Lecture 1_2:
Introduction
Control, Actuation & Sensing System

Robotics

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Outlines

- Control System
- Actuation System
- Sensing System

Control System

Control System

- A system for programming and control the manipulator and other devices.

- The control system of an industrial robot is a quite complex device, in general composed by a multi-processor system, connected to other local devices for controlling, monitoring and data storage purposes.

Main Functions:

- User interface
- Data storage
- Motion planning
- Real-time control of joints' motion
- Sensor data acquisition
- Interaction and synchronization with other machines
- Interaction with other computational resources

Actuation System

- **Actuation System**

1) Electric Actuator

- 1-1) Brushed DC Motor
- 1-2) Brushless DC Motor
- 1-3) Stepper Motor
- 1-4) Linear Motor

2) Hydraulic Actuator

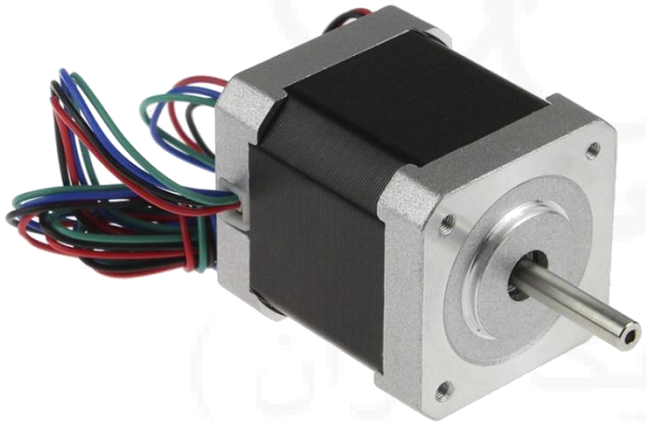
3) Pneumatic Actuator

4) Soft Actuator

5) …

Actuation System

1) Electric Actuator



Actuation System

1) Electric Actuator

- **Advantages:**
  - High speed and precision
  - Easy to be controlled
  - High diffusion, relatively low cost
  - Simple to be used
  - Small dimensions

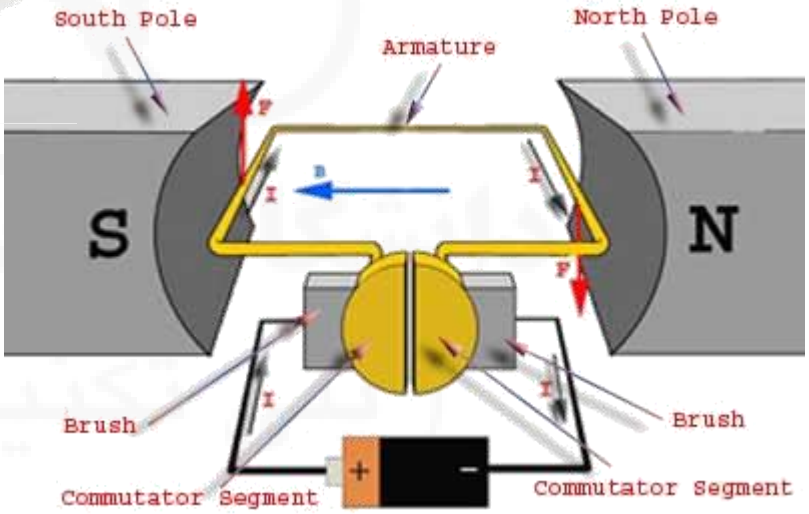
- **Disadvantages:**
  - Reduction gears (increased cost & size)
  - Nonlinear effects (backslash, dead zones, …) due to reduction gears
  - Not enough power for particular applications

- **Examples**:
  - Brushed DC motors
  - Brushless
  - Stepper
  - Linear Motors & …

