FAHAD BIN SULTAN UNIVERSITY
College of Engineering
Department of Mechanical Engineering

MECH 490 Control Systems

Chapter 1

Introduction

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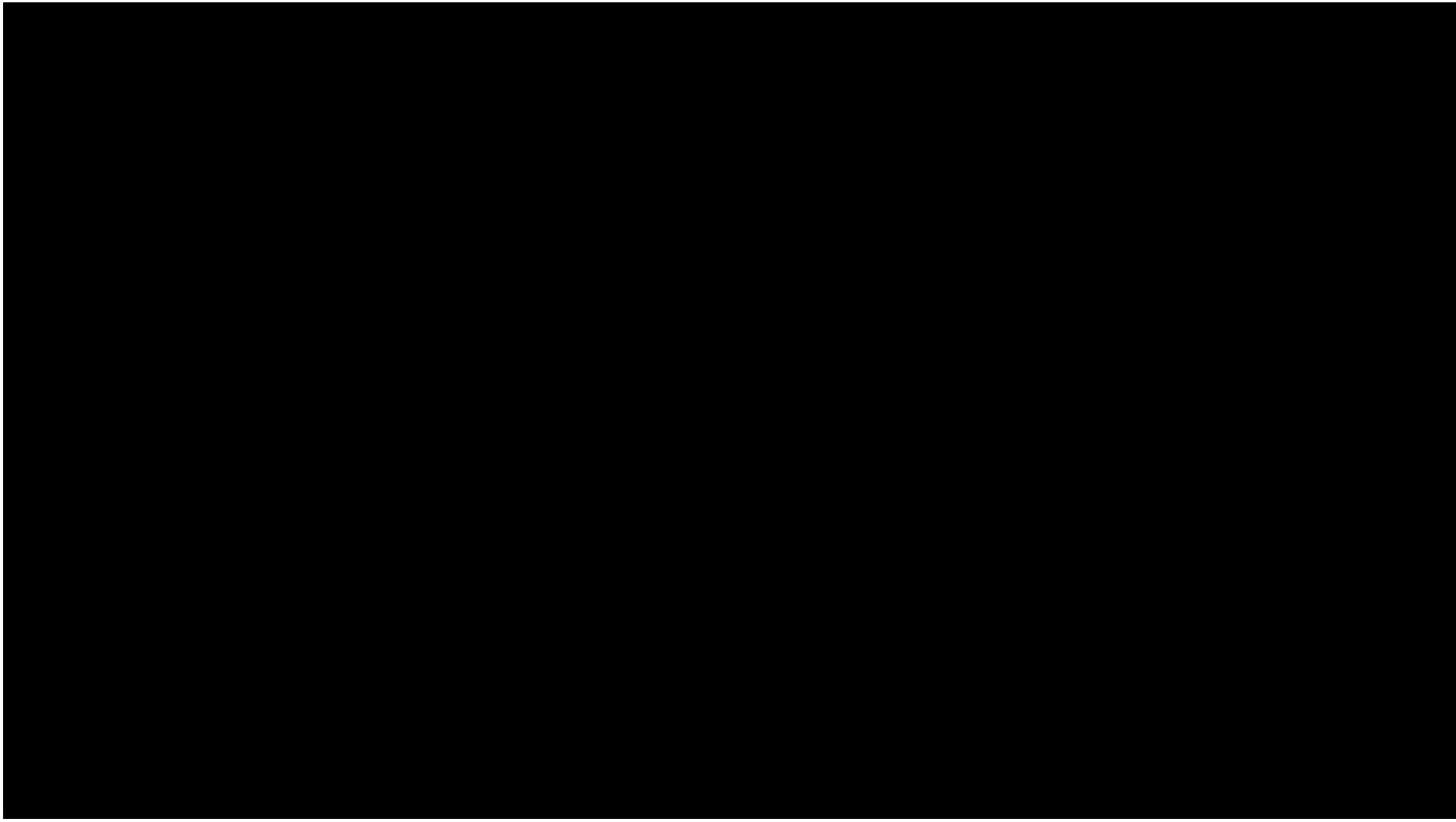
Outlines

- Definitions and Terminologies
- The Basic Types of Control
- General Structure of Control Systems
- Control-System Classifications
- Examples of Control Systems (Open and closed loop)
- Control development and intelligent system: *examples*



Background

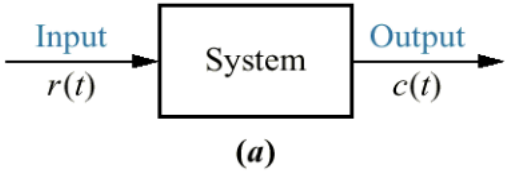
- *Engineering* is concerned with understanding and controlling the materials and forces of nature for the ***benefit of humankind***.

- **What is Control Theory?**
  - **The field of control systems deals with applying or choosing the inputs to a given system to make it behave in a certain way** (i.e., make the state or output of the system follow a certain trajectory). A key way to achieve this is via the use of feedback, where the input depends on the output in some way. This is also called closed loop control.

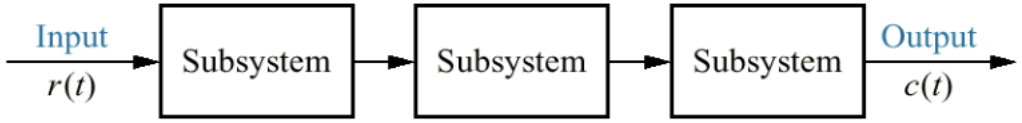
- A control system is an interconnection of components **forming a system** configuration that will **provide a desired system response**.
  - The basis for analysis of a system is the foundation provided by linear system theory, which assumes a cause–effect relationship for the components of a system

Definitions and Terminologies (1)

- ***System:*** A system is a combination of components that act together and perform a certain objective. A system is not limited to physical ones. The concept of the system can be applied to abstract, dynamic phenomena such as those encountered in economics. The word system should, therefore, be interpreted to imply physical, biological, economic, and the like, systems.



(a)



(b)

a. Block diagram representation of a system; **b.** block diagram representation of an interconnection of subsystems

Note: The input, $r(t)$, stands for *reference input*. The output, $c(t)$, stands for *controlled variable*.

Definition . A System is anything with inputs and outputs

Definitions and Terminologies (2)

- ***Plant:*** **A plant is a set of machine parts function together to perform a particular operation such as heating system, chemical reactor …. Power plant/station ..** a spacecraft
- ***Process:*** is a one where a progressively continuing towards a particular goal of an end-product. Example all kinds of systems in nature, chemical process, biological process (HUMAN creation) economic, and social

In this course, we shall call any physical object to be controlled (such as a mechanical device, a heating furnace, a chemical reactor, or a spacecraft) ***a plant or process***

Definitions and Terminologies (3)

- **Controlled Variable and Manipulated Variable:**
  - The controlled variable is the quantity or condition that is measured and controlled.
  - The manipulated variable is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable. Normally, the controlled variable is the output of the system.
  - Example: in controlling the temperate in Air condition system
    - Temperature is the controlled variable
    - Increasing the motor speed/pressure is the manipulated variable
- **Control:** measuring the value of the controlled variable of the system and applying the manipulated variable to the system to correct or limit deviation of the measured value from a desired value.

