# Sensors

# Sensors

- A sensor measures a physical quantity and converts that measurement reding into a digital representation.
- This digital representation is passed to another device to transform into useful data that can be consumed by humans or intelligent devices.
- A parallel can be drawn with humans and the use of their five senses to learn about their surroundings, where the brain makes the intelligent decisions based on the data provided.
- However, sensors are not limited to human-like sensory data. They can measure anything worth measuring that too with a greater precision than human sensors.
- They can be embedded in physical objects connected to the Internet by wired or wireless networks.

# Transducers

- Sensor is the device that detect the change in the environment.
- Transducer is the device which transform energy from one form to another.
- It also transforms a non-electrical physical into an electrical signal.
- It provide output response to specific input measured which may be physical quantity.

# Sensors v/s Transducers

**Sensors**

- A device that convert physical parameters to electrical output.
- The uses of Sensor is for sensing element itself.
- All the sensors are not transducers.
- It detects change in physical stimulus and turn it into a signal.
- Examples of Sensor: Temperature Sensor, and Proximity Sensor.

**Transducers**

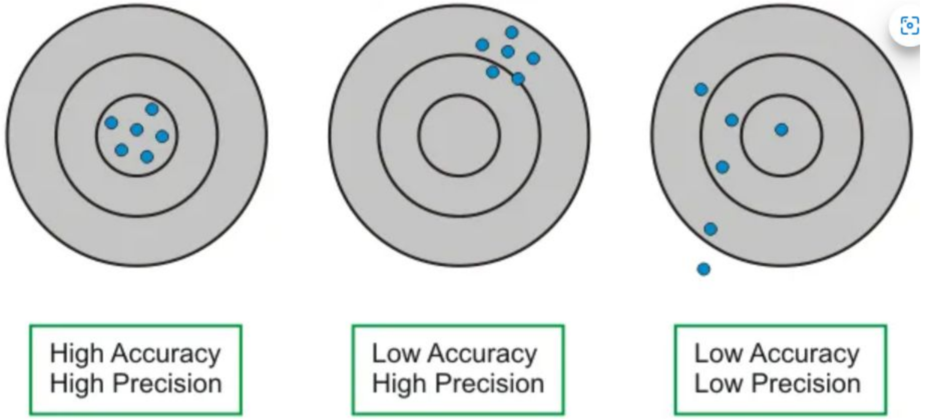
- A device that convert energy one form to another form is know as Transducer.
- The uses of transducer is for sensing element and also for circuitry.
- All Transducers contain a Sensor.
- It transfers power form one system to another in the same or in different form.
- Example of Transducer: Strain gauge, and Piezoelectric

# Sensor features

- Range
  - It is the minimum and maximum value of physical variable that the sensor can sense or measure.
  - For example, a Resistance Temperature Detector (RTD) for the measurement of temperature has a range of -200 to 800 ̊C.
- Span
  - It is the difference between the maximum and minimum values of input.
  - In above example, the span of RTD is 800 – (-200) = 1000oC.
- Accuracy
  - The error in measurement is specified in terms of accuracy.
  - It is defined as the difference between measured value and true value.