Actuation System

1) Electric Actuator

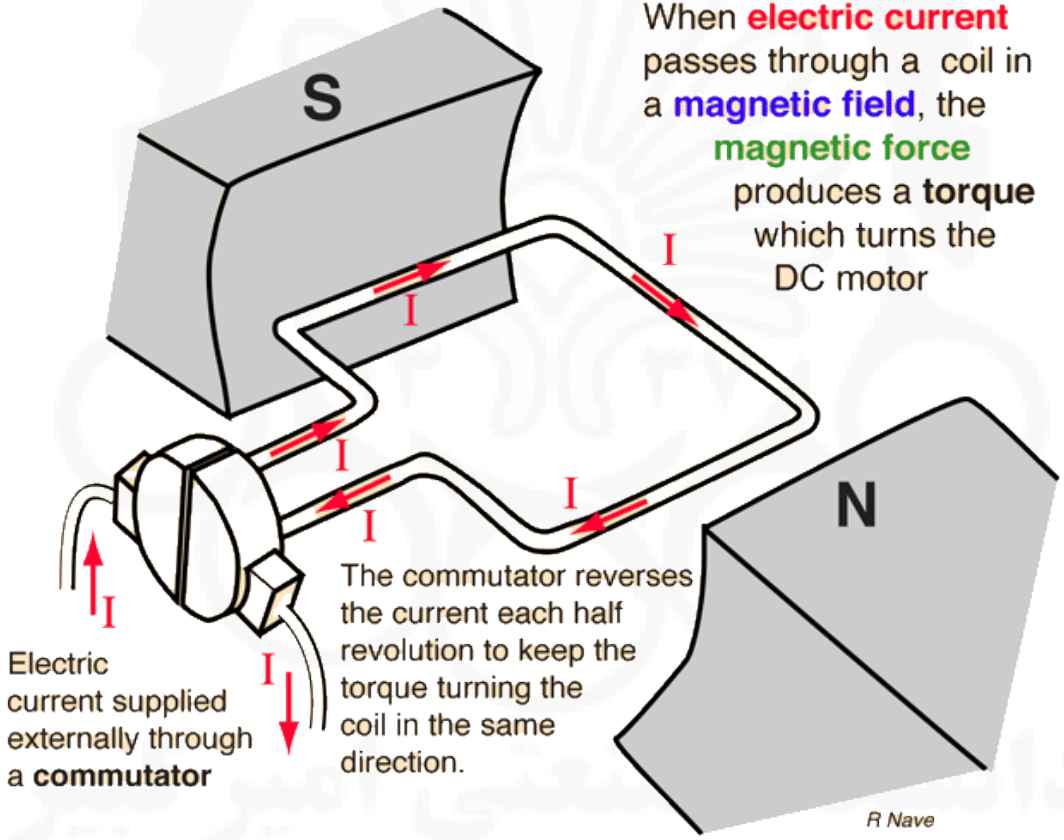
1-1) Brushed DC Motor



Actuation System

1) Electric Actuator

1-1) Brushed DC Motor

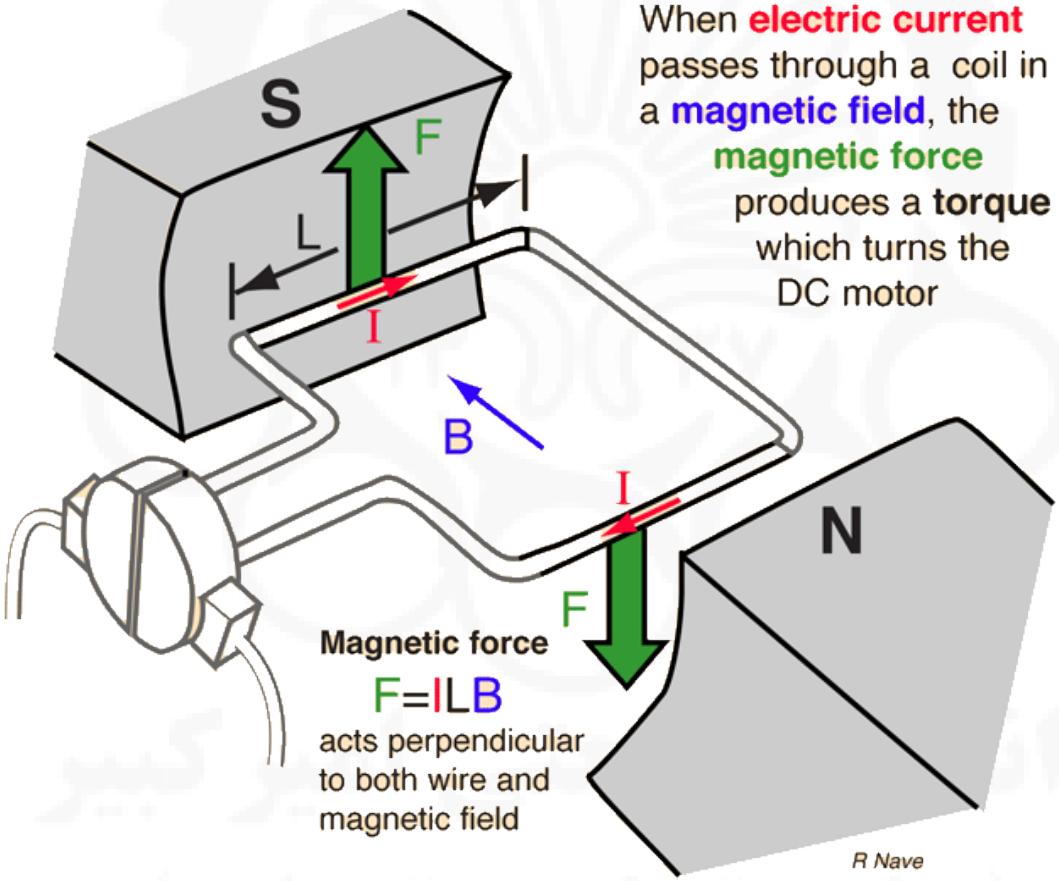


← Outline

Actuation System

1) Electric Actuator

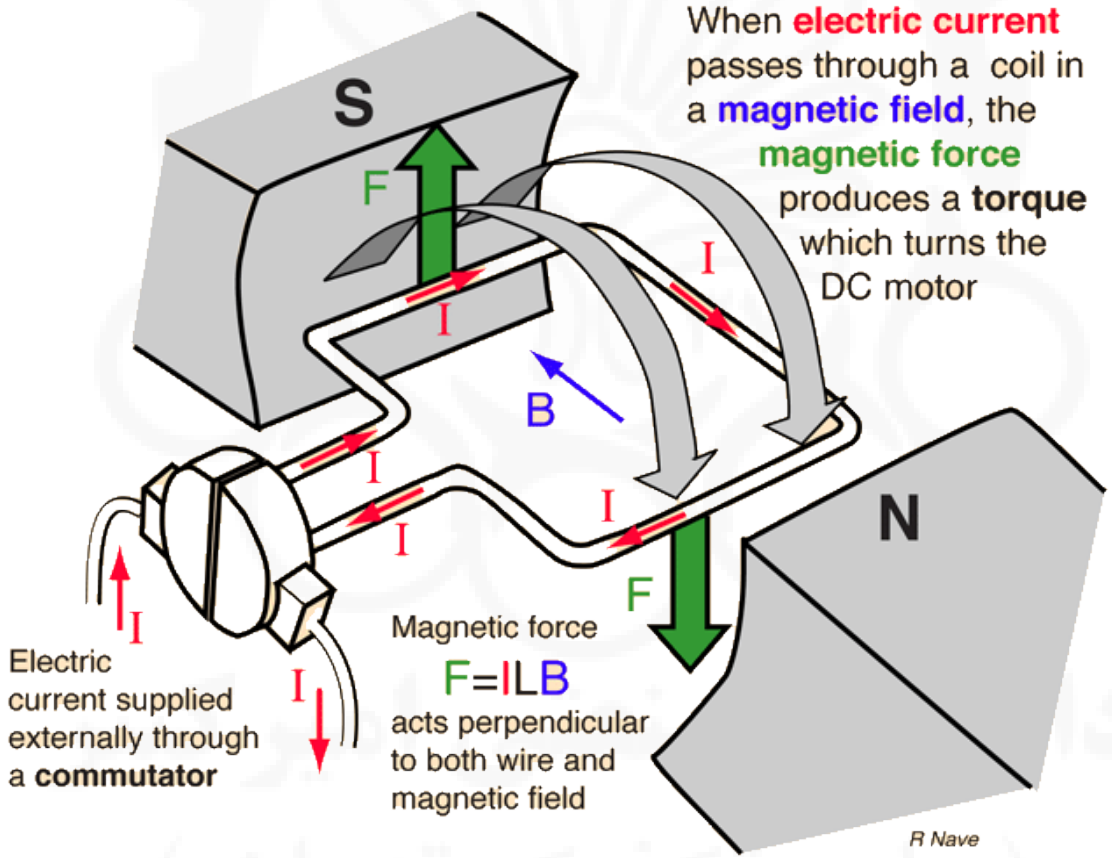
1-1) Brushed DC Motor



Actuation System

1) Electric Actuator

1-1) Brushed DC Motor



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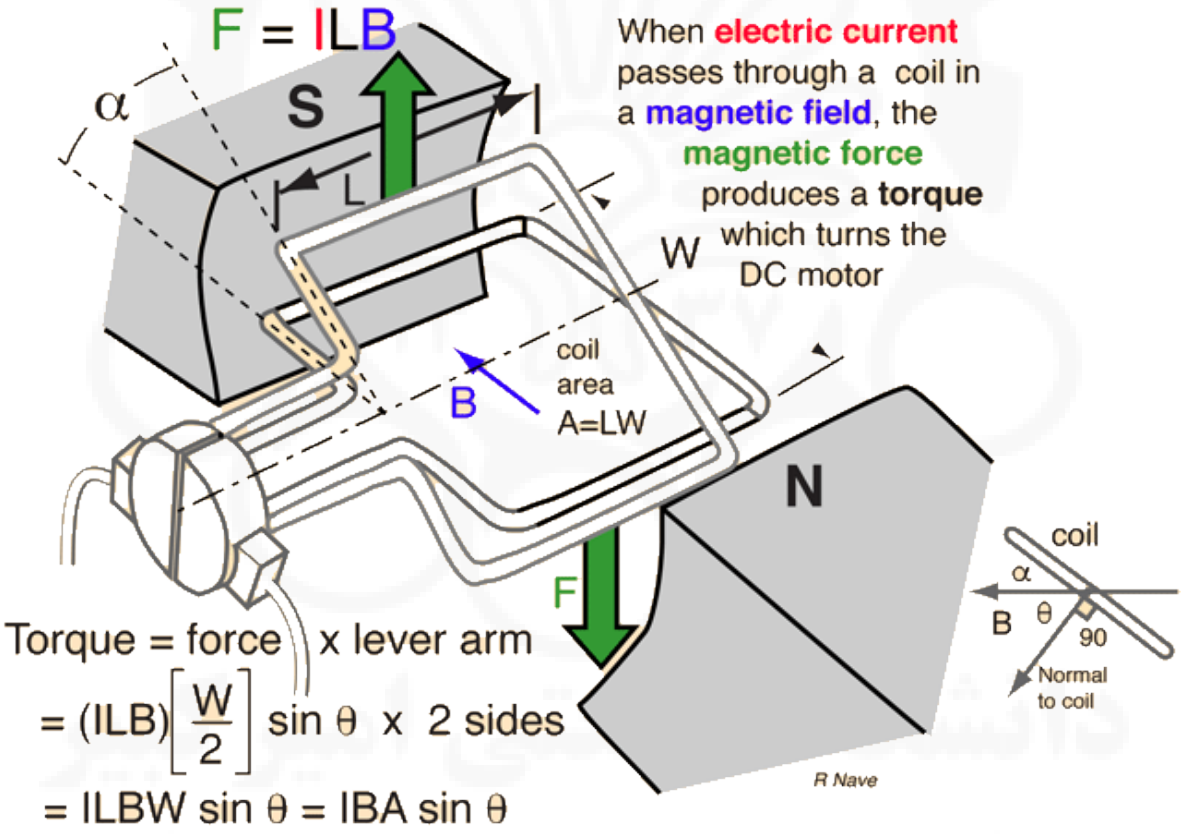
Actuation System

1) Electric Actuator

1-1) Brushed DC Motor



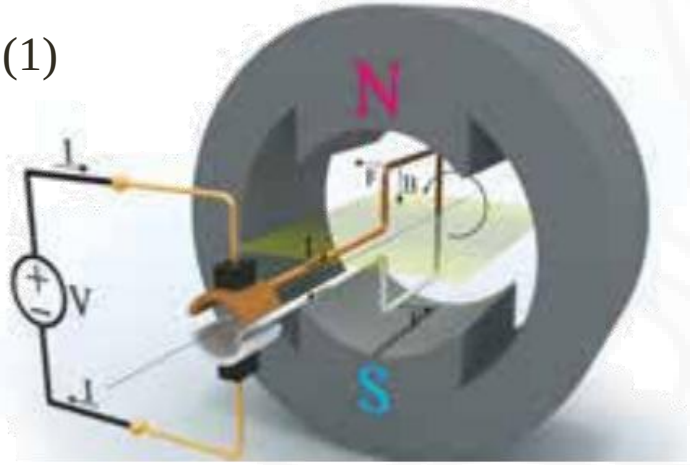
← Outline

Actuation System

1) Electric Actuator

1-1) Brushed DC Motor

(1)



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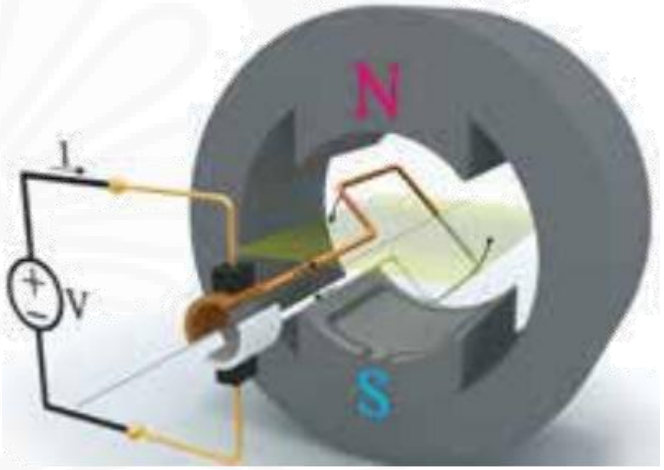

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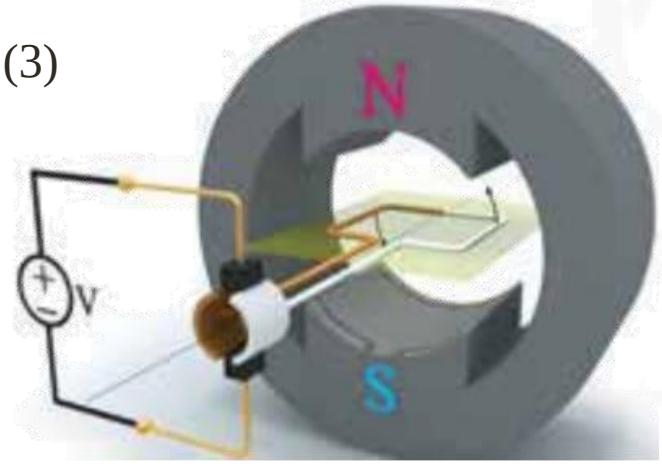

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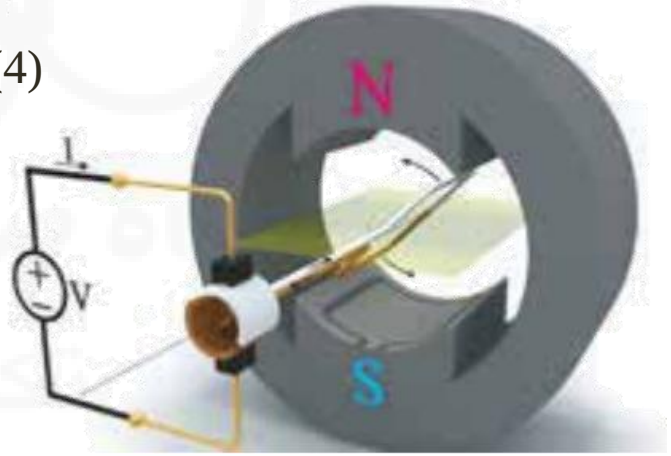
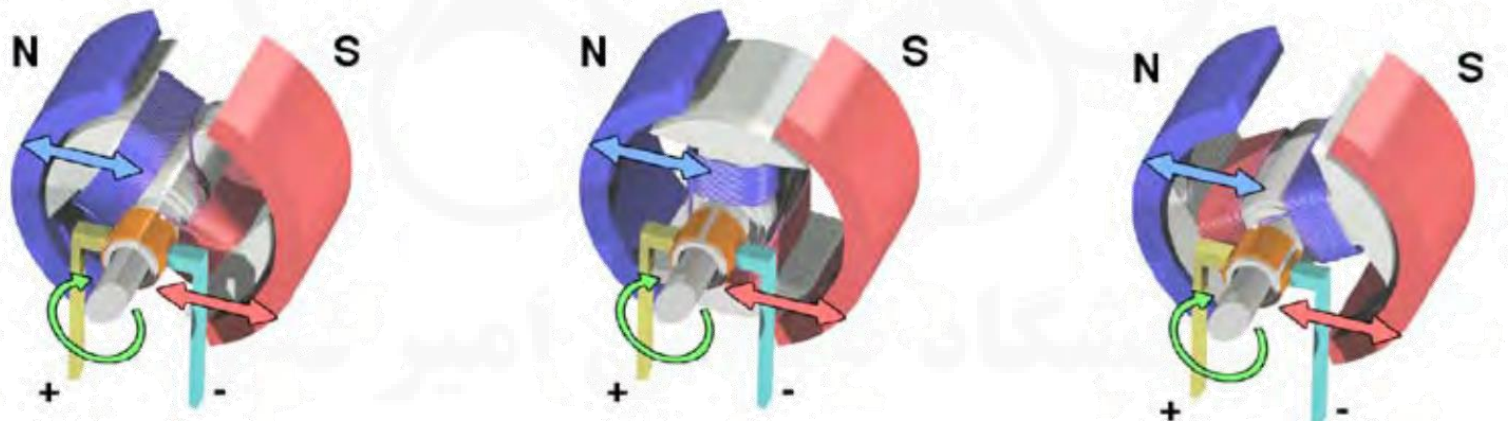


Actuation System

1) Electric Actuator

1-1) Brushed DC Motor

- Current is flowing through the armature.
- Permanent magnets torque the armature.
- When armature is aligned with magnets, commutator (“brush”) reverses current and magnetic field.



← Outline

Actuation System

1) Electric Actuator

1-1) Brushed DC Motor

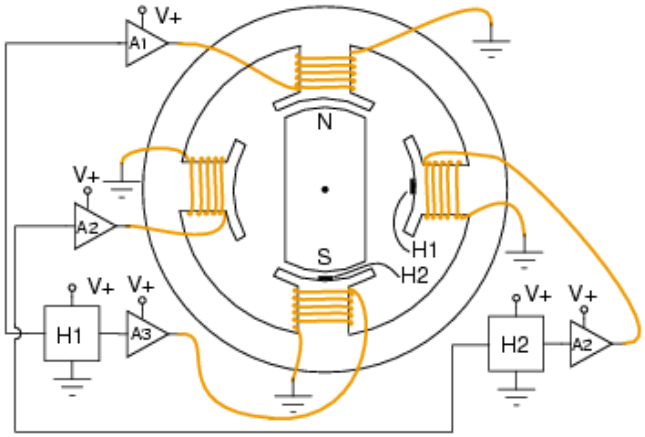
- Multiple coils added to allow motor to smooth output torque and to start from any position.

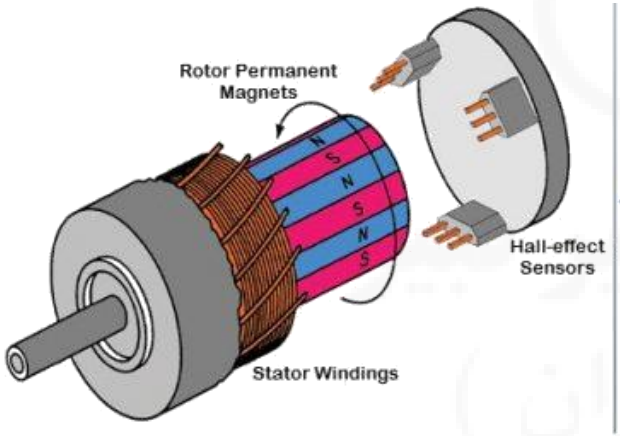
Actuation System

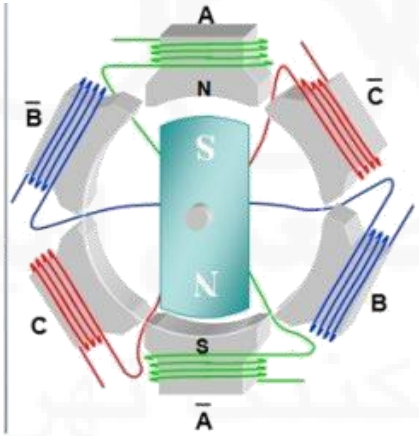
1) Electric Actuator

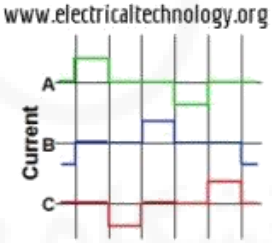
1-2) Brushless DC Motor (BLDC)

- **Electronic controller** commutates the electromagnetic force, providing a rotating field.









