Introduction to Control Systems

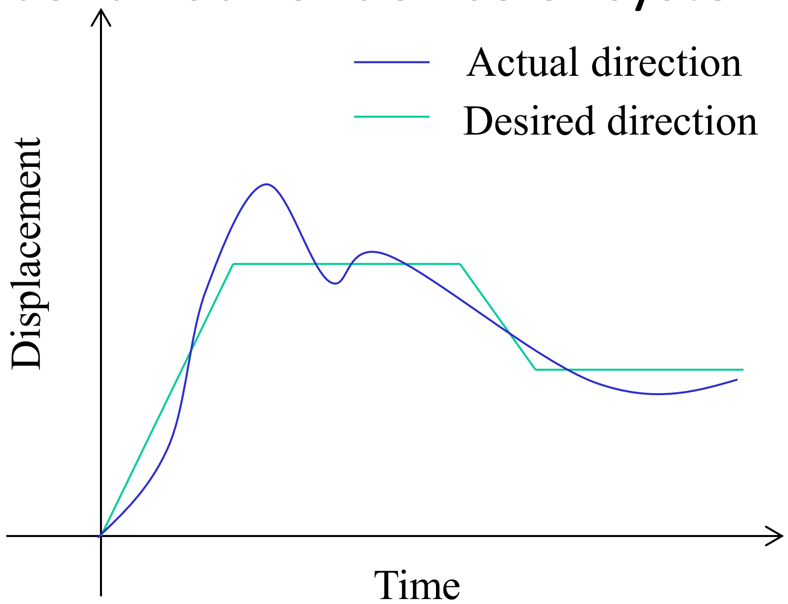
XMUT315 Control Systems Engineering

Topics

- Why do we need to study control systems?
- Revision on the system
- Feedback
- Open loop/closed loop
- Time response
- Dynamics of the system
- Analysis
- Models

Control?

- A control system is needed to manage and regulate the behaviour of device or system.



Plot:

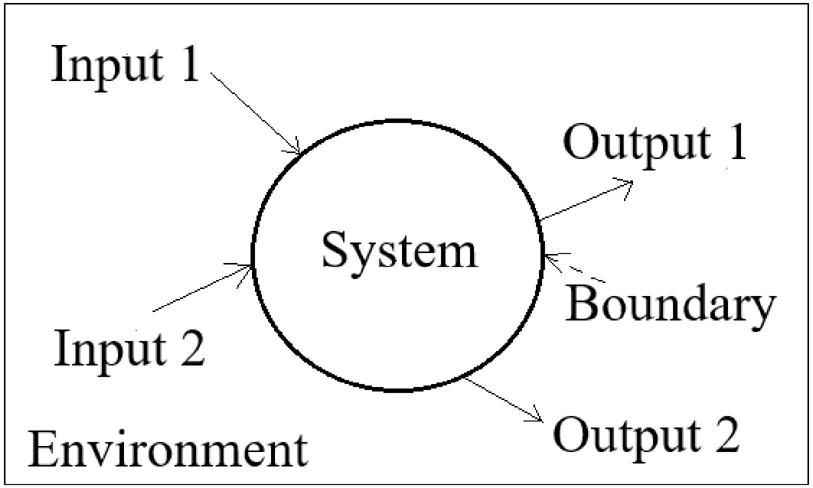
1. Input distance to the car suspension system from the car going up the curb (a step) over time.
2. Output the distance of the driver at the same time.

Why Use Control?

- Achieve the aims of your system efficiently and effectively:
  - track reference.
  - speed of response.
  - avoid overshoots.
  - avoid steady-state errors.
- Autonomous operation.
- Avoid disturbances.
- Minimise noises.
- Understand natural systems.

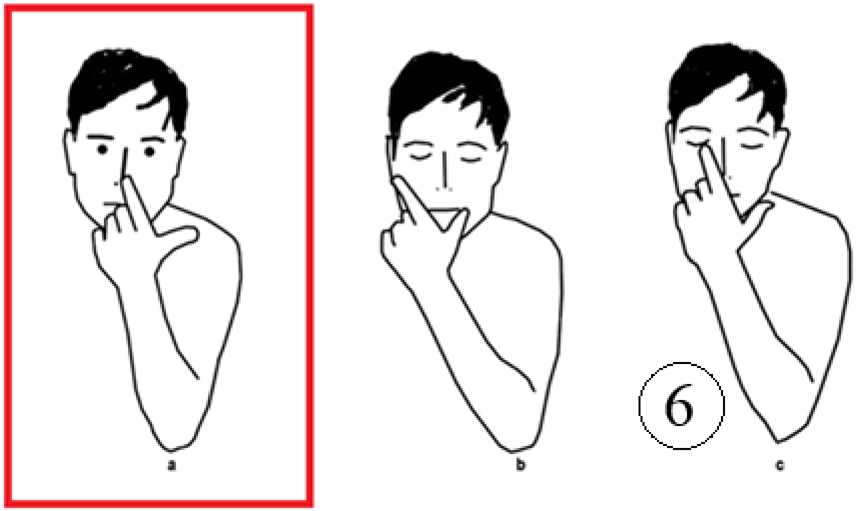
What is a System?

- System takes input(s) and gives out output(s).
- Systems exist in an environment, and they have a clear boundary with it.
- Systems are built of signals (i.e. variables), constants, and differential operators.
- In practice, especially for complex systems, systems are often made up of sub-systems!



Are Systems Perfect?

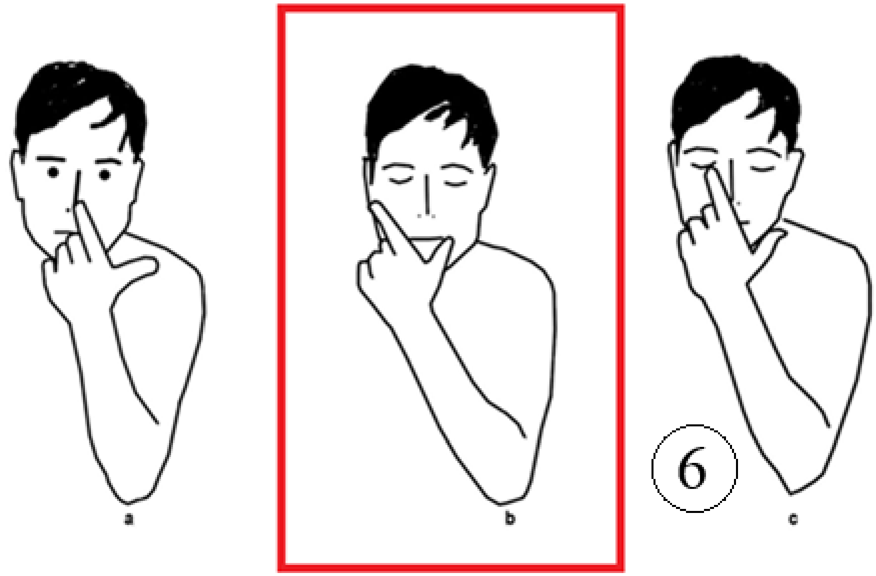
1. Open eyes (e.g. a system with feedback):
   - Extend your arms out at shoulder height.
   - Touch the tips of your little fingers in front of your nose!



