Digital Control Systems (CCE 341)
By
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Lecture 1

Contents of the Lecture

I.   **Course Plan**

II.   **Introduction to digital control systems**

I. Course Plan

Textbooks

DIGITAL CONTROL ENGINEERING
Analysis and Design
Second Edition
M. SAMI FADALI   ANTONIO VISIOLI

Digital Control of Dynamic Systems
THIRD EDITION
Gene F. Franklin
J. David Powell
Michael Workman
Ellis-Kagle Press eEdition-2

Pearson International Edition
Modern Control Systems
ELEVENTH EDITION
Richard C. Dorf   Robert H. Bishop

Course Academic Calendar

Week Num	Date	Content
Week1	25/9/2025	Introduction
Week2	02/10/2025	Sampled Data Systems and the Z-Transform
Week3	09/10/2025	Properties of z-transform, Inverse z-Transforms
Week4	16/10/2025	Difference equations
Week5	23/10/2025	Open Loop Discreate Time System Analysis
Week6	30/10/2025	Closed Loop Discreate Time System Analysis
Week7	06/11/2025	Midterm
Week8	13/11/2025	System Time Response
Week9	20/11/2025	Mapping from S-plane to Z-plane
Week10	27/11/2025	Damping Ratio and undamped natural frequency in the Z-plane
Week11	04/12/2025	Stability of Sampled Systems
Week12	11/12/2025	Root Locus for Sampled Data Systems
Week13	18/12/2025	Nyquist Criterion and Bode Diagrams
Week14	25/12/2025	Digital Controller Design

Grades distribution

Total: 100

- Final Written Exam: 50
- Midterm Written Exam: 15
- Section: 10
- Oral/Lab: 20
- Quizzes: 5

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# II. Introduction to digital control systems

Introduction

- **Control engineering is concerned with controlling a dynamic system or plant.**

- A control engineer manipulates the input variables and shapes the response of a plant in an attempt to influence the output variables such that a required response can be obtained.

- **A dynamic system can be a mechanical system, an electrical system, a fluid system, a thermal system, or a combination of two or more types of system.**

- The behavior of a dynamic system is described by differential equations.

$$\dot{\mathbf{x}}(t) = \mathbf{A}(t)\mathbf{x}(t) + \mathbf{B}(t)\mathbf{u}(t)$$
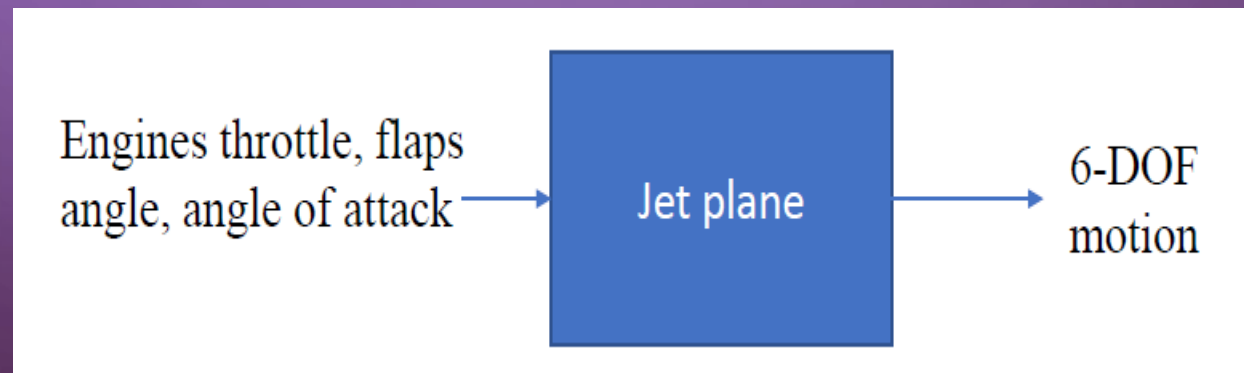
- **Given the model (differential equation), the inputs and the initial conditions, we can easily calculate the system output.**

SISO Vs MIMO

- **A plant can have single input and single output (SISO), example DC motor**
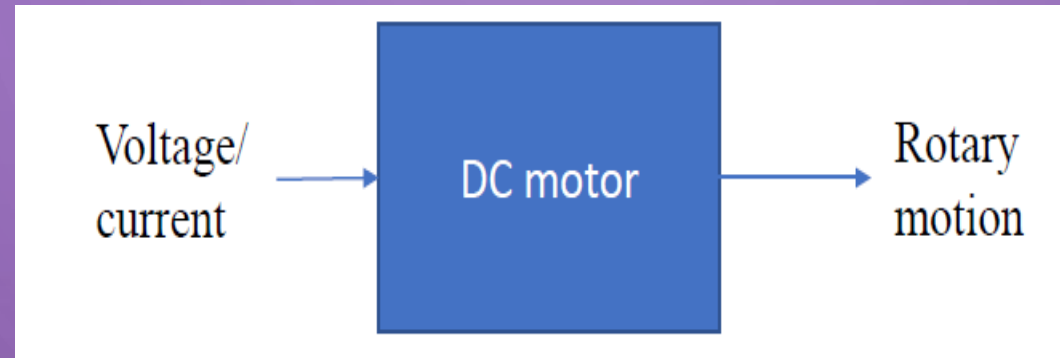
- **Multi-inputs and multi-outputs (MIMO), example : Jet plane**

- **Most real-world systems are MIMO**

Continuous-time vs Discrete-time

- Generally, a plant is a continuous-time system where the inputs and outputs are also continuous in time.

- For example, an electromagnetic motor is a continuous-time plant whose input (current or voltage) and output (rotation) are also continuous signals.

- In discrete-time systems, the inputs and outputs are sampled at certain times (steps).

