In this chapter we describe a general process for designing a control system.

A control system consisting of interconnected components is designed to achieve a desired purpose. To understand the purpose of a control system, it is useful to examine examples of control systems through the course of history. These early systems incorporated many of the same ideas of feedback that are in use today.

Modern control engineering practice includes the use of control design strategies for improving manufacturing processes, the efficiency of energy use, advanced automobile control, including rapid transit, among others.

We also discuss the notion of a design gap. The gap exists between the complex physical system under investigation and the model used in the control system synthesis.

The iterative nature of design allows us to handle the design gap effectively while accomplishing necessary tradeoffs in complexity, performance, and cost in order to meet the design specifications.
Course Synopsis

• Provides a background of control principles in various engineering applications. Basic mathematical tools such as Laplace transform, transfer function, block diagram, signal flow graph, mathematical modeling of dynamic systems, time response analysis, stability of linear system, root locus and frequency domain analysis are utilized.
Course Outcomes (CO)

× CO1
  + Ability to apply various mathematical principles (from calculus and linear algebra) to solve control system problems.

× CO2
  + Ability to obtain mathematical models for such mechanical, electrical and electromechanical systems.

× CO3
  + Ability to derive equivalent differential equation, transfer function and state space model for a given system.

× CO4
  + The ability to perform system’s time and frequency-domain analysis with response to test inputs. Analysis includes the determination of the system stability.
**System** – An interconnection of elements and devices for a desired purpose.

**Control System** – An interconnection of components forming a system configuration that will provide a desired response.

**Process** – The device, plant, or system under control. The input and output relationship represents the cause-and-effect relationship of the process.

![Diagram of system and process](image_url)
• The interaction is defined in terms of variables.
  
i. System input
  
ii. System output
  
iii. Environmental disturbances
Control System

• **Control** is the process of causing a system variable to conform to some desired value.

• **Manual control** → **Automatic control** (involving machines only).

• A **control system** is an interconnection of components forming a system configuration that will provide a desired system response.
**Open-Loop Control Systems** utilize a controller or control actuator to obtain the desired response.

**Closed-Loop Control Systems** utilizes feedback to compare the actual output to the desired output response.

**Multivariable Control System**
Control System Classification

Missile Launcher System

Open-Loop Control System
Control System Classification

Missile Launcher System

Closed-Loop Feedback Control System
Manual Vs Automatic Control

- **Control** is a process of causing a system variable such as temperature or position to conform to some desired value or trajectory, called reference value or trajectory.

- For example, driving a car implies controlling the vehicle to follow the desired path to arrive safely at a planned destination.
  
  i. If you are **driving the car yourself**, you are performing manual control of the car.

  ii. If you use **design a machine**, or use a computer to do it, then you have built an automatic control system.
Control System Classification

Multi Input Multi Output (MIMO) System
Purpose of Control Systems

i. Power Amplification (Gain)
   – Positioning of a large radar antenna by low-power rotation of a knob

ii. Remote Control
    – Robotic arm used to pick up radioactive materials

iii. Convenience of Input Form
    – Changing room temperature by thermostat position

iv. Compensation for Disturbances
    – Controlling antenna position in the presence of large wind disturbance torque
Historical Developments

i. Ancient Greece (1 to 300 BC)
   – Water float regulation, water clock, automatic oil lamp

ii. Cornellis Drebbel (17th century)
   – Temperature control

iii. James Watt (18th century)
    – Flyball governor

iv. Late 19th to mid 20th century
   – Modern control theory
Watt’s Flyball Governor
Human System

The Vetruvian Man
Human System

i. Pancreas
   + Regulates blood glucose level

ii. Adrenaline
   + Automatically generated to increase the heart rate and oxygen in times of flight

iii. Eye
    + Follow moving object

iv. Hand
    + Pick up an object and place it at a predetermined location

v. Temperature
    + Regulated temperature of 36°C to 37°C
History

18th Century James Watt’s centrifugal governor for the speed control of a steam engine.

1920s Minorsky worked on automatic controllers for steering ships.

1930s Nyquist developed a method for analyzing the stability of controlled systems

1940s Frequency response methods made it possible to design linear closed-loop control systems

1950s Root-locus method due to Evans was fully developed

1960s State space methods, optimal control, adaptive control and

1980s Learning controls are begun to investigated and developed.

