Chapter 01

Introduction

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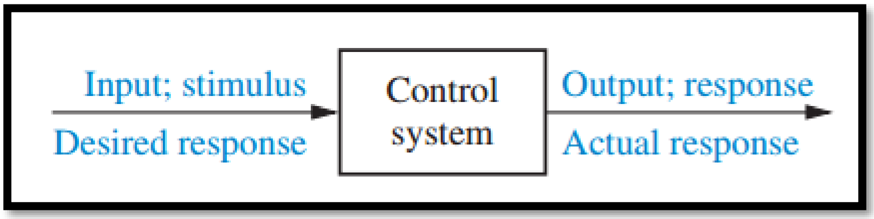
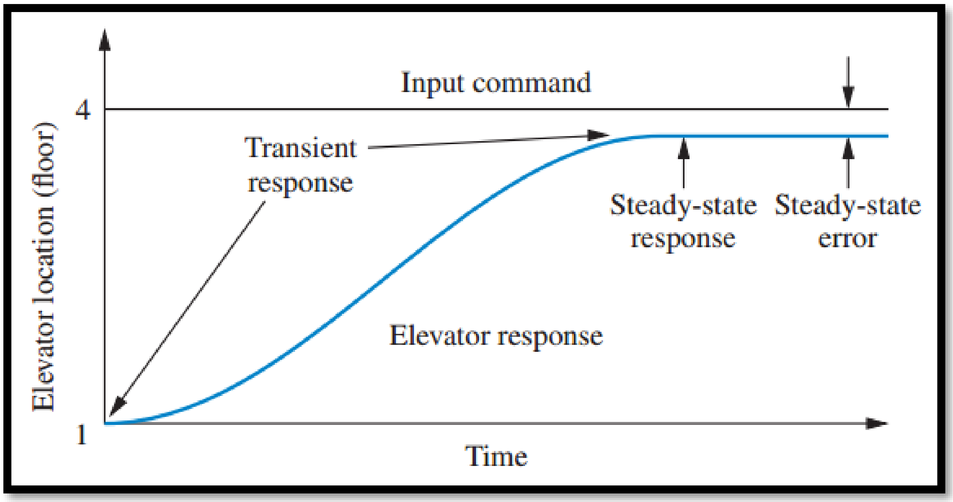
■ Control systems

- The basic strategy by which a control system operates is logical and natural. In fact, the same strategy is employed in **living organisms** to **maintain temperature**, **fluid flow rate**, and a host of other **biological functions**. This is natural process control.
- The technology of artificial control was first developed using a **human** as an integral part of the control action. When we learned how to use machines, electronics, and computers to replace the human function, the term **automatic control** came into use
- A control system consists of subsystems and processes (or plants) assembled for the purpose of obtaining a desired output with desired performance, given a specified input. Figure below shows a control system in its simplest form, where the input represents a desired output



- For example, consider an elevator. When the fourth-floor button is pressed on the first floor, the elevator rises to the fourth floor with a speed and floor leveling accuracy designed for passenger comfort. The push of the fourth-floor button is an input that represents our desired output, shown as a step function in Figure below.

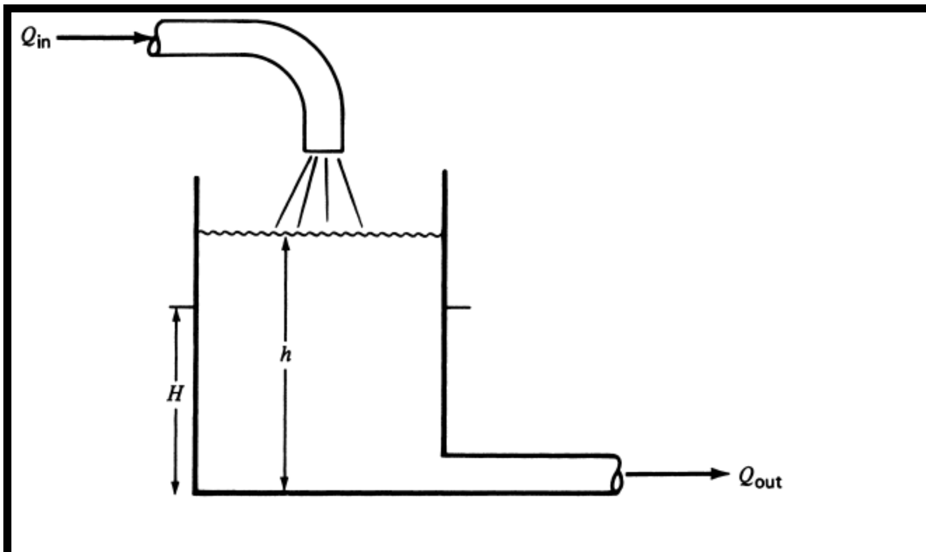


- The performance of the elevator can be seen from the elevator response curve in the figure.
- Two major measures of performance are apparent: (1) the **transient response** and (2) the **steady-state error**. In our example, **passenger comfort and passenger patience** are **dependent upon the transient response**. If this response is too fast, passenger comfort is sacrificed; if too slow, passenger patience is sacrificed. The steady-state error is another important performance specification since passenger safety and convenience would be sacrificed if the elevator did not level properly.

Process-Control Principles

In process control, the **basic objective is to regulate the value of some quantity**. To **regulate** means to **maintain that quantity at some desired value regardless of external influences**. The **desired value** is called the **reference value or setpoint**.

Figure below shows the process to be used for this discussion. Liquid is flowing into a tank at some rate, Q_{in} , and out of the tank at some rate, Q_{out}. The liquid in the tank has some height or level, h. It is known that the output flow rate varies as the square root of the height, $Q_{out} = K\sqrt{h}$, so the higher the level, the faster the liquid flows out. If the output flow rate is not exactly equal to the input flow rate, the level will drop, if $Q_{out} > Q_{in}$,or rise, if $Q_{out} < Q_{in}$.

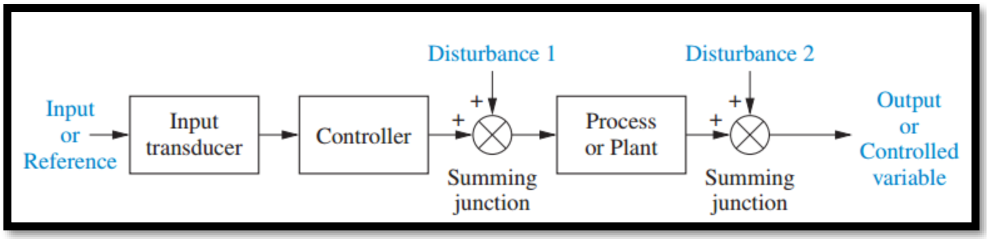


The objective is to regulate the level of liquid in the tank, *h*, to the value *H*.