- Discrete signal is a sequence of numbers corresponds for each sample taken while a continuous signal has value at any time.
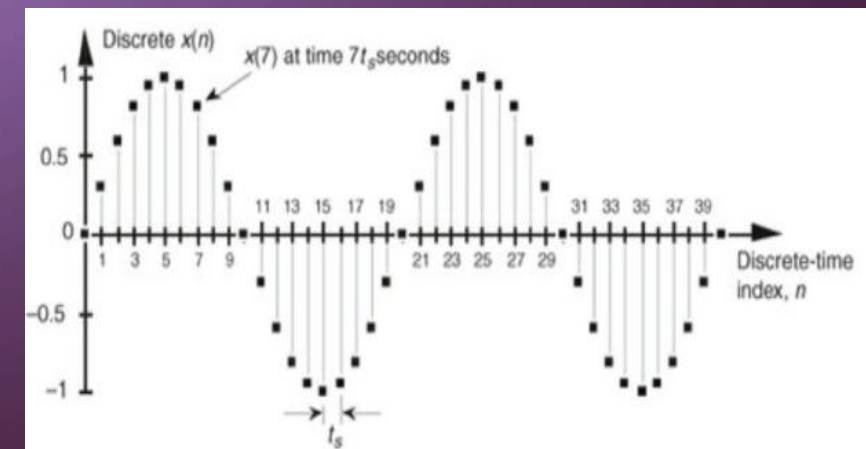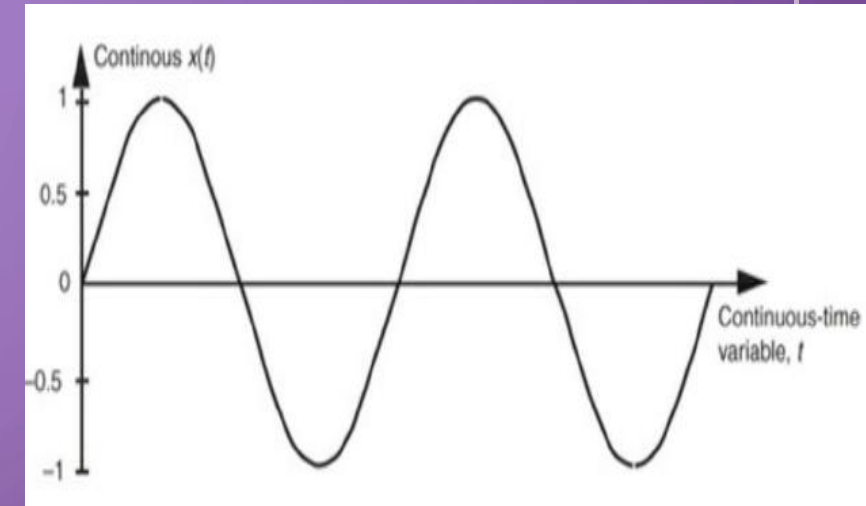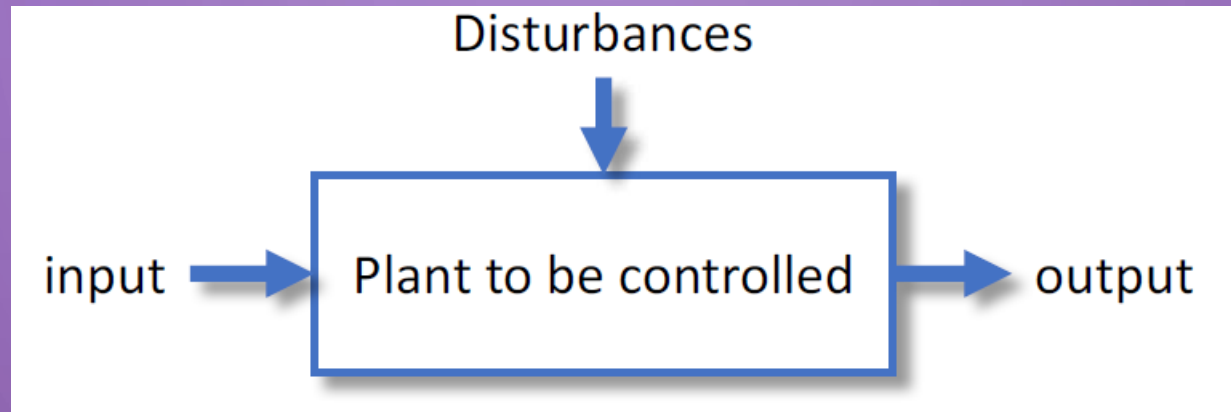
Control systems

Control system

mechanical, optical, or electronic device, or set of devices, that manages, commands, directs or regulates the behavior of other devices or systems to maintain a desired output.

Two approaches for control:
1. Open loop control
2. Closed–loop (feedback) control

Open-loop control

Disturbances

input → Plant to be controlled → output

❑ adjust input to keep the output as close as possible to some desired value.

❑ However, because of the unknowns in the system model and the effects of external disturbances open-loop control is not accurate.

