Course: Automatic Control System Technology

Lecture 1: Describe a control system

Lecturer: UWASEKURU GISA Jean De Dieu

The purpose of the course

This course of Automatic Control System Technology is taught to students in Third Year of Electrical Technology. With the main aim of equipping them with skills, knowledge and attitudes required to apply automatic control system technologies.

At the end of this course, students will be able to describe a control system, determine control system models and analyze the control system's performance.

The course's syllabus

This course covers the following lectures :

1. Describe a control system
2. Describe Laplace transform fundamentals
3. Determine Inverse Laplace transform
4. Demonstrate the application of Laplace transform to solve linear Differential Equations
5. Model electrical systems
6. Model mechanical systems
7. Determine the Transfer function model of a LTI control system
8. Develop a control system block diagram model
9. Develop a control system signal flow graph model
10. Conduct the first order system time response analysis
11. Conduct the analysis of second order system time response
12. Perform the system stability analysis
13. Develop a state space model of a system

Lecture 1:Describe a control system

Session objectives:

By the end of this lecture, you will be able to :

- ❖Define a control system
- ❖Describe basic components of a control system
- ❖Provide examples of control system applications
- ❖Classify control systems
- ❖Describe and give examples of open loop control systems
- ❖Describe and give examples of closed loop control systems
- ❖Differentiate open-loop and closed loop control systems
- ❖Describe important properties of systems

Define a control system

- A **system** is an interconnection of elements and devices for a **desired purpose**.
- A **control system** is an interconnection of components forming a system configuration so as to provide a **desired system response**.

  Richard C.Dorf & Robert H.Bishop(2022), Modern Control Systems, 14th Edition, Pearson Education, page 30 and 31.

Describe basic components of a control system

- The basic ingredients of a control system can be described by: objectives of control, control-system components and results.
- The basic relationship among these three ingredients is illustrated in Figure 1.

Figure 1: Basic components of a control system

Farid Golnaraghi & Benjamin C. Kuo (2019), Automatic Control Systems,10th Edition, McGraw-Hill Education, page 37.

Describe basic components of a control system

- In control engineering, objectives are **inputs** and results are **outputs**.
- The **input** is the stimulus, excitation or command applied to a control system. Inputs can be physical variables or abstracts ones such as reference, set point or desired values for the output.
- The **output** is the actual response resulting from a control system. The output may or may not be equal to the specified response implied by the input.

Describe basic components of a control system

The objective of the control system is to control the outputs in some prescribed manner by the inputs through the elements of the control system.

Describe basic components of a control system

- In addition to input and output, the very simplest control system should possess the following elements: **Controller and process** also called **plant** or **controlled system**.
- A complete control system possesses a **comparator, controller, actuator, controlled process and feedback.**

Provide examples control system applications

Control systems are having a pivotal role in the development and advancement of modern civilization and technology.

❖ Control systems are found in our daily lifestyle; for instance,

- ✓ a bathroom toilet tank,
- ✓ a home-heating system,
- ✓ a refrigerator,
- ✓ an air-conditioner,
- ✓ an automobile, etc., are all control systems

Gopal M (2007),Control Systems: Principles and Design, 3rd Edition, Tata McGraw-Hill, page 1.

Provide examples control system applications

- Control systems are indispensable in modern industrial processes. They are found in all sectors of the industry, such as:
  - ✓ quality control of manufactured products,
  - ✓ automatic assembly line,
  - ✓ space technology and weapon systems,
  - ✓ transportation systems,
  - ✓ power systems, robotics, and so on.

Gopal M (2007),Control Systems: Principles and Design, 3rd Edition, Tata McGraw-Hill, page 1.