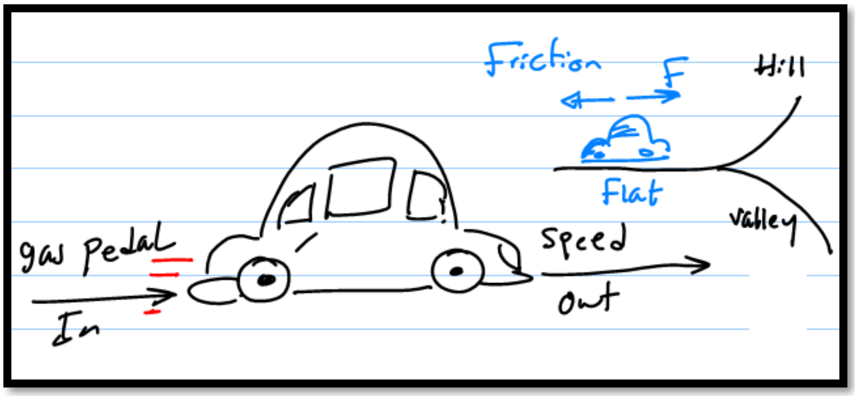
This process has a property called **self-regulation**. This means that for some input flow rate, the liquid height will rise until it reaches a height for which the output flow rate matches the input flow rate. A **self-regulating system does not provide regulation of a variable to any particular reference value**. In this example, the liquid level will adopt some value for which input and output flow rates are the same, and there it will stay. But if the input flow rate changed, then the level would change also, so it is not regulated to a reference value.

Open-loop systems

- Open loop control uses a controller and an actuator to obtain the desired response
- System without feedback
- It starts with a subsystem called an **input transducer**, which converts the form of the input to that used by the **controller**. The controller drives a process or a plant. The input is sometimes called the **reference**, while the **output** can be called the **controlled variable**

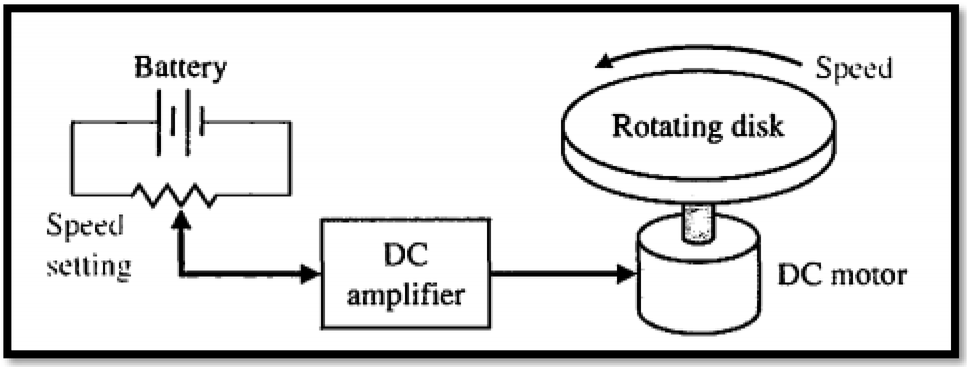


- The distinguishing characteristic of an open-loop system is that it cannot compensate for any disturbances that add to the controller's driving signal
- For example, **toasters** are open-loop systems, as anyone with burnt toast can attest. The controlled variable (output) of a toaster is the color of the toast. The device is designed with the assumption that the toast will be darker the longer it is subjected to heat. The toaster does not measure the color of the toast; it does not correct for the fact that the toast is rye, white, or sourdough, nor does it correct for the fact that toast comes in different thicknesses
- **Car driver control systems**: By pressing the **gas pedal** (**control input**) she hopes that the car's speed will come up to the desired value, but has no means of verifying the actual increase in speed. Such a control system, in which the **control input is applied without the knowledge of the plant output**, is called an **open-loop control system**

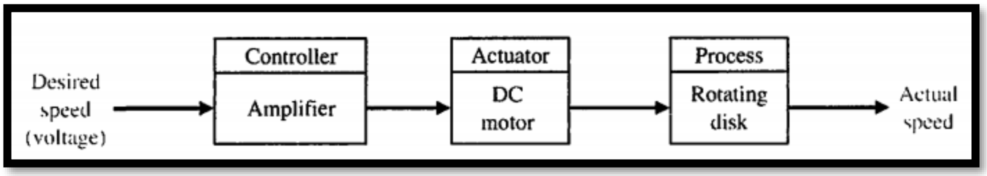


Imagine trying to obtain a constant speed of your car without benefit from built in automatic cruise control What happen when a car encounters a hill, or a valley? Without varying the input "gas pedal" the car will slow down or speed up and the desired constant speed will not be maintained ➔ problem of open loop — drawback

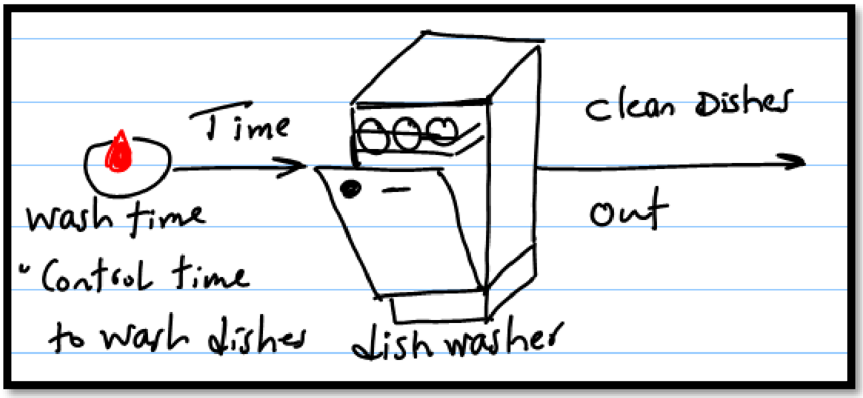
- **Rotating disk speed control**: This system uses a battery source to provide a voltage that is proportional to the desired speed. This voltage is amplified and applied to the motor.



