Control System Basics

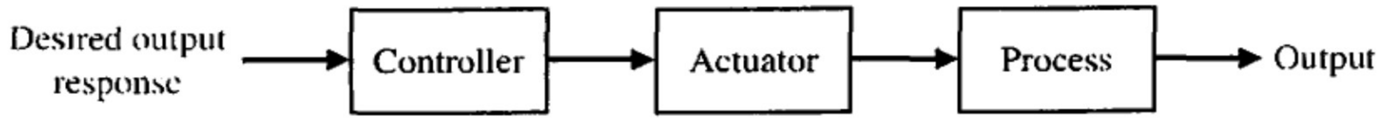
Introduction

- Foundation provided by linear system theory, which assumes a cause-effect relationship for the components of a system
- A control system is defined as an interconnection of components forming a system that will provide a desired system response
- Because the desired system response is known:
  - a signal proportional to the error between the desired and the actual response is generated.
  - The use of this signal to control the process results in a closed-loop sequence of operations that is called a feedback system.

Open Loop System

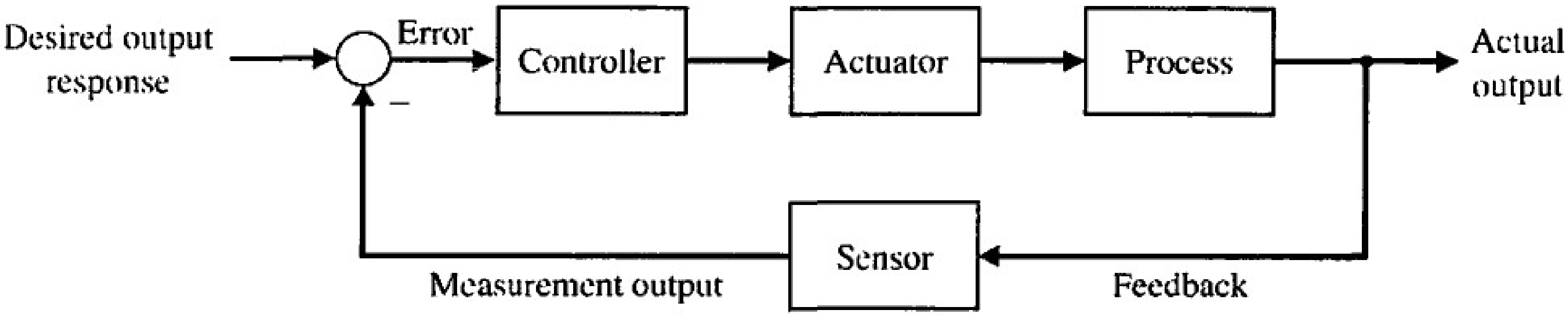
FIGURE 1.1
Process to be controlled.

FIGURE 1.2
Open-loop control system (without feedback).



- Foundation provided by linear system theory, which assumes a cause-effect relationship for the components of a system
- The disturbance, directly influences the output.
- In the absence of feedback, the control system is highly sensitive to disturbances and to changes in parameters.

Close Loop System



- Systems in nature, such as biological and physiological systems; feedback is inherent in these systems.
- Example: the human heartrate control system is a feedback control system. (sympathetic and parasympathetic input from two different nerve system)
- Figure represents a single loop feedback system

Close Loop System

- There are plenty of control system with multiple feedback loop.