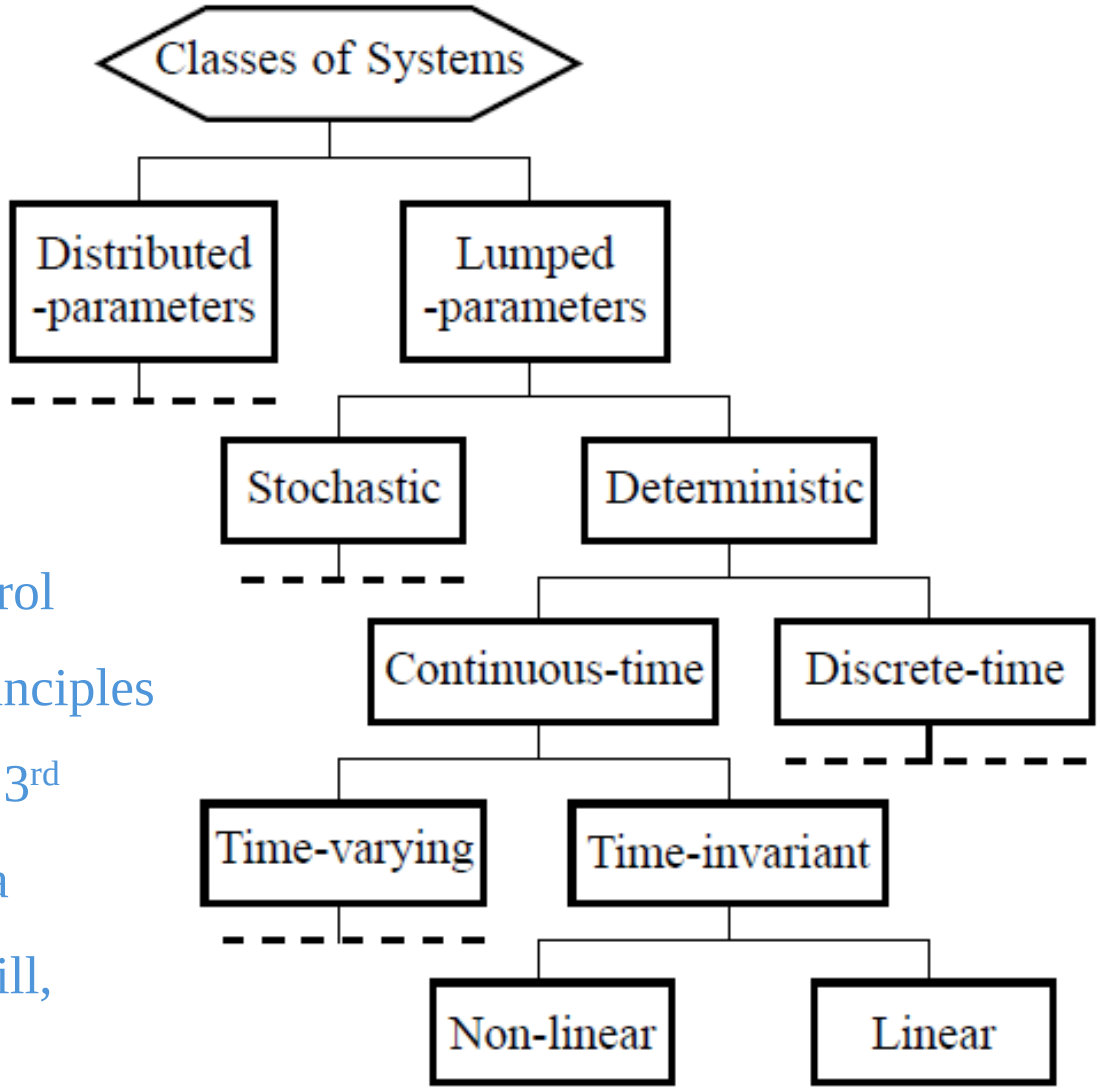
Classify control systems

Control systems may be classified in a number of ways, depending upon the purpose of the classification.

1. Control systems can be classified according to the equations used to describe them:

- ✓ The family tree shown in Figure 2 (next slide) illustrates the major system classifications.
- ✓ The dashed lines in the figure indicate the existence of subdivisions similar to the others shown at the same level.

Classify control systems



Gopal M (2007),Control Systems: Principles and Design, 3rd Edition, Tata McGraw -Hill, page 26.