Definitions and Terminologies (4)

- ***Disturbances:*** A disturbance is a signal that tends to adversely affect the value of the output of a system. If a disturbance is generated within the system, it is called *internal, while an external* disturbance is generated outside the system and is an input.
- Example for external disturbance are :
  - Opening the windows under air condition operation
  - Open the fridge's door

Definitions and Terminologies (5)

- ***Feedback Control systems*:**

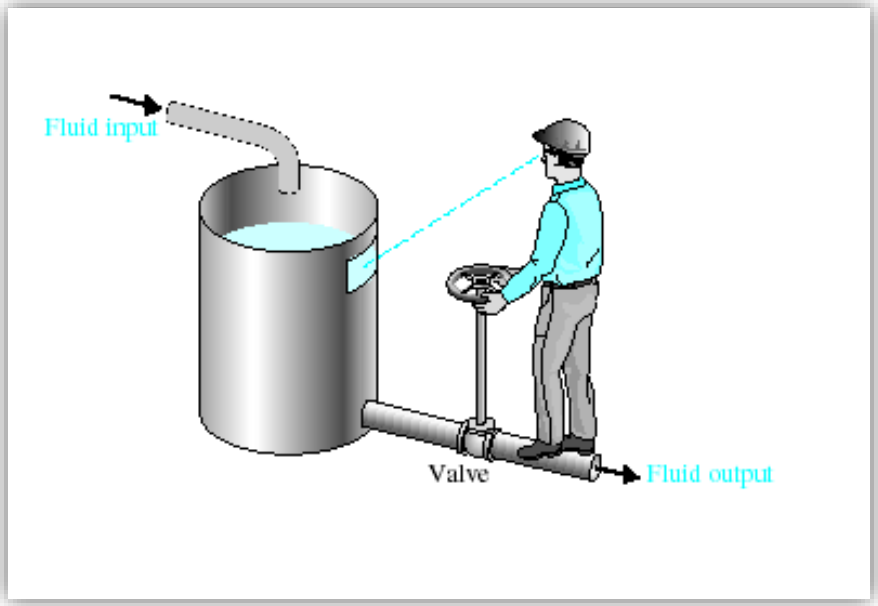
  A system that maintains a prescribed relationship between the output and the reference input by comparing them and using the difference as a means of control is called a *feedback control system.*

  An example would be a room-temperature control system. By measuring the actual room temperature and comparing it with the reference temperature (desired temperature), the thermostat turns the heating or cooling equipment on or off in such a way as to ensure that the room temperature remains at a comfortable level regardless of outside conditions.

What is “Automatic Control”?

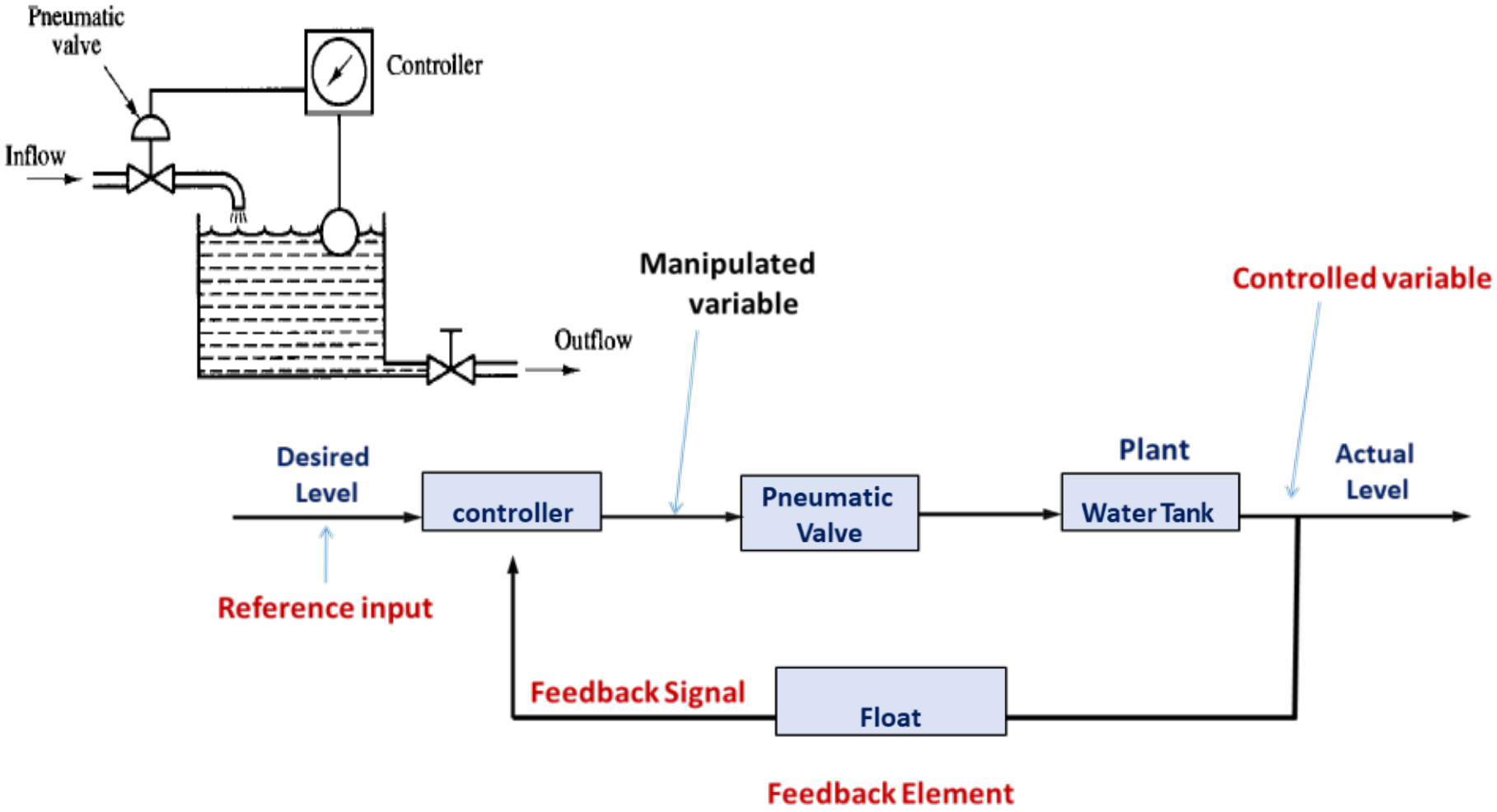
- Not manual!
- Why do we need automatic control?
  - Convenient (room temperature, laundry machine)
  - Dangerous (hot/cold places, space, bomb removal)
  - Impossible for human (nanometer scale precision positioning, work inside the small space that human cannot enter, huge antennas control, elevator)
  - It exists in nature. (human body temperature control)
  - High efficiency (engine control)
- Many examples of automatic control around us

Manual Liquid-level control system



A manual Control Systems 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.