Construction, Working Principle and Operation of BLDC Motor (Brushless DC Motor)

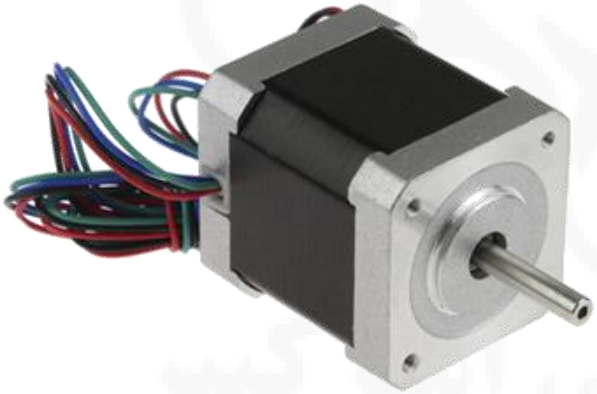
Actuation System

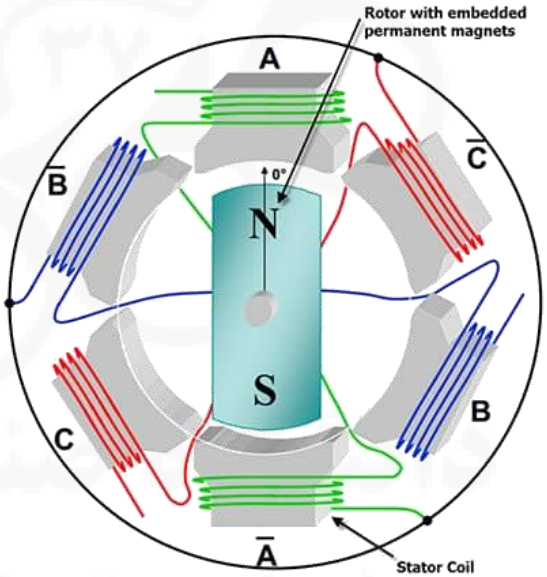
1) Electric Actuator

1-3) Stepper Motor

- Brushless, synchronous motor that moves in discrete steps.

- Precise, quantized control without feedback.



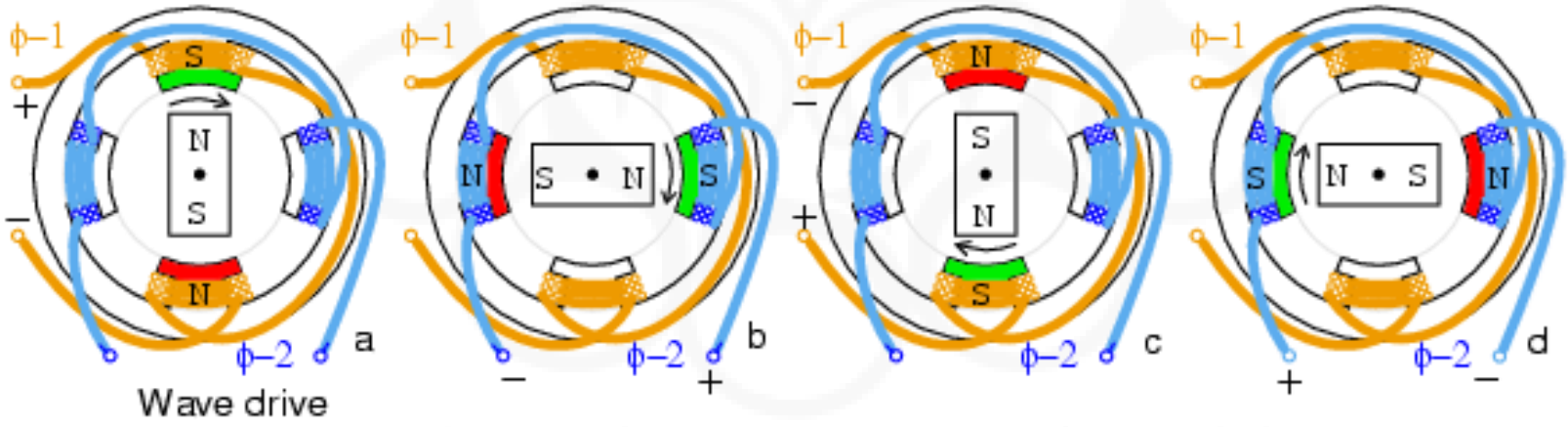


← Outline

Actuation System

1) Electric Actuator

1-3) Stepper Motor

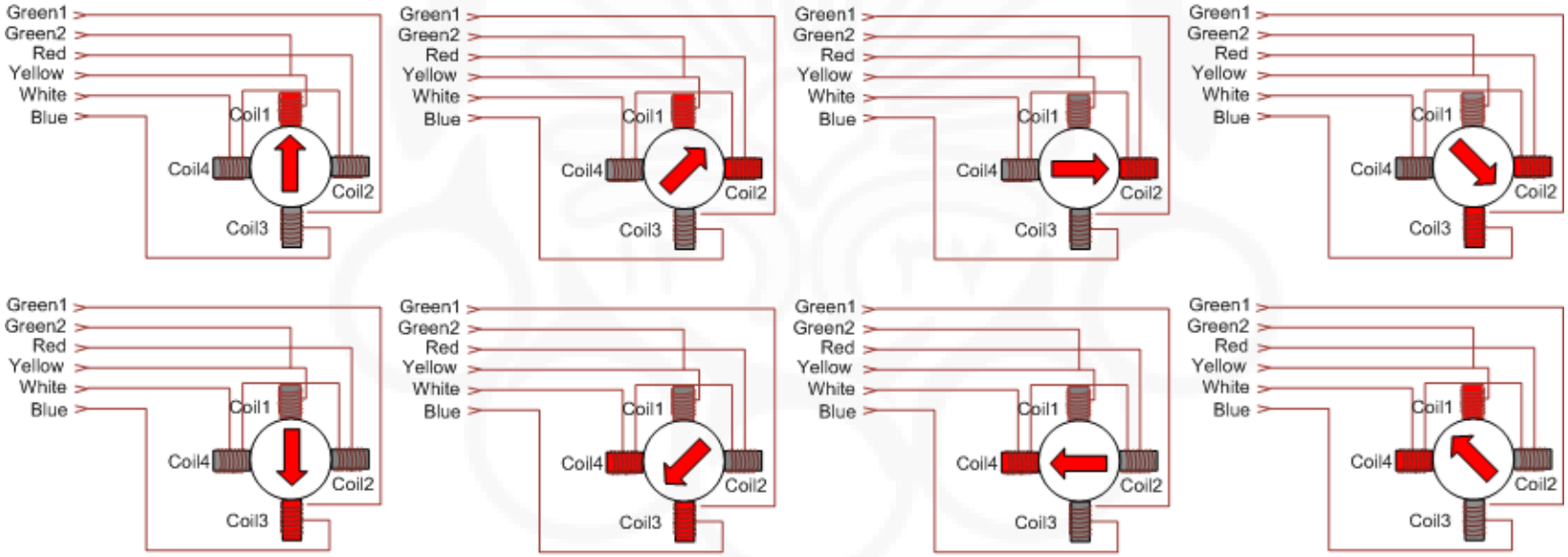


← Outline

Actuation System

1) Electric Actuator

1-3) Stepper Motor



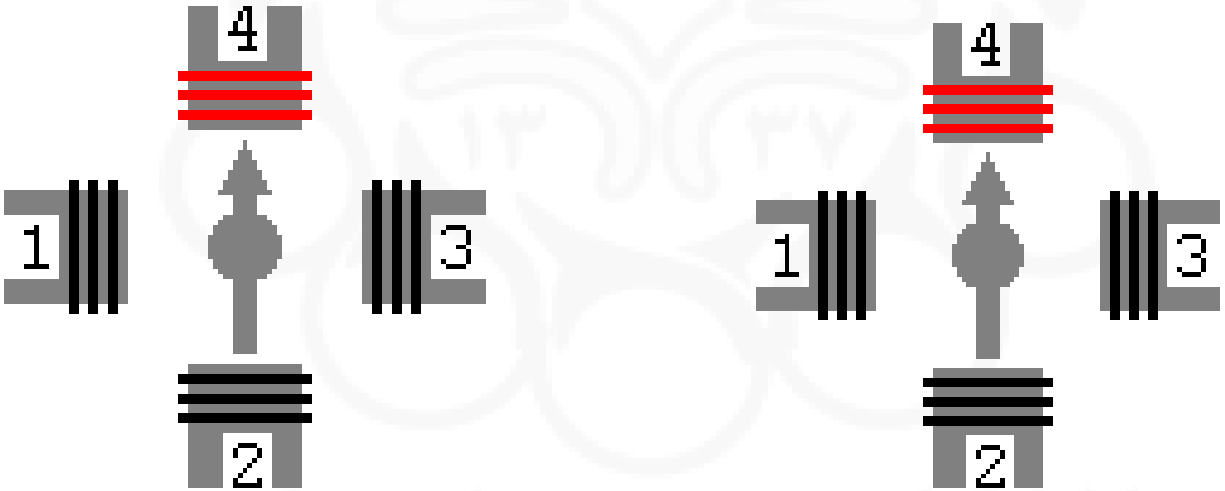
← Outline

Actuation System

1) Electric Actuator

1-3) Stepper Motor

Wave Drive & Half Drive



← Outline

Actuation System

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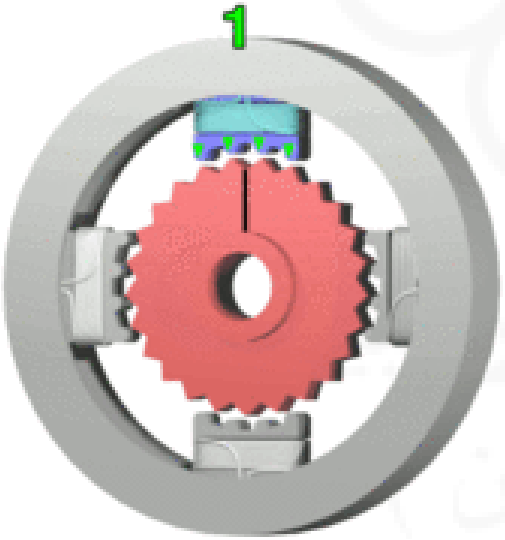
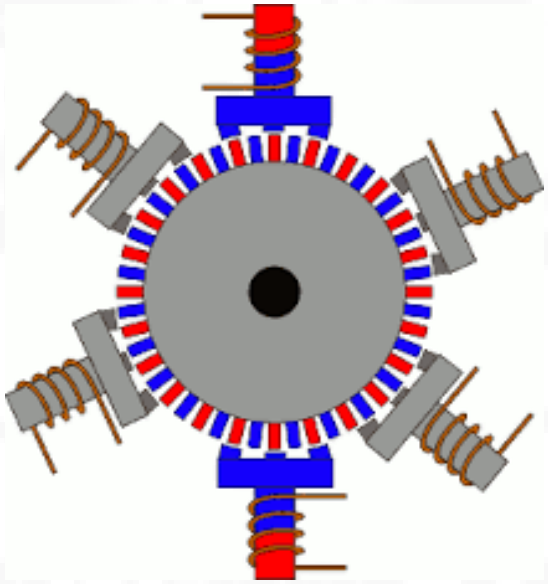
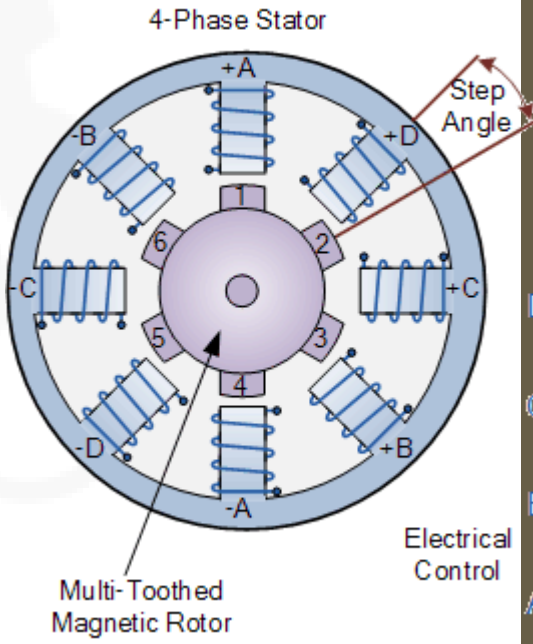
1-3) Stepper Motor







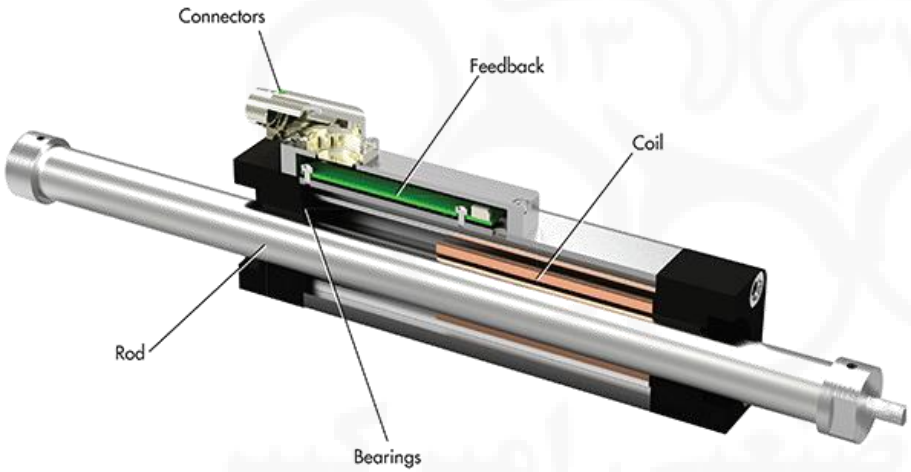
← Outline

Actuation System

1) Electric Actuator

1-4) Linear Motor

- It is an electric motor that has had its stator and rotor "unrolled" so that instead of producing a torque (rotation) it produces a linear force along its length.