- The block diagram of the open-loop system identifying the controller, actuator, and process is shown in figure below

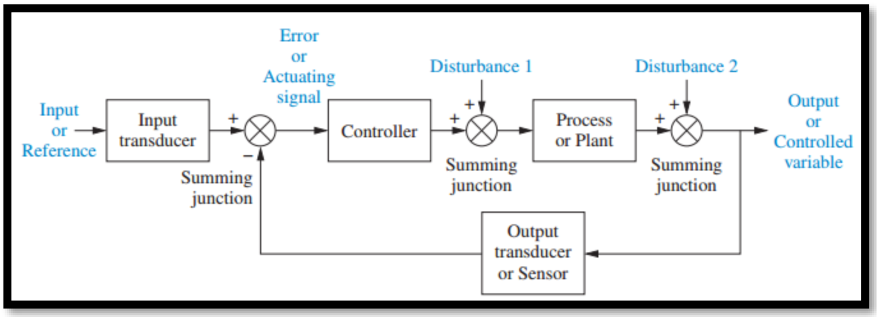


- **Dish washer:**



The goal of dish washer is to clean the dishes, which is the output, once the user sets the wash time, which control the time to clean dishes, the dish washer will run to that set time. Now this is happened regardless of the cleanness of the dishes

The disadvantages of open-loop systems, namely sensitivity to disturbances and inability to correct for these disturbances, may be overcome in **closed-loop systems**. The generic architecture of a closed-loop system is shown in figure below

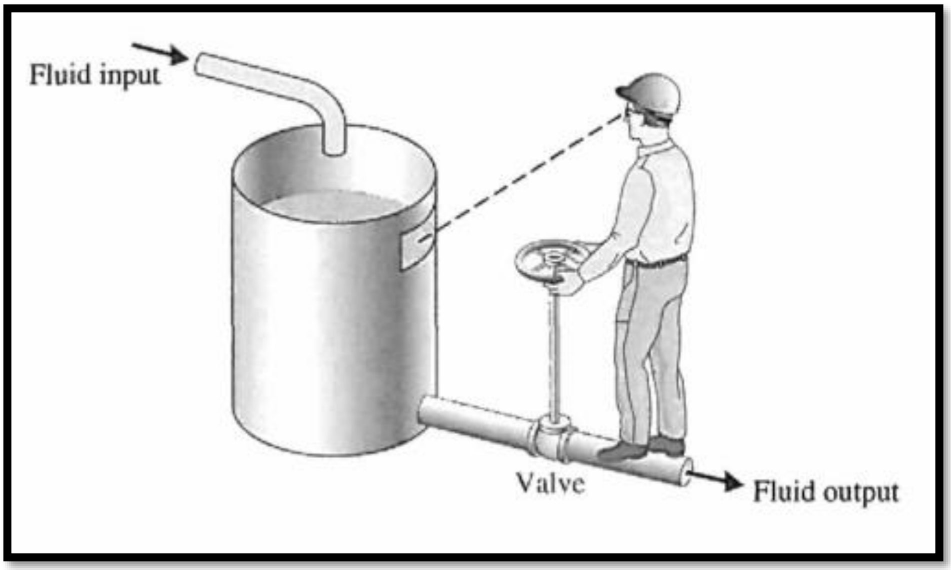


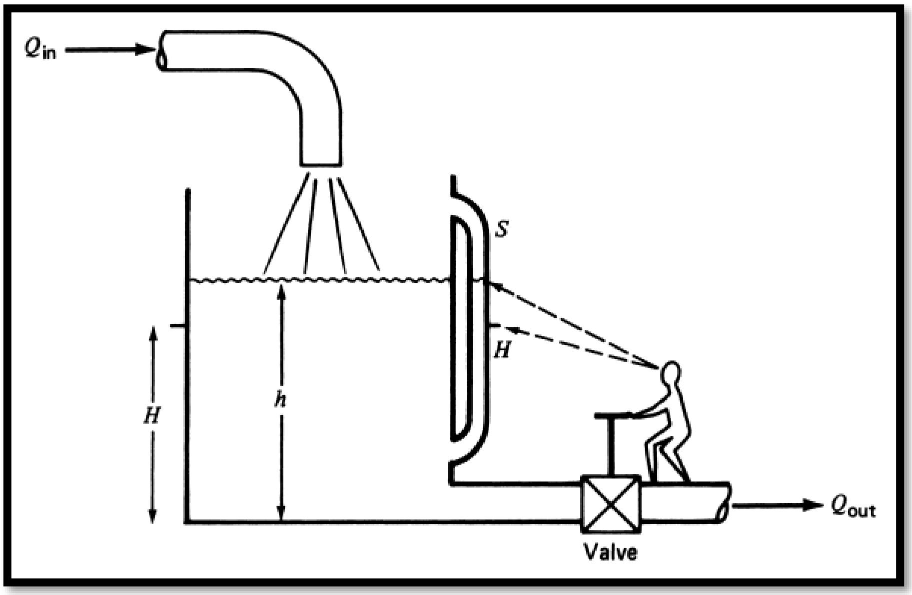
The input transducer converts the form of the input to the form used by the controller. An output transducer, or sensor, measures the output response and converts it into the form used by the controller. For example, if the controller uses electrical signals to operate the valves of a temperature control system, the input position and the output temperature are converted to electrical signals. The input position can be converted to a voltage by a potentiometer, a variable resistor, and the output temperature can be converted to a voltage by a thermistor, a device whose electrical resistance changes with temperature.

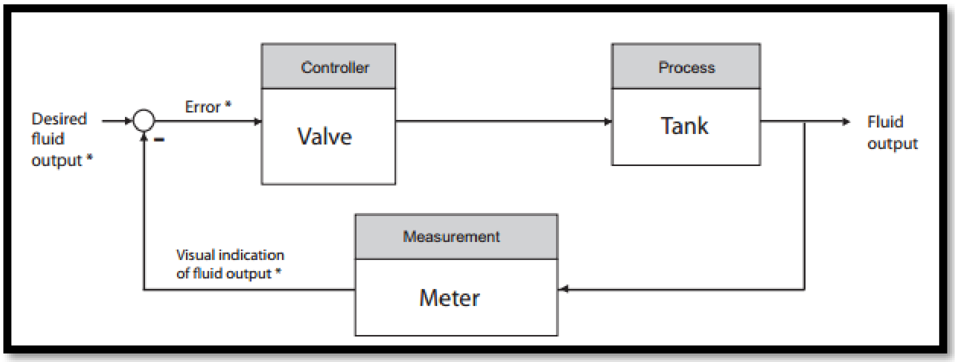
Closed-loop systems

- The **closed-loop system** compensates for disturbances by measuring the output response, feeding that measurement back through a **feedback** path, and **comparing** that response to the input at the summing junction. If there is any **difference** between the two responses, the system drives the plant, via the **actuating signal**, to make a correction. If there is no difference, the system does not drive the plant, since the plant's response is already the desired response