Automatic Liquid-level control system



Open-loop control systems

- Open-loop control systems. Those systems in which the output has no effect on the control action are called open-loop control systems.
- In other words, in an open-loop control system the output is neither measured nor fed back for comparison with the input.
- In the presence of disturbances, an open-loop control system will not perform the desired task.
- Open-loop control can be used, in practice, only if the relationship between the input and output is known and if there are neither internal nor external disturbances.

Open-loop control systems

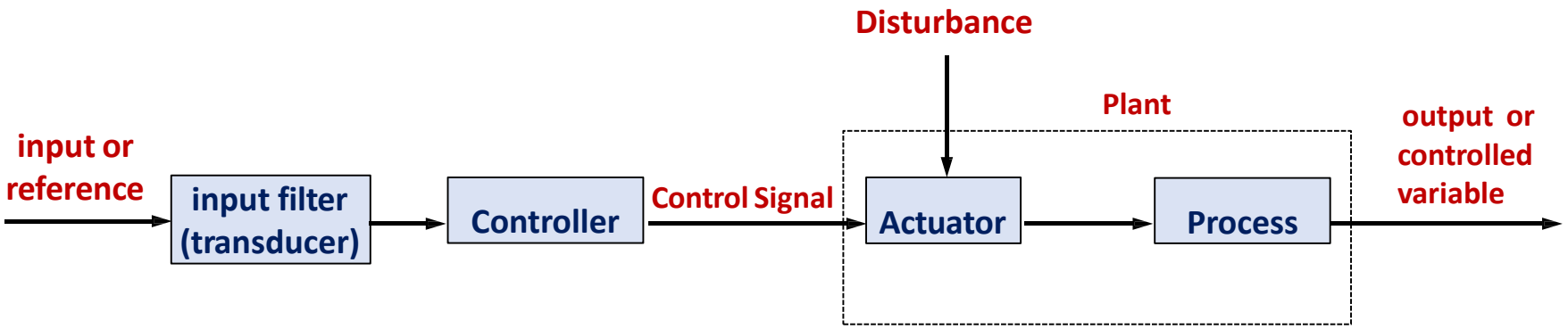
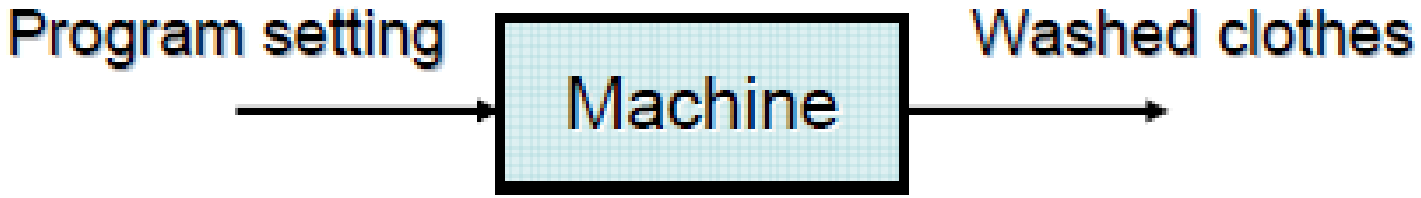


Fig. 1.2 An open-loop system

Example: Laundry machine

- A laundry machine washes clothes, by setting a program.



- A laundry machine does not measure how clean the clothes become.
- Control without measuring devices (sensors) are called ***open-loop control.***

Examples of an open-loop

- Common examples of an open-loop control system are :
  - A microwave oven set to operate for a fixed time.
  - Electrical Toaster in the kitchen set to operate for a fixed time and Temperature set point
  - TV remote control
  - Washing machines
  - Clothes dryer (timer based) !!!! How to make it closed loop.?

To convert the open loop system into closed loop : Add sensor and feed it back !!!

Open-loop control systems

Advantages:

- Simple construction, ease of maintenance, and less expensive.
- There is no stability concern.
- Convenient when output is hard to measure or measuring the output precisely is economically not feasible. (For example, in the washer system, it would be quite expensive to provide a device to measure the quality of the washer's output, cleanliness of the clothes).

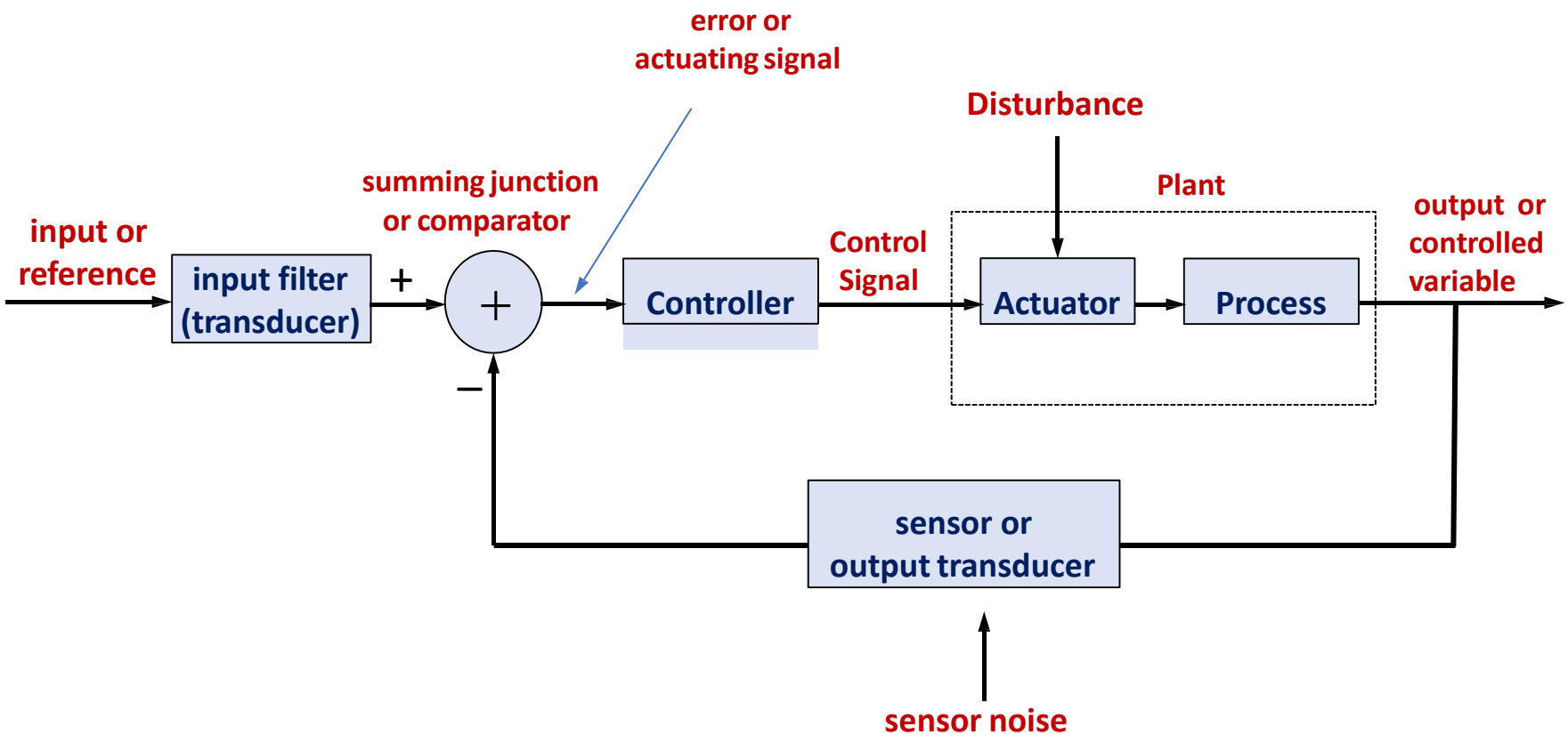
Disadvantages:

- Disturbances and changes in calibration cause errors, and the output may be different from what is desired.
- Recalibration is necessary from time to time.

Closed-loop control systems

- Closed-loop control systems. Feedback control systems are often referred to as closed-loop control systems.
- In practice, the terms feedback control and closed-loop control are used interchangeably.
- In a closed-loop control system the actuating error signal, which is the difference between the input signal and the feedback signal , is fed to the controller so as to reduce the error and bring the output of the system to a desired value.

Closed-loop (feedback) control



An example of a closed-loop control system

1. Thermostat --> furnace (constant temperature)
2. Air condition (constant temperature)
3. Toaster setting (light/dark) --> toast (IF the toaster has heat sensors)
4. Refrigerator cold/hot setting --> refrigerator inside temperature (constant)
5. Clothes dryer with moisture sensor
6. Driving CARS (Must be closed loop control system, otherwise …. Accidents will occur)

Closed-loop control systems

Advantages:

- High accuracy
- Not sensitive to disturbance
- Controllable transient response
- Controllable steady state error

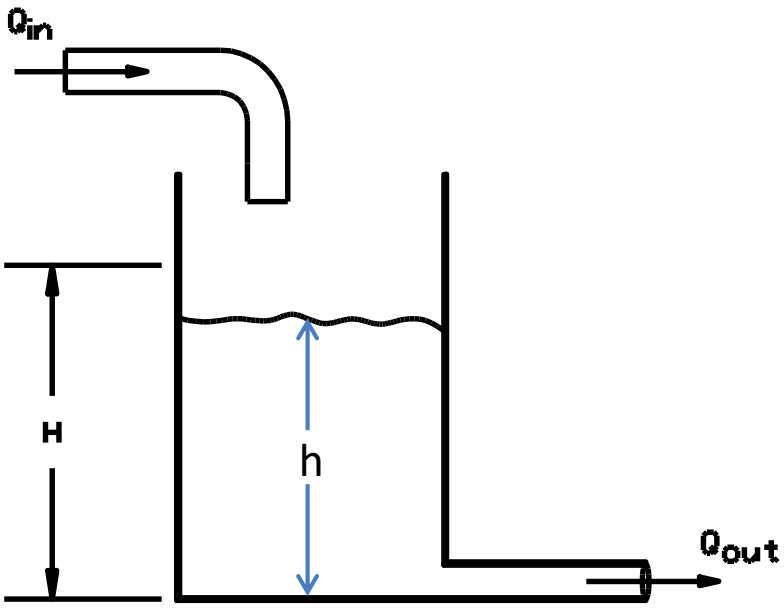
Disadvantages:

- More Complex, and More Expensive.
- Possibility of instability.
- Need for output measurement.
- Recalibration is necessary from time to time.

The Control Problem

Fundamental Control Concepts

Maintain a variable of process at a desired value while rejecting the effects of outside disturbances by manipulating another system variable.



Examples:

Heating and Cooling homes and offices
Automobile cruise control
Hold the position of a mechanical linkage
Maintain level in a tank

Q_{out} depends on h
If $Q_{out} = Q_{in}$, h constant
$Q_{out} > Q_{in}$, tank empties
$Q_{out} < Q_{in}$, tank overflows