Closed–loop (Feedback) control
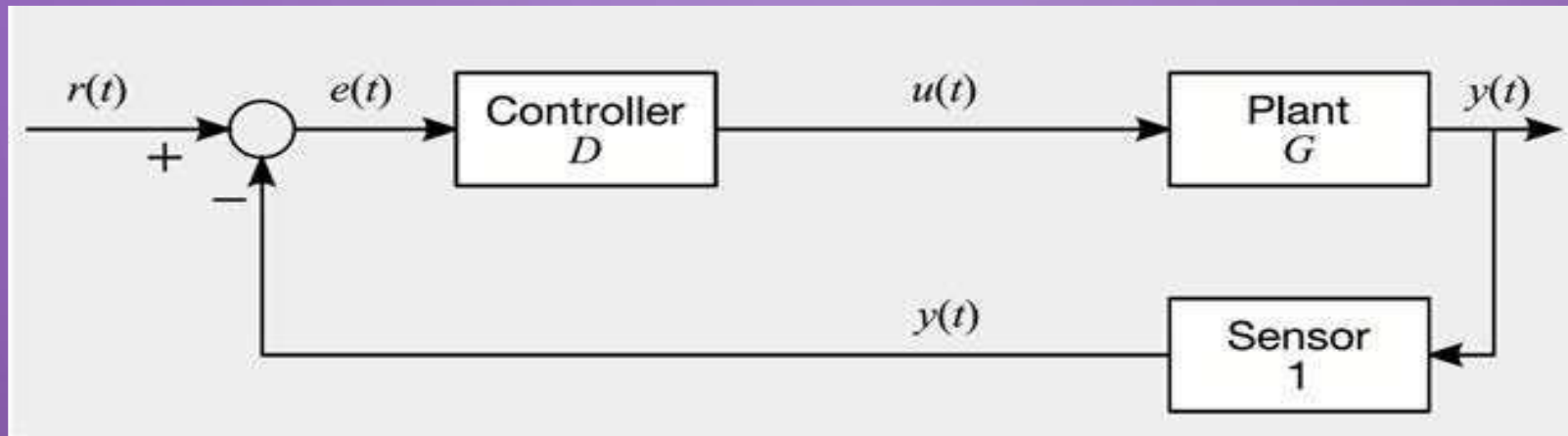
❑ measurements of plant output is used to modify its input.

❑ controller receives the error signal, then generates a suitable value of the plant input, hence closing the loop.

A controller (or a compensator) is usually employed to read the error signal and drive the plant in such a way that the error tends to zero.

Advantages of closed-loop control

1. Remove (isolate or reject) the unwanted disturbance signal(s).

2. Closed-loop systems have the advantage of greater accuracy than open-loop systems.

3. They are also less sensitive to disturbances and changes in the environment.

4. The time response and the steady-state error can be controlled in a closed-loop system.

Transfer Function
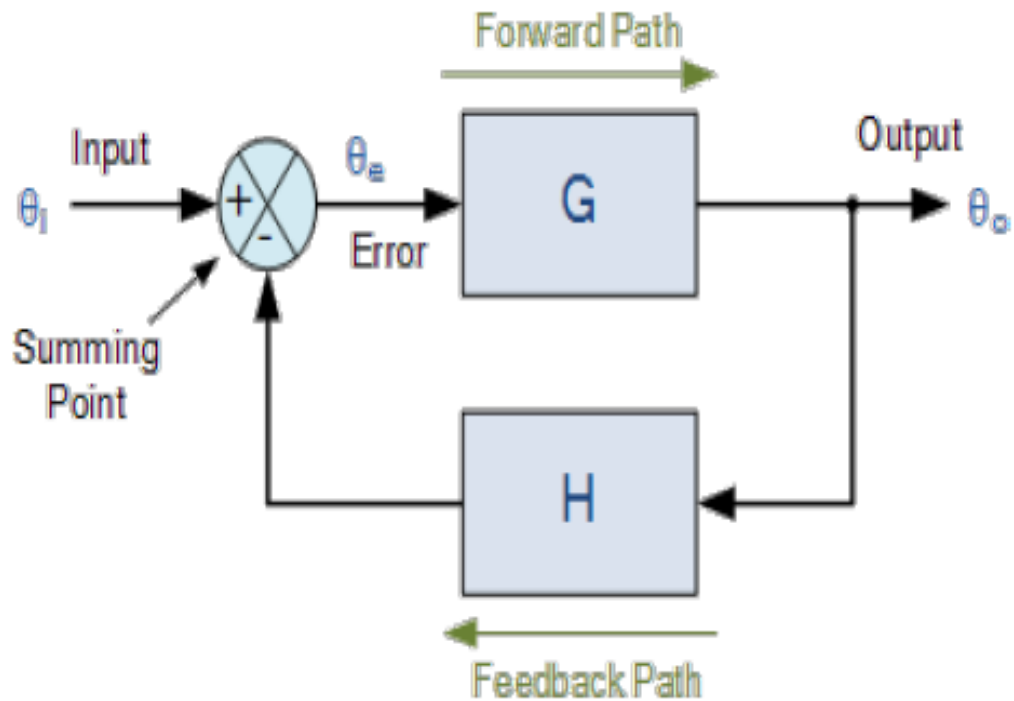
$$\frac{\text{Output}}{\text{Input}} = \frac{\theta_o}{\theta_i} = \frac{G}{1 + GH}$$

Sensors

- Sensors are devices which measure the plant output.

For example

✓ A thermistor is a sensor used to measure the temperature.

✓ A tachogenerator is a sensor used to measure the rotational speed of a motor.

✓ An accelerometer is used to measure the acceleration of a moving body.

Roll =
Rotation on X axis
(tilted right or left)

Pitch =
Rotation on Y axis
(tilted up or down)

Yaw =
Rotation on Z axis
(accelerometer cannot measure yaw)
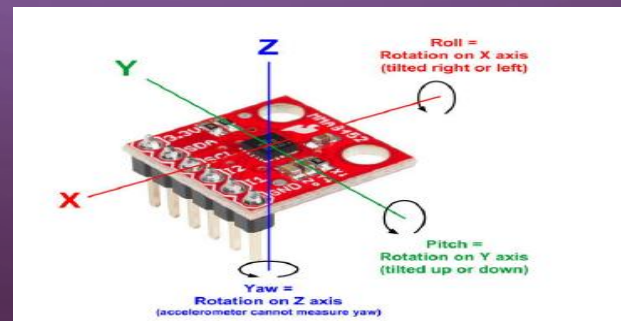
Sensors

- **Most sensors are analog devices**, and their outputs are analog signals (e.g.voltage or current).