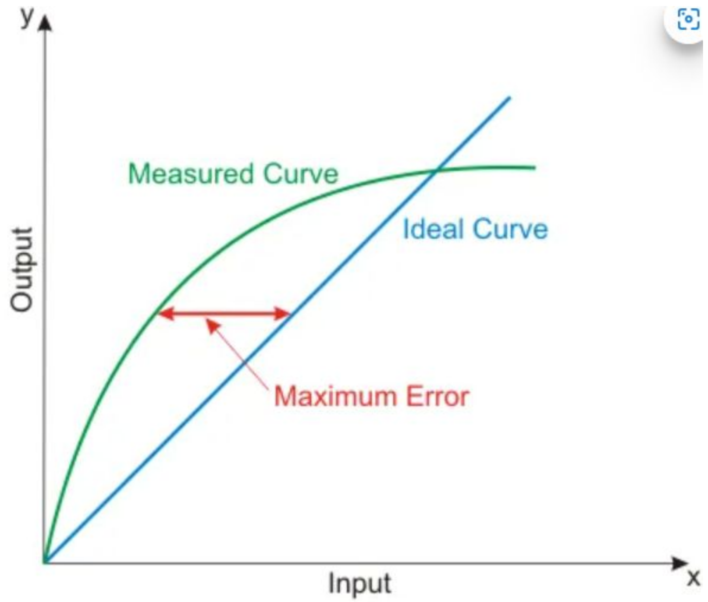
# Sensor features

- Precision
  - It is defined as the closeness among a set of values.
  - It is different from accuracy.
  - Let $X_t$ be the true value of the variable X and a random experiment measures $X_1$, $X_2$, …. $X_i$ as the value of X.




  - We will say our measurements $X_1$, $X_2$,… $X_i$ are precise when they are very near to each other but not necessarily close to true value $X_t$.
  - However, if we say $X_1$, $X_2$,… $X_i$ are accurate, it means that they are close to true value $X_t$ and hence they are also close to each other.
  - Hence accurate measurements are always precise.

# Sensor features




- Sensitivity
  - It is the ratio of change in output to change in input.
- Linearity
  - Linearity is the maximum deviation between the measured values of a sensor from ideal curve.
- Hysteresis
  - It is the difference in output when input is varied in two ways- increasing and decreasing.
- Resolution
  - It is the minimum change in input that can be sensed by the sensor.

# Sensor features

- Reproducibility
  - It is defined as the ability of sensor to produce the same output when same input is applied.
- Repeatability
  - It is defined as the ability of sensor to produce the same output every time when the same input is applied and all the physical and measurement conditions kept the same including the operator, instrument, ambient conditions etc.
- Response Time
  - It is generally expressed as the time at which the output reaches a certain percentage (for instance, 95%) of its final value, in response to a step change of the input.

# Resolution

- Consider an office ruler, the divisions are in millimeters and centimeters. The smallest unit that can be measured is 1mm. Thus, the best resolution of a ruler is 1 mm.


- The *sensor resolution* or *measurement resolution* is the smallest change that can be detected in the quantity that it is being measured.
- A sensor with a lower resolution will only detect or report displacements in whole centimetres, for example. When a sensor with a higher resolution is used, it is possible to do this down to millimetres.
- Critical applications require sensors with high resolution.

# Analog sensors

- Analog sensors produce continuous analog output signal.
- This continuous output signal produced by the analog sensors is proportional to the quantity measured.
- Practical examples of various types of analog sensors are: accelerometers, pressure sensors, light sensors, sound sensors, temperature sensors etc.

# Digital sensors

- Unlike analog sensor, Digital Sensor produce discrete values (0 and 1's).
- Electronic sensors in which data conversion and data transmission take place digitally are digital sensors.
- Measurements such as pH level, conductivity, dissolved oxygen, ammonium, nitrate etc. are conducted using digital sensors.

**Analog sensors**

- Continuous Signal is representing physical measurements
- Denoted by Sine Waves
- Subject to deterioration by noise
- Draws large power
- Observational error may occur

**Digital sensors**

- Digital signal representing discrete time signals generated by digital modulation
- Denoted by Square Waves
- Noise immune without deterioration
- Comparatively less power is needed
- Free from Observational error

# Scalar sensors

- A scalar quantity is defined as the physical quantity with only magnitude and no direction.
- Some physical quantities can be described just by their numerical value without directions.
- The sensors which measure a scalar quantity are known as scalar sensors.
- Scalar sensors produce output signal which is proportional to only the magnitude of the quantity being measured irrespective of the direction.
- Examples: Temperature sensor, Color sensor, strain sensor etc.

