Numerical Control

4th Class, Production Engineering
Department of Production Engineering and Metallurgy,
University of Technology, Baghdad

Lecturer: Dr. Laith Abdullah Mohammed

Requirements and Grading:
First term Exam: 10%, Second term Exam: 10%
Final Exam: 60%
Homeworks, Quizess and Class attendance: 10%
Laboratory (CNC Lab): 10%

Software:

Maple
MATLAB & Simulink

References:
Control System:

What is a control system?
To answer this, we need to understand the “objectives” of the system to be controlled. **In Industry:** the objectives of manufacturing processes are satisfy the *precision* and *cost* requirements of the products. **In Transportation:** control automobile and airplane to satisfy *accurate* and *safe* trans. Then *The means of achieving these objectives involve the use of control systems that implement certain control strategies*. Control systems found in all sectors of industry such as: [Quality Control of manufactured products, automatic assembly line, machine tool control, space technology, weapon systems, computer control, robotics,………].

Basic Components of a Control System:

- **Objectives** (Inputs, actuating signals)
- **Control System**
- **Results** (Outputs, controlled variables)
Basic Definitions:

- **Control System** is a combination of components or subsystems connected in such a way to give a desired/specified system performance.

- **Plant/System** is the physical object that needs to be controlled, examples include power system, chemical process, spacecraft, economic system etc.

- **Disturbance** is an unwanted signal that affects the output of a system adversely.

- **Feedback Control System** is a system where in the actual input to the system being controlled is the difference between the reference input and the actual output.

- **Automatic Regulating System** is a feedback system in which the reference input (or desired output) is a constant value. Example: electric power system.

- **Process Control System** is an automatic regulating system in which the output variable or variables include temperature, pressure, flow, liquid level, etc.

- **Open-loop Control System** is a system in which the output has no effect on the input to the system. Examples: washing machine, electric switch, Automatic Door Opening & Closing system.

- **Closed-loop Control System** is a feedback control system. Examples: Human being, Home Heating system, Ship Stabilization system.

**Mathematical Modeling:** Finding a mathematical model of the system to be controlled is the first step in the design of control systems. There are two types of mathematical models we study in control. They are: Transfer Functions and State-Space Equations.
Types of Control Systems:

1- Open Loop Control System:

Reference Input (r) → Controller → Actuating Signal (u) → Controlled Process → Controlled Variable (y)

Features: Less accurate, Simple, cheap. Controller can be an amplifier, mechanical linkage, or other control element. Examples: Electric Washing Machine, Spraying, Drilling, On/Off processes.

2- Closed Loop Control System (Feedback Control System)

Reference Input (r) → Controller → Difference Variable → Controlled Process → Controlled Variable (y) → Sensor → Error Detector

Reference Input (r)
Block Diagram of closed loop speed control system.
To obtain more accurate control, the controlled signal \((y)\) should be feedback and compared with the reference input \((r)\), and an actuating signal proportional to the difference of the input and the output must be sent through the system to correct the error. Reference input \((w_r)\) is desired speed, Engine speed \((w)\) should equal \((w_r)\) and any difference such as load torque \((T_L)\) is sensed by the speed transducer and the error detector. The controller will operate on the difference and provide a signal to correct error.
Application of Load Torque ($T_L$)

Typical Response of the Open Loop Speed Control System

Typical Response of the Closed Loop Speed Control System

Regulator System

The effect of feedback on a control system:

1- reduction of system error.
2- stability.
3- sensitivity.
Dynamic systems:

Studying the time behavior of the physical system under investigation. Most physical processes can be described by balance equations of the form,

\[
\text{rate of change} = \text{production rate} - \text{loss rate}
\]

\[\frac{\text{of quantity}}{\text{of quantity}} - \frac{\text{of quantity}}{\text{of quantity}}\]

**Continuous systems:** the rate of change component gives rise to a first-order differential equation.

**Discrete systems:** events occur at discrete time intervals and the balance equation is written in terms of discrete difference equations.

**Single input-single output (SISO) systems:** a single differential equation is used to describe the relationship between the input quantity, \( u(t) \), and the output quantity, \( y(t) \). For Example: a position control system has only one input (desired position) & one output (actual output position).

**Multiple input and multiple outputs (MIMO) systems:** described by a set of differential equations. For such systems, the input and output quantities are represented as vector quantities, \( u(t) \) and \( y(t) \), respectively.

**State Variable Approach:** The formal matrix methods treatment of dynamic system analysis.
Continuous Versus Discrete Modeling

First Order Continuous Time System

For continuous time systems that display exponential growth or decay, the basic growth/decay law can be stated as "The rate of change is proportional to the amount present." This can be written mathematically as

$$\frac{dx(t)}{dt} = ax(t) \quad \text{where} \quad a = \begin{cases} >0 & \text{growth constant} \\ <0 & \text{decay constant} \end{cases}$$

The solution for this system is given as,

$$x(t) = e^{at}x_0 \quad \text{where} \ x_0 = \text{initial amount present}$$

All system variables are the functions of a continuous time variable (t).

Example: the speed control of a D.C. Motor using tachogenerator feedback.
First Order Discrete Time System

For discrete time systems that display geometric growth or decay, the basic growth/decay law can be stated as "The value at interval \( k+1 \) is proportional to the value at \( k \)." Mathematically, this can be written as

\[
x_{k+1} = ax_k \quad \text{where} \quad a = \begin{cases} 
>0 & \text{growth constant} \\
<0 & \text{decay constant}
\end{cases}
\]

and \( k \) is the discrete time index. This discrete time variable is sometimes written as \( t_k = kT \), where \( T \) is the sampling period. The solution to this difference equation can be obtained by assuming a solution of the form \( x_k = c^k \), where \( c \) is some constant to be determined. In this case, it is easy to show that \( c = a \) and the solution becomes a simple geometric series,

\[
x_k = a^k
\]

In discrete time system one or more system variables are known only at certain discrete intervals of time.

Example: Microprocessor or computer based systems.
Digital & Sampled Data Control System:

In recent years, Microprocessors & microcomputers are used in the control systems to obtain necessary controlling action. Such controllers use digital signals which exists only at finite instants, in the form of short pulses (Digital controllers). Thus the digital control system is hybrid system using the combination of continuous time signals & digital signals. To obtain analog signal from digital, Digital to Analog (DAC) converters are used while to obtain digital signals from analog, Analog to Digital (ADC) converters are used. The input & output of a digital controller are both in digital form. The digital signals exist in the form of coded digital data at discrete intervals of time. Such signals are obtained from computers, microprocessors, ADC and digital sensing elements.

Applications: radar tracking systems, Industrial robots, Modern Industrial control system, aircraft control systems.

![Digital Control System](image-url)
Sampled Data System:

Many times digital signals are obtained by sampling the continuous time signals at regular intervals. The switch can be used as a sampler. When switch is closed for short duration of time, signal is available at the output and otherwise it is zero. Such signal is called sampled signal which exists in a digital form. The digital controllers accept such sampled error signals to produce controlled variable in digital form. This is converted to analog signal using DAC and hold circuits. The hold circuits convert sampled signal back to analog signal. This signal is used to control the process. The system using such sampler and hold circuits is called sampled data control system. The input & feedback signals both are continuous in nature. The accuracy of sampled signals is less than the digital signals. Hence digital control systems are more accurate than sampled data systems.