- These sensors can be **used directly in continuous-time systems.**

- Analog sensors **cannot be connected directly to a digital computer.**

- **An analog-to-digital (A/D) converter** is needed to convert the analog output into digital form so that the output can be connected to a digital computer.

- Some sensors (e.g. temperature sensors) provide digital outputs and can be directly connected to a digital computer.

Digital control system
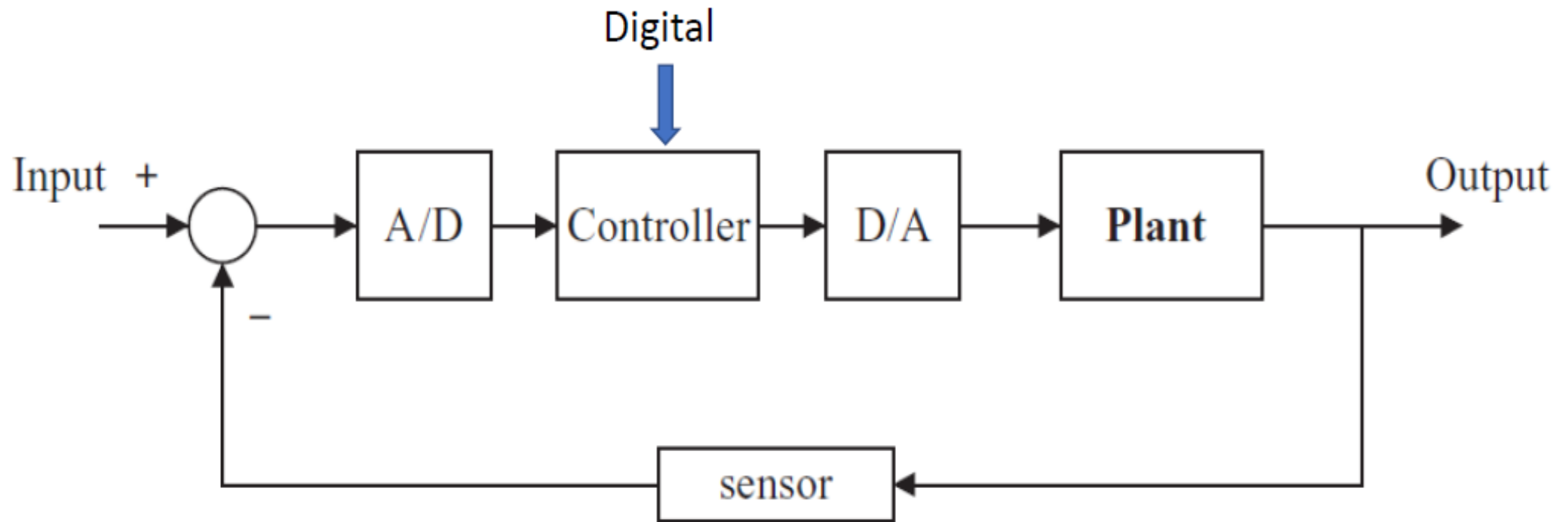
D/A and A/D
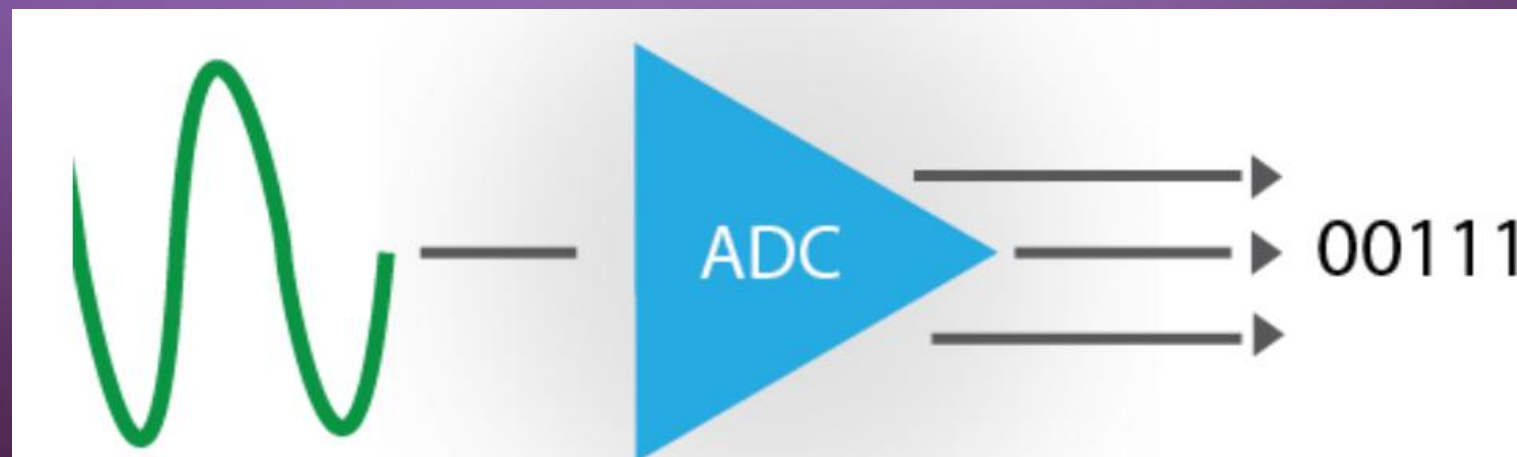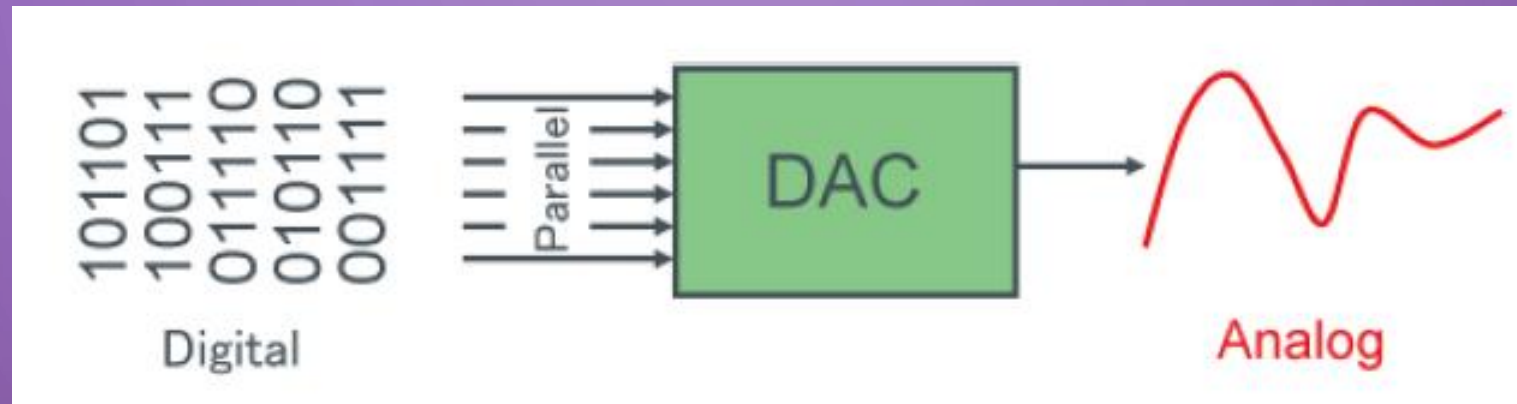
Analog to Digital Converter (ADC)

