Lesson 1
BME 444 - Control Systems

By the end of this lecture students will be able to:
- Define control system, system law, transfer function, system properties
- Explain how engineers and scientists approach systems
- Define open loop and closed loop control system
- Define input/reference, controller, summing junction, process/plant, output/controlled variable
- Draw a block diagram of a system given a description

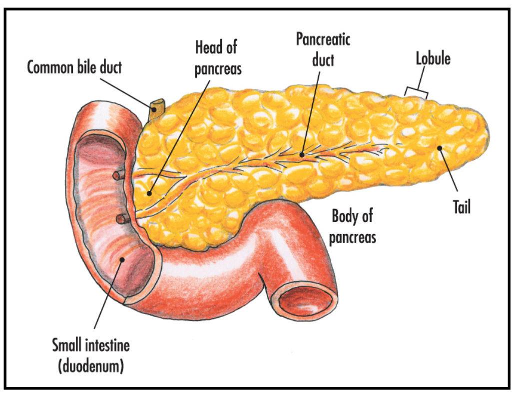
1. Systems

A system converts inputs to outputs. Inputs can be voltages, chemical species, forces, displacements, and so on. Outputs are the same. Components inside the system convert the inputs to outputs and can be resistors, capacitors, springs, gears, levers, chemical reactions, etc.

The components inside the system are modeled by equations called laws. The equations have constants that are called properties. All systems can be represented by a *block diagram*:

Exercise 1: Examples of systems are listed below. Sketch a block diagram of each.

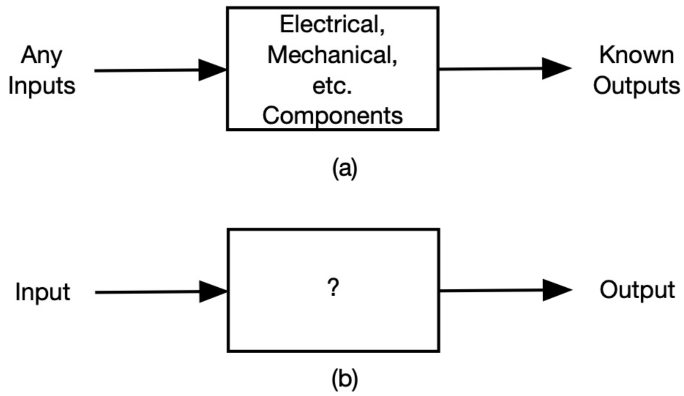
Implantable Pacemaker



Pancreas

2. Looking at systems from different vantages

There are a couple of ways to think about systems. Engineers are typically concerned with designing systems from scratch. Their job is to pick components and assemble them so that the system will give specific outputs for certain inputs. In contrast, scientists are often interested in giving a system inputs and measuring the outputs with a goal of figuring out what components are in the system.



Visualizing systems. (a) Engineer's view. (b) Scientist's view.

3. Example physical system

Imagine a small room that has a spring attached to the ceiling. The spring can only move vertically. A person can apply a force, $F(t)$, to the spring and the spring will stretch by an amount $y(t)$. We drop the (t) because we assume everything changes with time. This is a simple system in which the input is F and the output is y.

What is the system law that relates input to output? The force generated by the spring is proportional to its displacement. This force is equal and opposite to the applied force.

$$F_s = F \qquad \text{and} \qquad F_s = Ky$$

$$\text{so } F = Ky \text{ or } y = \frac{F}{K}$$

The block diagram for this system would look like:

In other words, the input times the system law gives the output. The system law, $1/K$, is called the *transfer function* of the system because it relates inputs to outputs.

Each line gets a quantity (force, displacement, etc.)

3. Control Systems

A control system is a collection of subsystems/ processes/plants that obtain a desired output with desired performance given an input. (Nise, 1993)

As a concrete example, consider a central home heating unit. The input is the temperature you set on the thermostat. The output is the house temperature. The system you are modeling is the thermal properties of the house.

Graphical responses of the system are crucial to understanding system behavior. Let's assume that the house is initially at 68 ºF and you adjust the thermostat to 75 ºF. What would a plot of the house temperature look like versus time?

3.1. Open Loop Systems

Control systems come in two configurations: open loop and closed loop. To continue with the analogy of a home furnace, imagine you are in a house and the only source of heat is a large space heater. On the space heater, there is no temperature control, just Low, Med, and High. What does the block diagram of this system look like?