Note: having awareness about the state and condition of the system improves your ability to manage and control the system.

Are Systems Perfect?

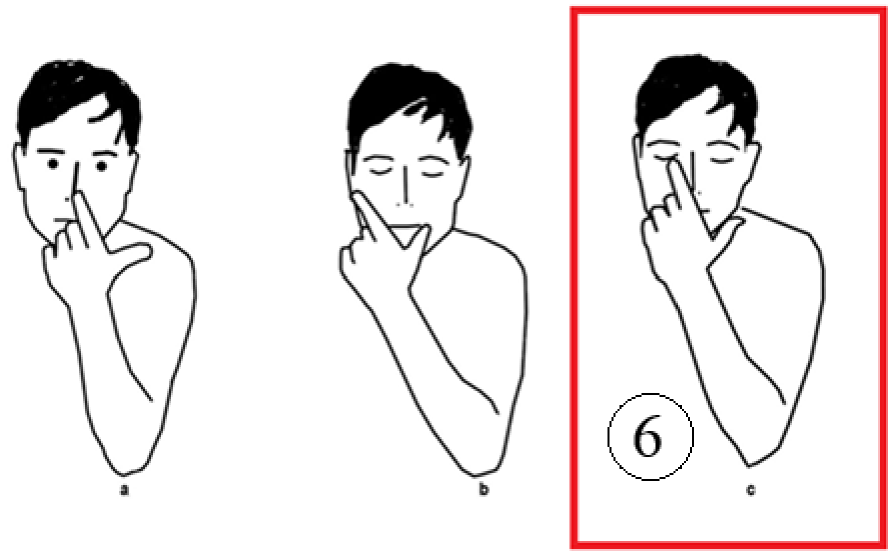
2. Close eyes (e.g. a system without feedback):
   - Extend your arms out at shoulder height.
   - Touch the tips of your little fingers in front of your nose.



Note: Without knowing the current state and condition of the system, it is difficult to manage and control the system.

Are Systems Perfect?

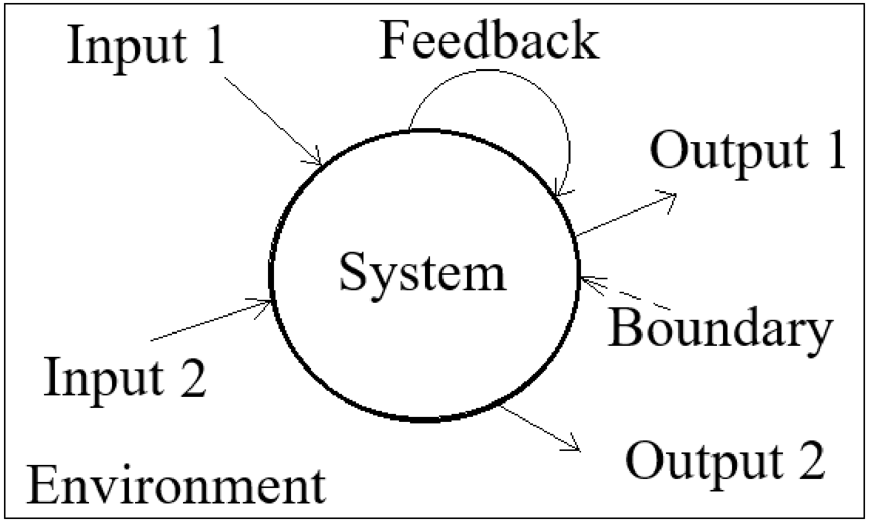
3. Strangeness (e.g. a system with disturbances):
   - Make a circle with your right foot going in the clockwise position.
   - While you are doing that, draw a six with your right hand.



Note: noise and disturbance in the system complicate your ability to manage and control it.

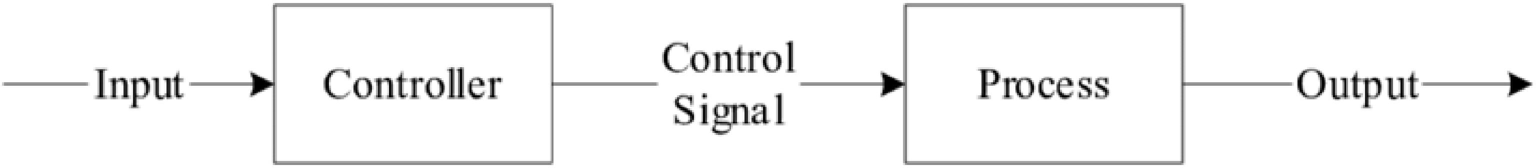
Feedback in System

- In feedback, the *output signal* is fed back to the *input signal.*
- Type of feedback could be (-) negative feedback (subtracting) or (+) positive feedback (adding up).
- In control systems, feedback typically consists of five basic components: input, process being controlled, output, sensing elements, and controller/actuating devices.



Open Loop vs. Closed Loop

1. Open loop: it is simple to implement but does not know the actual value of the control variable, so it is vulnerable to changing the conditions.
2. Closed loop: it accounts for changes in conditions, but at the expense of *increased complexity* and can become *unstable* if care is not taken in its design.



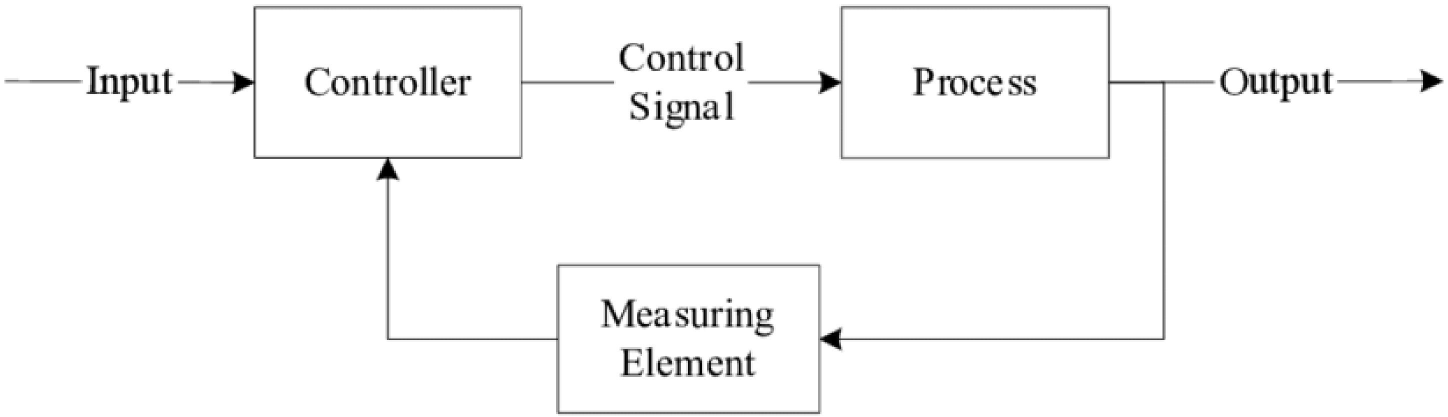
Open Loop System

Open Loop vs. Closed Loop

Questions:

1. Explain the advantages and disadvantages of open-loop control.
2. Explain the advantages and disadvantages of closed-loop control.

