block diagram* for the system examined**

Specific & Generic Component Block Diagrams



Recall previous system

- ***Control Input: force u***
- ***Output: displacement x(t)***

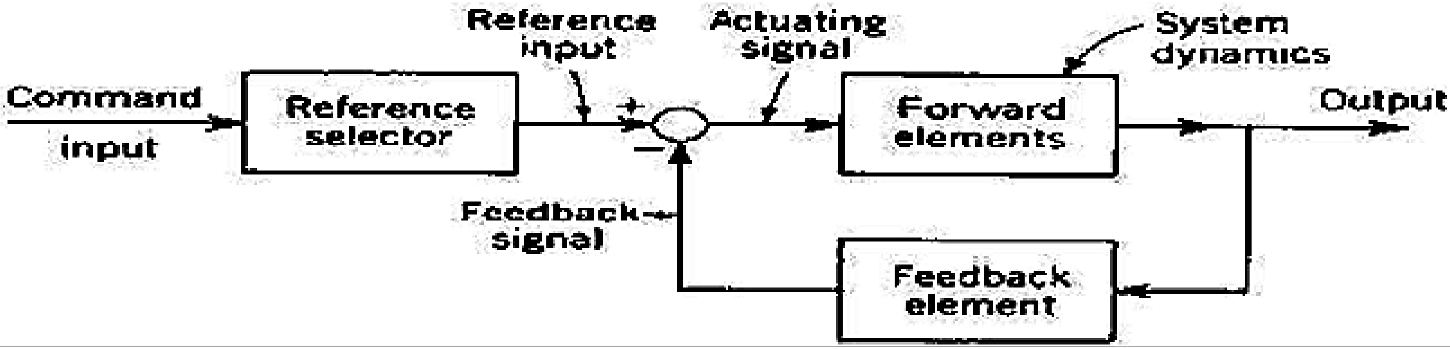
Component block diagram for the system examined

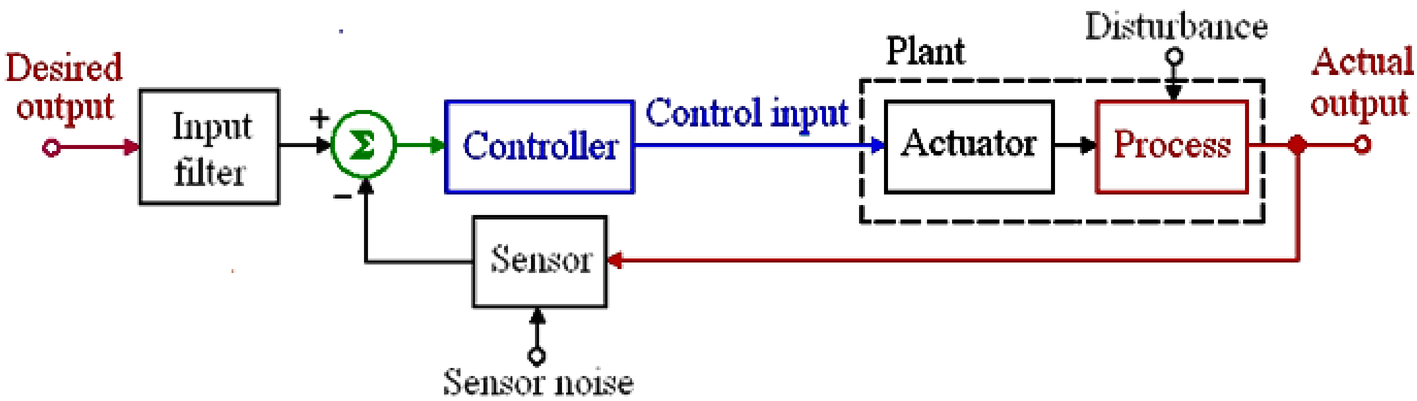
Generic component block diagram

Definitions of Process, Actuator & Plant

- Process = component whose the output is to be controlled,   Ex: *Mass*
- Actuator = device that can influence the control input variable of the process, Ex: *Spring*
- Plant = actuator + process,   Ex: *Spring/mass system*

Generic Component Block Diagram of an Elementary FEEDBACK Control



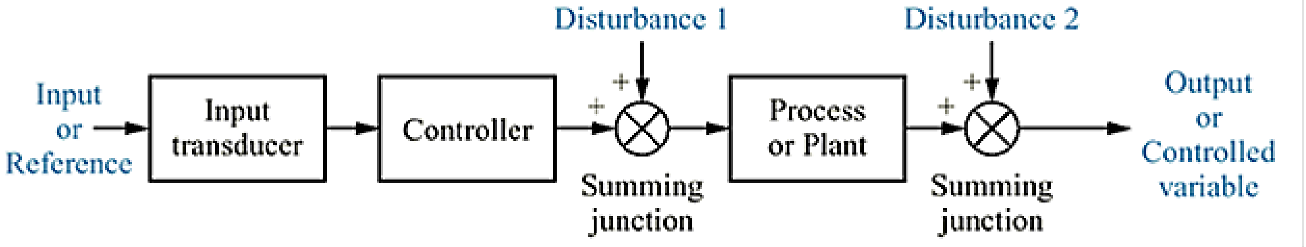


- **Control input** = external variable (signal/action) applied to the plant
- **Controller** = computes the desired control input variable
- **Sensor** = measures the actual output variable

- **Comparator** (or Σ) = computes the difference between the desired and actual output variables to give the controller a measure of the system error
- Our general system also includes: Disturbance & Sensor noise
- Typically, the sensor converts the measured output into an electric signal for use by the controller. An input filter is then required.
- **Input filter =** converts the desired output variable to electric form for later manipulation by the controller

System configurations - *open and closed loop systems*

- ***Open-loop control***: An open-loop control is applied to achieve desired system response using a controller or an actuator without feedback.