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1) Electric Actuator

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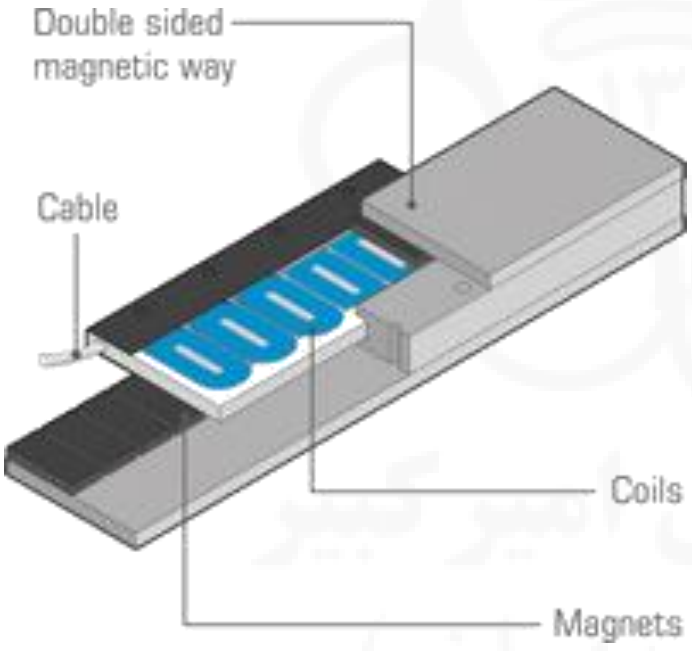
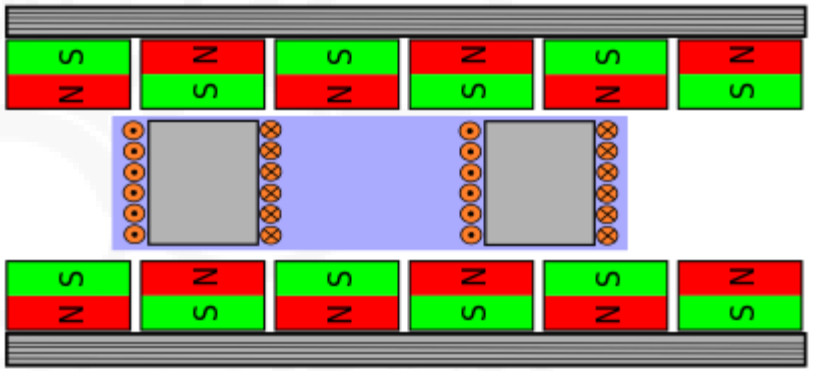
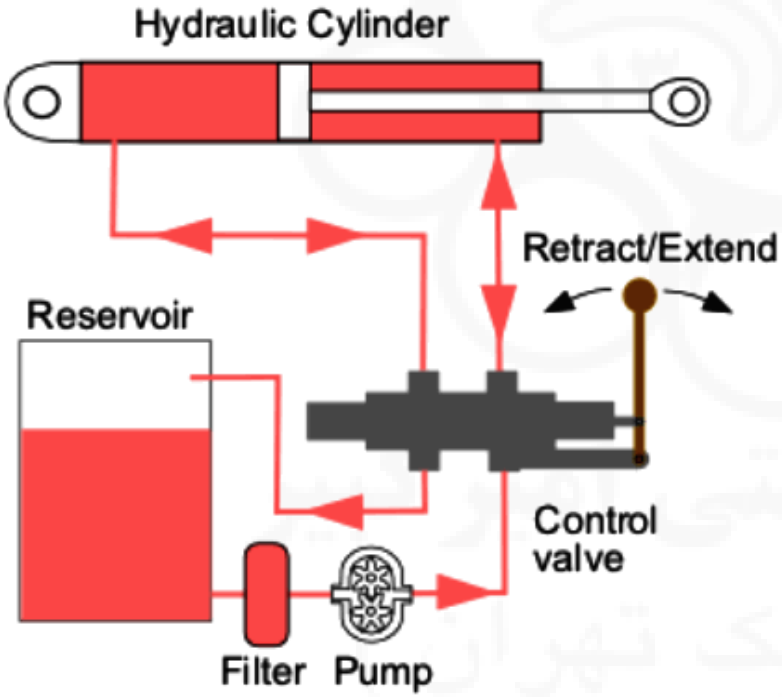


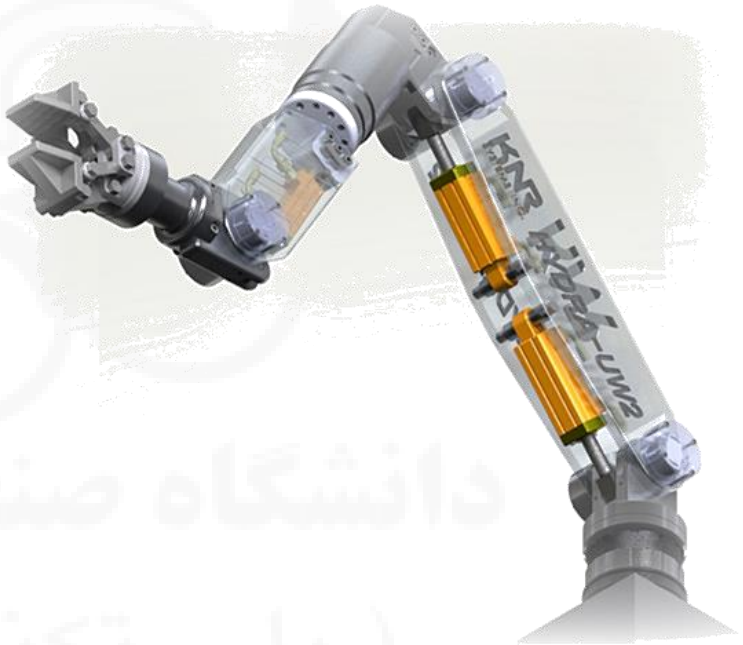


← Outline

Actuation System

2) Hydraulic Actuator





← Outline

Actuation System

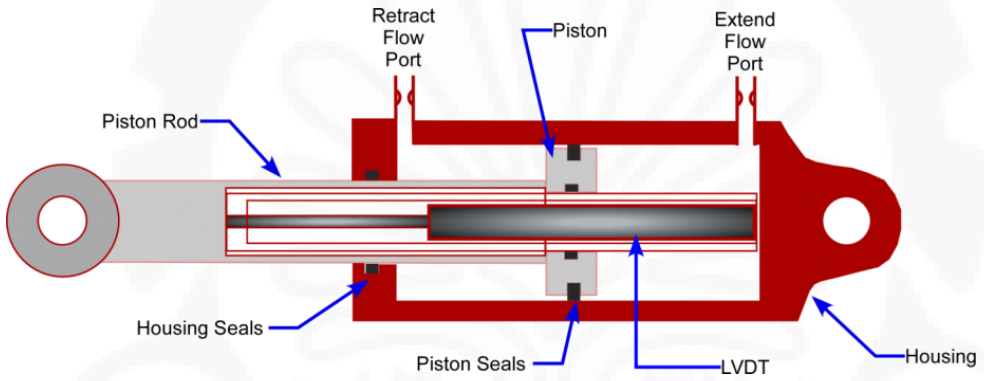
2) Hydraulic Actuator

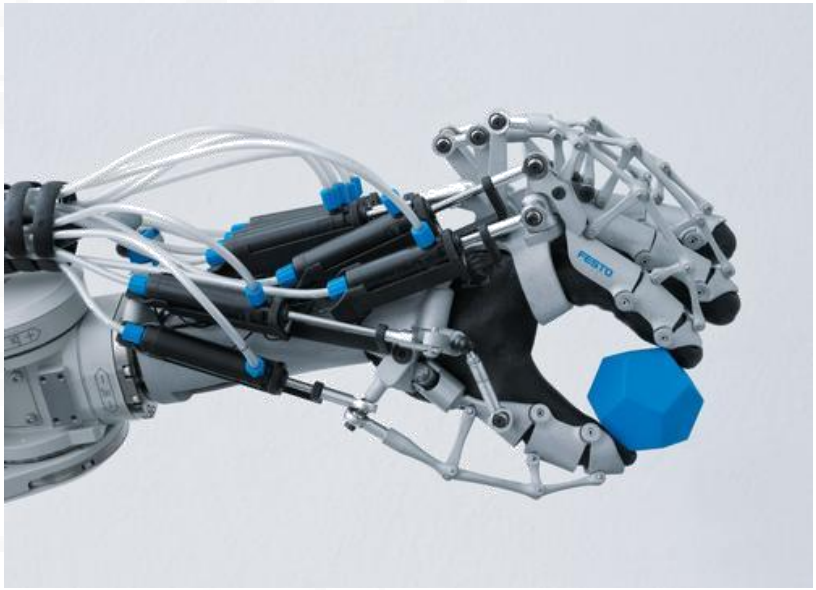
- **Advantages:**
  - High power
  - Once in position, the configuration is maintained thanks to the oil
  - Easy to be controlled

- **Disadvantages:**
  - Relatively high costs for small dimensions
  - Noise and oil leakages
  - More space needed.

Actuation System

3) Pneumatic Actuator





← Outline

Actuation System

3) Pneumatic Actuator

- **Advantages:**
  - Relatively low cost
  - High velocity

- **Disadvantages:**
  - Low accuracy (air is compressed)
  - Noisy
  - Leakages
  - Need of special filters for air

Actuation System

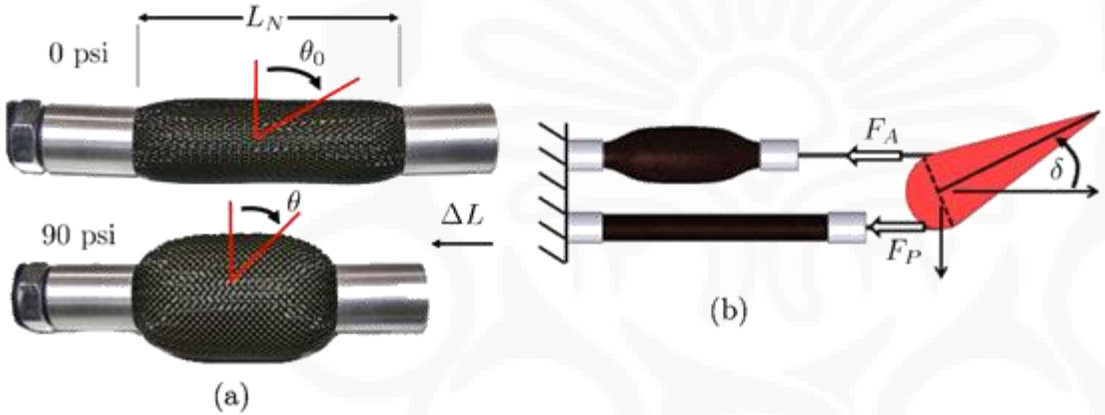
4) Soft Actuator

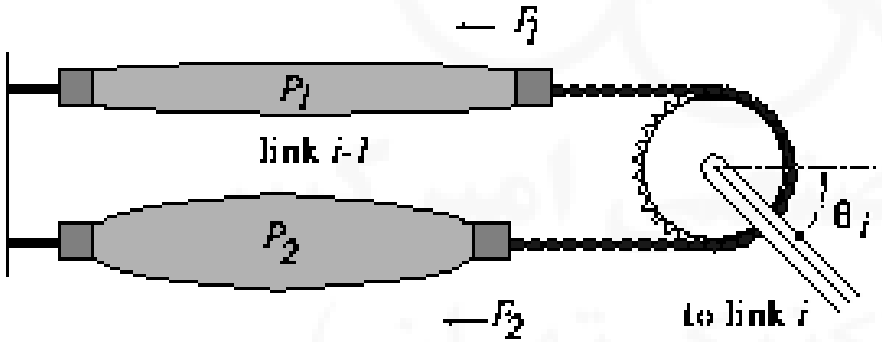
← Outline

Actuation System

4) Soft Actuator

- Pneumatic analog of muscle (Mckibben).
  The actuator contracts under pressure.