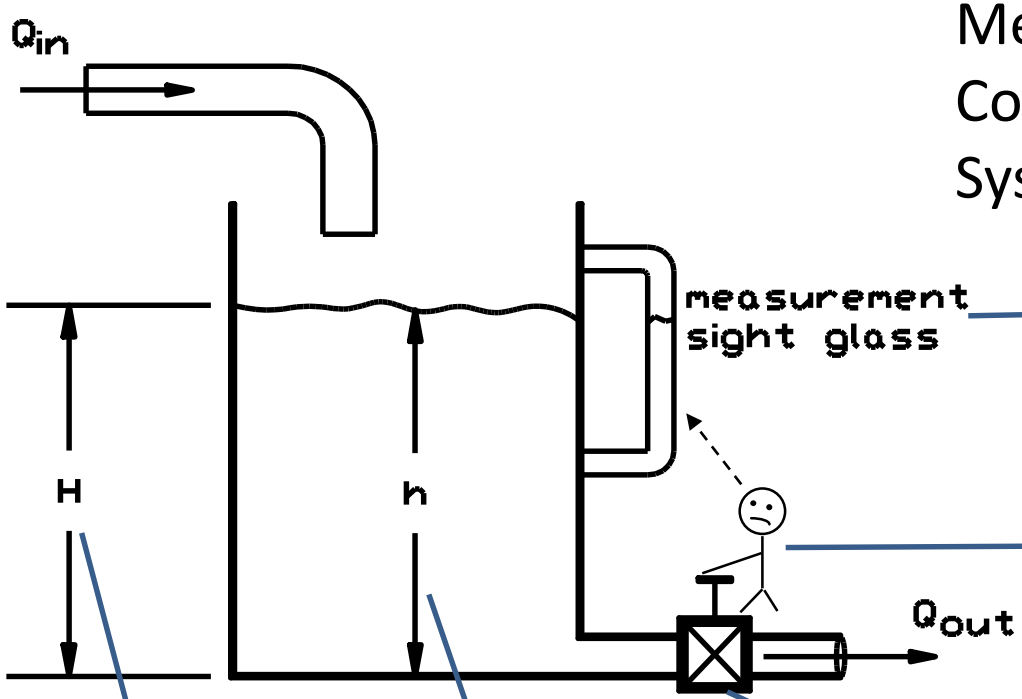
Basic Subsystems of Control

Feedback Control Subsystems

Measurement

Control decision

System modification



Measuremen t- sight glass

Control Decision Human adjusts Q_{out} to maintain h =H

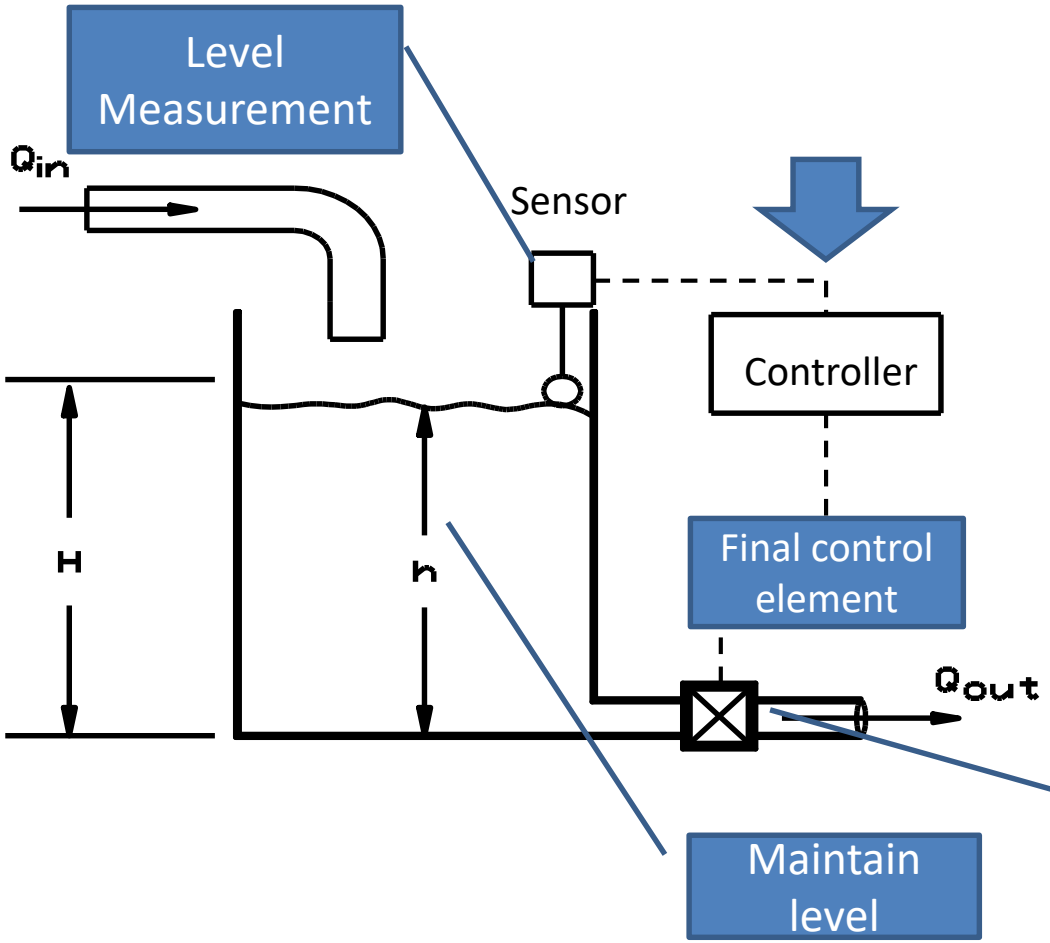
Reference (setpoint) h = control variable