# Vector sensors

- A vector quantity is defined as the physical quantity that has both directions as well as magnitude.
- The sensors which measure a vector quantity are known as vector sensors.
- Vector sensors produce output signal which is proportional to magnitude as well as direction of the quantity being measured.
- Eg: Accelerometer

# Sensor types

## Position Sensor

- A position sensor measures the position of an object.
- The position measurement can be either in absolute terms (absolute position sensor) or in relative terms (displacement sensor)
- Position sensors can be linear, angular, or multi-axis
- Eg: Potentiometer, inclinometer, proximity sensor

## Occupancy and Motion sensor

- Occupancy sensors detect the presence of people and animals in a surveillance area.
- Motion sensors detect movement of people and objects.
- Occupancy sensors generate a signal even when the object is stationary whereas motion sensors do not.
- Electric eye, radar

# Sensor types

## Velocity and Acceleration Sensors

- Velocity sensor, linear or angular, indicates how fast an object moves along a straight line or how fast it rotates.
- Acceleration sensor measures changes in velocity.
- Eg. Gyroscope, Accelerometer

## Force Sensor

- Force sensors detect if a physical force is applied and if the magnitude of force is beyond a threshold.
- Eg. Force gauge, viscometer, tactile sensor (touch sensor)

# Sensor types

## Pressure Sensor

- Pressure sensors are related to force sensors, measuring force applied by liquids or gases.
- Pressure is measured in terms of Force per unit area.
- Eg: Barometer, Bourdon gauge, piezometer.

## Flow Sensor

- Detect the rate of fluid flow.
- They measure the volume of fluid that has passes through a system in a given period of time.
- Eg: Anemometer, mass flow sensor, water meter

# Sensor types

## Acoustic Sensors

- Measure sound levels and convert that information into digital or analog data signals.
- Eg: Microphone, Geophone, Hydrophone

## Humidity Sensors

- Detect humidity i.e. amount of water vapor in air.
- Humidity levels can be measured in various ways such as absolute humidity, relative humidity etc.
- Eg. Hygrometer, Humistor, soil moisture sensor

# Sensor types

## Light Sensors

- Detect the presence of light.
- Eg. Infrared sensor, Photodetector, Flame detector.

## Temperature Sensors

- Measure the amount of heat or cold that is present in a system.
- They can be of contact type where the sensor needs to be in contact of the object being sensed.
- Or they can be of non-contact type where they measure temperature through radiation.
- Eg: Thermometer, temperature gauge

# Sensor types

## Chemical Sensors

- Measure the concentration of chemicals in a system.
- When subjected to a mix of chemicals, they sense the concentration of the target chemical.
- Eg: Smoke detector

## Biosensors

- Detect various biological elements such as tissues, cells, antibodies etc.
- Eg: Blood glucose biosensor, pulse oximetry, electrocardiograph

# Actuators

# Actuators

- Sensors are used to measure a physical quantity and convert the measurement into electric signals, that can be consumed by an intelligent agent.
- Actuators on the other hand, receive a control signal (electric signal or digital command) that triggers a physical effect (some type of motion).