Sensing System

- **Sensing System**

1) Position Sensor

1-1) Angular Encoder

1-2) Linear Encoder

1-3) Potentiometer

1-4) Linear Variable Differential Transformer (LVDT)

2) Velocity Sensor

3) Acceleration Sensor

3-1) Spring Deflection Accelerometer

3-2) Force Rebalance Accelerometer

3-3) Micro Electro Mechanical System (MEMS) Accelerometer

4) Strain Gauges

5) Ultrasonic Sensor

6) Vision

Sensing System

1) Position Sensor

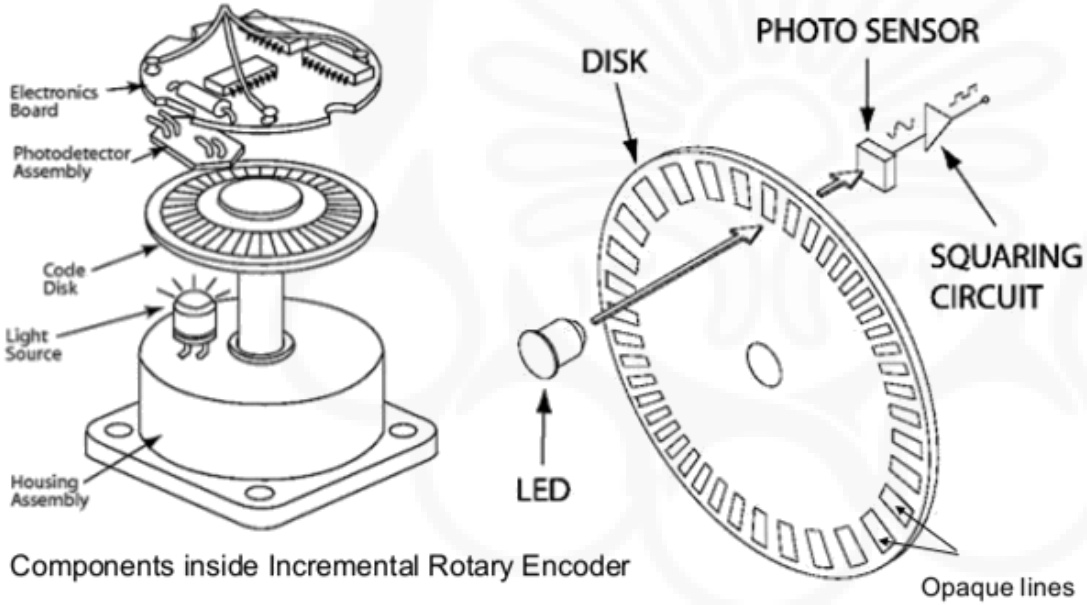
← Outline

Sensing System

1) Position Sensor

1-1) Angular Encoder

- **Incremental**



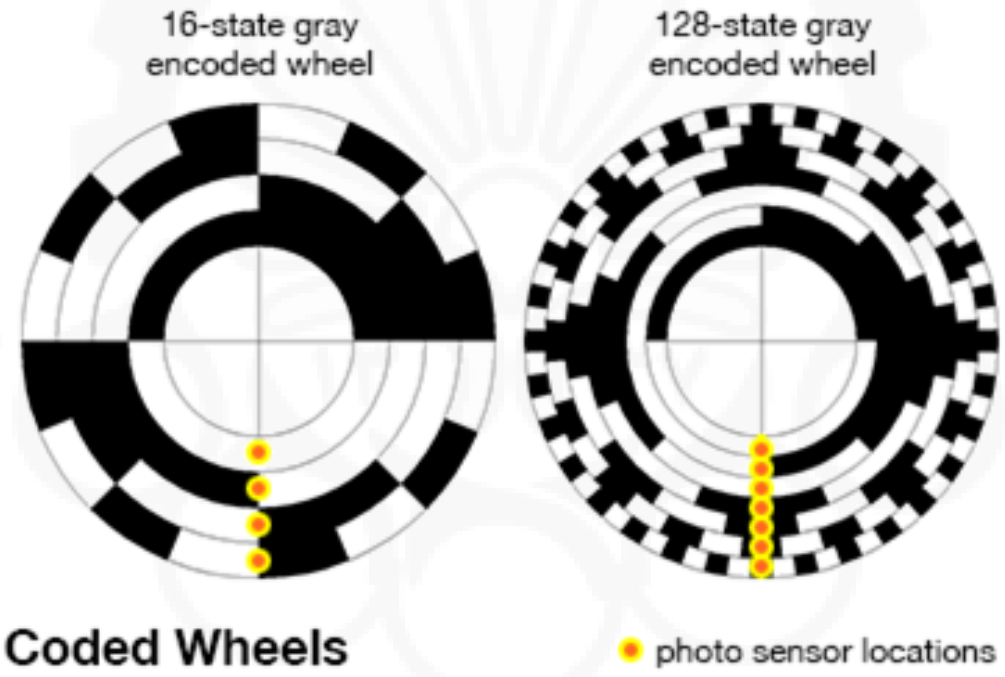
Components inside Incremental Rotary Encoder

Sensing System

1) Position Sensor

1-1) Angular Encoder

- **Absolute**

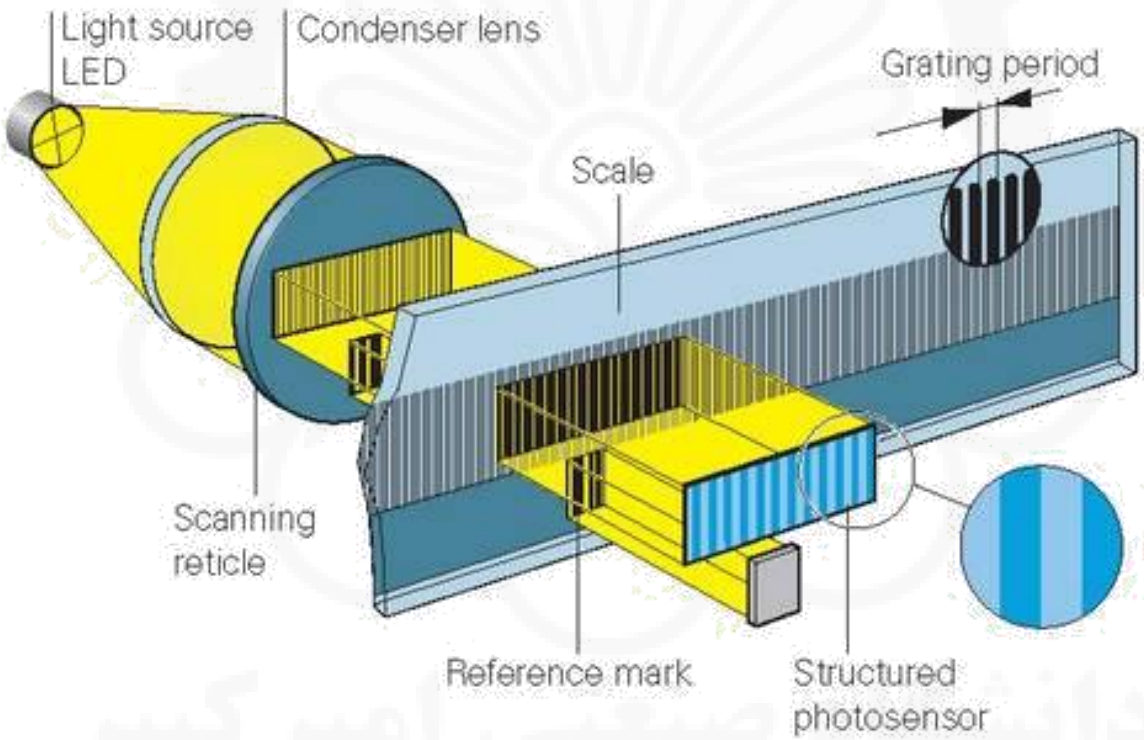


← Outline

Sensing System

1) Position Sensor

1-2) Linear Encoder



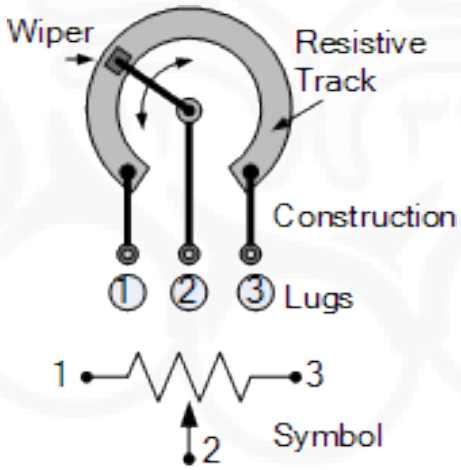
← Outline

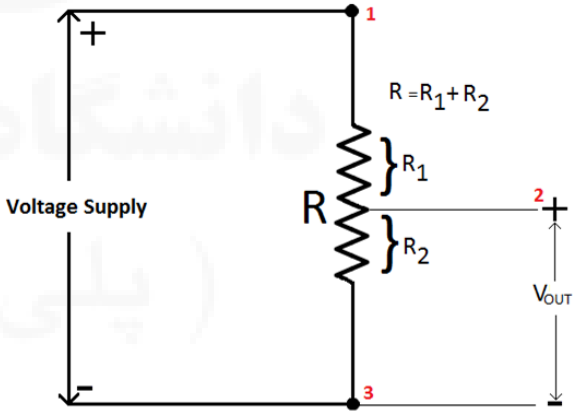
Sensing System

1) Position Sensor

1-3) Potentiometer

- **Rotary**
- It is working based on a variable resistor.
- By using a variable resistor, it acts as a voltage divider.



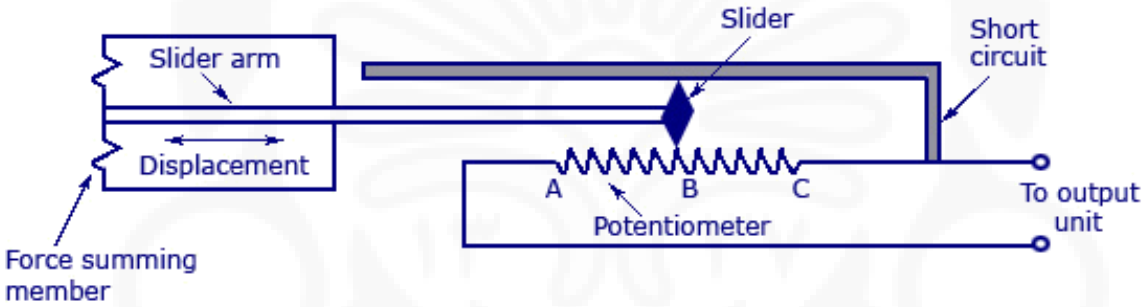


Sensing System

1) Position Sensor

1-3) Potentiometer

- **Linear**



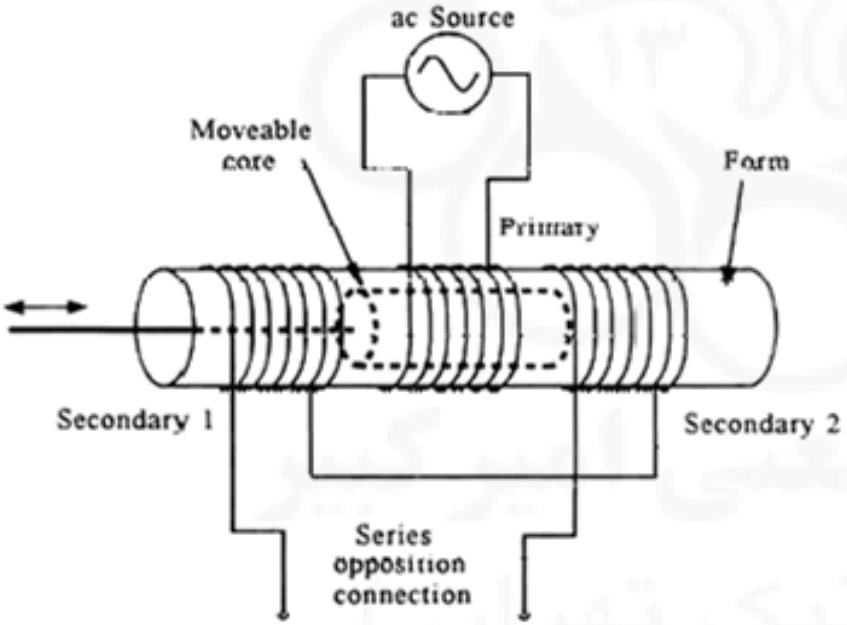
Linear Potentiometer

← Outline

Sensing System

1) Position Sensor

1-4) Linear Variable Differential Transformer (LVDT)

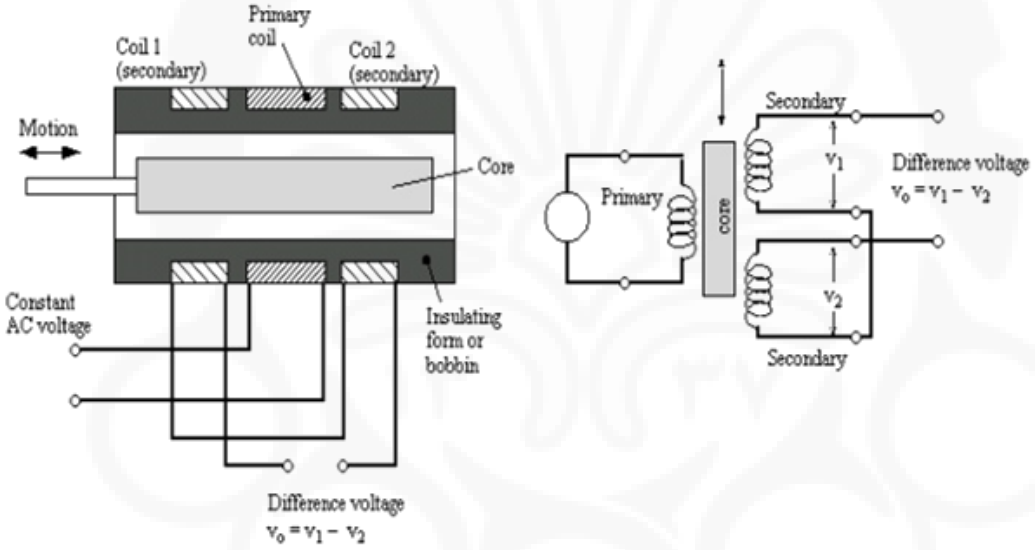


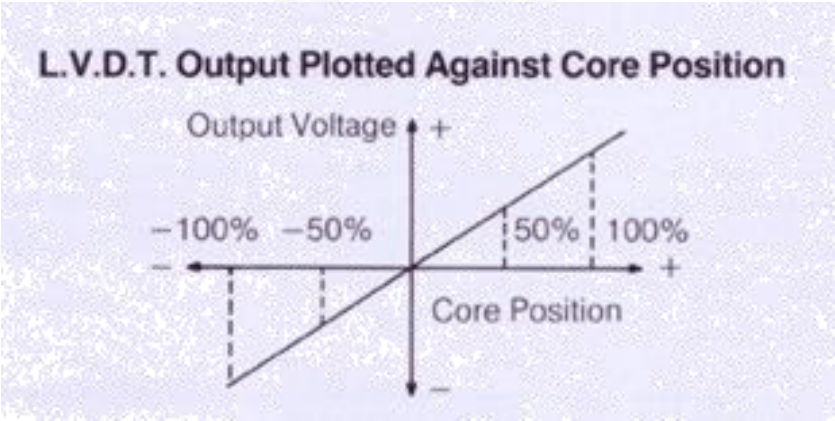
← Outline

Sensing System

1) Position Sensor

1-4) Linear Variable Differential Transformer (LVDT)