Process- Maintain tank level

Final Control Element Valve

Automatic Control Systems

Use sensors and analog or digital electronics to monitor and adjust system



Elements of Automatic Control

Process – single or multiple variables

Measurement – sensors

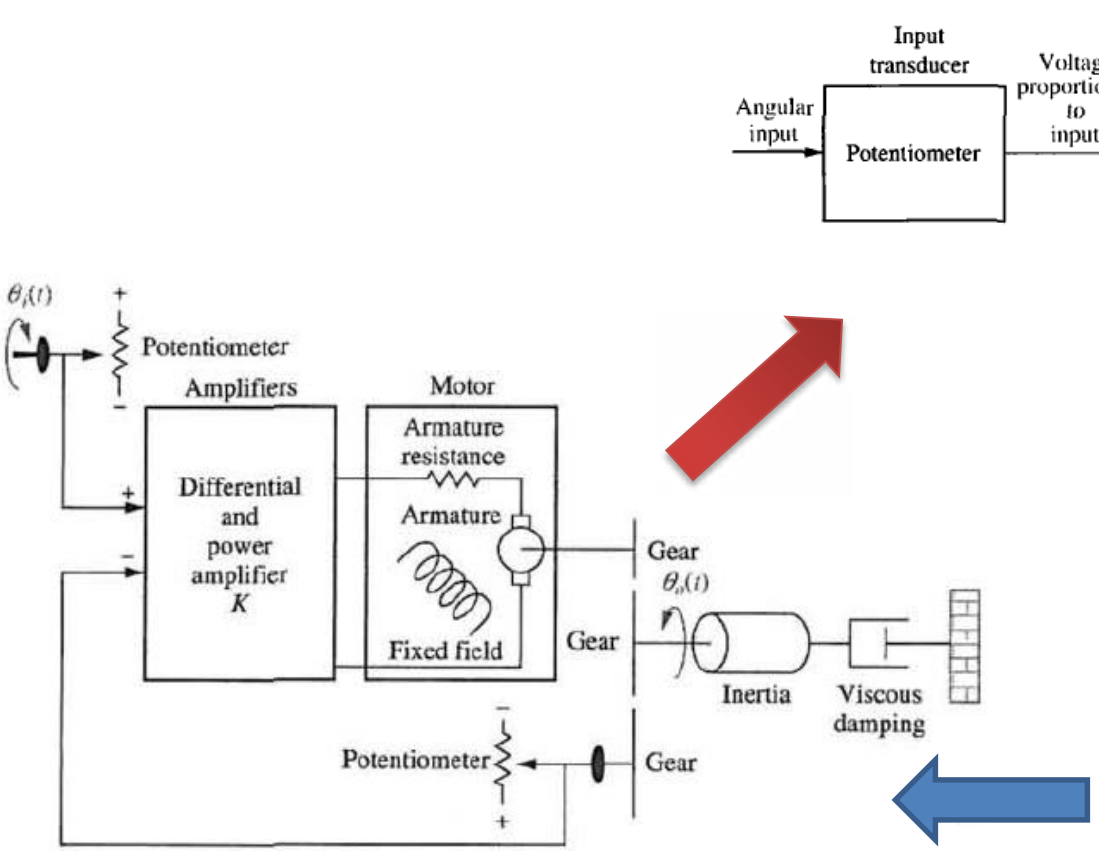
Error Detection – compare H to h

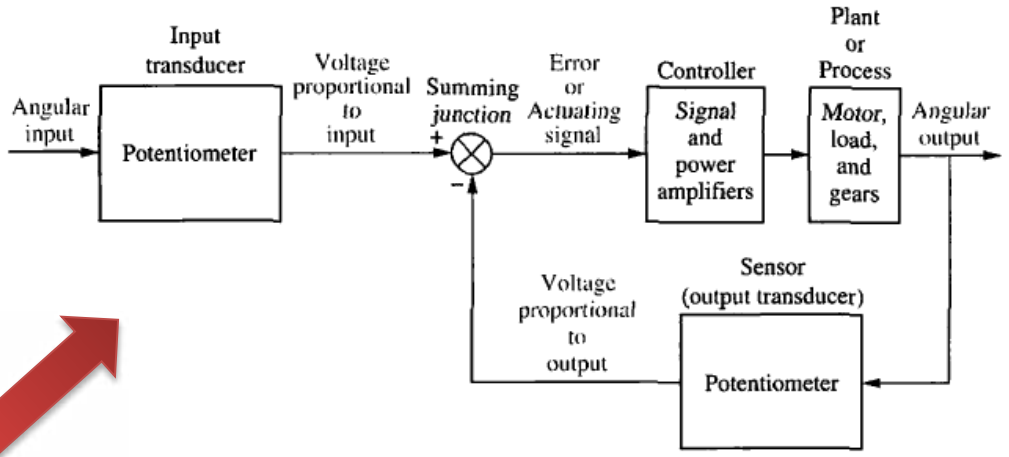
Controller – generate corrections

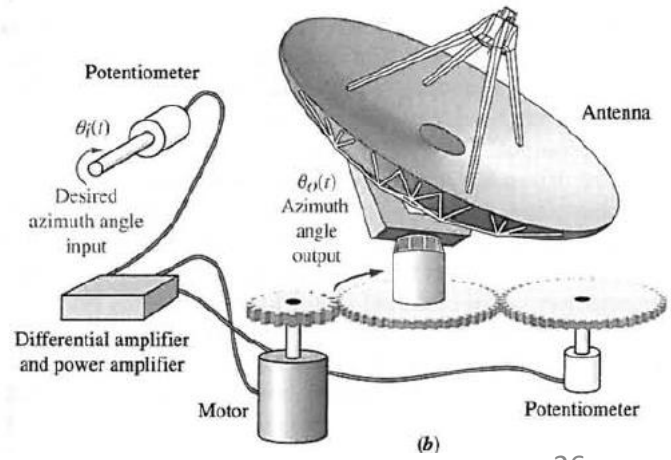
Final Control Element – modify process

Example: Antenna

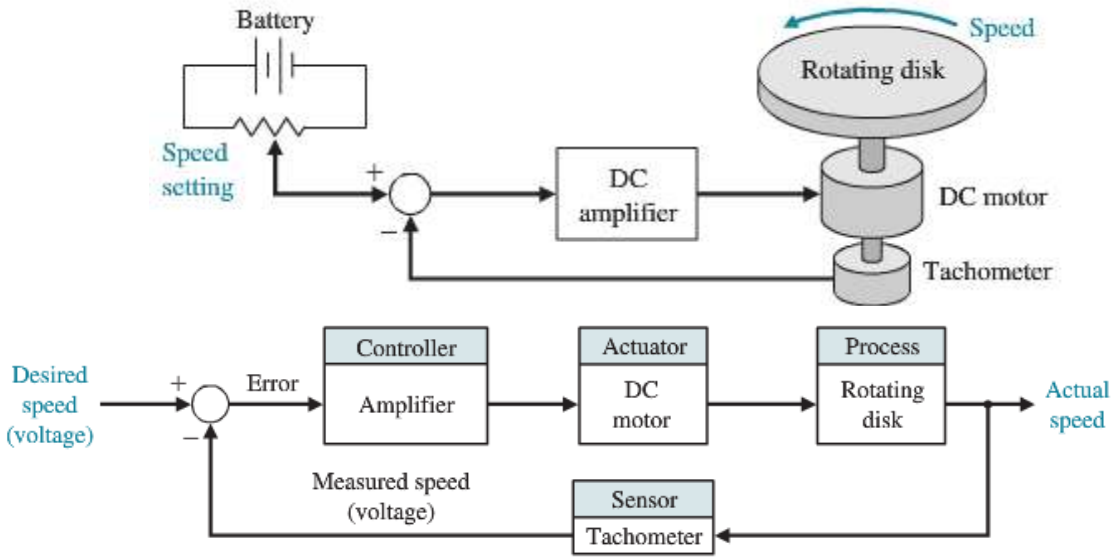
- Antenna Azimuth: An Introduction to Position Control Systems