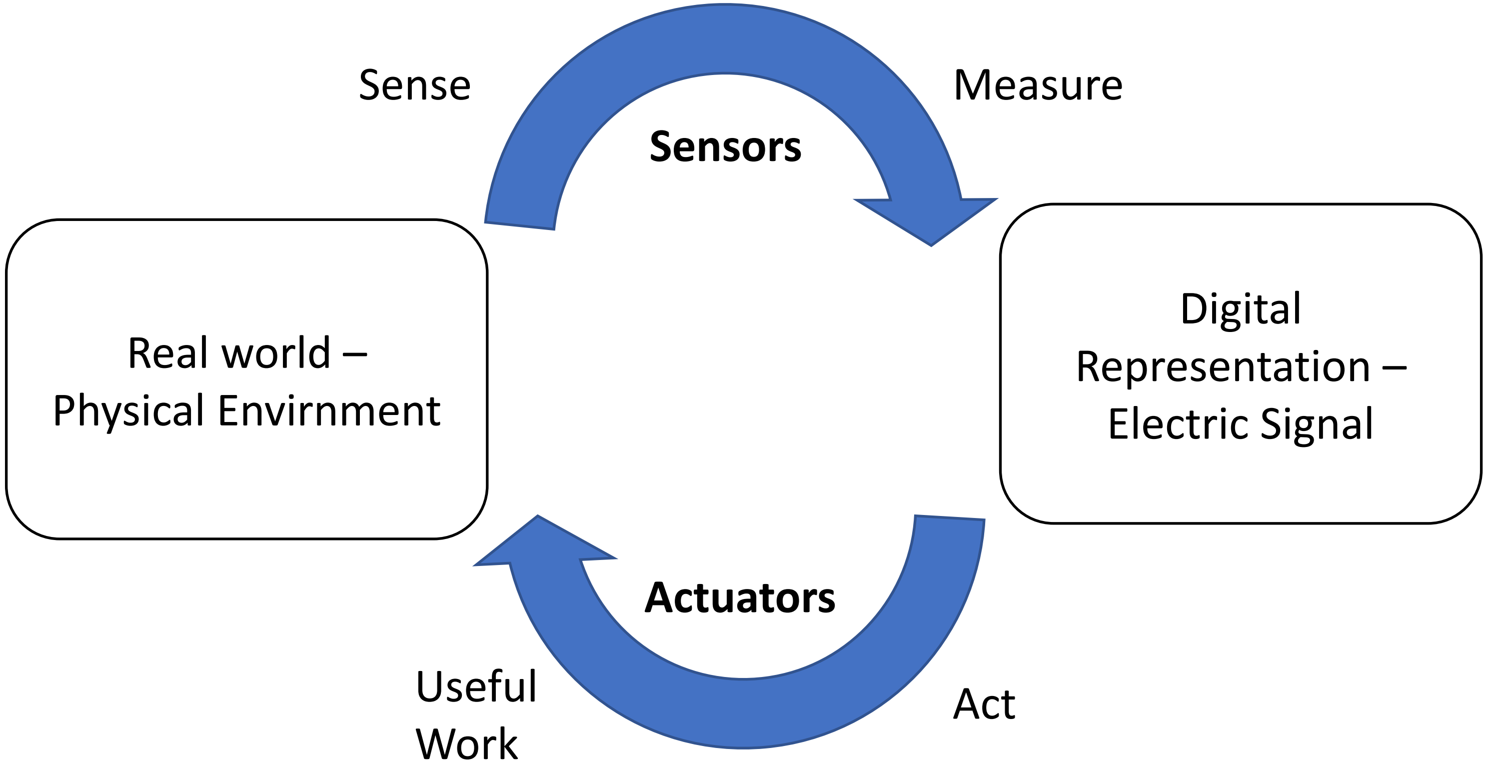


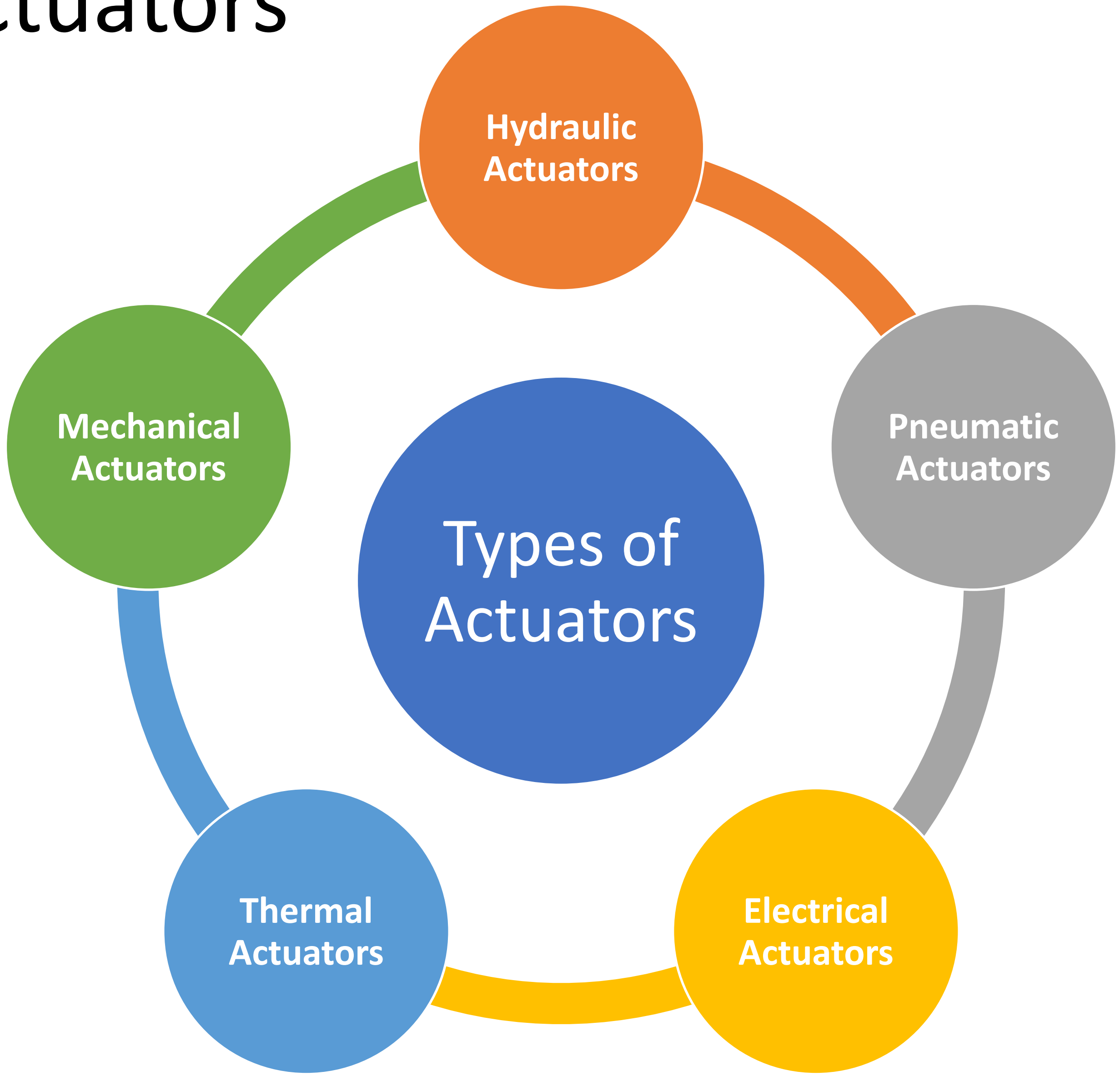



**Diagram to show the interaction of sensors and actuators with the physical world**

# Actuators

- The operation of sensors and actuators is analogous to the human operation.
- Humans use the 5 senses to sense their environment.
- This information is converted into electrical impulses that are sent to the brain for processing.
- The human brain signals movement and the nervous system carries this information to the appropriate past of muscular system.
- In a similar manner, the IoT sensors sense the physical world and send the electric signals to a microprocessor or a microcontroller.
- The processor sends the electric signal to an actuator, that translates the signal to some type of movement which has a measurable impact on the physical world.

# Types of Actuators



# Types of Actuators

## 1. Hydraulic Actuators

- A hydraulic actuator uses hydraulic power to perform a mechanical operation.
- They are actuated by a cylinder or fluid motor.
- The mechanical motion is converted to rotary, linear, or oscillatory motion, according to the need of the IoT device.
- Ex- construction equipment uses hydraulic actuators because hydraulic actuators can generate a large amount of force.
- **Advantages :**
  - Hydraulic actuators can produce a large magnitude of force and high speed.
- **Disadvantages :**
  - Hydraulic fluid leaks can cause efficiency loss and issues of cleaning.
  - It is expensive.
  - It requires noise reduction equipment, heat exchangers, and high maintenance systems.

# Types of Actuators

## 2. Pneumatic Actuators

- A pneumatic actuator uses energy formed by vacuum or compressed air at high pressure to convert into either linear or rotary motion.
- Example- Used in robotics, use sensors that work like human fingers by using compressed air.
- **Advantages :**
  - They are a low-cost option and are used at extreme temperatures where using air is a safer option than chemicals.
  - They need low maintenance, are durable, and have a long operational life.
  - It is very quick in starting and stopping the motion.
- **Disadvantages :**
  - Loss of pressure can make it less efficient.
  - The air compressor should be running continuously.
  - Air can be polluted, and it needs maintenance.