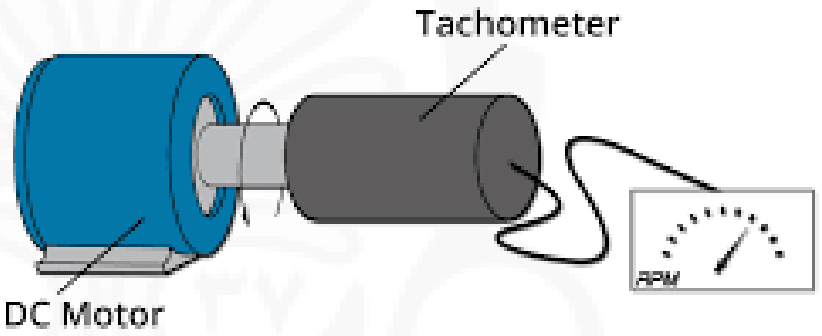




← Outline

Sensing System

2) Velocity Sensor



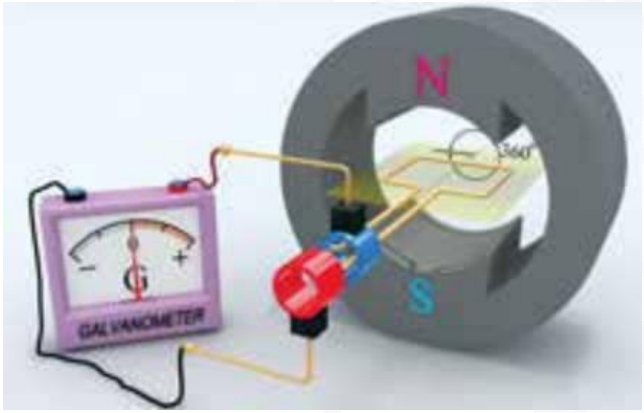
← Outline

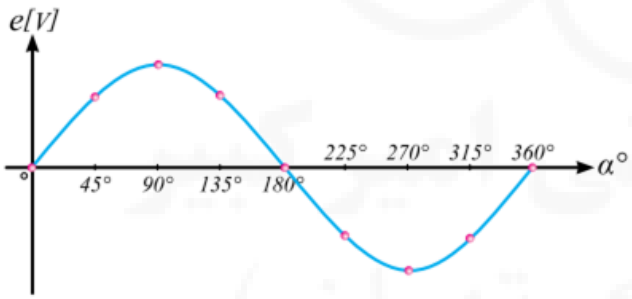
Sensing System

2) Velocity Sensor

❑ Tachometer

- **Mechanical tachometers** works as like as generators.
- Working principals are in contract with the DC motors.

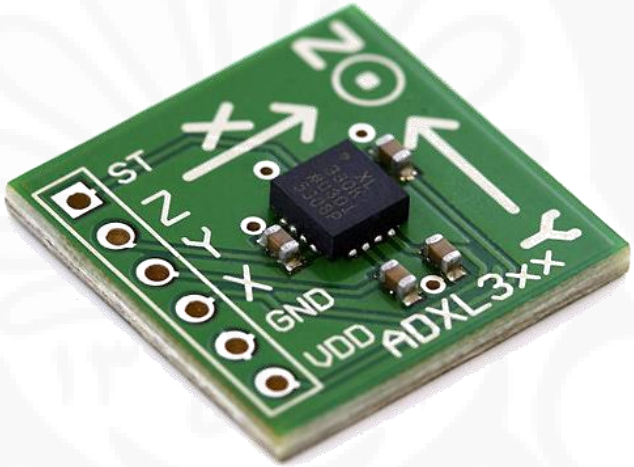




← Outline

Sensing System

3) Acceleration Sensor

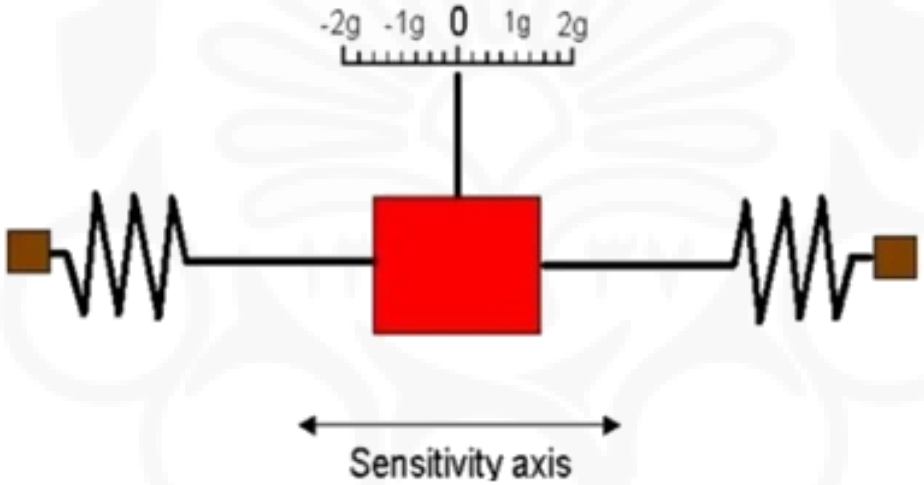


Sensing System

3) Acceleration Sensor

3-1) Spring Deflection Accelerometer

- Deflection is proportional to acceleration



$$\Delta\ddot{x} = -k_s \Delta x / m$$

$$\Delta x = \frac{m}{k_s} \Delta\ddot{x}$$

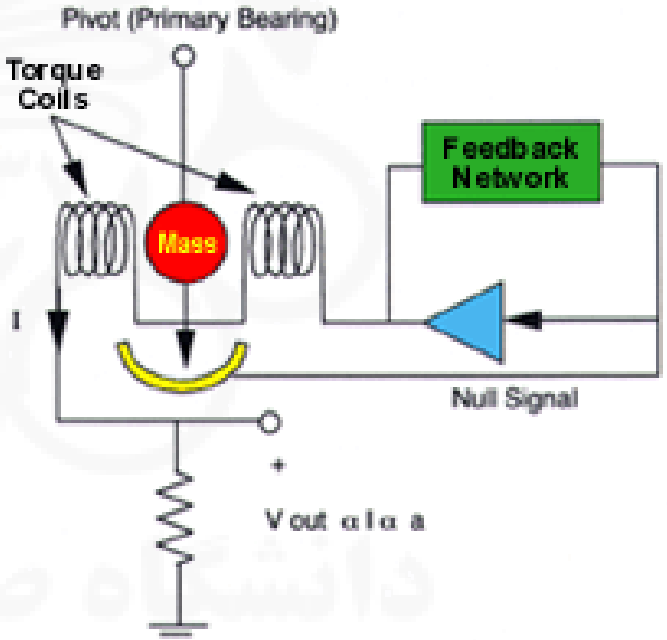
← Outline

Sensing System

3) Acceleration Sensor

3-2) Force Rebalance Accelerometer

- Torquer voltage required to re-center the proof mass becomes the measure of acceleration.
- It is an example of closed-loop control.



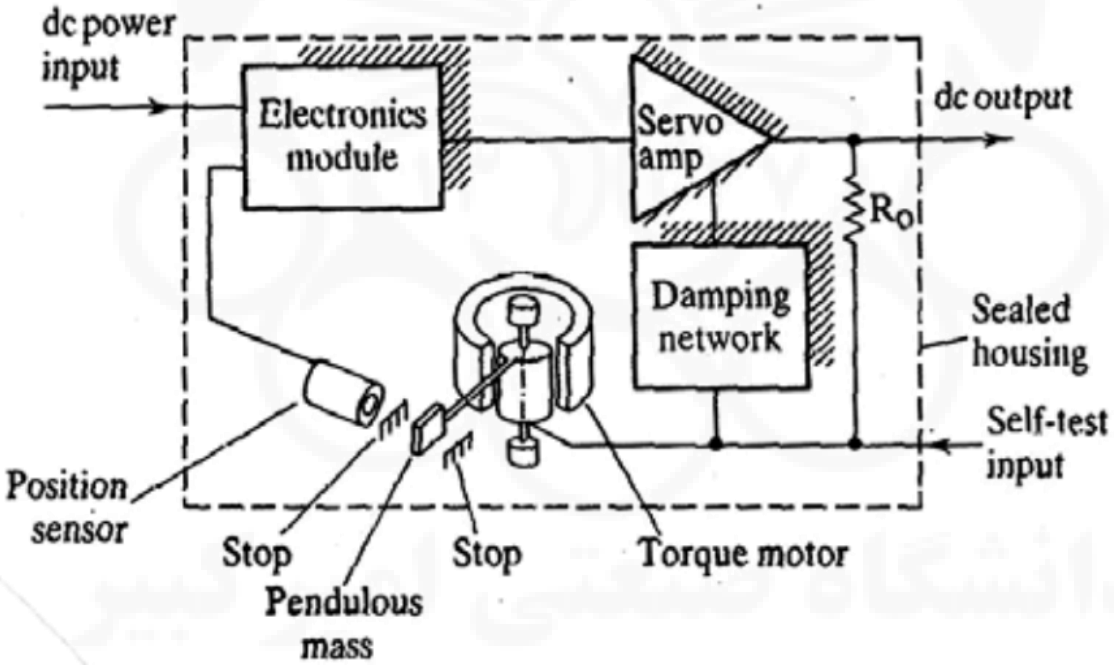
$$\Delta\ddot{x} = f_x / m = \frac{torque / moment\ arm}{m} \Rightarrow \Delta x \simeq 0$$

Sensing System

3) Acceleration Sensor

3-2) Force Rebalance Accelerometer

- Deflection is proportional to acceleration



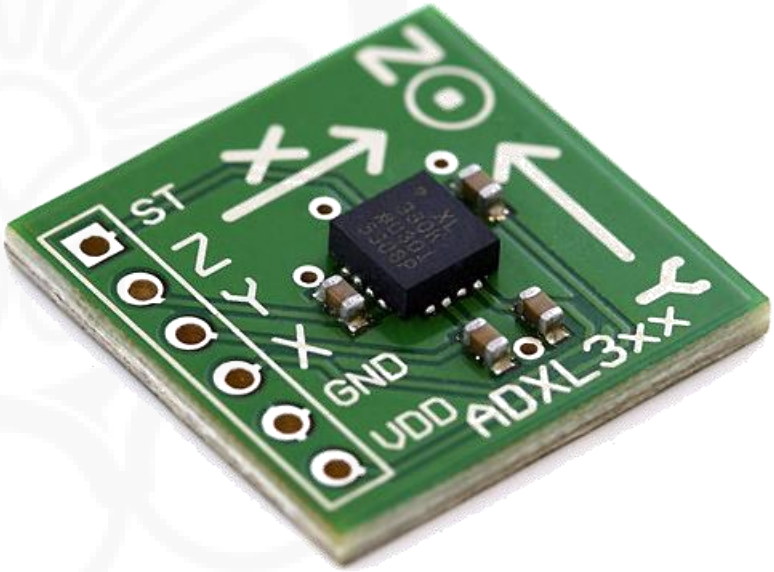
← Outline

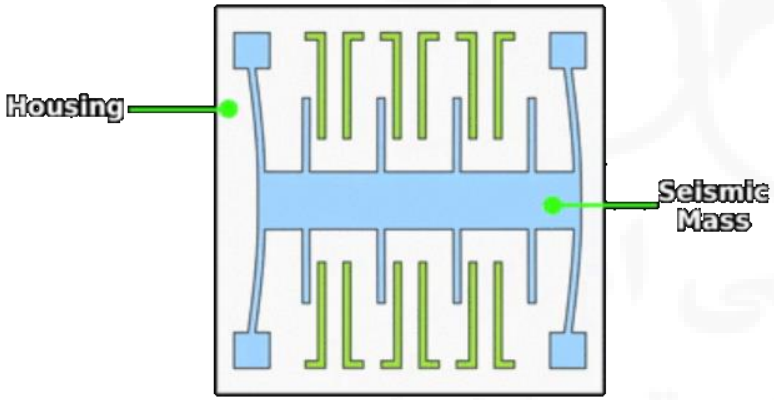
Sensing System

3) Acceleration Sensor

3-3) Micro Electro Mechanical System (MEMS) Accelerometer

- IMU (Inertial Measurement Unit)