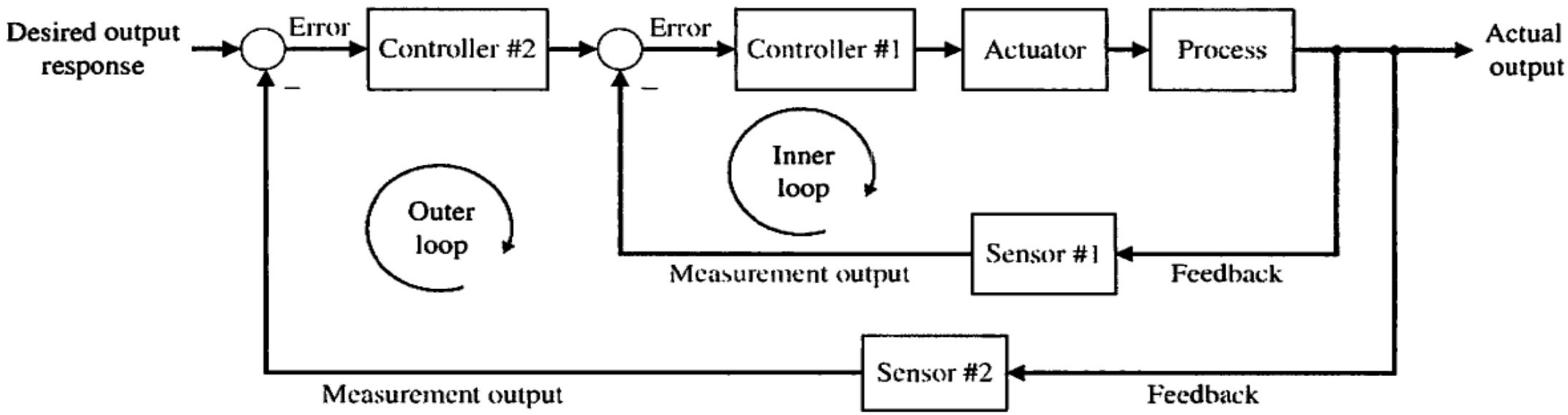


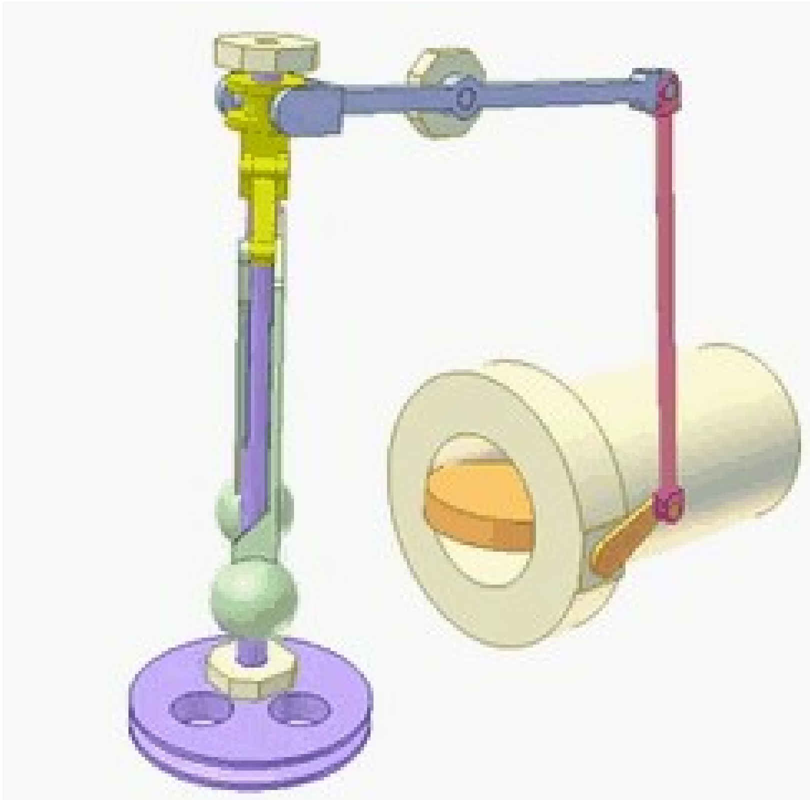
FIGURE 1.5 Multiloop feedback system with an inner loop and an outer loop.

Closed Loop System

- **Disadvantage:** Cost, Complexity
- Decreased sensitivity of the system to variations in the parameters of the process.
- Improved rejection of the disturbances.
- Improved measurement noise attenuation,
- Improved reduction of the steady-state error of the system.
- Easy control and adjustment of the transient response of the system