Note: Closed-loop control is sometimes called feedback control.



Closed Loop System

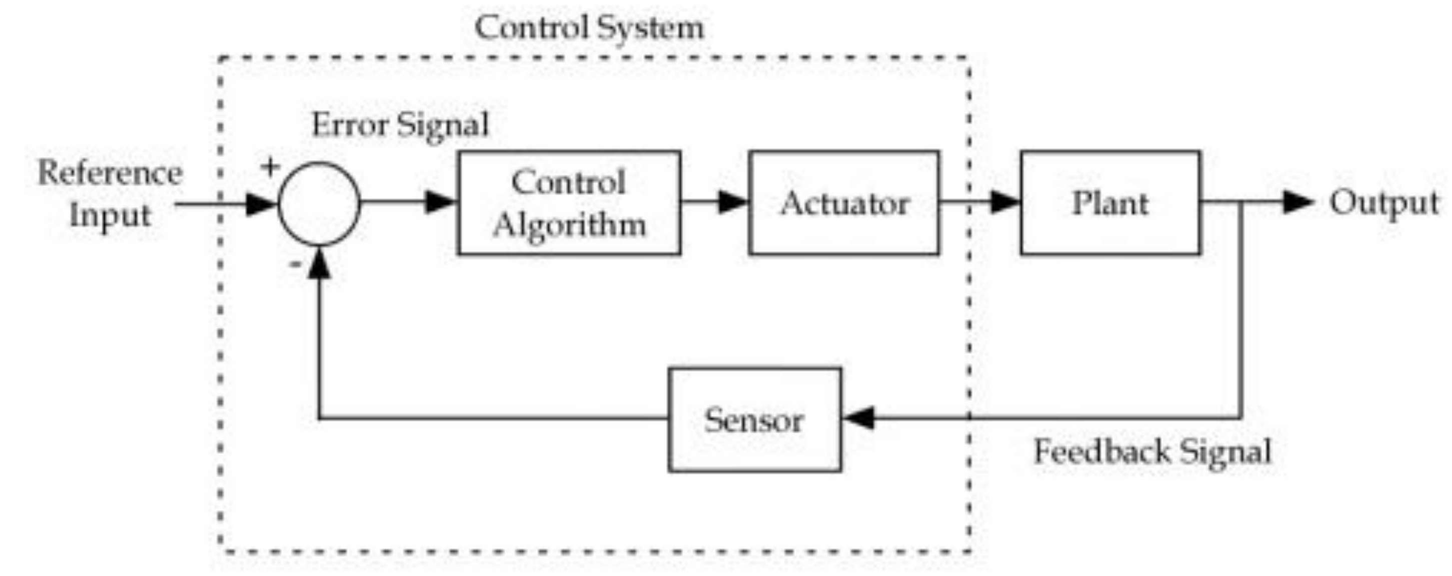
Engineering Systems

- An engineering system is a set of components connected together to accomplish a useful task.
- When building up a model system:
  - Components should be easily identifiable.
  - Components should have a simple and clearly defined interaction with other components.
  - Components numbers should be minimised.

Identification and Modelling of System

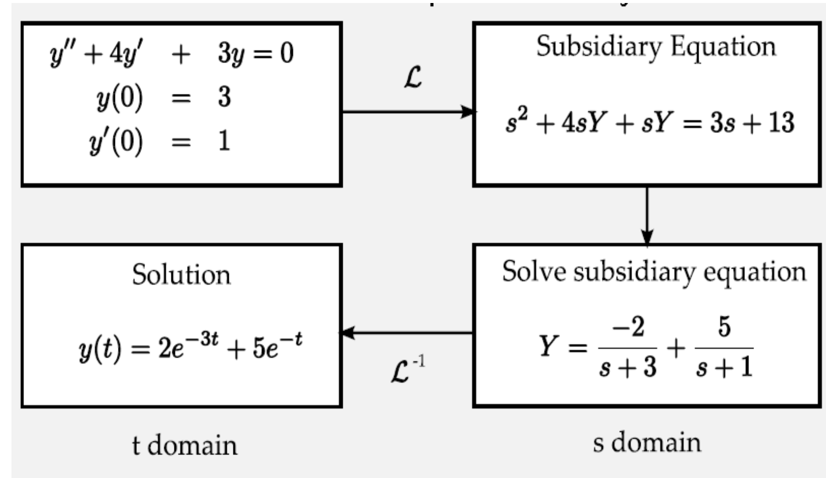
To determine the input-output relationships of the system:

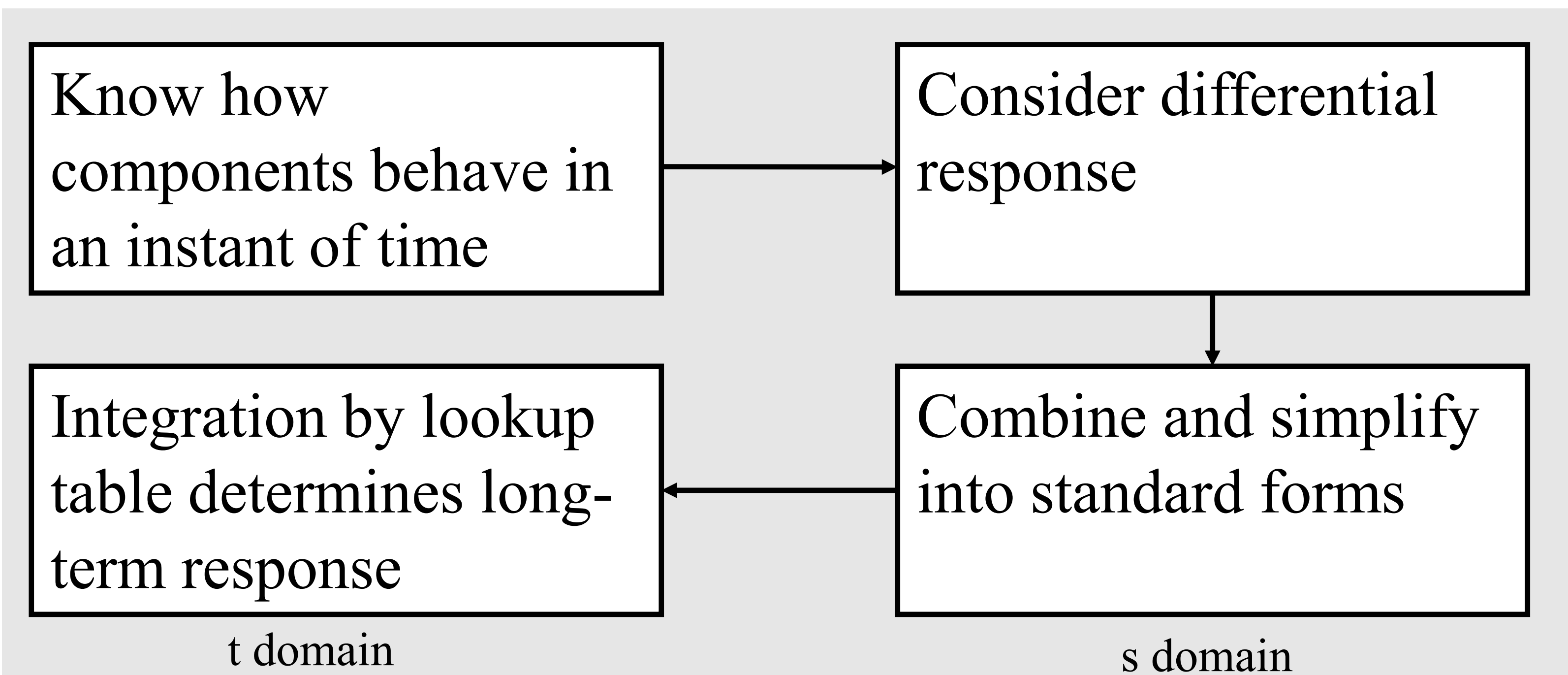
- Use block diagram components [basic block, summing junction, and take-off point].
- Identify the input signal [a variable].
- Consider internal signals [modified variables].
- Determine the output signal [another variable].