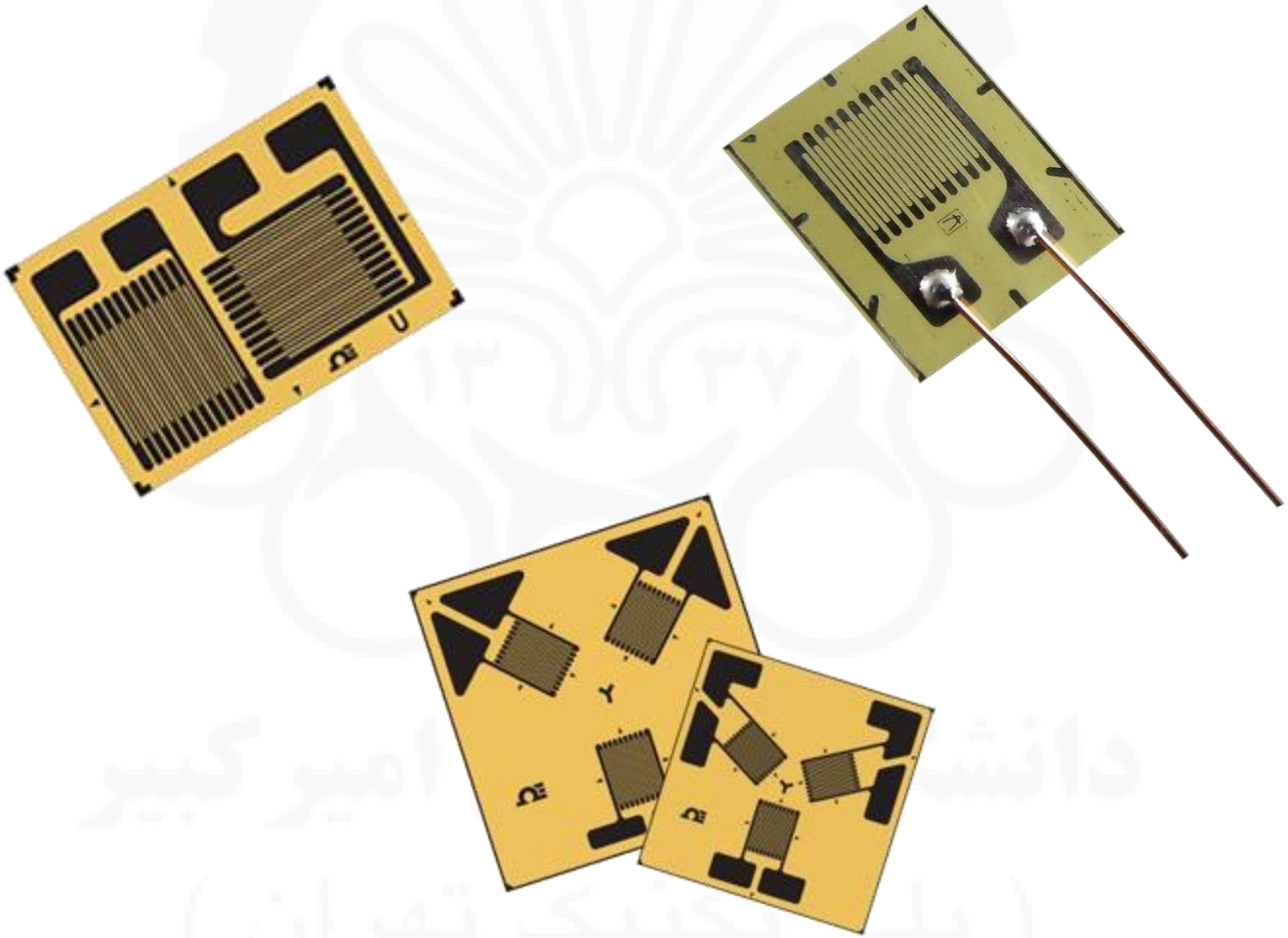




← Outline

Sensing System

4) Strain Gauge

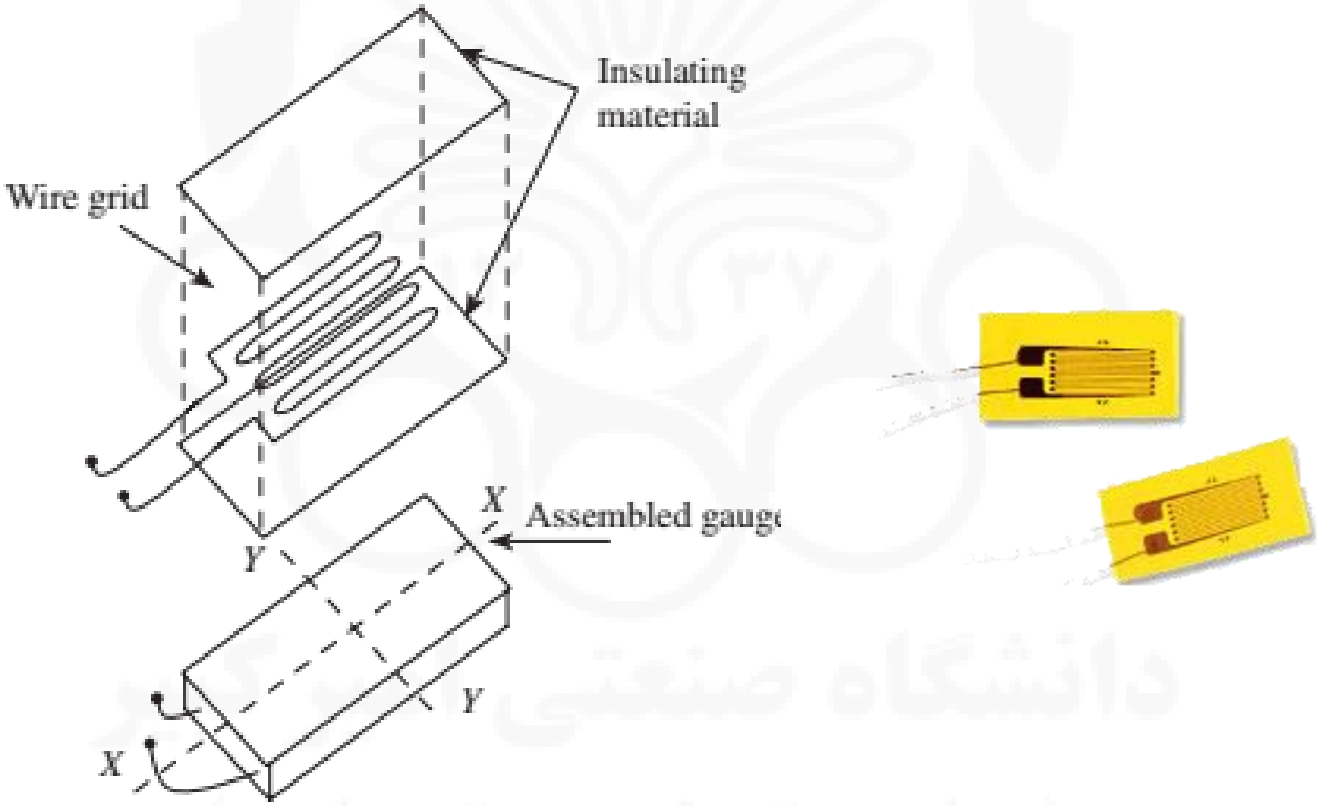


← Outline

Sensing System

4) Strain Gauge

- A thin wire in the form of a grid pattern is cemented in between thin sheets of insulating materials such as paper or plastic.

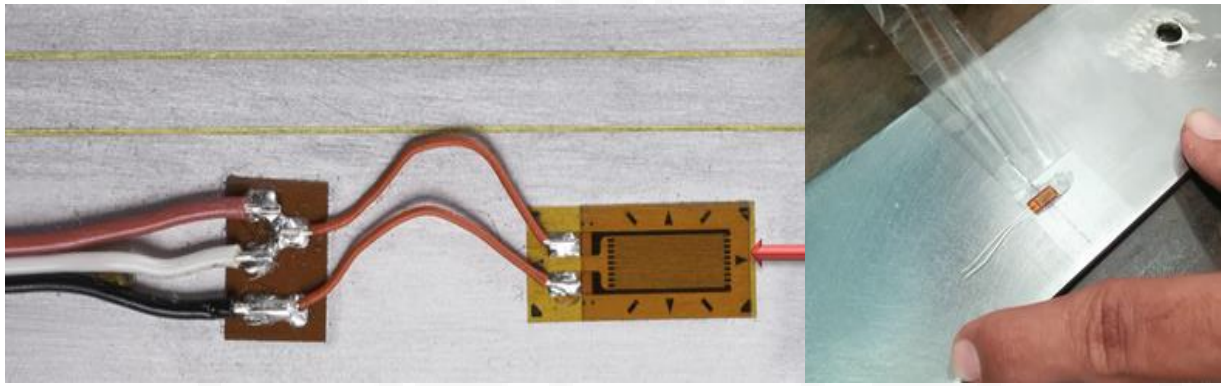


← Outline

Sensing System

4) Strain Gauge

- The gauges are bonded to the surface under study using a thin layer of adhesive.



- Waterproofing is provided by applying a layer of wax or lacquer on the gauge.

← Outline

Sensing System

4) Strain Gauge

- **Gauge Factor**
- It is the most important parameter of strain gauges.

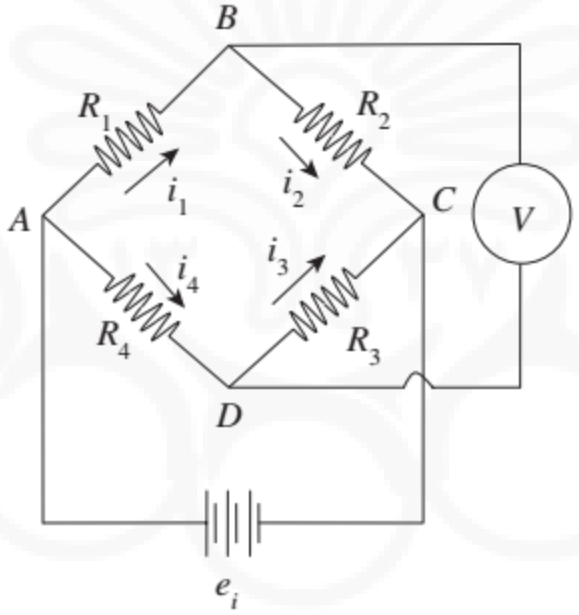
$$G.F. = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

- It is a measure of the amount of resistance change for a given strain and therefore serves as an index of the **strain sensitivity** of the gauge.

Sensing System

4) Strain Gauge

- **Methods of Strain Measurement**
- It employs a highly sensitive **resistance bridge arrangement** for strain measurement.



- Balancing Condition

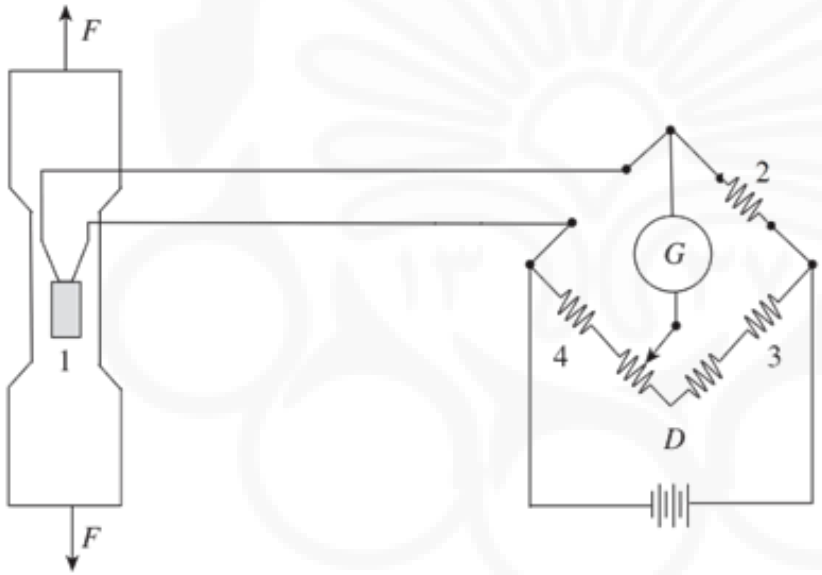
$$V_{BD} = 0 \quad \rightarrow \quad \frac{R_1}{R_2} = \frac{R_4}{R_3} \qquad or \qquad R_1 R_3 = R_2 R_4$$

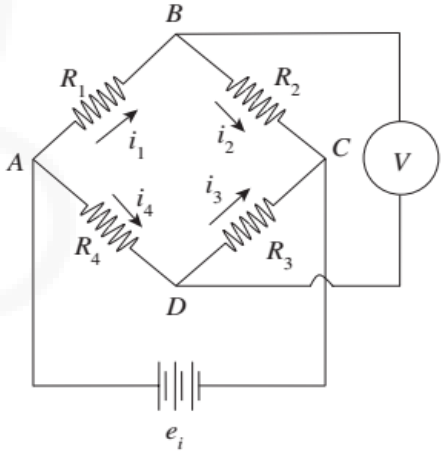
← Outline

Sensing System

4) Strain Gauge

- **Methods of Strain Measurement**
- Now, a strain gauge can be substituted by one of the resistors.