Present and on-going research fields. Recent application of modern control theory includes such non-engineering systems such as biological, biomedical, economic and socio-economic systems

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Control System Components

i. System, plant or process
   – To be controlled

ii. Actuators
   – Converts the control signal to a power signal

iii. Sensors
    – Provides measurement of the system output

iv. Reference input
    – Represents the desired output
General Control System

Set-point or Reference input

Controller

Actuator

Process

Sensor

Disturbance

Feedback Signal

Actual Output

Set-point or Reference input

Controller

Actuator

Process

Sensor

Disturbance

Feedback Signal

Actual Output
Control System Design Process

1. Establish control goals
2. Identify the variables to control
3. Write the specifications for the variables
4. Establish the system configuration and identify the actuator
5. Obtain a model of the process, the actuator and the sensor
6. Describe a controller and select key parameters to be adjusted
7. Optimize the parameters and analyze the performance

If the performance meet the specifications, then finalize design

If the performance does not meet specifications, then iterate the configuration and actuator
Examples of Modern Control Systems

(a) Automobile steering control system.
(b) The driver uses the difference between the actual and the desired direction of travel to generate a controlled adjustment of the steering wheel.
(c) Typical direction-of-travel response.
Examples of Modern Control Systems

A negative feedback system block diagram depicting a basic closed-loop control system. The control device is often called a “controller.”
Examples of Modern Control Systems

A manual control system for regulating the level of fluid in a tank by adjusting the output valve. The operator views the level of fluid through a port in the side of the tank.
Examples of Modern Control Systems

A three-axis control system for inspecting individual semiconductor wafers with a highly sensitive camera.
Examples of Modern Control Systems

Coordinated control system for a boiler-generator.
Examples of Modern Control Systems

A computer control system.
Examples of Modern Control Systems

The Utah/MIT Dextrous Robotic Hand: A dextrous robotic hand having 18 degrees of freedom, developed as a research tool by the Center for Engineering Design at the University of Utah and the Artificial Intelligence Laboratory at MIT. It is controlled by five Motorola 68000 microprocessors and actuated by 36 high-performance electropneumatic actuators via high-strength polymeric tendons. The hand has three fingers and a thumb. It uses touch sensors and tendons for control.

(Photograph by Michael Milochik. Courtesy of University of Utah.)
Examples of Modern Control Systems

A feedback control system model of the national income.
Examples of Modern Control Systems

A laboratory robot used for sample preparation. The robot manipulates small objects, such as test tubes, and probes in and out of tight places at relatively high speeds [41].

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The Future of Control Systems

The Future of Control Systems

Future evolution of control systems and robotics.
Design Example

Input angle, $\theta_i(t)$ + 50 volts
\[\begin{align*}
A & \\
B & \\
C & \\
- 50 \text{ volts} & \\
\text{Output} & \\
\text{voltage, } v_o(t) & \\
\end{align*}\]
Design Example

ELECTRIC SHIP CONCEPT

Vision

- Integrated Power System
  - Electric Drive
  - Reduce # of Prime Movers
  - Fuel savings
  - Reduced maintenance

- All Electric Ship
  - Reduced Manning
  - Automation
  - Eliminate auxiliary systems (steam, hydraulics, compressed air)

- Electrically Reconfigurable Ship
  - Technology Insertion
  - Warfighting Capabilities

Increasing Affordability and Military Capability

Design Example

- Propulsion Motor
- Motor Drive
- Generator
  - Main Power Distribution
- Power Conversion Module
  - Ship Service Power
- Prime Mover
Design Example

CVN(X) FUTURE AIRCRAFT CARRIER
Design Example
Design Example
Design Example

(a) Open-loop (without feedback) control of the speed of a turntable.
(b) Block diagram model.
Design Example

(a) Closed-loop control of the speed of a turntable.
(b) Block diagram model.
Initial wages + Actual wages + 

Process Industry

Prices

Wage increase

Automatic cost of living increase

Cost of living

$K_1$
Stretch of the lungs $u$

Lung stretch receptors

Nerve frequency $v$

Medulla, brain

Nerve frequency $w$

Heart

Heart rate $x$

Nerve frequency $z$

Pressure receptors

Pressure $y$

Vascular system
Design Example

The blood glucose and insulin levels for a healthy person.
(a) Open-loop (without feedback) control and (b) closed-loop control of blood glucose.
Sequential Design Example

(a) A disk drive ©1999 Quantum Corporation. All rights reserved.  (b) Diagram of a disk drive.
Sequential Design Example

Closed-loop control system for disk drive.