Two drawbacks of open loop systems: (1) they cannot correct for disturbances and (2) they do not know when the desired setting is reached. In the case of the space heater, it applies constant heat regardless of how hot the room gets.

Important note on block diagrams: they do not have to have the number of blocks shown above. They can have more, or less. It's up to you, as an engineer, to figure out how many blocks they have and in what configuration.

3.2. Closed Loop Systems

Systems with these configurations are also called *feedback* control systems.

Now let's assume you upgrade your home and you have a standard furnace with a thermostat on the wall. What does the block diagram of this system look like?

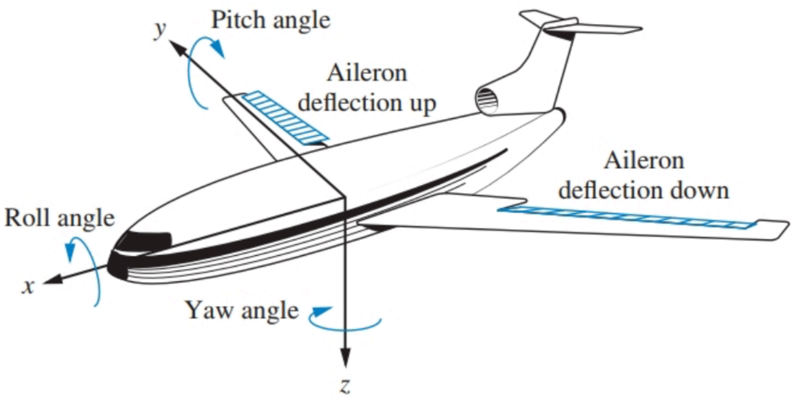
4. Analysis and Design Objectives

We use controls systems in two different ways in BME:
(1) Analysis = making a model of the system (physiology)
(2) Design = making a control system with specific characteristics (medical device design)

5. Practice Problems

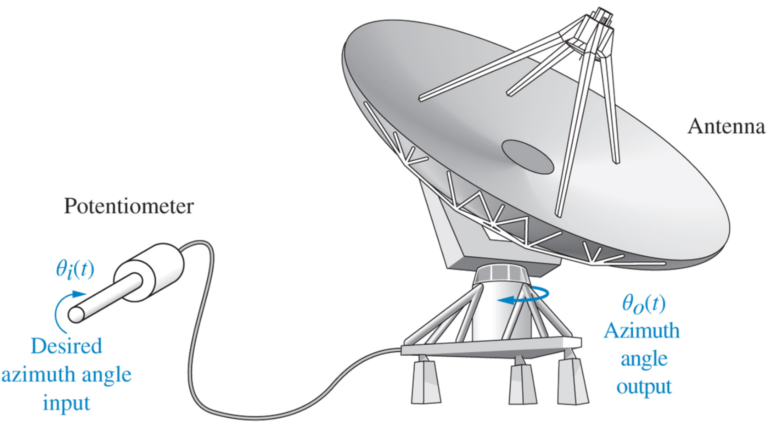
(1) A temperature control system operates by sensing the difference between the thermostat setting and the actual temperature and then opening a fuel valve an amount proportional to this difference. Draw a functional closed-loop block diagram of the system, identifying the input and output transducers, the controller, and the plant. Also, identify input and output signals of all the subsystems.

(2) An aircraft's attitude varies in roll, pitch, and yaw as shown below. Draw a functional block diagram for a closed-loop system that stabilizes the roll as follows: The system measures the actual roll angle with a gyro and compares the actual roll angle with the desired roll angle. The ailerons respond to the roll-angle error by undergoing an angular deflection. The aircraft responds to this angular deflection, producing a roll and rate. Identify the input and output transducers, the controller, and the plant. Identify the nature of each signal.

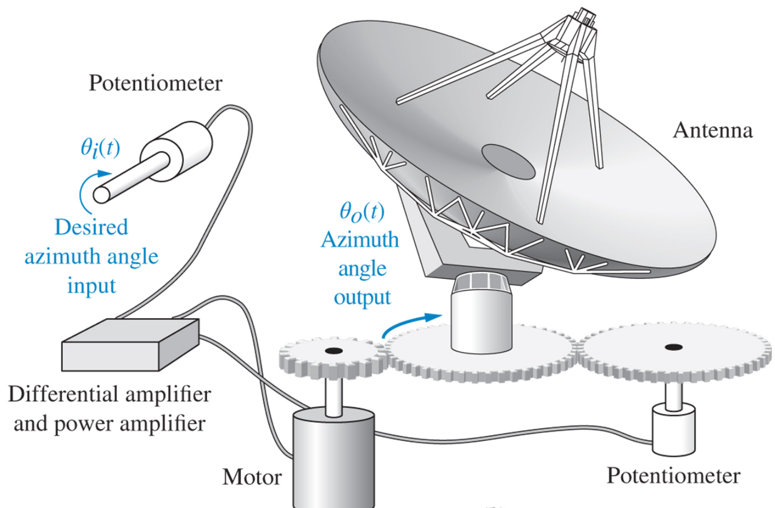


6. Example of the Design Process

i. Determine requirements: “We want to be able to turn a knob and have the radar point in that direction”