❖ For balancing the resistance of the bridge, the arrangement has portions of slide wire resistance D.

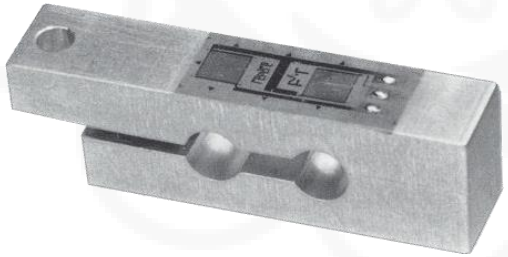
← Outline

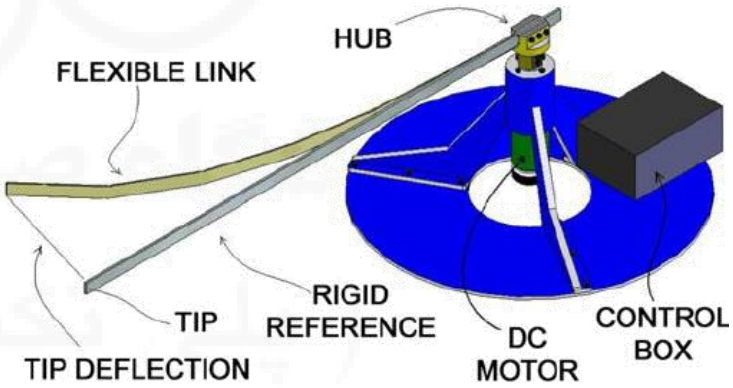
Sensing System

4) Strain Gauge

- **Applications**
- A strain-sensitive transducer can measure of quantities such as force, pressure, displacement, and acceleration.

  - Displacement Measurement (Flexible link manipulators)
  - Force Measurement
  - Pressure Measurement

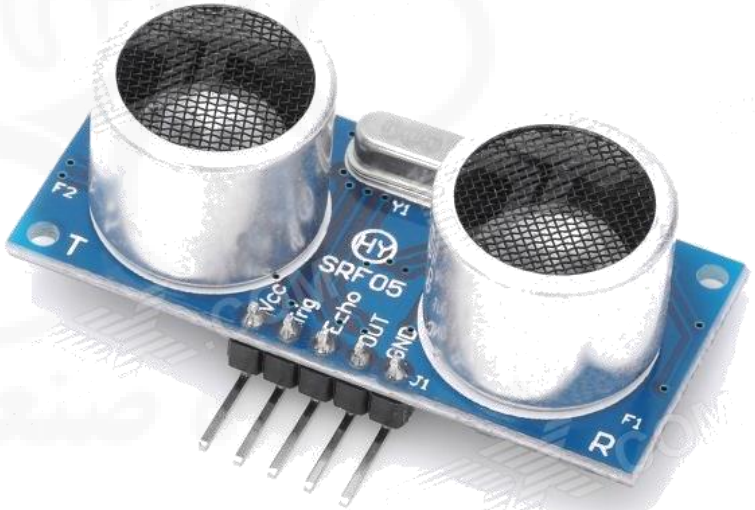




← Outline

Sensing System

5) Ultrasonic



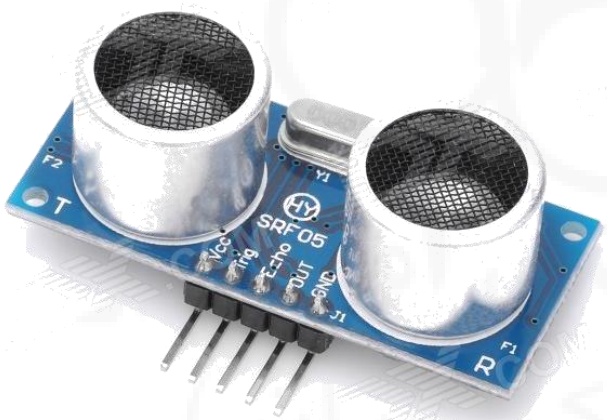
← Outline

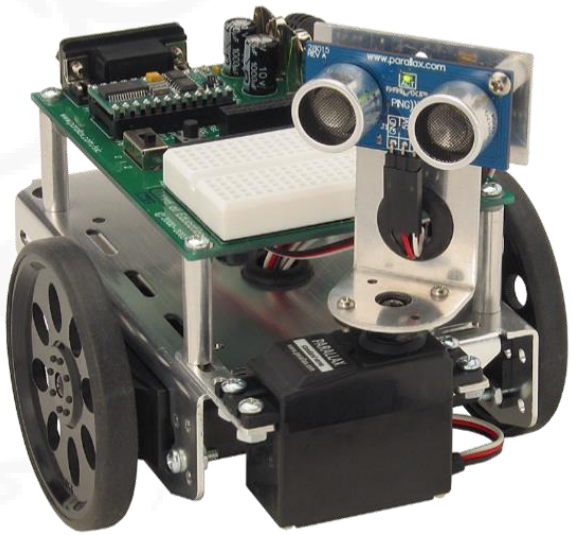
Sensing System

5) Ultrasonic

- Ultrasonic sensors are usually used for
  - Object Detection
  - Distance measurement
  - Velocity measurement

- It works based on:
  - Time
  - Frequency



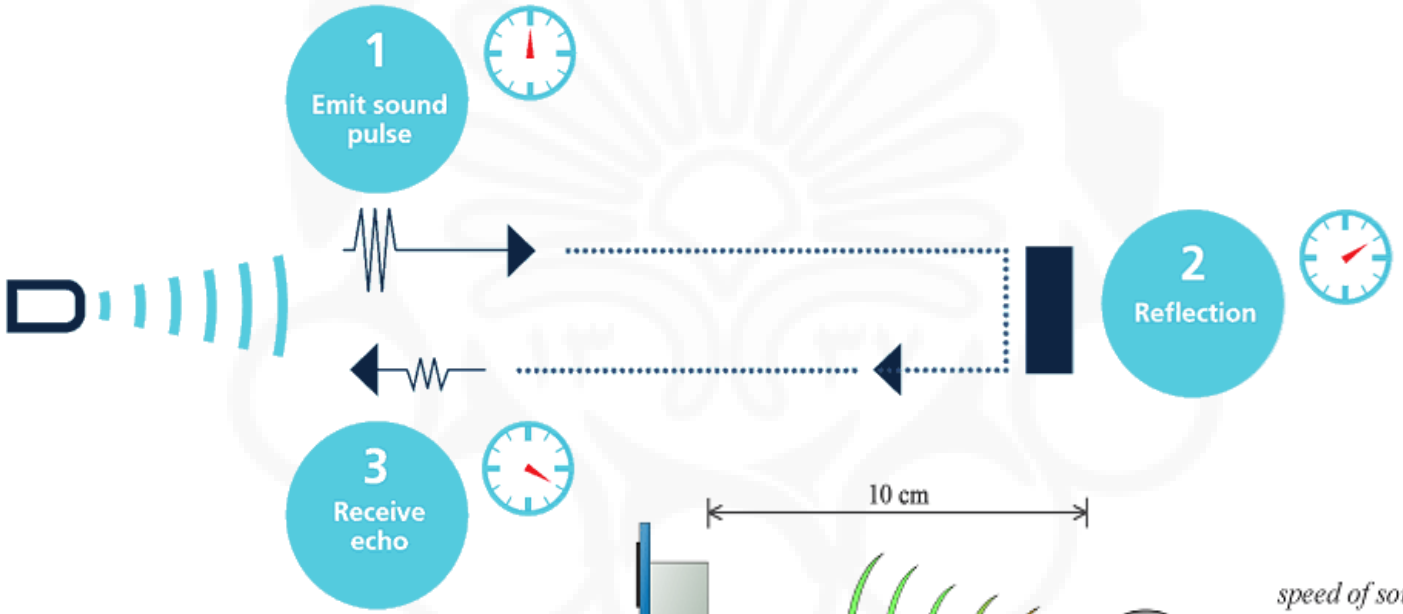


← Outline

Sensing System

5) Ultrasonic

- **Time Based**



speed of sound:

$v = 340\ m/s$

$v = 0{,}034\ cm/\mu s$

Measure time:

$t = 294\ \mu s$

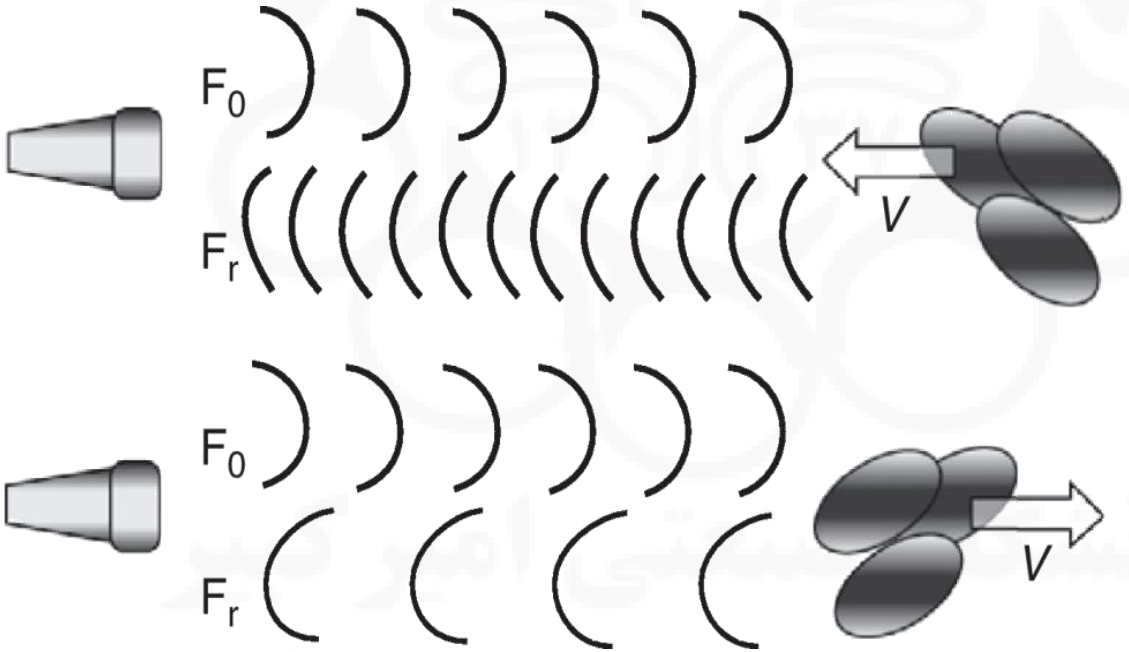
Distance:

$s = t \cdot 0{,}034 / 2$

Sensing System

5) Ultrasonic

- **Frequency Based (Doppler)**
- By measuring the frequency change, the velocity can be determined.



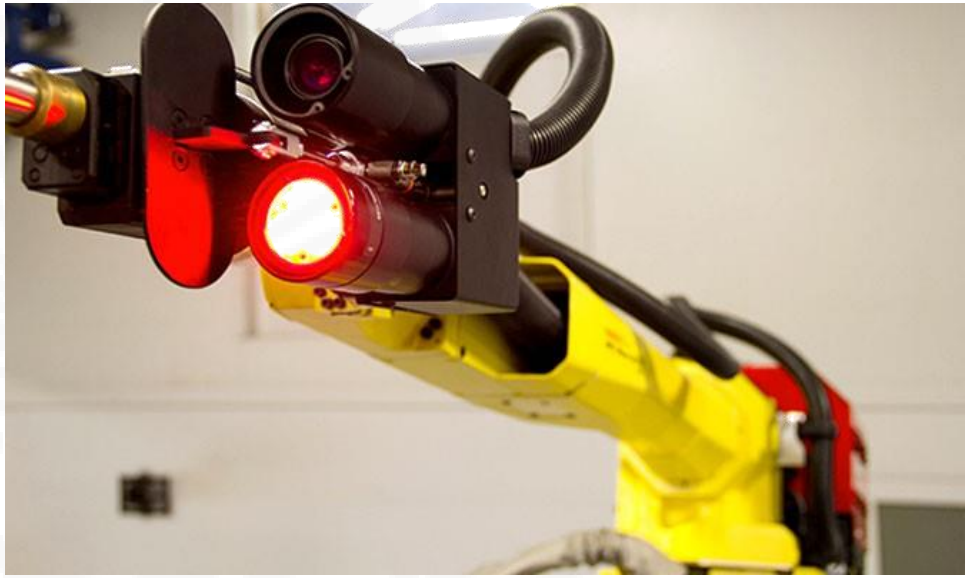
$$F_r = F_0 + \delta F$$

$$F_r = F_0 - \delta F$$

← Outline

Sensing System

6) Vision



The END

- **References:**

1) .