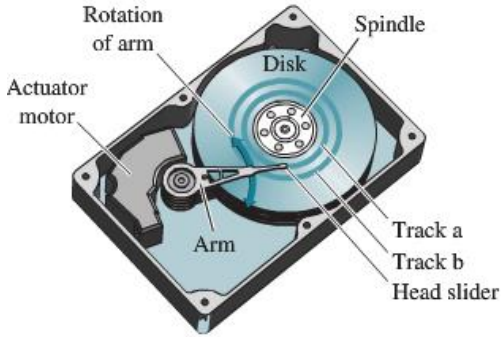


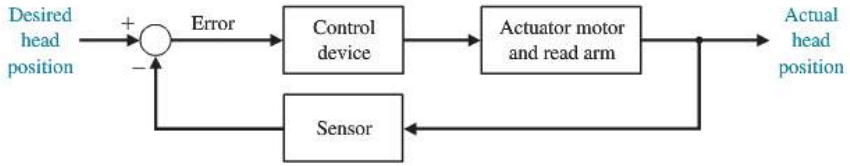


Control Applications



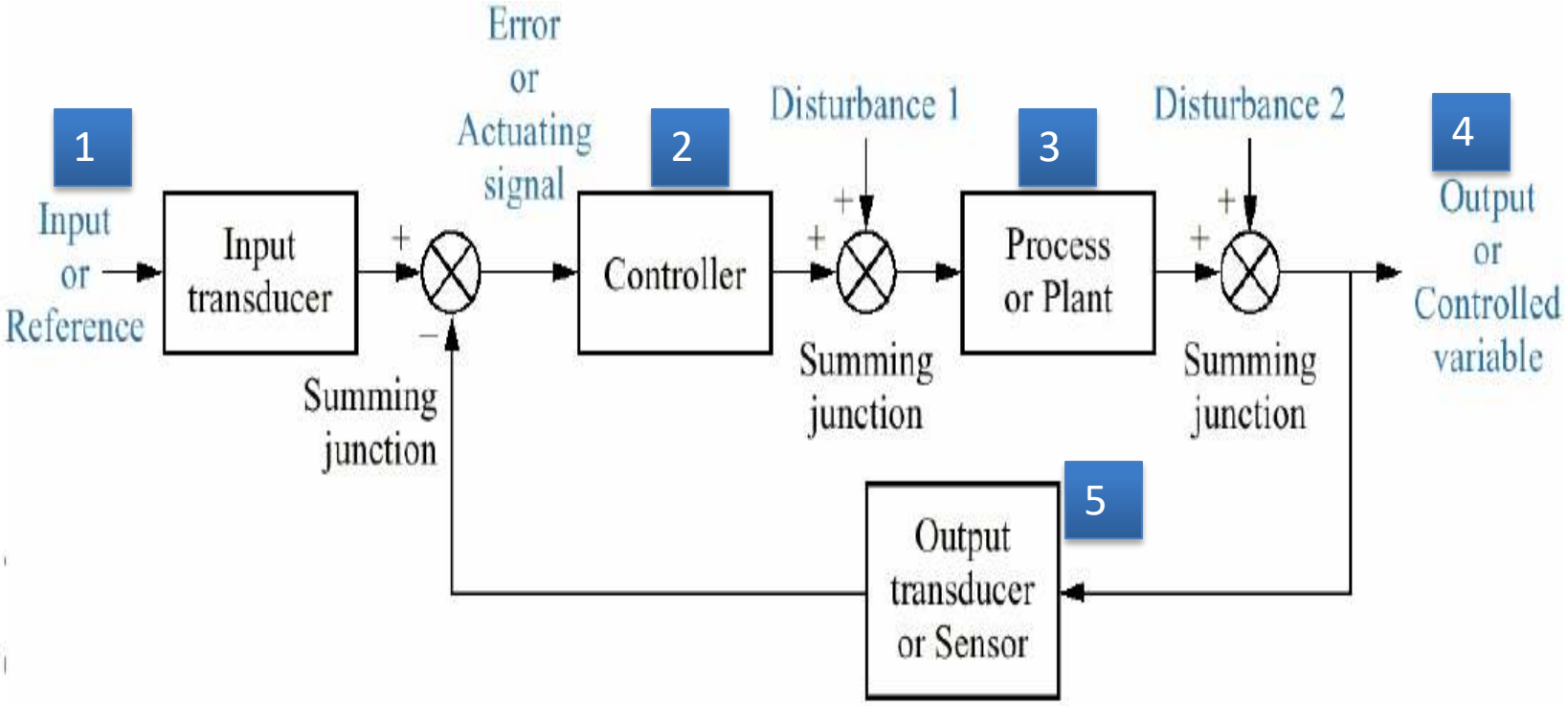
control speed of a rotating disk.





Closed-loop control system for disk drive

General Structure of Control Systems



Elements in control systems:

- System/Plant/Process
- Sensors
- Actuators
- Controllers

Properties of control systems:

- Stability
- Performance
- Robustness

Control System Components

- System, plant or process (- The portion of the system (or operation) to be controlled
- Actuators (**converts** the **control signal** to a **power signal**; (i.e., a device that causes the process to provide the output).) such as: Relay, hydraulic motor, hyd. cylinder
- Sensors (provides measurement of the system output)
- Reference input (represents the desired output)
- Error detection (forms the control error)
- Controller (operates on the control error to form the control signal, sometimes called compensators)

Control System Classification (1)

- According to number of loops:
  - **Single loop** Control System
  - **Multi-loop** Control System : consists of inner loop and outer loop.

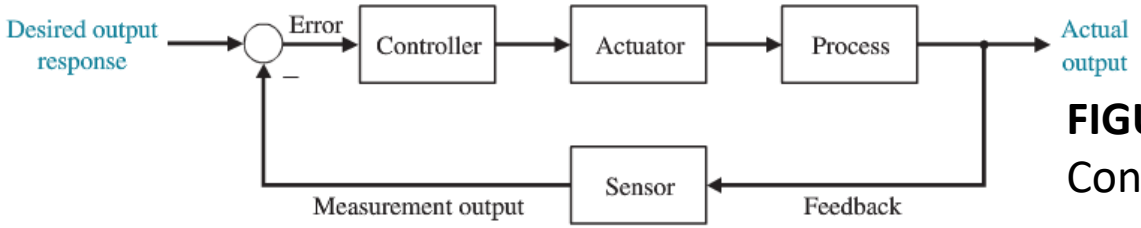


FIGURE single loop feedback Control system (with feedback).

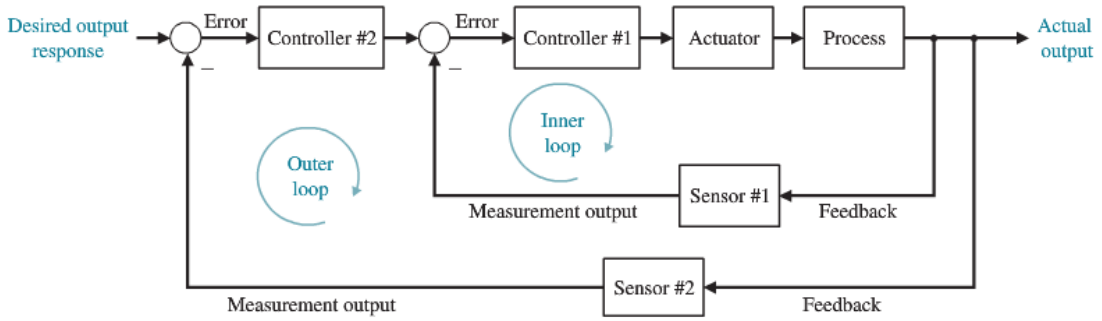
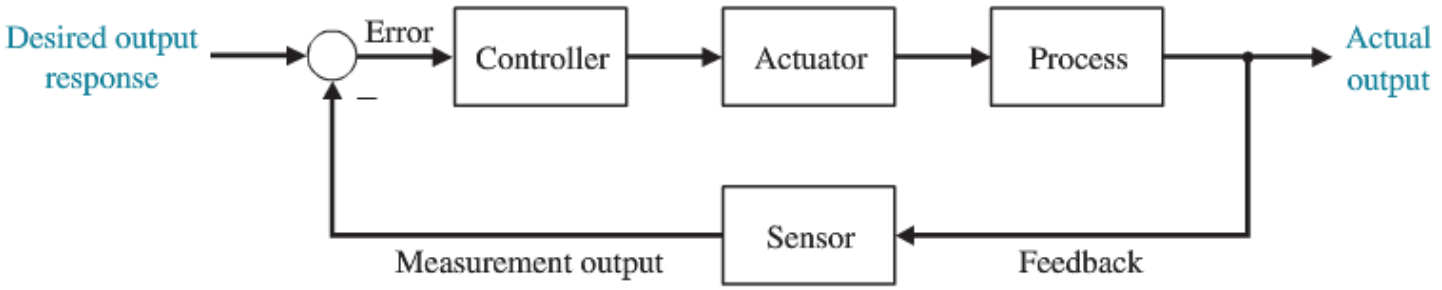


FIGURE Multi-loop feedback system with an inner loop and an outer loop.