# Types of Actuators

## 3. Electrical Actuators

- An electric actuator uses electrical energy, is usually actuated by a motor that converts electrical energy into mechanical torque.
- An example of an electric actuator is a solenoid based electric bell.
- **Advantages :**
  - It has many applications in various industries as it can automate industrial valves.
  - It produces less noise and is safe to use since there are no fluid leakages.
  - It can be re-programmed and it provides the highest control precision positioning.
- **Disadvantages :**
  - It is expensive.
  - It depends a lot on environmental conditions.

# Types of Actuators

**4. Thermal/Magnetic Actuators**

- These are actuated by thermal or mechanical energy.
- Shape Memory Alloys (SMAs) or Magnetic Shape-Memory Alloys (MSMAs) are used by these actuators.
- An example of a thermal/magnetic actuator can be a piezo motor using SMA.
- These are Compact, light in weight, economical, and offer high power density.

**5. Mechanical Actuators**

- A mechanical actuator executes movement by converting rotary motion into linear motion.
- It involves pulleys, chains, gears, rails, and other devices to operate.
- Example – A crankshaft.

# Motors - **DC Motor**

- A DC motor is an electrical machine that converts electrical energy (direct current) into mechanical energy (rotation).
- The working of DC motor is based on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force.
- The main components of DC motor are as follows:
  - Armature or Rotor
  - Field Coil or Stator
  - Commutator
  - Brushes

# Motors - **DC Motor (Components)**

- Armature or Rotor
  - The armature of a DC motor is a cylinder of magnetic laminations that are insulated from one another.
  - The armature is perpendicular to the axis of the cylinder.
  - The armature is a rotating part that rotates on its axis and is separated from the field coil by an air gap.
- Field Coil or Stator
  - A DC motor field coil is a non-moving part on which winding is wound to produce a magnetic field.
  - This electro-magnet has a cylindrical cavity between its poles.

# Motors - DC Motor

- Commutator
  - The commutator of a DC motor is a cylindrical structure that is made of copper segments stacked together but insulated from each other using mica.
  - The primary function of a commutator is to supply electrical current to the armature winding.
- Brushes
  - The brushes of a DC motor are made with graphite and carbon structure.
  - These brushes conduct electric current from the external circuit to the rotating commutator.
  - The commutator and the brush unit are concerned with transmitting the power from the static electrical circuit to the mechanically rotating region or the rotor.

# Motors - Servo Motor

- A servo motor is an electrical device, that rotate parts of a machine with high efficiency and with great precision.
- The output shaft of this motor can be moved to a particular angle, position and velocity that a regular motor does not have.
- The Servo Motor utilizes a regular motor and couples it with a sensor for positional feedback.
- The motor is controlled with an electric signal, either analog or digital, which determines the amount of movement which represents the final command position for the shaft.

# Motors - Servo Motor (Components)

- The servo motor consists of two winding stator and rotor windings.
- The stator winding is wound on the stationary part of the motor, and this winding is also called field winding of the motor.
- The rotor winding is wound on the rotating part of the motor and this winding is also called the armature winding of the motor.
- The motor consists of two bearings on the front and backside for the free movement of the shaft.
- The encoder has the approximate sensor for determining the rotational speed and revolution per minute of the motor.