Laplace Operator ‘*s*’

In the derivation of the system equation, the Laplace transform is useful for eliminating the mathematical differentiation and integration and replacing them with simple algebraic processes.



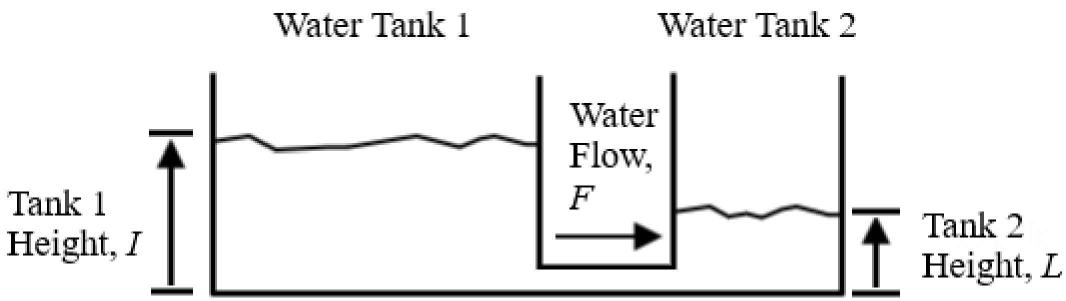


Control Systems Analysis and Design

- Evaluate and identify key components or parts of the system.
- Determine the model of the system (e.g. especially for the complex systems).
- Apply appropriate analysis and/or design techniques.
- Measure and test the relevant parameters of the system.
- Identify problem and/or potential improvement or enhancement in the system.
- Design an effective solution to address the problem and to realise the improvement or enhancement.
- Further measurement or test to ensure that the problem is fixed and the solution is successful.

(Two) Water Tanks Model

As an introduction, consider dynamic systems: these *change with time.* As an example, consider a water system with two tanks:

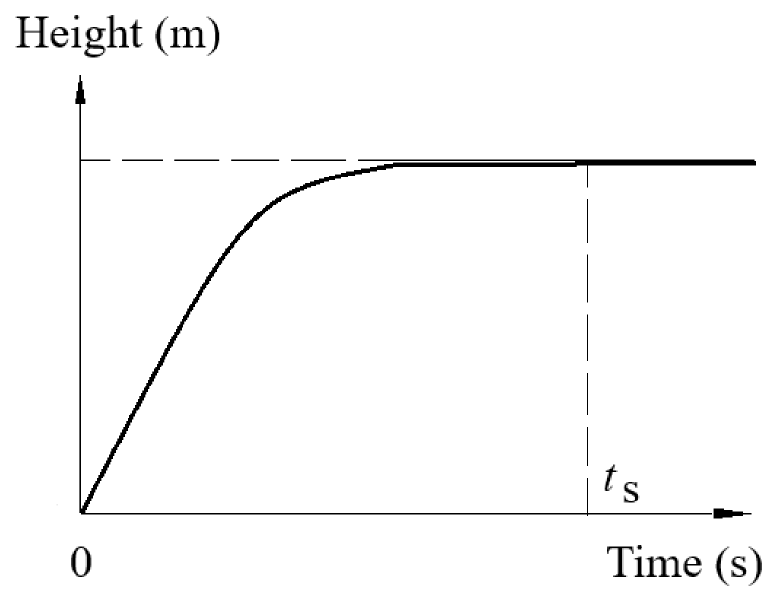


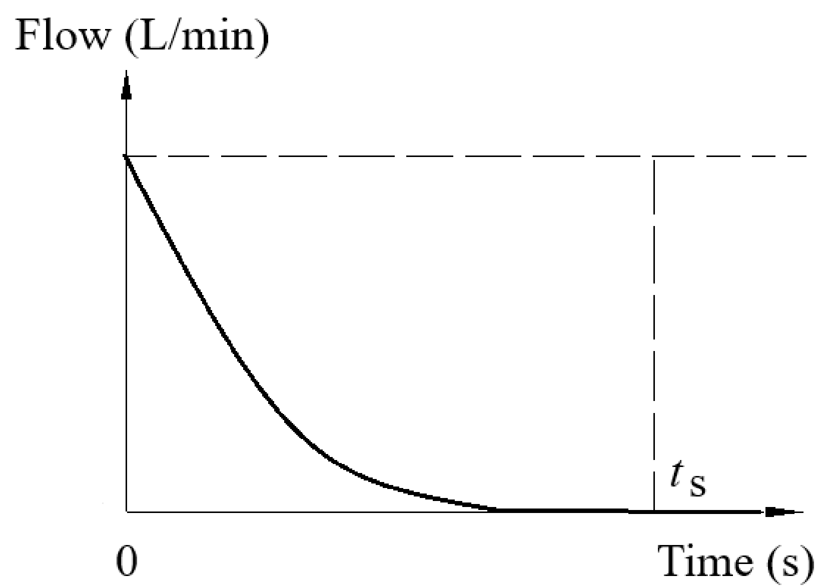
- Water will flow from the first tank to the second tank.
- When will it stop following?
- Stops when the levels are equal.
- Why stop then? Why flow at all?
- Plot the time response of the system?

Dynamic Flows in Water Tank Model

Level (L) change and water flow (F) – not instantaneous:

- Initially: large height difference $\rightarrow$ large flow $\rightarrow L$ up a lot.
- Then: height difference less $\rightarrow$ less flow $\rightarrow L$ increases, but by less.
- Later: height difference 'lesser' $\rightarrow$ less flow $\rightarrow L$ up, but by less, etc.
- Graphically the variation of level L and flow F is:





Analysis of Water Tank Model

Steps for analysing the water tank system:

- Using relevant theorems in physics, determine differential equation for L in terms of initial height of the tank, I.
- Apply the Laplace transform to the differential equation to simplify the difference equation.
- Apply a unit step input for simulating the sudden opening of the valve to let the water flow from one tank to another.
- Simplify the equation and apply inverse Laplace transform to determine variation of L in the time domain.
- Analyse behaviour and characteristics of the system based on the results.
- Consider relevant solution to improve or fix the system.