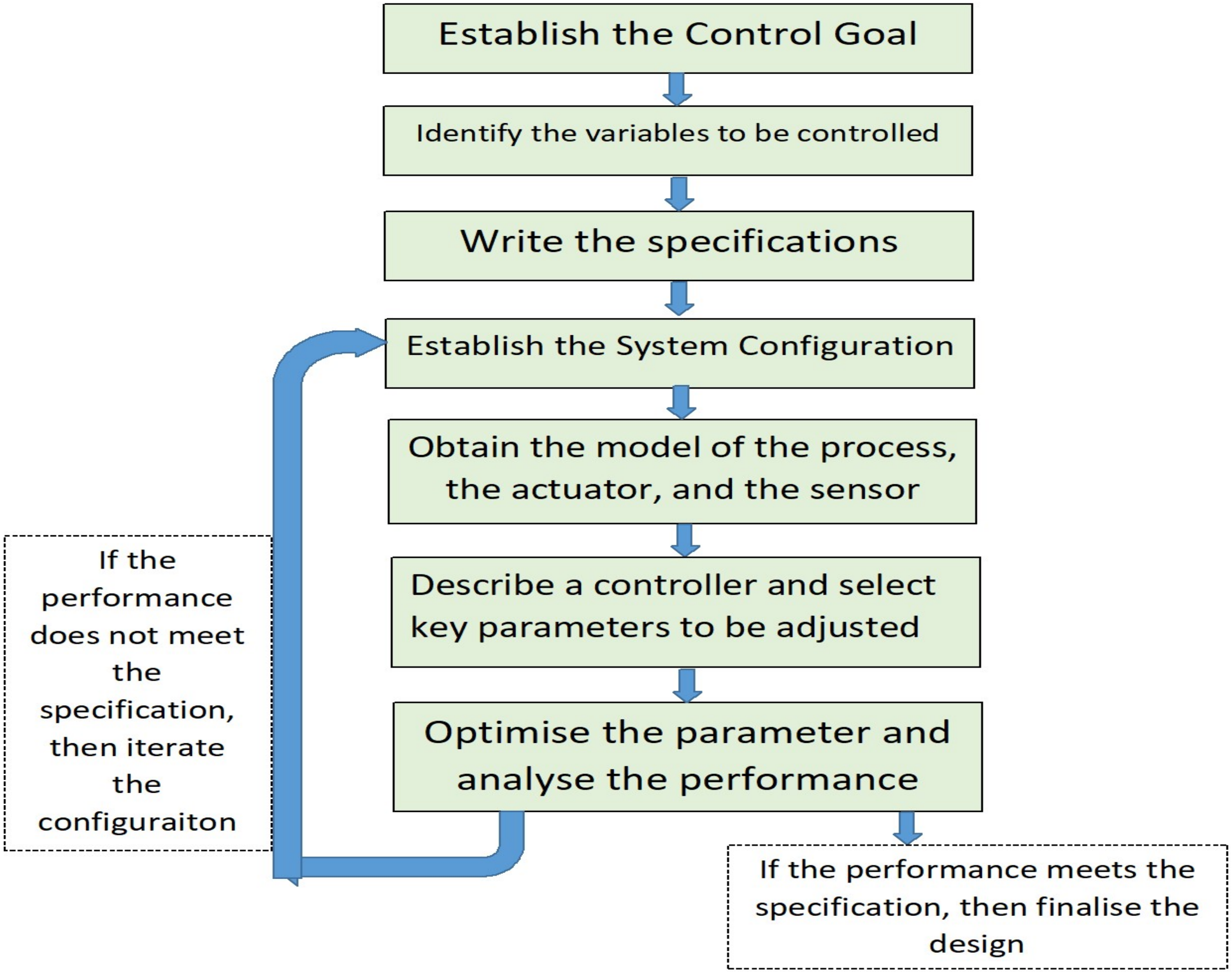
Brief History of Control System

- Dates back to 300 B.C.
- In Greece, water clock used float regulator
- An Oil lamp devised by Philon also used float regulator to maintain constant oil level [250 B.C.]
- First automatic control was designed in 1769 by James Watt.
  - Flyball governor (Centrifugal Governor) for controlling the speed of steam engine



Engineering Design

- Engineering Design is the process of conceiving or inventing the forms, parts, and details of a system to achieve a specified purpose.
- The main approach to the most effective engineering design is **parameter analysis and optimization**.
- Parameter analysis is based on the following iterative processes:
  - (1) identification of the key parameters,
  - (2) generation of the system configuration, and
  - (3) evaluation of how well the configuration meets the needs.
- Once the key parameters are identified and the configuration synthesized, the designer can **optimize** the parameters.