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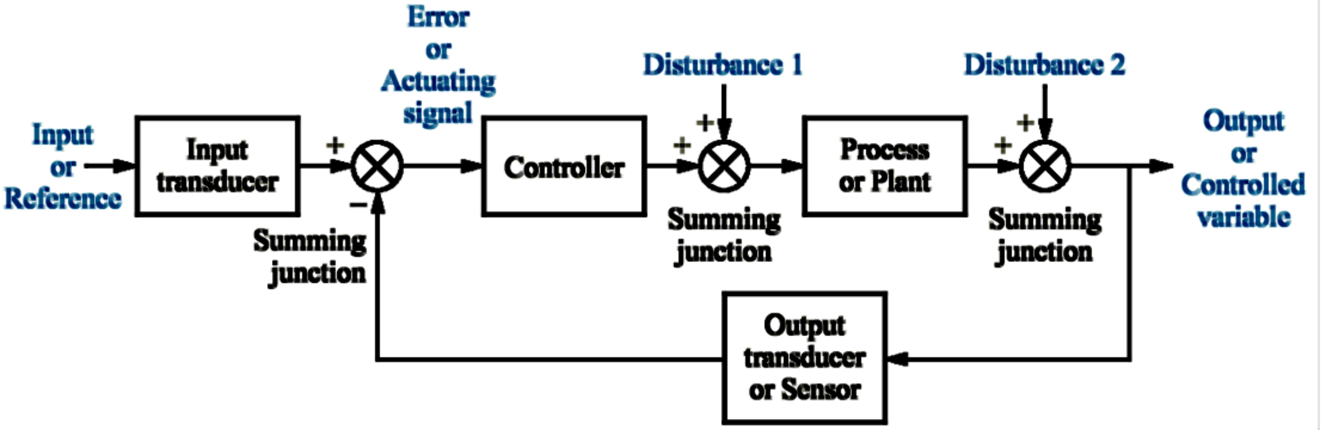
Features of open loop control:

Two outstanding features of open-loop control systems are:
1. Their ability to perform accurately is determined by their calibration. To **calibrate** means to establish or reestablish the input-output relation to obtain desired system accuracy.
2. They are not usually troubled with problems of ***instability***

- ***Closed-loop/feedback control***: A closed-loop control is used to achieve desired system response using a controller with the output measurement as a feedback signal. The use of feedback enables us to improve system performance at the cost of introducing the measurement noise and stability problem.



Computer Controlled Systems

In modern systems, the controller (or compensator) is a digital computer. The advantage of using a computer is that many loops can be controlled or compensated by the same computer through time sharing. Furthermore, any adjustments of the compensator parameters required to yield a desired response can be made by changes in software rather than hardware.

Analysis and Design objectives of a control system

Let's define our analysis and design objectives

1.) **Transient Response :** We analyze the system for its existing transient response. We then adjust parameters or design components to yield a desired transient response. (this is our first analysis and design objective)

2.) **Steady-State Response :** We are concerned about the accuracy of steady-state response. We analyze system's steady-state error, and then design corrective action to reduce steady-state error. (this is our second analysis and design objective)

3.) **Stability :** Discussion of transient response and steady state error is moot if the system does not have *stability*! For a linear sytem, we can write;

Total response = Natural response + Forced response

For a control systems to be useful, the natural response must eventually approach to zero, thus leaving only the forced response. If the natural response approaches to zero, we can say the system is "stable"

Some definitions related to control systems:

Command input: The motivating input signal to the system, which is independent of the output of the system and exercises complete control over it (if the system is completely controllable).

Reference selector (reference input element). The unit that establishes the value of the reference input. The reference selector is calibrated in terms of the desired value of the system output.

Reference input. The reference signal produced by the reference selector, i.e., the command expressed in a form directly usable by the system. It is the actual signal input to the control system.

Disturbance input. An external disturbance input signal to the system that has an unwanted effect on the system output.

Forward element (system dynamics): The unit that reacts to an actuating signal to produce a desired output. This unit does the work of controlling the output and thus may be a power amplifier. *Feedback element*: The unit that provides the means for feeding back the output quantity, or a function of the output, in order to compare it with the reference input.

Output (controlled variable). The quantity that must be maintained at a prescribed value, i.e., following the command input without respond-ing the disturbance inputs.

Actuating signal. = Reference input – feedback signal. It is the input to the control unit that causes the output to have the desired value.

The fundamental difference between the open-and closed-loop systems is the feedback action, which may be continuous or discontinuous. In one form of discontinuous control the input and output quantities are periodically sampled and discontinuous. Continuous control implies that the output is continuously fed back and compared with the reference input compared; i.e., the control action is discontinuous in time. This is commonly called a digital, discrete-data or sampled-data feedback control system.

Servomechanism (often abbreviated as servo). The term is often used to refer to a mechanical system in which the steady-state error is zero for a constant input signal. Sometimes, by generalization, it is used to refer to any feedback control system.

Regulator. This term is used to refer to systems in which there is a constant steady-state output for a constant signal. The name is derived from the early speed and voltage controls, called speed and voltage regulators.