Time Response Analysis of Water Tank Model

- Using Bernoulli equation for coupled tanks, the system equation is:

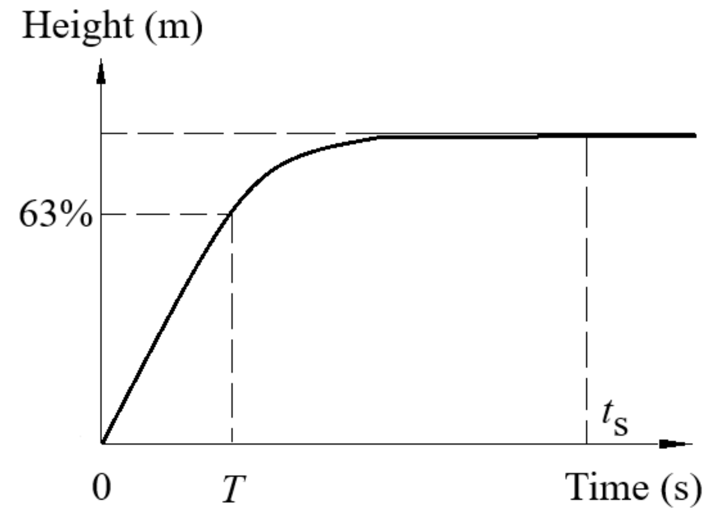
$$\frac{dL}{dt} = \frac{I - L}{CR}$$

- Applying Laplace transform, put into 's' domain and rearrange:

$$sL = \frac{I - L}{CR} \quad \text{and} \quad \frac{L}{I} = \frac{1}{1 + CRs}$$

- Add a unit step input for I (i.e. $1/s$):

$$L = \frac{1}{s}\left(\frac{1}{1 + CRs}\right)$$



- Rearrange and apply inverse transform to determine variation of L:

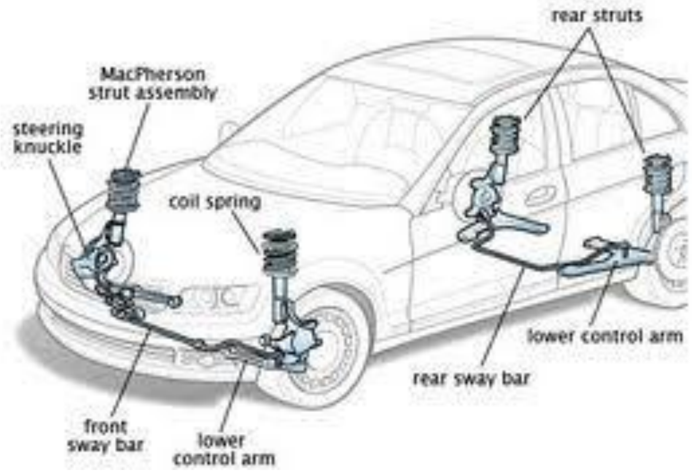
$$L = 1 - e^{-\frac{t}{T}}$$

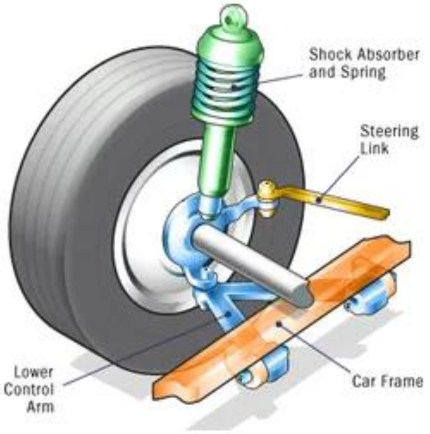
- As t gets larger, exponential term disappears and L tends to input I.

Car Suspension Model

Mechanical system:

- A shock absorber is designed to absorb or dampen the compression and rebound of the springs and suspension.
- They control the unwanted and excess spring motion and keep your tires in contact with the road at all times.
- Explain what happens when a car goes over a bump?

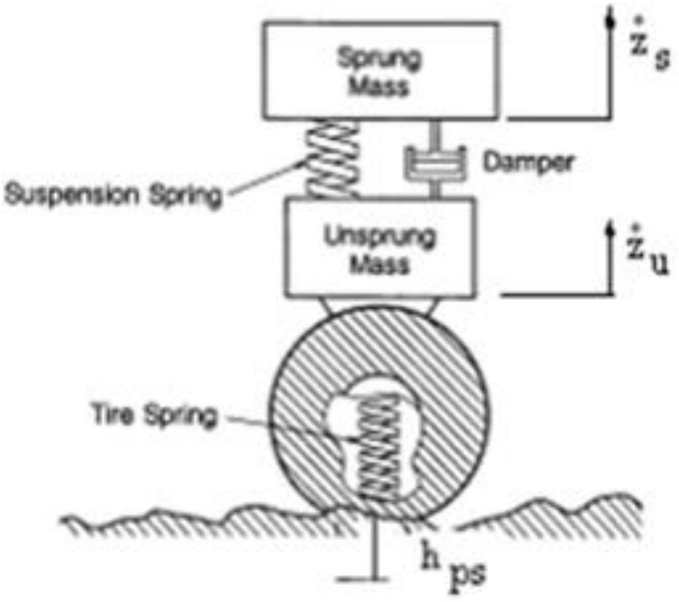




Car Suspension Model

For explaining what happens when a car goes over a bump, we need to simplify it to single-input-single-output system:

- Form individual component models of the system.
- Determine their relationships (use physical laws!).
- Combine (and simplify if possible).



This gives us an instantaneous differential equation, but we want a time response!

Standard Mechanical Systems Model

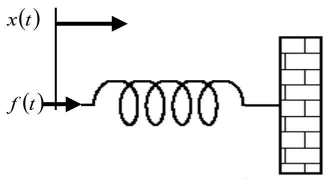
- Standard modelling components of mechanical system e.g. spring (S), damper (D), and mass (M).

  Where: k = spring constant, b = damper constant, m = mass, and x = displacement.