Establish the Control Goal
Identify the variables to be controlled
Write the specifications
Establish the System Configuration
Obtain the model of the process, the actuator, and the sensor
Describe a controller and select key parameters to be adjusted
Optimise the parameter and analyse the performance
If the performance does not meet the specification, then iterate the configuraiton
If the performance meets the specification, then finalise the design

Mathematical Models of Systems

Introduction

- To understand and control complex systems, one must obtain quantitative **mathematical models** of these systems.
- Mathematical models of physical systems are key elements in the design and analysis of control systems.
- The dynamic behaviour is generally described by ordinary differential equations.
- Furthermore, if these equations can be **linearized,** then the **Laplace transform** can be used to simplify the method of solution.
- In practice, the complexity of systems and our ignorance of all the relevant factors necessitate the introduction of **assumptions** concerning the system operation.

Introduction (contd.)

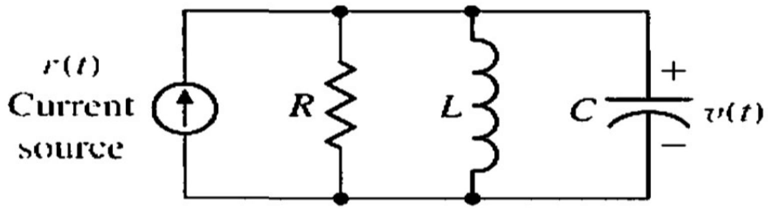
- The input-output relationship for components and subsystems are derived in the form of transfer functions
- The transfer function blocks can be organized into block diagrams or signal-flow graphs to graphically depict the interconnections.
- Block diagrams (and signal-flow graphs) are very convenient and natural tools for designing and analysing complicated control systems.

Dynamic System Modelling Steps

1. Define the system and its components.
2. Formulate the mathematical model and fundamental necessary assumptions based on basic principles.
3. Obtain the differential equations representing the mathematical model.
4. Solve the equations for the desired output variables.
5. Examine the solutions and the assumptions.
6. If necessary, reanalyse or redesign the system.