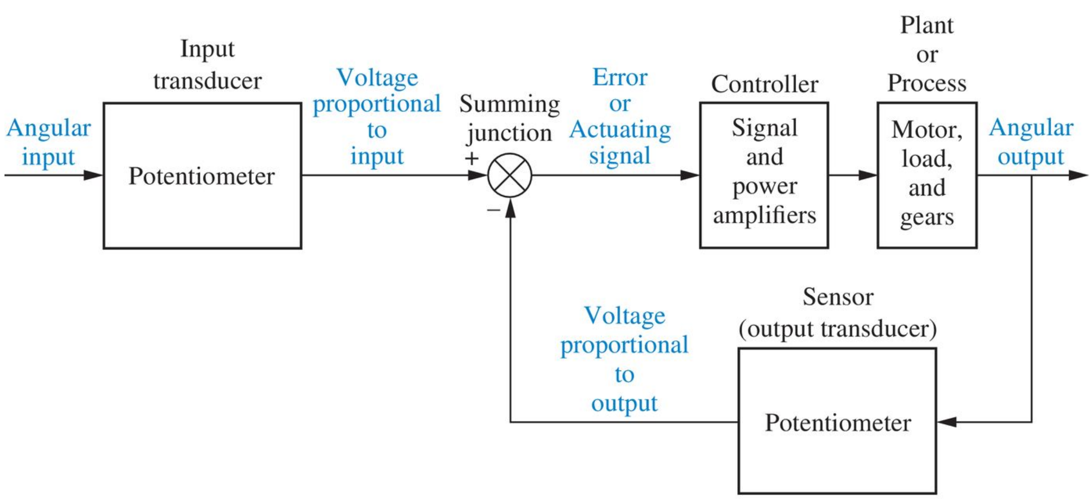


(a)



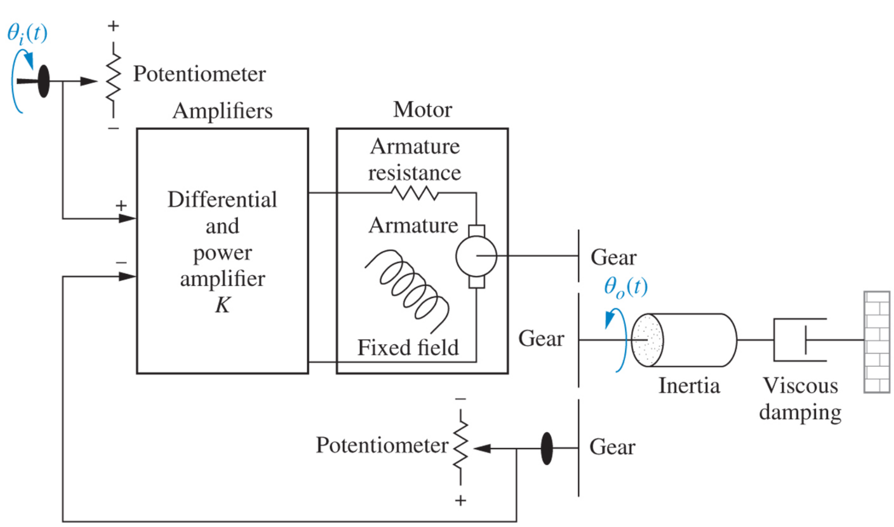
(b)

ii. Functional Block Diagram:



(d)

iii. Schematic



(c)

iv. Equations

$$a_n\frac{d^nc(t)}{dt^n} + a_{n-1}\frac{d^{n-1}c(t)}{dt^{n-1}} + \ldots + a_0c(t) = b_m\frac{d^mr(t)}{dt^m} + b_{m-1}\frac{d^{m-1}r(t)}{dt^{m-1}} + \ldots + b_0r(t)$$

v. Simplify
vi. Analyze, design and test