Figure 2. Major classes of system equation

Classify control systems

❖ **Lumped-parameter and Distributed-parameter control systems:**

✓ A **lumped-parameter control system:** It is a control system that can be represented by **ordinary differential equations**. RC and RLC circuits are examples of lumped parameter control systems.

✓ A **distributed-parameter control system:** It is a control system that can be described by **partial differential equations**.

Example: a transmission line: Its characteristics are always described by partial differentials equations.

Classify control systems

❖ **Deterministic and Stochastic control systems:**

- ✓ A **deterministic control system:** the output of a deterministic control system is predictable and repetitive for certain input signal.
- ✓ A **stochastic control system:** the output of a stochastic or random control system is unpredictable and non-repetitive for certain input signal.

Classify control systems

❖ **Continuous-Time and Discrete-Time control systems:**

- ✓ **A continuous-time control system** is a control system in which inputs, outputs, and internal states signals are defined for every instant of time. **Example:** Analog filters
- ✓ **A discrete-time control system** is a control system which processes signals at specific time intervals (sampling instants). **Example:** Digital controllers in modern embedded systems

Classify control systems

❖ **Time-variant and Time-invariant control systems:**

- ✓ **A time-variant control system:** It is a control system where one or more of its parameters vary with time. **Example:** A guided-missile control system in which the mass of the missile decreases as the fuel on board is being consumed during flight.
- ✓ **A time-invariant control system:** It is a control system where none of its parameters vary with time.

Example: a control system made of inductors, capacitors and resistors only.

Classify control systems

❖ **Linear and Non-linear control system:**

- ✓ A **Linear control system:** It is a control system which satisfies to properties homogeneity and of additivity. It satisfies to the property of superposition.
- ✓ **Non-linear control system:** It is a control system that does not satisfy properties of homogeneity and Additivity,

Classify control systems

❖ **Natural and Man-made control systems:**

- ✓ **Natural control system:** It is a control system that is created by nature. **Examples:** solar system, digestive system of any animal, etc.
- ✓ **Man-made control system:** It is a control system that is created by humans. **Examples**: automobile, power plants etc.

Classify control systems

❖ **Automatic and Combinational control systems:**

- ✓ **Automatic control system:** It is a control system that is made by using basic theories from mathematics and engineering. This system mainly has sensors, actuators and controllers.
- ✓ **Combinational control system:** It is a control system that is a combination of natural and man-made control systems. **Example:** driving a car

Classify control systems

2. Control systems can also be classified according to the number of their inputs and outputs

- ✓ **Single-Input-Single-Output (SISO) control system** : It is a control system that has only one input and one output.
- ✓ **Multi-Input-Multi-Output (MIMO) control system**: It is a control system that has more than one input and more than one output.

Classify control systems

3. Control systems can further be classified according their control action:

- ✓ An **Open-loop control system** follows a predefined control action based on the input, regardless of the actual output.It operates without feedback.
- ✓ A **closed-loop control system:** the control action depends on both input and output of the system.

  It uses **feedback** to compare the actual output with the desired output and adjusts the control action accordingly.

Describe and give examples open-loop control systems

- The Figure 3 illustrates elements of an **open-loop control system.** An input or command is applied to the **controller** whose output acts as the actuating signal (manipulated variable) to then controls the **process.**