❑ **samples** **analog signal (typically a voltage) and then converts these samples into an integer number (quantization) suitable for processing by digital computer.**

❑ **usually approximated as a sampler (a switch).**
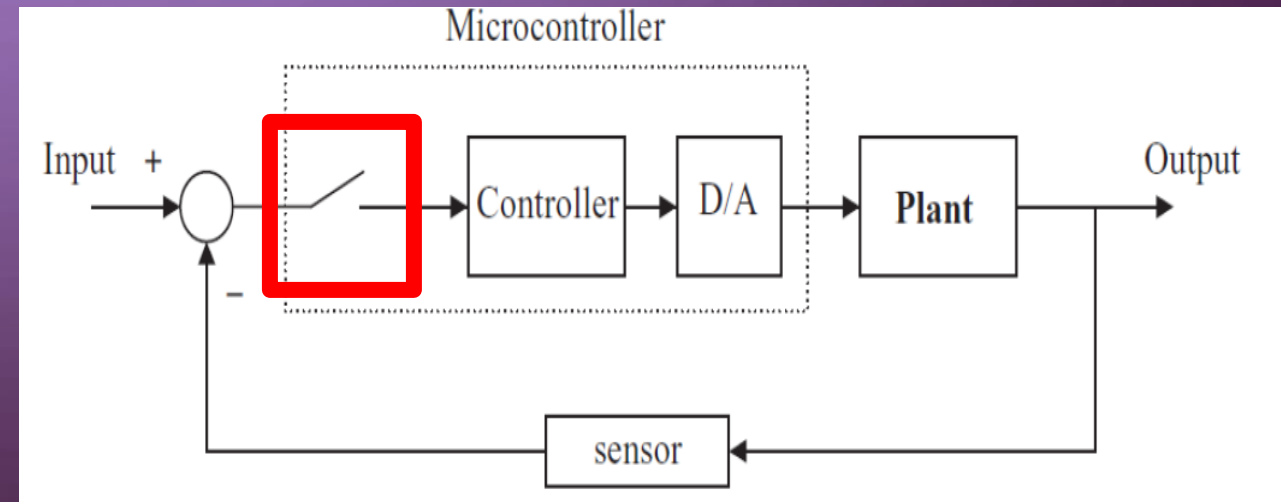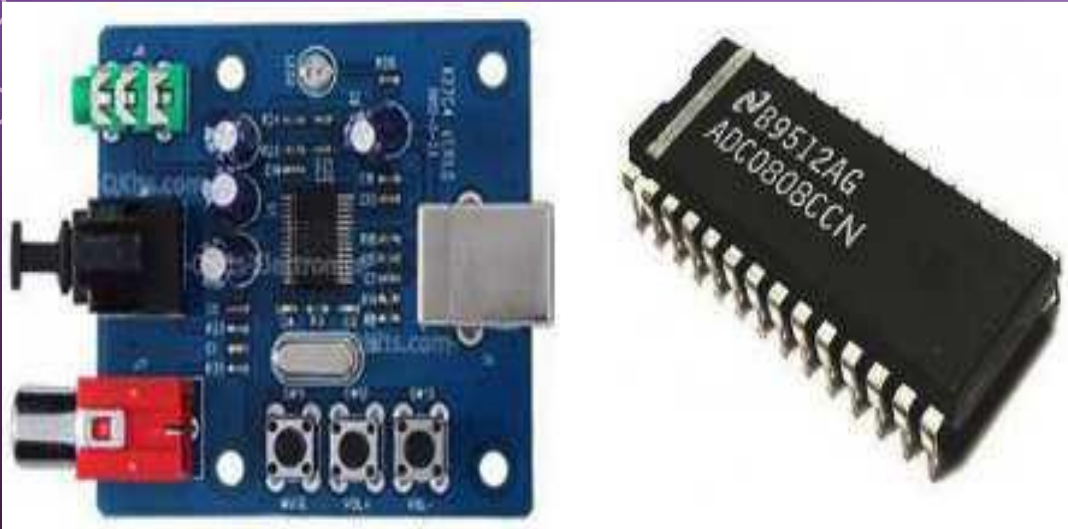
Digital to Analog Converter (DAC)

❑ converts the digital (integer) number calculated by the computer into a voltage so as to drive the output of the plant as desired.