- Force acting in the spring:

$$F_{spring}(t) = kx$$

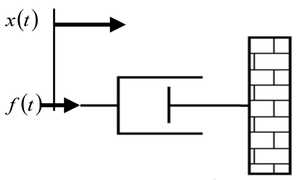
Spring



- Force acting in the damper:

$$F_{damper}(t) = b\left(\frac{dx}{dt}\right)$$

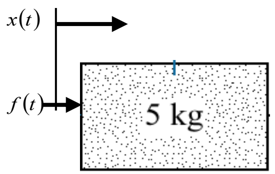
Damper



- Force acting in the mass:

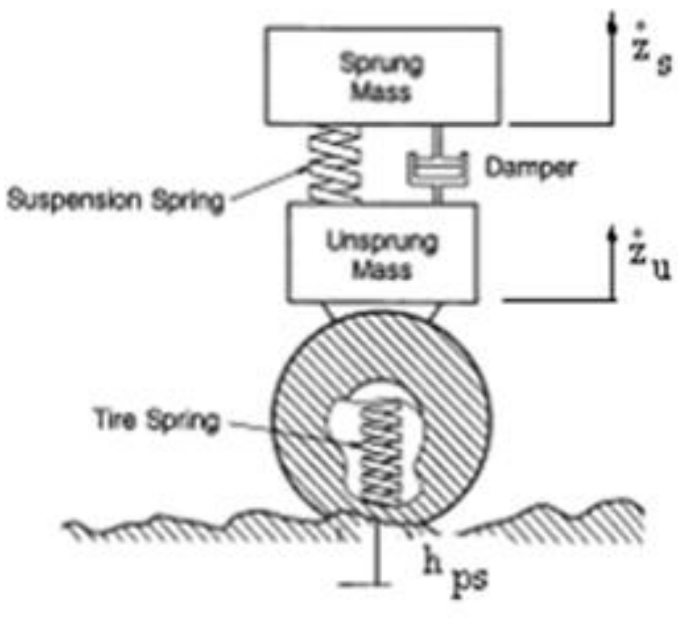
$$F_{mass}(t) = m\left(\frac{d^2x}{dt^2}\right)$$

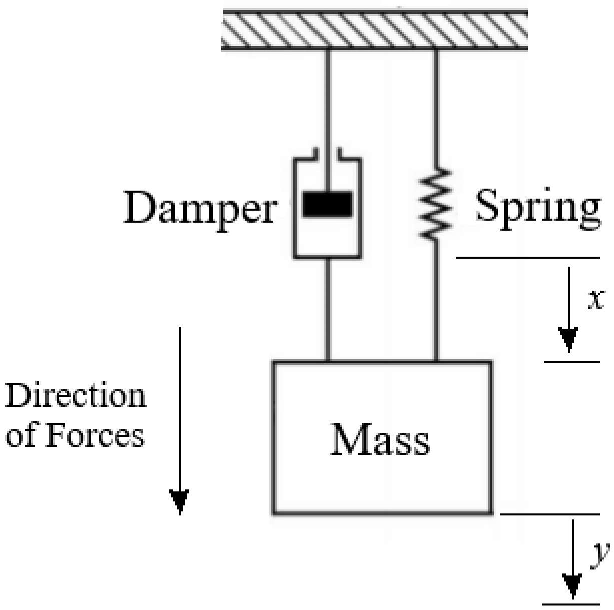
Mass



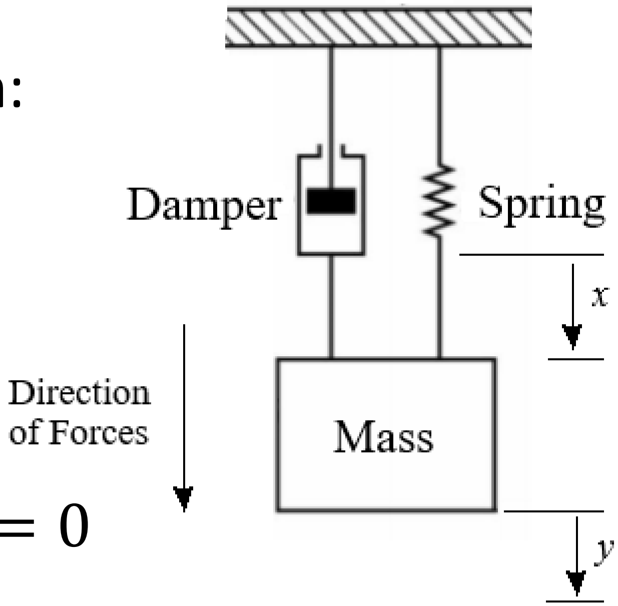
Mechanical System of Car Suspension Model

- Physical system, as represented with a mechanical system model, is still very complex to model.
- This often involves further simplification of components of the system.





Mechanical System of Car Suspension Model



- Applying Newton's second law of motion:

$$\sum F(t) = 0$$

- Forces in the car suspension system:

$$F_{mass}(t) + F_{spring}(t) + F_{damper}(t) = 0$$

Where:

y = distance due to applied force; x = displacement.

$$F_{mass}(t) = m\left(\frac{d^2y(t)}{dt^2}\right); \quad F_{spring}(t) = k\big(x(t) - y(t)\big)$$

$$F_{damper}(t) = b\left(\frac{dx(t)}{dt} - \frac{dy(t)}{dt}\right)$$

Block Diagram of Car Suspension Model

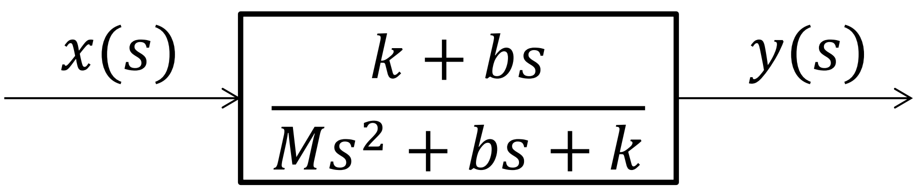
- Derive the differential equation (DE) for the system:

$$m\left(\frac{d^2y(t)}{dt^2}\right) + b\left(\frac{dy(t)}{dt}\right) + ky(t) = kx(t) + b\left(\frac{dx(t)}{dt}\right)$$

- Applying Laplace transform, create transfer-function equation of the system:

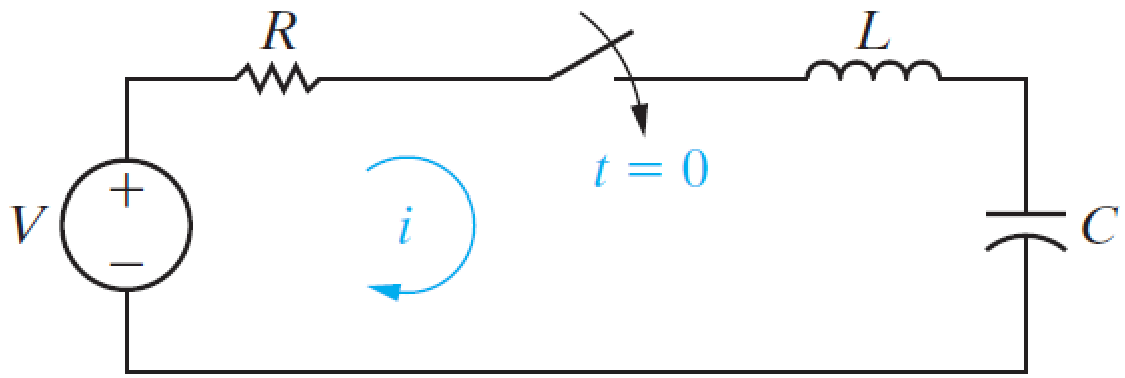
$$H(s) = \frac{dy(s)}{dx(s)} = \frac{k + bs}{Ms^2 + bs + k}$$

- Represent the model in the block diagram:



Question: Modelling of Electrical system

- Determine the block diagram for the following electrical system?
- Use standard modelling components of electrical system e.g. inductor (L), capacitor (C) and resistor (R).
- Analyse the behaviour of the circuit.