- **Closed-loop systems**, then, have the obvious advantage of greater accuracy than open-loop systems. They are **less sensitive to noise**, **disturbances**, and changes in the environment.
- **Transient response** and **steady-state error** can be controlled more conveniently and with greater flexibility in closed-loop systems, often by a simple adjustment of gain (**amplification**) in the loop and sometimes by **redesigning the controller**
- On the other hand, **closed-loop systems are more complex** and expensive than open-loop systems. A standard, open-loop **toaster** serves as an example: It is simple and inexpensive.
- A **closed-loop toaster** oven is more complex and more expensive since it has to **measure both color** (through light reflectivity) and **humidity** inside the toaster oven. Thus, the control systems engineer must consider the **trade-off** between the simplicity and low cost of an open-loop system and the accuracy and higher cost of a closed-loop system.
- In the past, control systems used a human operator as part of closed -loop control system

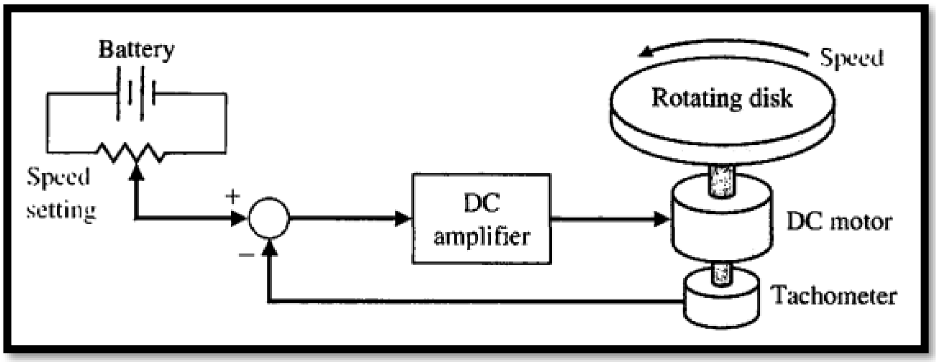

Fluid input
Valve
Fluid output


Q_{in}
S
H
H
h
Valve
Q_{out}

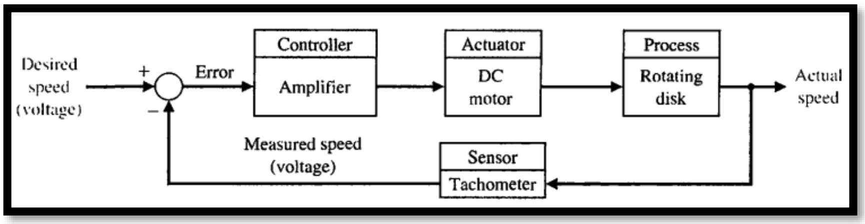


Rotating disk speed control

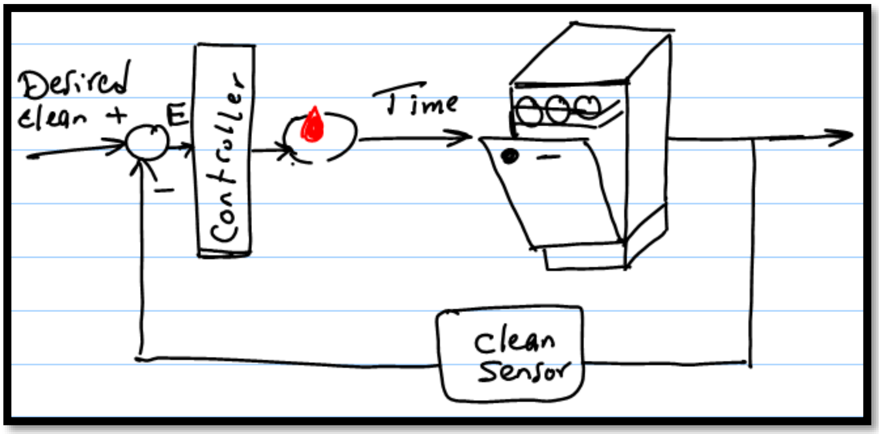
- To obtain a feedback system, we need to select a sensor. One useful sensor is a **tachometer** that provides an output voltage proportional to the speed of its shaft. Thus the closed-loop feedback system takes the form shown in Fig. below.



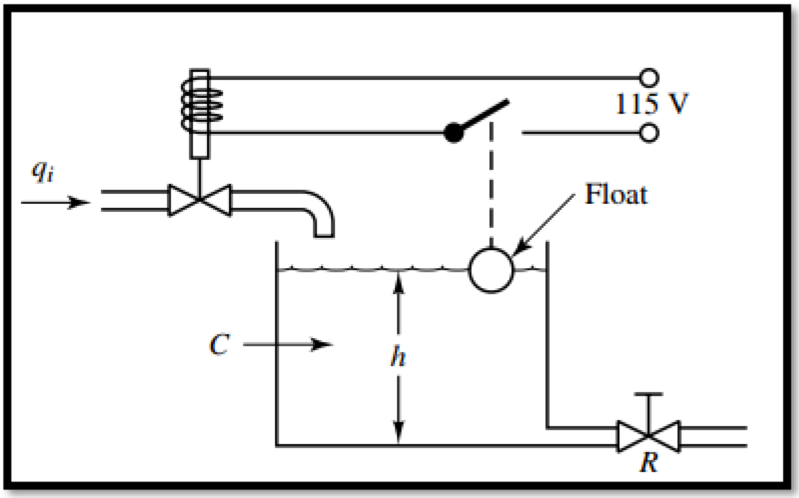
- The block diagram model of the feedback system is shown in Fig. below. The error voltage is generated by the difference between the input voltage and the tachometer voltage.