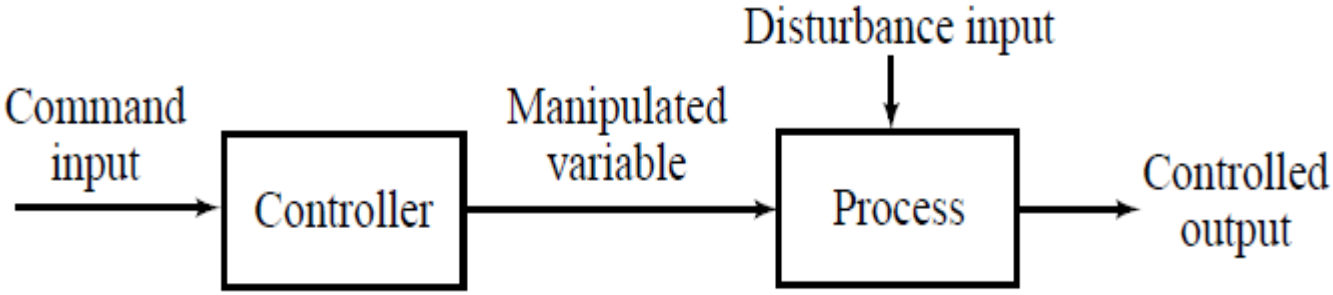


Figure 3. Elements of open loop control system

Gopal M (2007),Control Systems: Principles and Design, 3rd Edition, Tata McGraw-Hill,page 2.

Describe and give examples open-loop control systems

❖ **Examples of open-loop control systems**

- ✓ **Washing machine:** The operator manually sets the operating time of the machine. The machine stops operating after the set time, even if the desired cleanliness of clothes is not obtained. It does not measure how clean the clothes become.
- ✓ **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.

Describe and give examples open-loop control systems

❖ **Examples of open-loop control systems**

- ✓ **Traffic signal:** The system will not measure the density of the traffic before giving the signals.
- ✓ **Light Switch:** Lamps glow whenever the light switch is on irrespective of whether light is required or not.
- ✓ **Timer Based Clothes Drier:** This machine dries wet clothes for pre-adjusted time, it does this no matter how much the clothes are dried.

Describe and give examples closed-loop control systems

❖ The Figure 4 illustrates elements of a **closed-loop control system**.

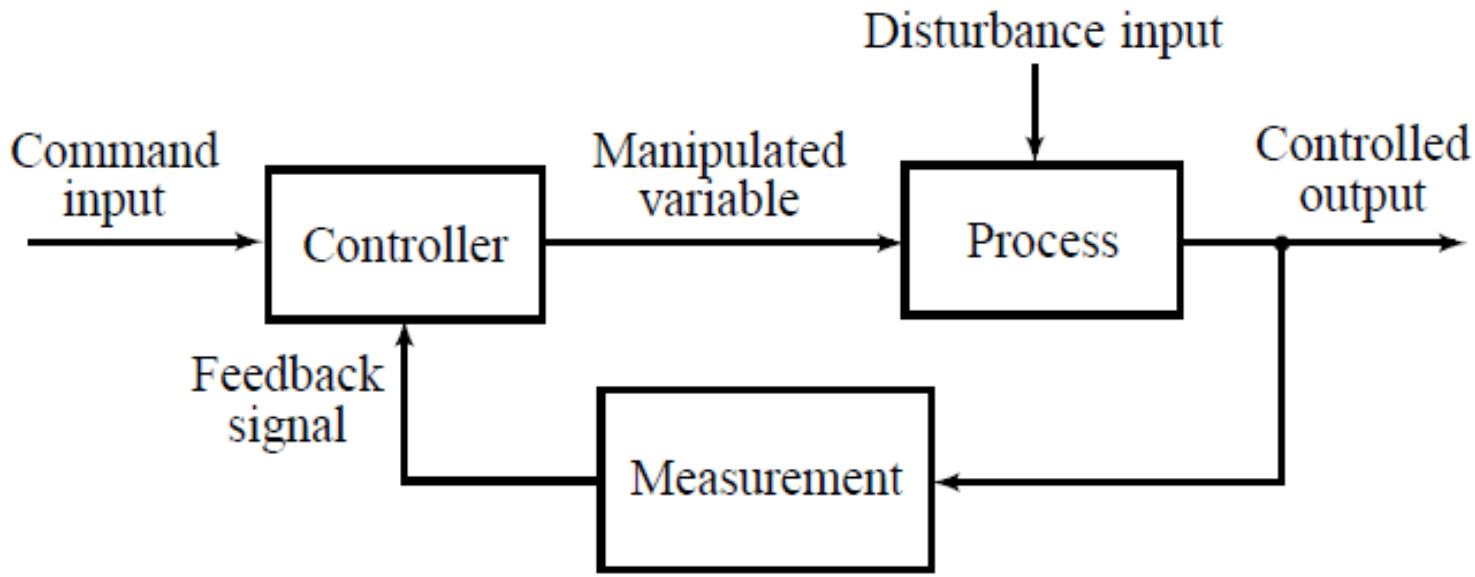


Figure 4. Elements of closed loop control system

Gopal M (2007),Control Systems: Principles and Design, 3rd Edition, Tata McGraw-Hill, page 2.