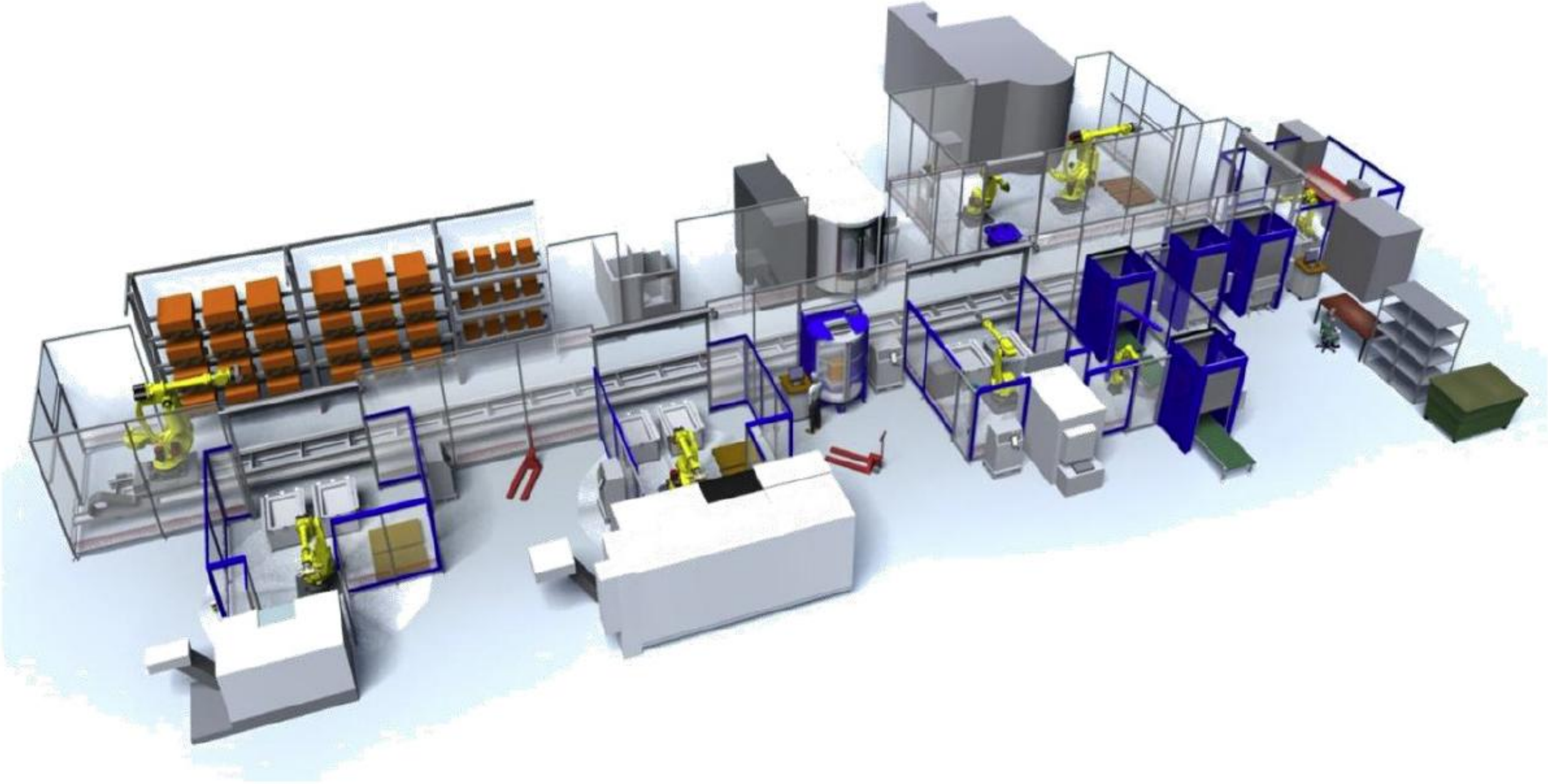


- The system is a second-order system with a transfer function:

$$\frac{V_C(s)}{V(s)} = \frac{1}{LCs^2 + RCs + 1}$$

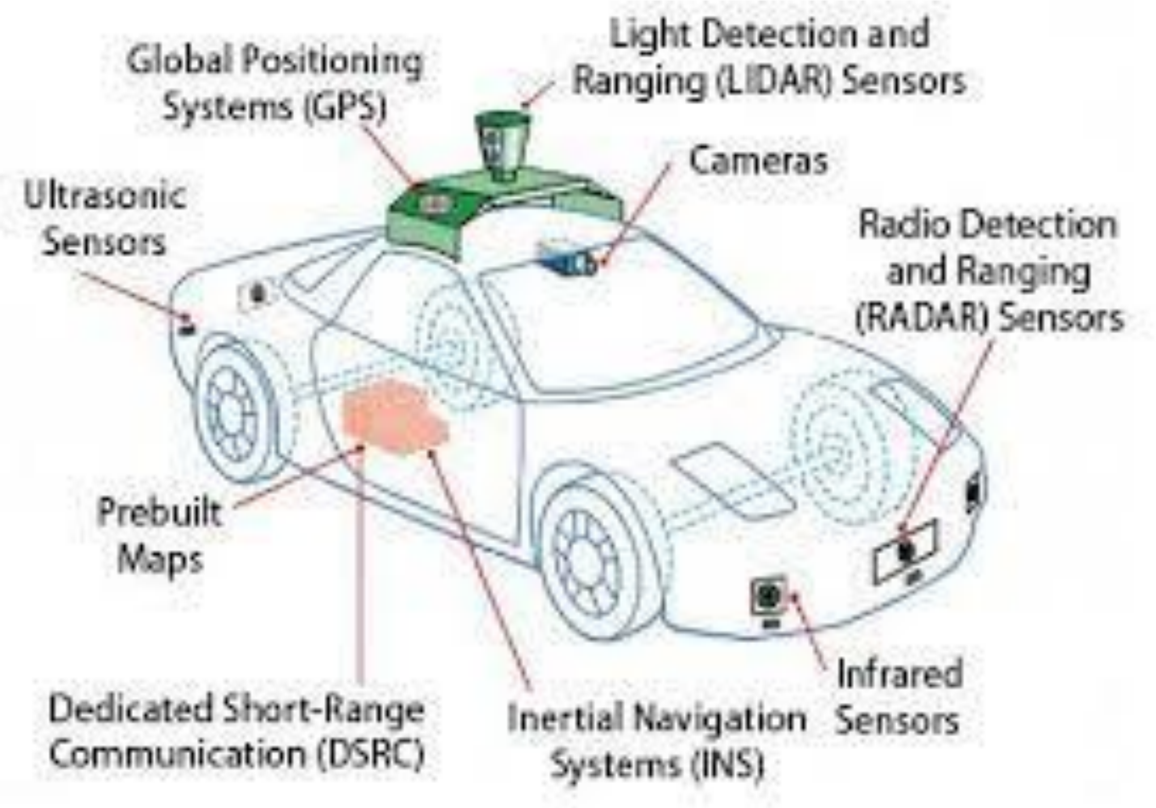
Examples of Application of Control System

- Self-configured and adjustable robotic setup in the automatic manufacturing system.