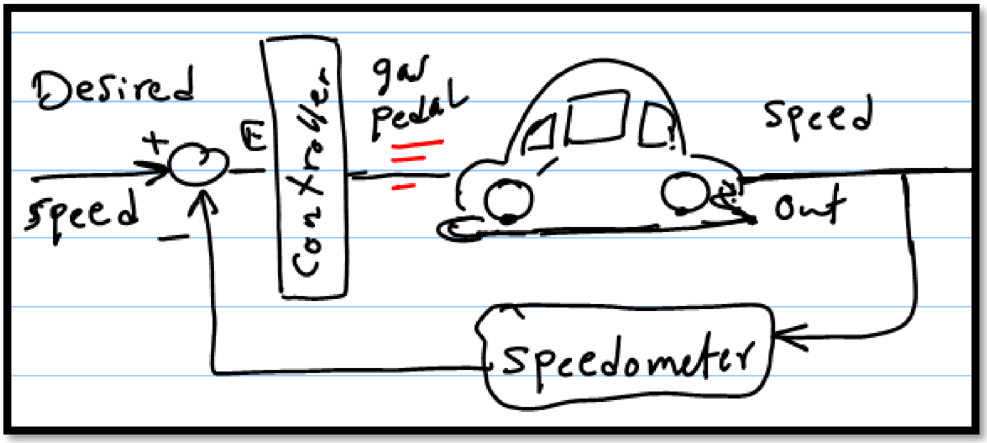
Dish washer:



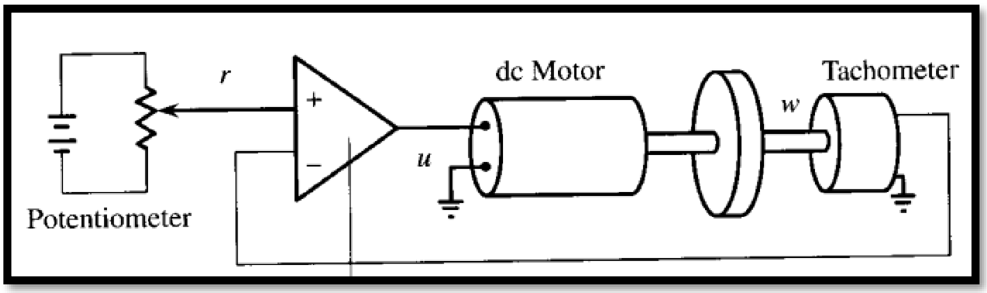
Liquid level control:

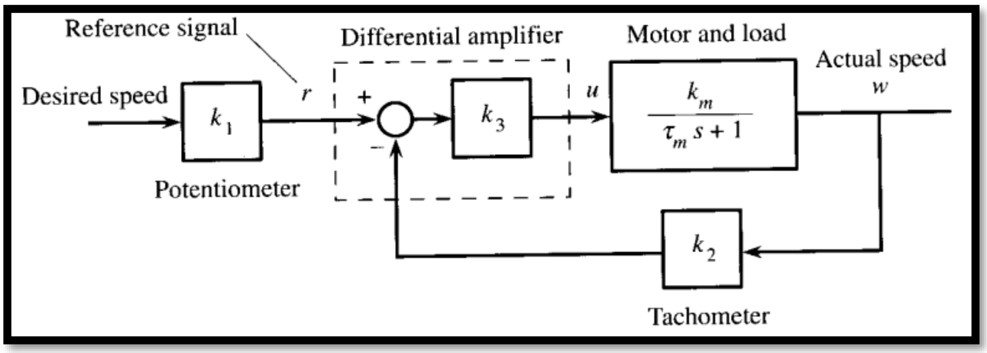


Car driver control systems:



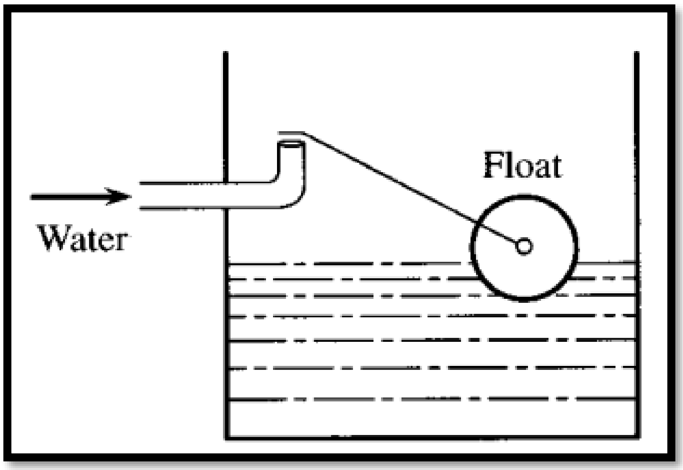
Velocity control system:

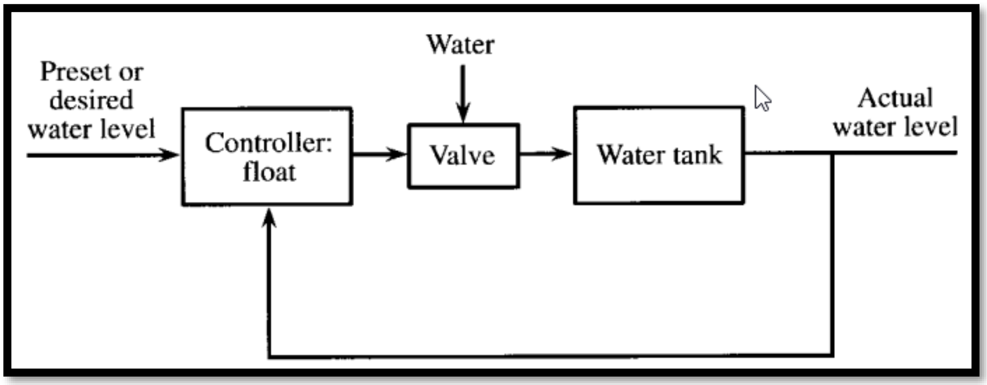


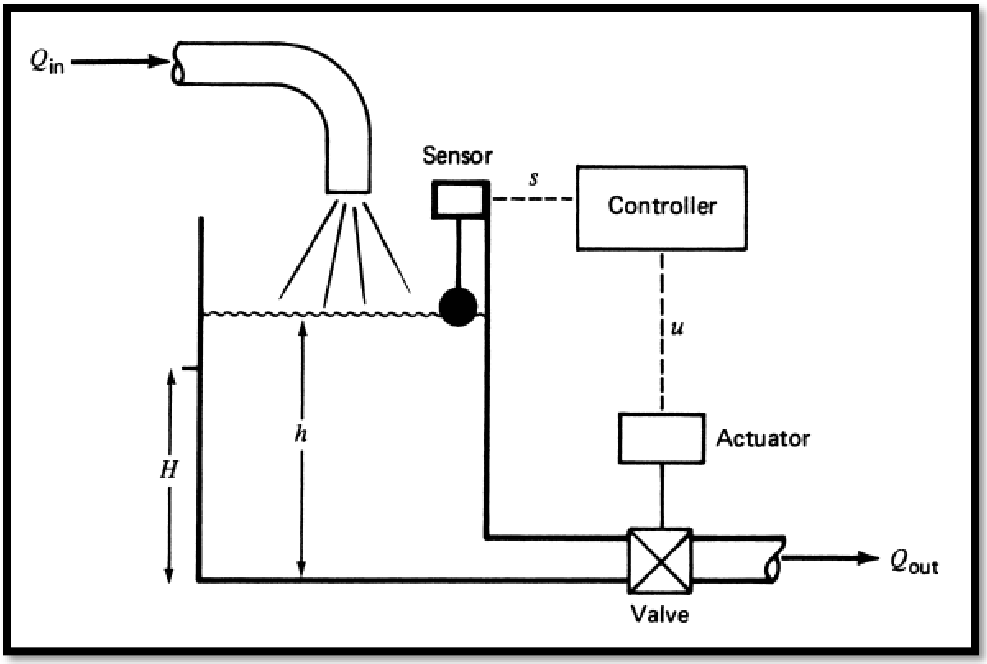


Bathroom toilet tank

The mechanism is designed to close the valve automatically whenever the water level reaches a preset height

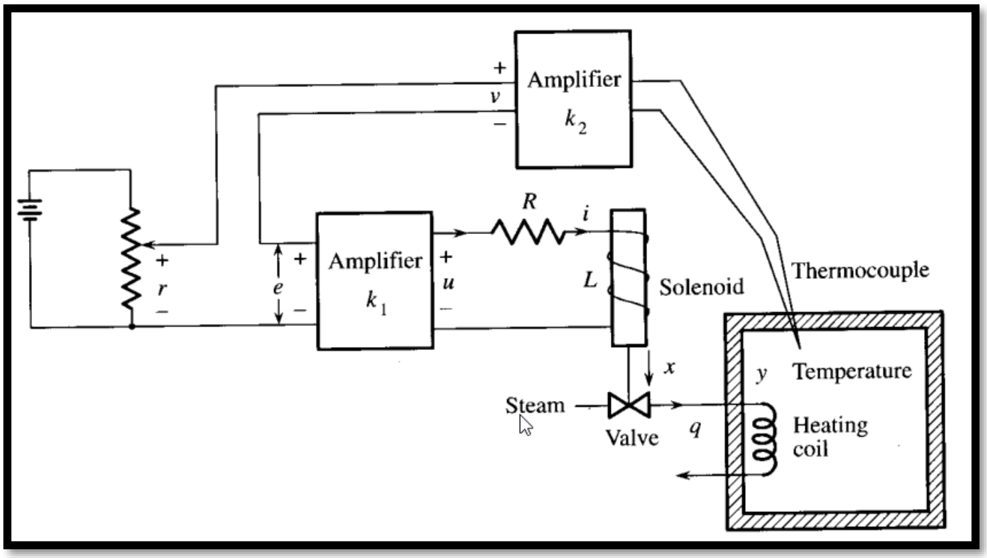






■ Temperature control

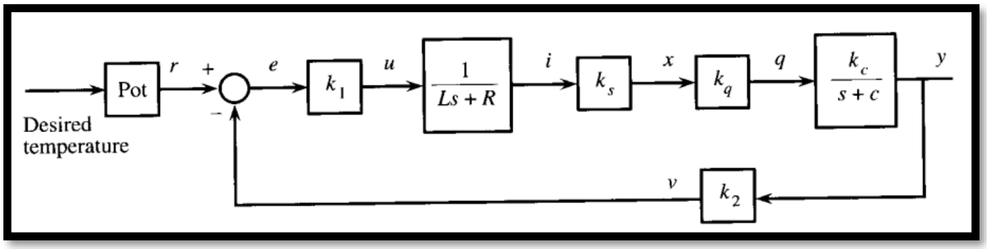
Temperature control is essential in many chemical processes. Consider the temperature control system shown below. The problem is to control the temperature inside the chamber. The chamber is heated by steam. The flow q of hot steam is proportional to the valve opening x; that is $q = k_q x$. The valve opening x is controlled by a solenoid and assumed to be proportional to the solenoid current i; that is $x = k_s i$.



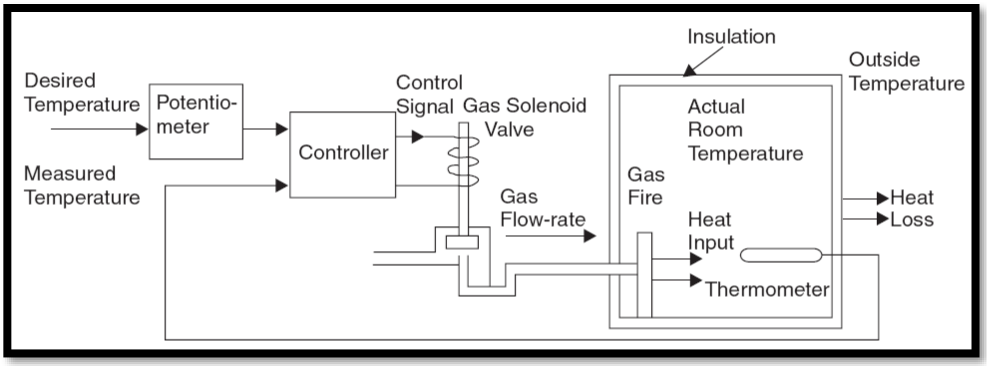
It is assumed that the chamber temperature y and the steam are related by