Differential Equations of Physical Systems

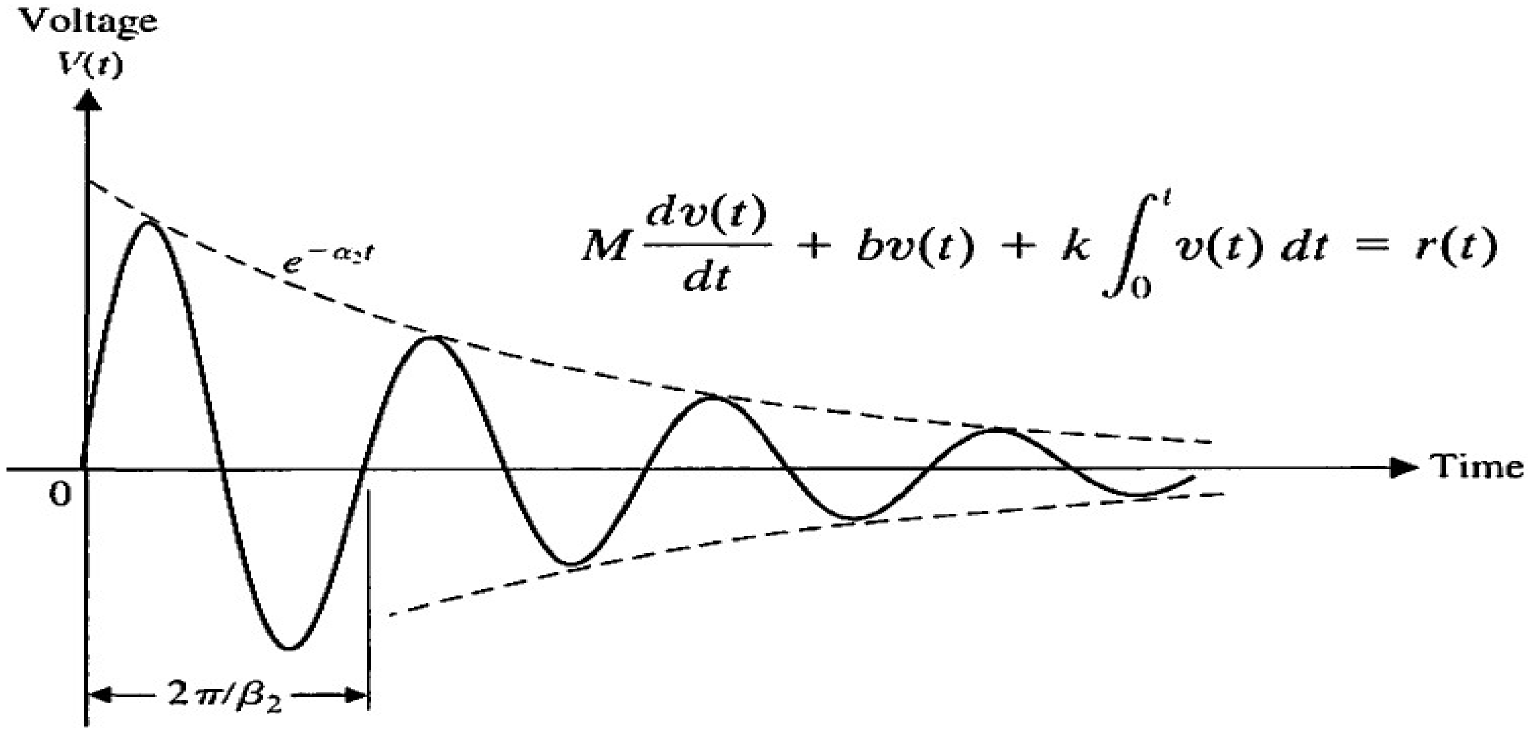
- The differential equations describing the dynamic performance of a physical system are obtained by utilizing the physical laws of the process.



- The above circuit can be solved with KCL, and the integrodifferential equation can be obtained as follows: $$\frac{v(t)}{R} + C\frac{dv(t)}{dt} + \frac{1}{L}\int_0^t v(t)\,dt = r(t).$$

- The solution of the differential equation describing the process may be obtained by classical methods such as the use of integrating factors and the method of undetermined coefficients

Typical voltage response of an RLC circuit



Linear Approximation of Physical Systems

- A great majority of physical systems are linear within some range of the variables
- In general, systems ultimately become nonlinear as the variables are increased without limit. [example: spring mass damper]
- Therefore the question of linearity and the range of applicability must be considered for each system.
- A system is defined as **linear** in terms of the system **excitation** and **response**.
- In general, a **necessary condition** for a linear system can be determined in terms of an excitation *x(t)* and a response *y(t).*

Linear Approximation of Physical Systems

- When the system at rest is subjected to an excitation $X_1(t)$, it provides a response $Y_1(t)$. Similarly, when the system is subjected to an excitation$X_2(t)$, it provides a corresponding response $Y_2(t)$.
  - For a linear system, it is necessary that the excitation $X_1(t) + X_2(t)$ result in a response $Y_1(t) + Y_2(t)$. This is usually called the **principle of superposition.**
- The magnitude scale factor must be preserved in a **linear system.**
  - Consider a system with an input $X(t)$ that results in an output $Y(t)$. Then the response of a linear system to a constant multiple ß an input x must be equal to the response to the input multiplied by the same constant so that the output is equal to ß$Y(t)$.
- This is called the property of **homogeneity.**
- **A linear system satisfies the properties of superposition and homogeneity.**

Example non-linear system

- A system characterized by the relation $y = x^2$
  - is not linear, because the superposition property is not satisfied.
- A system represented by the relation $y = mx + b$
  - is not linear, because it does not satisfy the homogeneity property
- However, this second system may be considered linear about an operating point x_0 and y_0 for small changes Δx and Δy.
- When $x = x_0 + \Delta$x and $y = y_0 + \Delta$ y, we have

$$y = mx + b$$

or $$y_0 + \Delta y = mx_0 + m\,\Delta x + b.$$ Therefore, $\Delta y = m\,\Delta x$,