❑ functions as a zero-order hold (ZOH), holding its output at a constant value until it receives the next discrete input.

❑ **Many microcontrollers incorporate built-in ADC and DAC circuits. These microcontrollers can be connected directly to analog signals.**
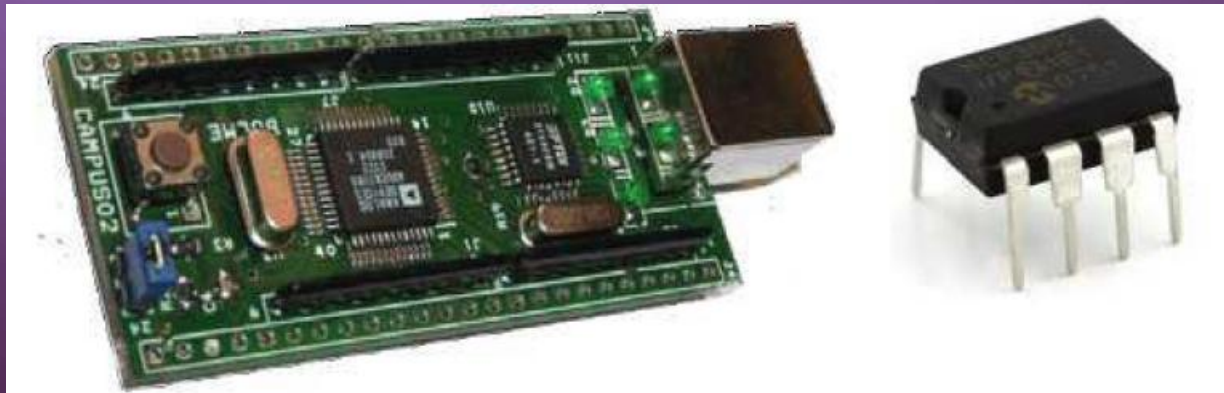
Digital control system

- With the advent of the digital computer and low-cost microcontroller processing elements, control engineers began to use these programmable devices in control systems.

- A digital computer can keep track of the various signals in a system and can make intelligent decisions about the implementation of a control strategy.

- Most control engineering applications nowadays are computer based, where a digital computer or a microcontroller is used as the controller.

- The purpose of developing the digital control theory is to be able to understand, design and build control systems where a computer is used as the controller in the system.

- In addition to the normal control task, a computer can perform supervisory functions, such as reading data from a keyboard, displaying data on a screen or liquid crystal display, turning a light or a buzzer on or off and so on.

Why Digital control

1. **Flexibility & Reprogrammability**
    Control algorithms can be easily modified or updated through software without changing hardware.

2. **High Accuracy & Precision**
    Digital computation avoids drift and nonlinearity common in analog circuits.

3. **Reliability & Stability**
    Less sensitive to noise, temperature variations, and component aging compared to analog controllers.

4. **Complex Control Strategies**
    Digital systems can implement advanced algorithms (adaptive control, optimal control, model predictive control) that are difficult or impossible with analog hardware.

5. **Data Storage & Processing**
    Digital controllers can store data, enable logging, and use historical information for diagnostics and optimization.

Why Digital control

6. **Integration with Computers & Networks**
   Easy to connect with digital communication systems, microcontrollers, and industrial networks for monitoring and automation.

7. **Cost Efficiency**
   With advances in microprocessors and DSPs, digital controllers are cheaper, smaller, and more energy efficient than complex analog hardware.

8. **Consistency & Repeatability**
   Software-based implementations ensure identical performance across multiple units.
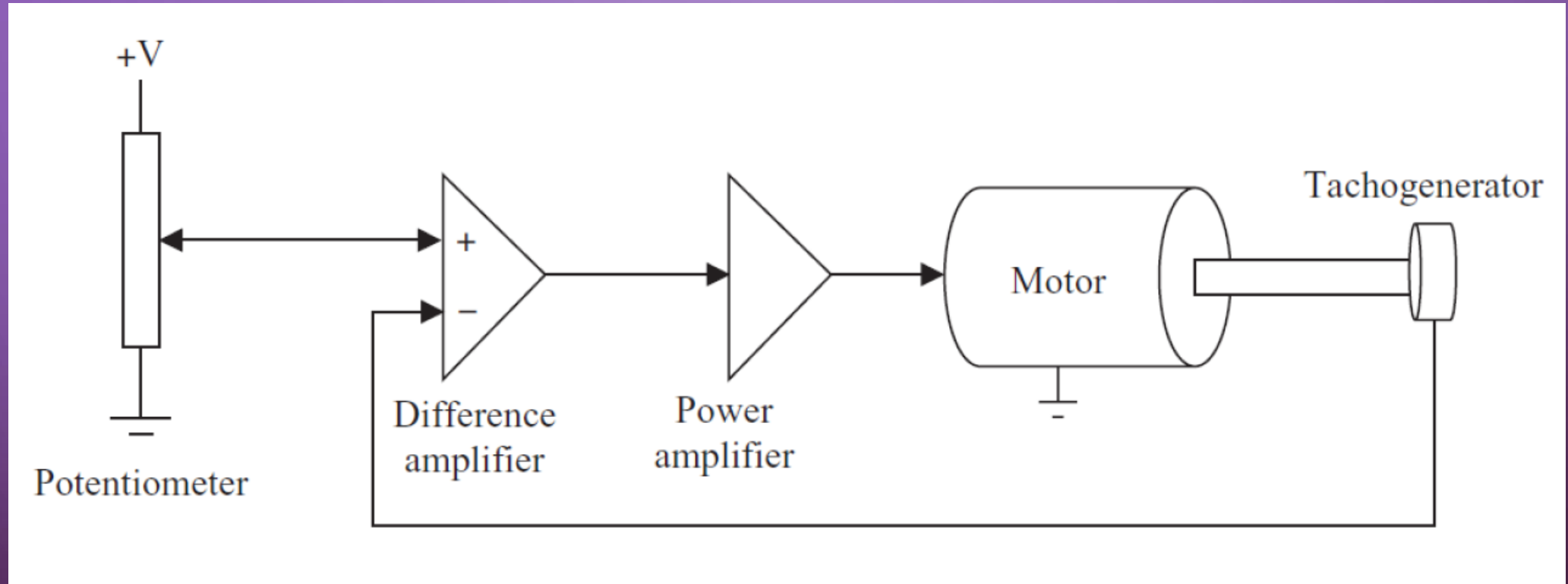
9. **Scalability**
   One digital platform can handle multiple control tasks or be scaled to more complex systems without major hardware changes.