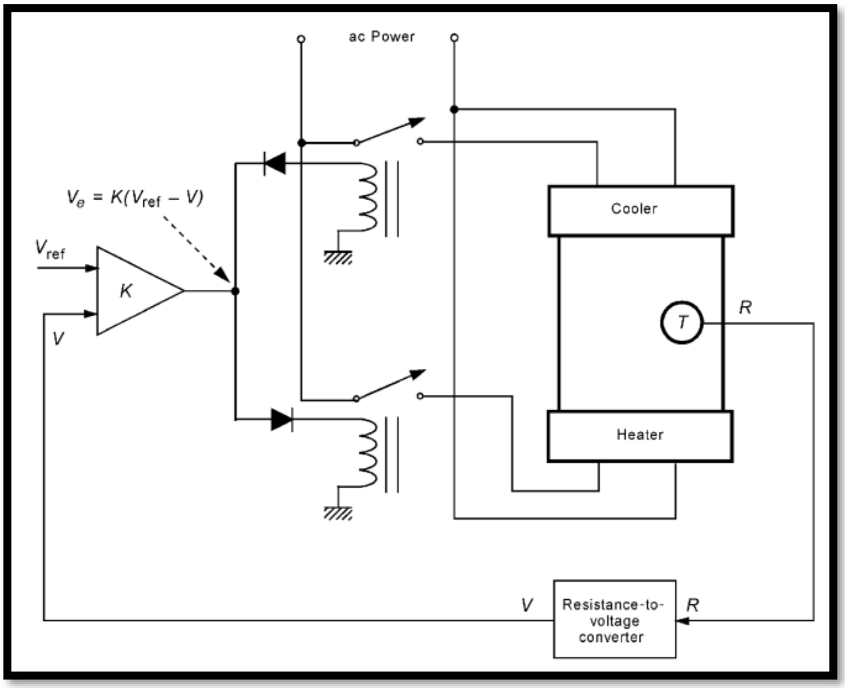
$$\frac{dy}{dt} = -cy + k_c q$$

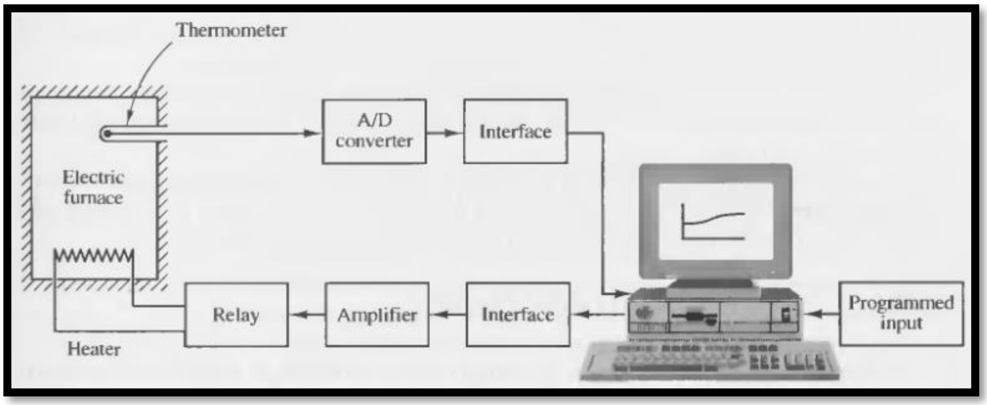
Where c depends on the insulation and the temperature difference between inside and outside chamber



The physical realization of a system to control room temperature is shown below. Here the output signal from a temperature sensing device such as a thermocouple or a resistance thermometer is compared with the desired temperature. Any difference or error causes the controller to send a **control signal** to the gas solenoid valve which produces a linear movement of the valve steam, thus adjusting the flow of gas to the burner of the gas fire. The desired temperature is usually obtained from manual adjustment of a potentiometer

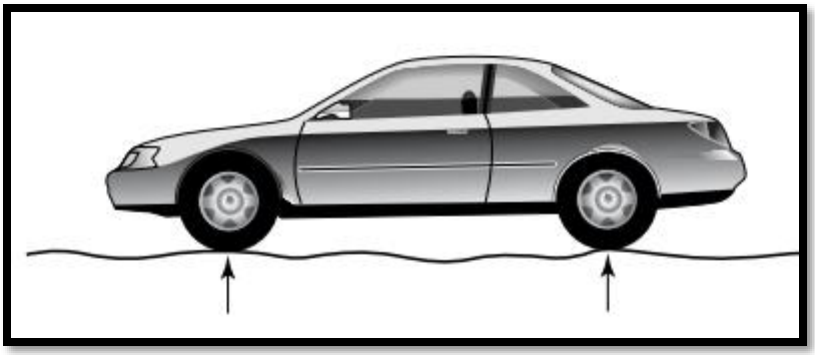


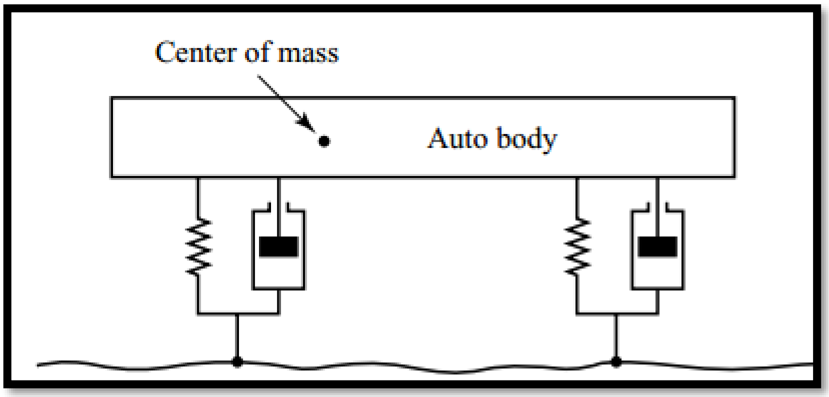




- **Car suspension system**

Figure below shows a schematic diagram of an automobile suspension system. As the car moves along the road, the vertical displacements at the tires act as the motion excitation to the automobile suspension system. The motion of this system consists of a translational motion of the center of mass and a rotational motion about the center of mass. Mathematical modeling of the complete system is quite complicated.





- **Personal Transporter (PT)**

A Segway Personal Transporter (PT) is a two-wheeled vehicle in which the human operator stands vertically on a platform. As the driver leans left, right, forward, or backward, a set of sensitive gyroscopic sensors sense the desired input. These signals are fed to a computer that amplifies them and commands motors to propel the vehicle in the desired direction. One very important feature of the PT is its safety: The system will maintain its vertical position within a specified angle despite road disturbances, such as up hills and down hills or even if the operator over-leans in any direction.

■ PROCESS-CONTROL BLOCK DIAGRAM

- To provide a practical, working description of process control, it is useful to describe the elements and operations involved in more generic terms. Such a description should be independent of a particular application and thus be applicable to all control situations.
- A model may be constructed using blocks to represent each distinctive element. The characteristics of control operation then may be developed from a consideration of the properties and interfacing of these elements.