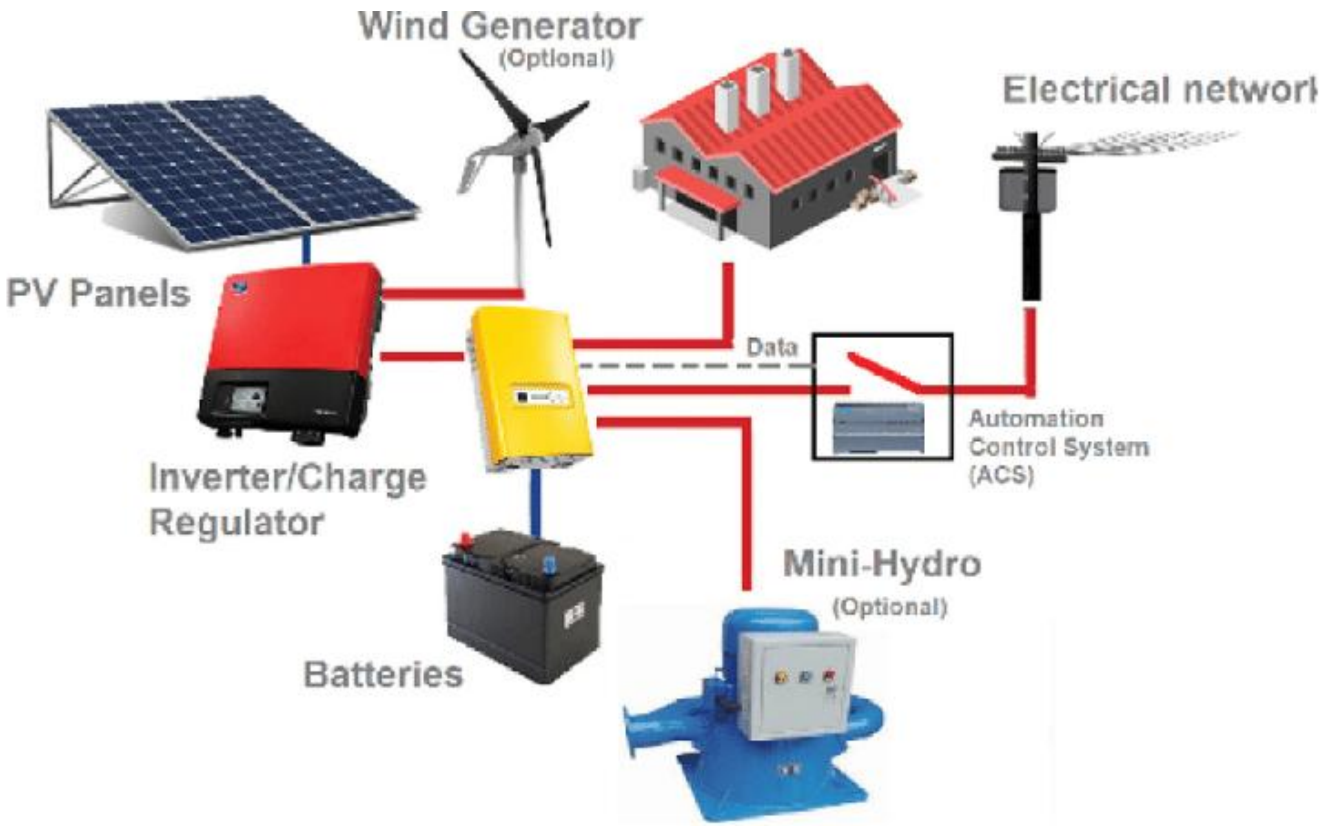
Examples of Application of Control System

- Autonomous navigation of the vehicle or transportation system.



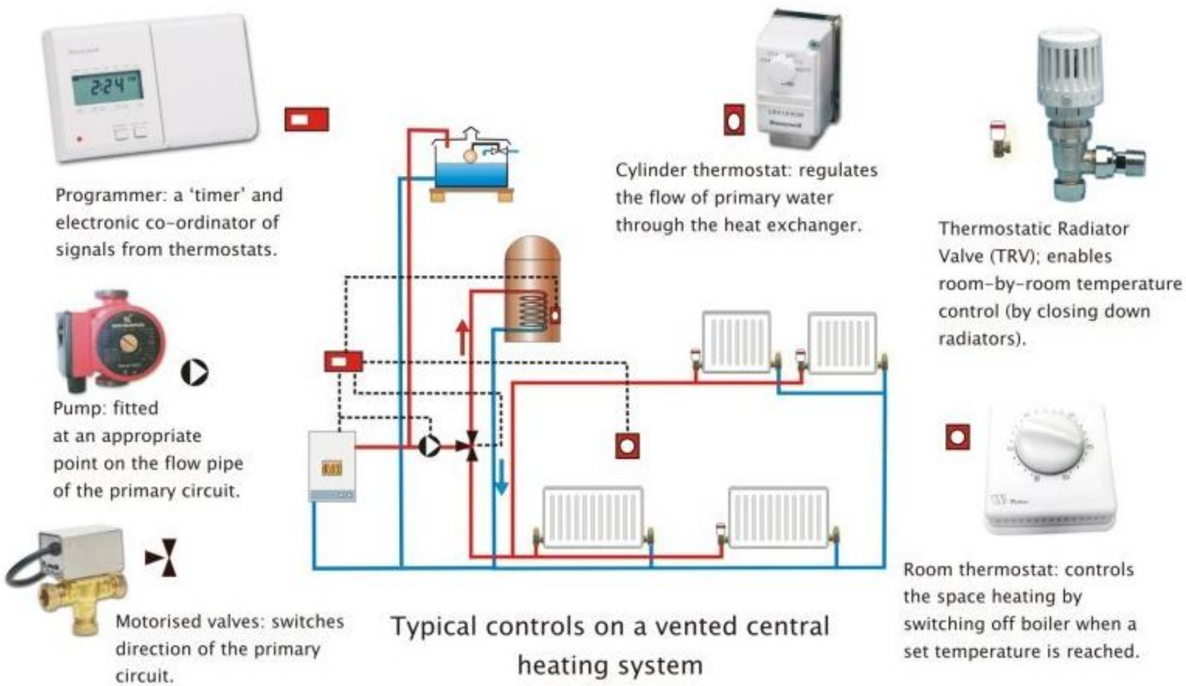
Examples of Application of Control System

- Control and management of the networked renewable energy resources.



Examples for Tutorial

- A vented central-heating system operates by sensing the difference between the thermostat setting and the actual temperature.
- Then, opening a fuel valve by an amount which is proportional to this difference.



Typical controls on a vented central heating system

Examples for Tutorial

a. Describe the fundamental concept and principle behind a typical temperature control system. [2 marks]

b. Draw a functional closed-loop block diagram identifying the input and output transducers, the controller, and the plant. [5 marks]

c. Further, identify and describe briefly the input and output signals of all subsystems previously described. [3 marks]