Control-System Classification(2)

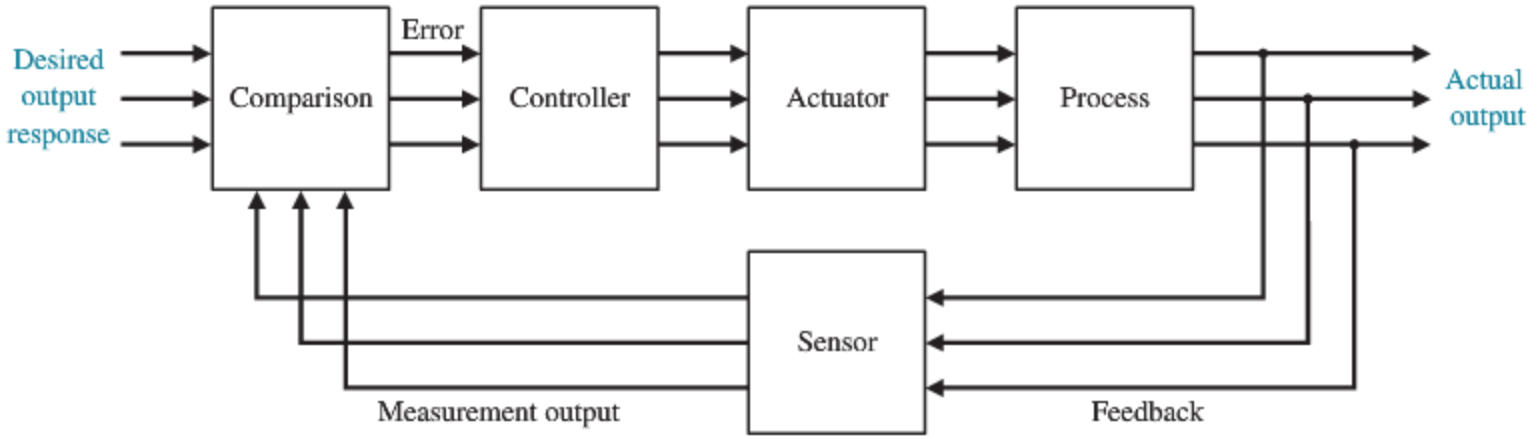
- According to Input/output channel
  - Single variable Single Input Single output (**SISO**)
  - Multivariable Control System : Multi Input Multi output (**MIMO**)

  - The SISO system is the focus of this course .



Multivariable Control System

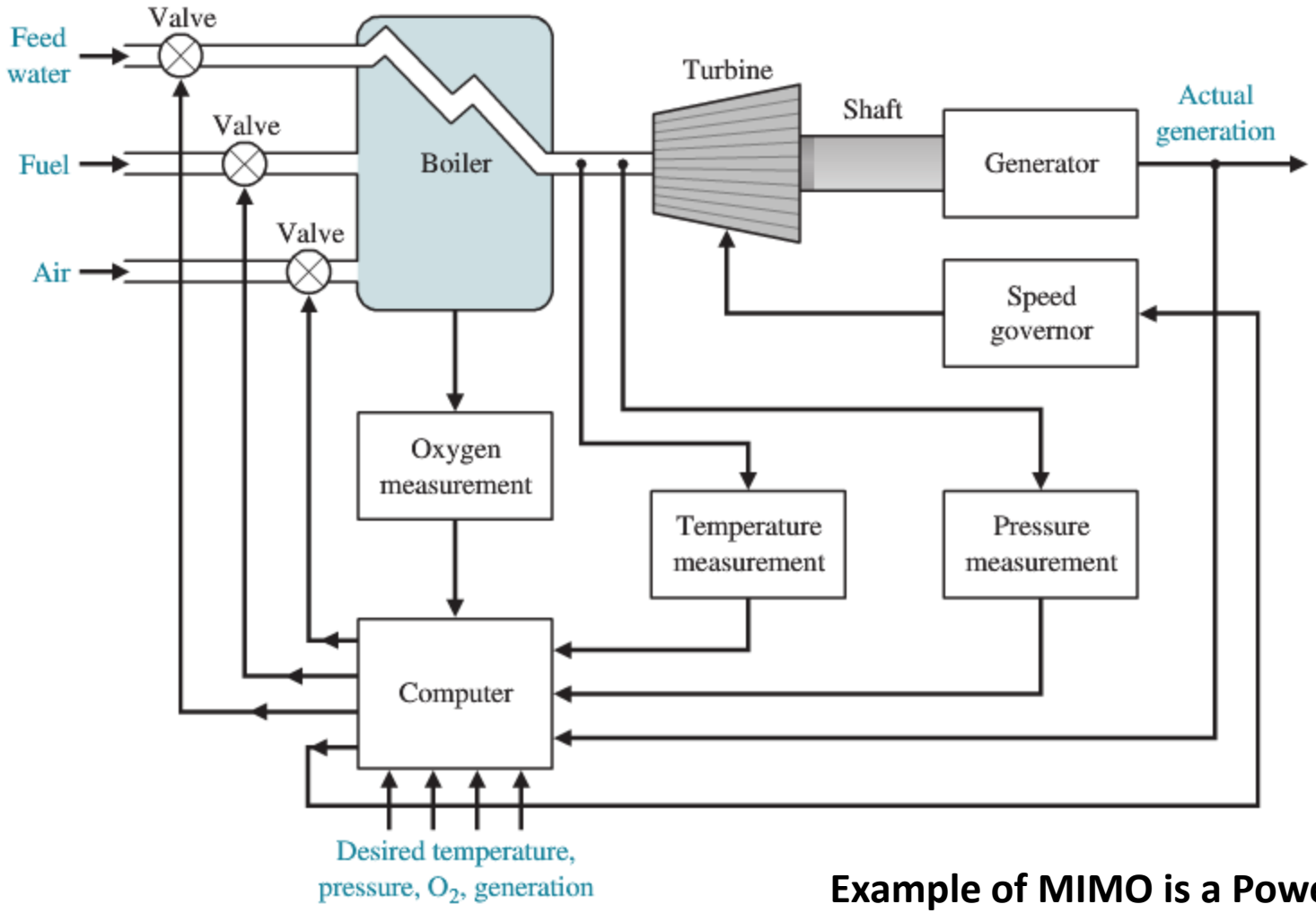
- Due to the increasing complexity of the system under control and the interest in achieving optimum performance, the importance of control system engineering has grown in the past decade. Furthermore, as the systems become more complex, the interrelationship of many controlled variables must be considered in the control scheme. A block diagram depicting a multivariable control system is shown in Figure 1.6.



Example of MIMO ???

FIGURE Multivariable control system.

Multivariable Control System Model



Example of MIMO is a Power Plant

Advantages of Control Systems (1)

We build control systems for four primary reasons:

- 1. Power amplification
- 2. Remote control
- 3. Convenience of input form
- 4. Compensation for disturbances

Advantages of Control Systems (2)

With control systems we can move large equipment with precision that would otherwise be impossible.

Example: We can point huge antennas toward the farthest reaches of the universe to pick up faint radio signals;

- controlling these antennas by hand would b impossible.
- Because of control systems, elevators carry us quickly to our destination, automatically stopping at the right floor .
- We alone could not provide the power required for the load and the speed; motors provide the power, and control systems regulate the position and speed.

Chapter summary

After the completion of the chapter, student should be able to (demonstrate) explain :

- Define some control terminologies (system, plant, process, actuator ,…)
- know the control system type/ classification
- Differentiate b/w open and closed loop system
- Recognize the control component from a given physical control system
- Recognize the structure(components) of a given control system and the role for each component.