■ Process

- Flow of liquid in and out of the tank, the tank itself, and the liquid all constitute a process to be placed under control with respect to the fluid level.
- In general, a process can consist of a complex assembly of phenomena that relate to some manufacturing sequence.
- Many variables may be involved in such a process, and it may be desirable to control all these variables at the same time.
- There are single variable processes, in which only one variable is to be controlled, as well as multivariable processes, in which many variables, perhaps interrelated,

may require regulation. The **process** is often also called the **plant**

- **Process control**
  - It refers to the methods that are used to control process variables when manufacturing a product. For example, factors such as the proportion of one ingredient to another, the temperature of the materials, how well the ingredients are mixed, and the pressure under which the materials are held can significantly impact the quality of an end product
  - All process systems consist of three main factors or terms: the **manipulated variables**, **disturbances**, and the **controlled variables**.
  - Typical manipulated variables are valve position, motor speed, damper position, or blade pitch.
  - The **controlled variables** are those conditions, such as temperature, level, position, pressure, pH, density, moisture content, weight, and speed, that must be maintained at some desired value.
  - For each controlled variable there is an associated **manipulated variable**. The control system must adjust the manipulated variables so the desired value or "set point" of the controlled variable is maintained despite any disturbances — **The factor that is changed to keep the measured variable at setpoint**

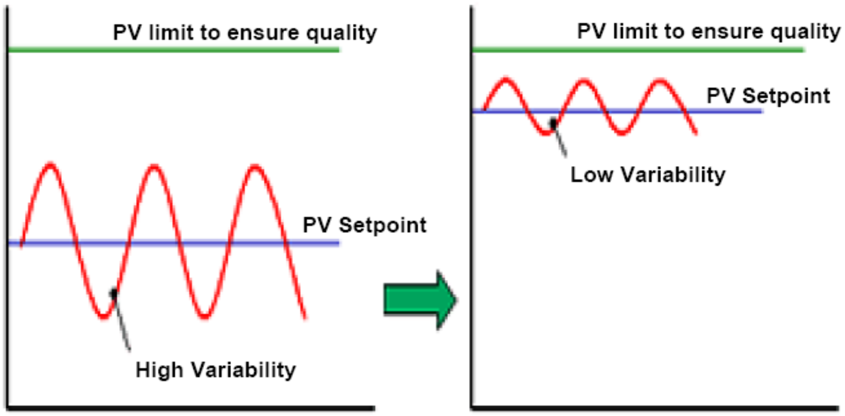
- **Disturbances:** There are other inputs over which the engineer has no control, and these will tend to deflect the plant outputs from their desired values.
- **Process variable:** Temperature – level – pressure
- **Set point: reference signal: desired signal**: The setpoint is a value for a process variable that is desired to be maintained. For example, if a process temperature needs to kept within 5 °C of 100 °C, then the setpoint is 100 °C
- **Actuator:** is the device that can influence the controlled variable of the process

  the central issue with the actuator is its ability to move the process output with adequate speed and range

process + actuator = plant

- **Why to control production process**
  - **Reduce variability**

    gasoline blending process, as many as 12 or more different components may be blended to make a specific grade of gasoline. If the refinery does not have precise control over the flow of the separate components, the gasoline may get too much of the high-octane components. As a result, customers would receive a higher grade and more expensive gasoline than they paid for, and the refinery would lose money. The opposite situation would be customers receiving a lower grade at a higher price



- Increase efficiency
- Ensure safety

- **General Requirements of a Control System**

The primary requirement of a control system is that it be **reasonably stable**. In other words, its speed of **response must be fairly fast**, and this response must show **reasonable damping**. A control system must also be able to **reduce the system error to zero** or to a value near zero

- **System Error**

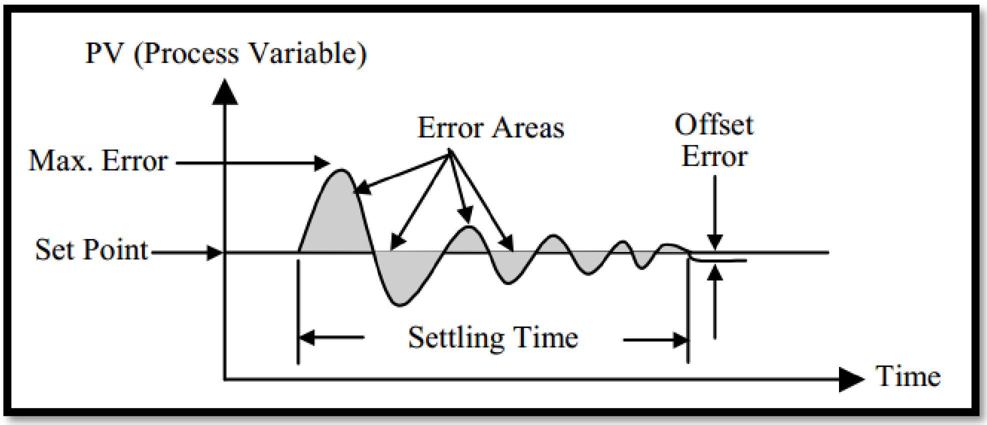
The system error is the **difference** between the value of the **controlled variable** set point and the value of the **process variable** maintained by the system

System Response

The main purpose of a control loop is to maintain some dynamic process variable (pressure, flow, temperature, level, etc.) at a prescribed operating point or set point. System response is the ability of a control loop to recover from a disturbance that causes a change in the controlled process variable

Control Loop Design Criteria

Many criteria are employed to evaluate the process control's loop response to an input change. The most common of these include settling time, maximum error, offset error, and error area



✍ **Note:**

Consider the problem of playing tennis at top international level. One can readily accept that one needs good eye sight (sensors) and strong muscles (actuators) to play tennis at this level, but these attributes are not sufficient. Indeed eye-hand coordination (i.e. control) is also crucial to success

<u>To achieve a good control:</u>

- System must be stable at all times
- System output must track the command input signal
- System output must be prevented from responding too much to disturbance inputs
- These goals must be met even if the model used in the design is not completely accurate or if the dynamic of the physical system change over time or with environmental change

■ OUTLINE OF THE BOOK

In what follows we shall briefly present the arrangements and contents of the book.

- **Chapter 1** has given introductory materials on control systems. **Chapter 2** presents basic Laplace transform theory necessary for understanding the control theory presented in this book. **Chapter 3** deals with mathematical modeling of dynamic systems in terms of transfer functions and state-space equations. **Chapter 4** treats transient-response analyses of first- and second-order systems. This chapter also gives details of transient-response analysis with **MATLAB**. **Chapter 5** first presents basic control actions and then discusses pneumatic, hydraulic, and electronic controllers. This chapter also discusses **Routh's stability** criterion.

- **Chapter 6** gives a root-locus analysis of control systems. General rules for constructing root loci are presented. Detailed discussions for plotting root loci with MATLAB are included.