10. **Easier Testing & Simulation**
    Digital controllers can be simulated, tested, and debugged extensively before real-world implementation, reducing errors and risks.

Is it digital or analog control system?

Analog control system

- The following figure shows a typical closed-loop analog speed control system where the desired speed of the motor is set using a potentiometer.

- A tachogenerator produces a voltage proportional to the speed of the motor, and this signal is used in a feedback loop and is subtracted from the desired value in order to generate the error signal.

- Based on this error signal the power amplifier drives the motor to obtain the desired speed. The motor will rotate at the desired speed as long as the error signal is zero.
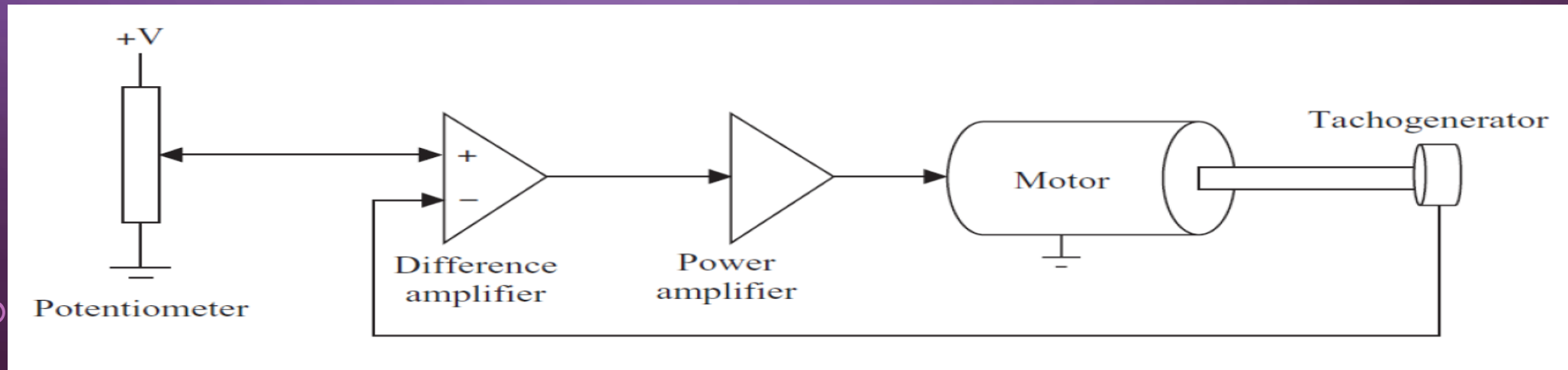
Can we convert analog to digital control system?
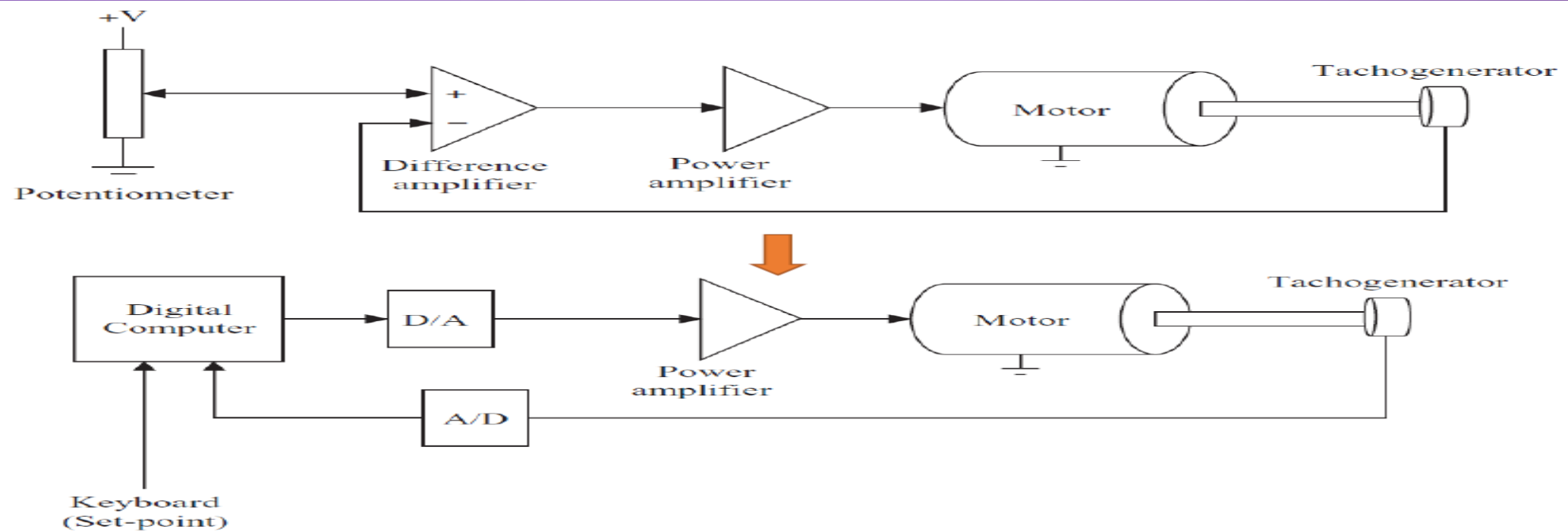
- The equivalent digital speed control system is shown in the following figure. Here, the desired speed is entered from the keyboard into the digital controller. The controller also receives the converted output signal of the tachogenerator. The error signal is calculated by the controller by subtracting the tachogenerator reading from the desired speed. A D/A converter is then used to convert the signal into analog form and feed the power amplifier. The power amplifier then drives the motor.