Describe and give examples closed-loop control systems

The **closed-loop control system**, as presented in **Figure 4,** utilizes measurement of the controlled output(actual response) in order to compare **the actual response** (output) with the **desired response(input**). The controller uses this difference (error signal) to produce an manipulated variable or signal that will then be used to control the process.

Describe and give examples closed-loop control systems

❖ **Examples of closed-loop control systems**

- ✓ **Automatic Electric Iron:** Heating elements are controlled by the output temperature of the iron
- ✓ **An Air Conditioner:** An air conditioner functions depending upon the temperature of the room.
- ✓ **Water Level Controller:** Input water is controlled by the water level of the reservoir.

Describe and give examples closed-loop control systems

❖ **Examples of closed-loop control systems**

- ✓ **Missile Launched and Auto Tracked by Radar (**missile launcher)**:** The direction of the missile is controlled by comparing the target and position of the missile.
- ✓ **Cooling System in Car:** It operates depending upon the temperature which it controls.

Differentiate open-loop and closed-loop control systems

Table 1. Comparison of open loop and closed loop control systems

No	Open loop control system	Closed loop control system
1	The feedback element is absent	The feedback element is always present.
2	An error detector is not present.	An error detector is always present.
3	It is a stable one.	It may become unstable.
4	Easy to construct.	Complicated construction.
5	It is economical.	It is costly.
6	Having a small bandwidth.	Having a large bandwidth.
7	It is inaccurate.	It is accurate.
8	Less maintenance.	More maintenance.
9	It is unreliable.	It is reliable.

Describe important properties of control systems

- The important properties of control systems are:
  - ✓ Time invariance
  - ✓ Linearity
  - ✓ Causality
- For **time invariance** and **linearity properties**, refer respectively to explanations on slide 17 and 18.

Describe important properties of control systems

❖ **Causality:**

- ✓ **Causal control systems** are systems for which output are independent of future inputs. In other words when an input is applied at t = 0, the response of the system does not start sooner than t = 0. The present value of the output signal depends only on the present and/or past value of the input.
- ✓ The impulse response of causal control systems is zero for negative instants of time.
- ✓ Causal control systems are **practically** or **physically realizable**

Describe important properties of control systems

❖ **Causality:**

✓ **Non-causal control system:** the output of non-causal system depends on future value of input. The present value of the output depends on past, present and future inputs. The non-causal system is not physically realizable.

✓ **Anti-causal system:** Its present output depends only the future values of the input. It has no dependency either on present or on the past values. The anti-causal system is not practically realizable.

Describe important properties of control systems

❖ **Linear Time Invariant (LTI) control system:**

A system exhibiting both linearity and time invariant properties is considered as linear time invariant control system.

❖ The dynamic behavior of **LTI** control systems are described by **linear, constant-coefficients, differential equations.**

$$\boldsymbol{m}\frac{d^2y(t)}{dt^2} + \boldsymbol{b}\frac{dy(t)}{dt} + y(t) = x(t)$$

where coefficients **m** and **b** are constants, and **x(t)** and **y(t)** are respectively input and output of LTI control system

Describe important properties of control systems

As this module is an introductory course to control systems, we will focus on design and analysis of causal, SISO, deterministic, Linear Time-Invariant (LTI) control systems in time and S domains.

References

1. Richard C.Dorf & Robert H.Bishop (2022), Modern Control Systems, 14th Edition, Pearson Education.
1. Farid Golnaraghi & Benjamin C. Kuo (2019), Automatic Control Systems,10th Edition, McGraw-Hill Education.
2. Gopal M (2007),Control Systems: Principles and Design, 3rd Edition, Tata McGraw-Hill.

THANK YOU