System modelling

- **Modelling (British)/ Modeling (US)** is the process of finding a mathematical model (relationship) between the inputs and the outputs of a given system such that for a given input, this relationship will give us the output of the system.
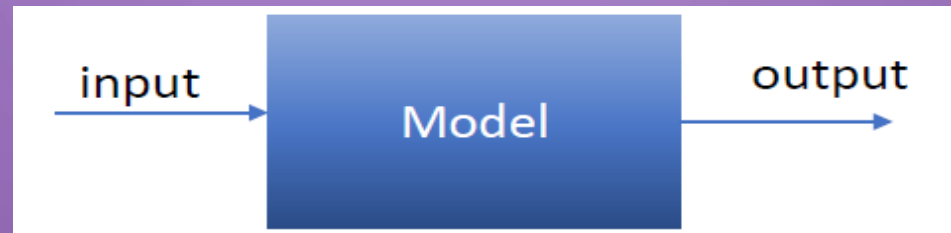
- The task of mathematical modelling is an important step in the analysis and design of control systems.

- The mathematical models of systems are obtained by applying the fundamental physical laws governing the nature of the components making these systems.

- For example, **Newton's laws** are used in the mathematical modelling of mechanical systems.

- Similarly, **Kirchhoff's laws** are used in the modelling and analysis of electrical systems.

CENTRALIZED AND DISTRIBUTED CONTROL SYSTEMS

❑ In a **centralized control system**, the controller algorithm is implemented in a **single** central computer. Hence, all sensors, actuators, input units and output units must be connected directly to this central computer.

❑ The advantages of centralized control are as follows:

1. It is easy to manage the computer.
2. Only one computer is used.
3. Less number of people are required.

CENTRALIZED AND DISTRIBUTED CONTROL SYSTEMS

❑ **A distributed control system (DCS)** consists of a **number of computers** installed at different locations, each performing an independent control action.

❑ Distributed control has emerged as a result of the sharp decrease in price, and the consequent widespread use, of computers. Also, the development of computer networks has made it possible to interconnect computers in a local area network (LAN), as well as in a wide area network (WAN).

❑ The main advantages of DCSs are as follows:

1.   A higher performance is obtained from a distributed system than from a centralized control system.

2.   A distributed system is more reliable than a centralized system. In the case of a centralized system, if the computer fails, the whole plant becomes unusable. In a DCS, if one computer fails, only a small part of the plant will be affected and the load of the failed computer can usually be distributed among the other computers.

3.   A DCS can easily be expanded by adding more computers to the network. For example, if 10 computers are used to control the temperature of 10 ovens, then if the number of ovens is increased to 15, it is easy to add five more computers tothe network.

4.   A DCS is more flexible than a centralized control system as it can be easily adjusted to plant requirements.

Hardware requirements for digital control

❑ **A general-purpose computer consists of the following basic building elements:**

1. Central processing unit (CPU)
2. Program memory
3. Data memory
4. Input–output devices

Software requirements for digital control

❑ **The software requirements in a control computer can be summarized as follows:**

1. the ability to read data from input ports;
2. the ability to send data to output ports;
3. internal data transfer and mathematical operations;
4. timer interrupt facilities for timing the controller algorithm.

❑ **All of these requirements can be met by most digital computers, and, as a result, most computers can be used as controllers in digital control systems.**

The control algorithms

- ❑ The controller algorithm in a computer is implemented as a program which runs continuously in a loop which is executed at the start of every sampling time.

- ❑ Inside the loop, the desired reference value is read, the actual plant output is also read, and the difference between the desired value and the actual value is calculated. This forms the error signal.

- ❑ The control algorithm is then implemented and the controller output for this sampling instant is calculated.

- ❑ This output is sent to a D/A converter which generates an analog equivalent of the desired control action.

- ❑ This signal is then fed to an actuator which in turn drives the plant to the desired point.

The control algorithms

❑ **The operation of the controller algorithm, assuming that the reference input and the plant output are digital signals, is summarized below as a sequence of simple steps:**

Repeat Forever

When it is time for next sampling instant

- Read the desired value, R
- Read the actual plant output, Y
- Calculate the error signal, $E = R - Y$
- Calculate the controller output, U
- Send the controller output to D/A converter
- Wait for the next sampling instant

End

The control algorithms

❑ **Similarly, if the reference input and the plant output are analog signals, the operation of the controller algorithm can be summarized as:**

Repeat Forever

When it is time for next sampling instant

- Read the desired value, R, from A/D converter
- Read the actual plant output, Y, from the A/D converter
- Calculate the error signal, $E = R - Y$
- Calculate the controller output, U
- Send the controller output to D/A converter
- Wait for the next sampling instant

End