# Motors - Stepper Motor

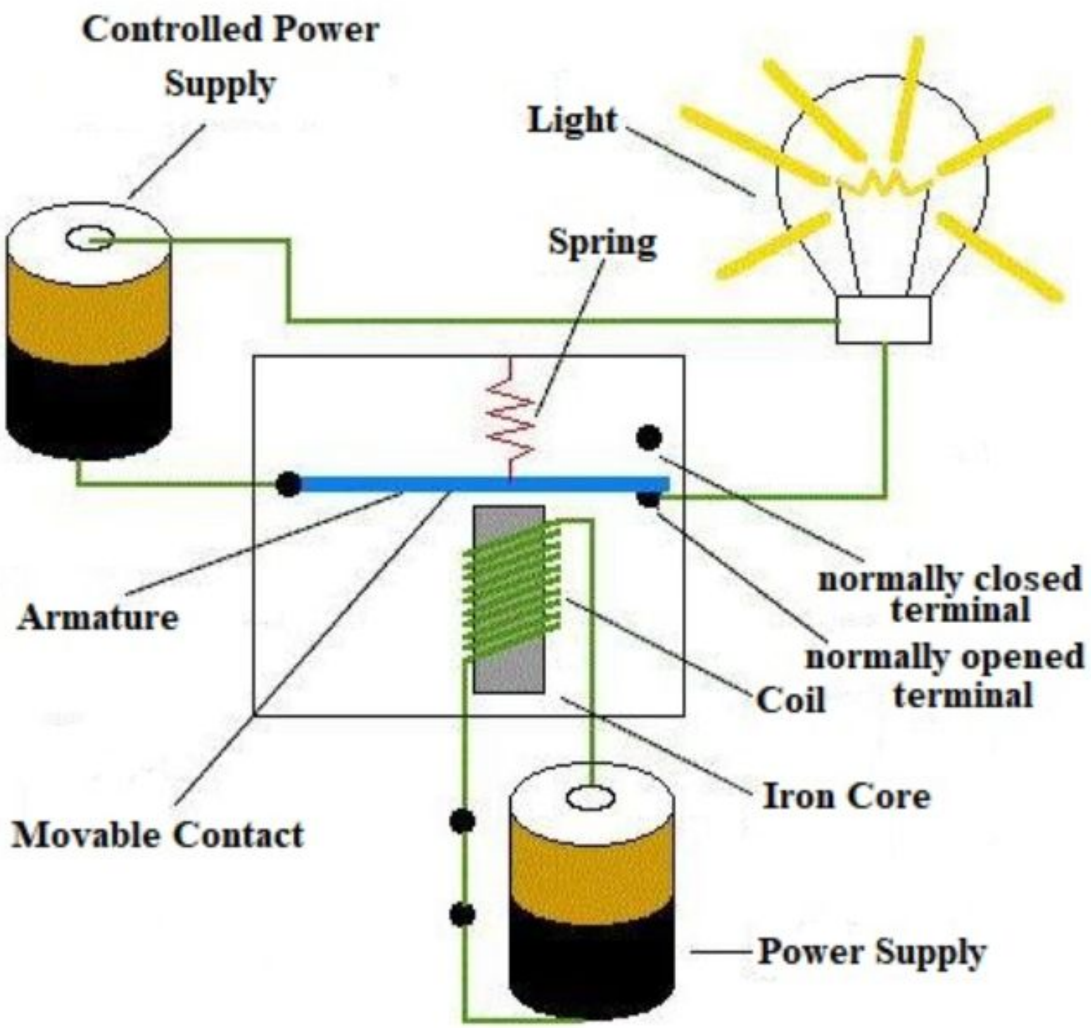
- Stepper motors are DC motors that move in discrete steps.
- They have multiple coils that are organized in groups called "phases".
- By energizing each phase in sequence, the motor will rotate, one step at a time.
- With a computer controlled stepping you can achieve very precise positioning and/or speed control.
- For this reason, stepper motors are the motor of choice for many precision motion control applications.

# Relays

- A relay is an electrically operated switch.
- Relays are used where it is necessary to control a circuit by an independent low-power signal, or where several circuits must be controlled by one signal.
- The traditional form of a relay uses an electromagnet to close or open the contacts.
- The relay has normally open contacts and normally closed contacts.
- The movable contact is a common terminal.

# Relays (Working)

- Consider a DC relay powered by a battery.
- When the coil of the relay is powered by a DC power supply, the coil with the iron core will generate the corresponding magnetic field.
- Due to this, the movable contact will move from the normally closed contact side to the normally open contact side.



# Relays (Working)

- The start/stop button, battery, and relay coil form a control loop.
- As long as this loop is closed, the current will flow through the coil and a magnetic field will be generated.
- The normally open contact, the lamp, and the control power supply (the other battery in the picture) form a loop.
- When the normally opened contact is closed, the loop is closed and the current will flow from the positive of control power supply to the bulb, passing through the closed normally opened contact to the negative pole, so that the light will on.
- When the start/stop button disconnects, the coil has no current.
- So that the armature will not be attracted by the magnetic force, and will be reset by the spring.
- So that the other end of the moving contact will go from the normally opened contact to the normally closed contact.
- The circuit of the bulb is forcibly disconnected and does not turn on.

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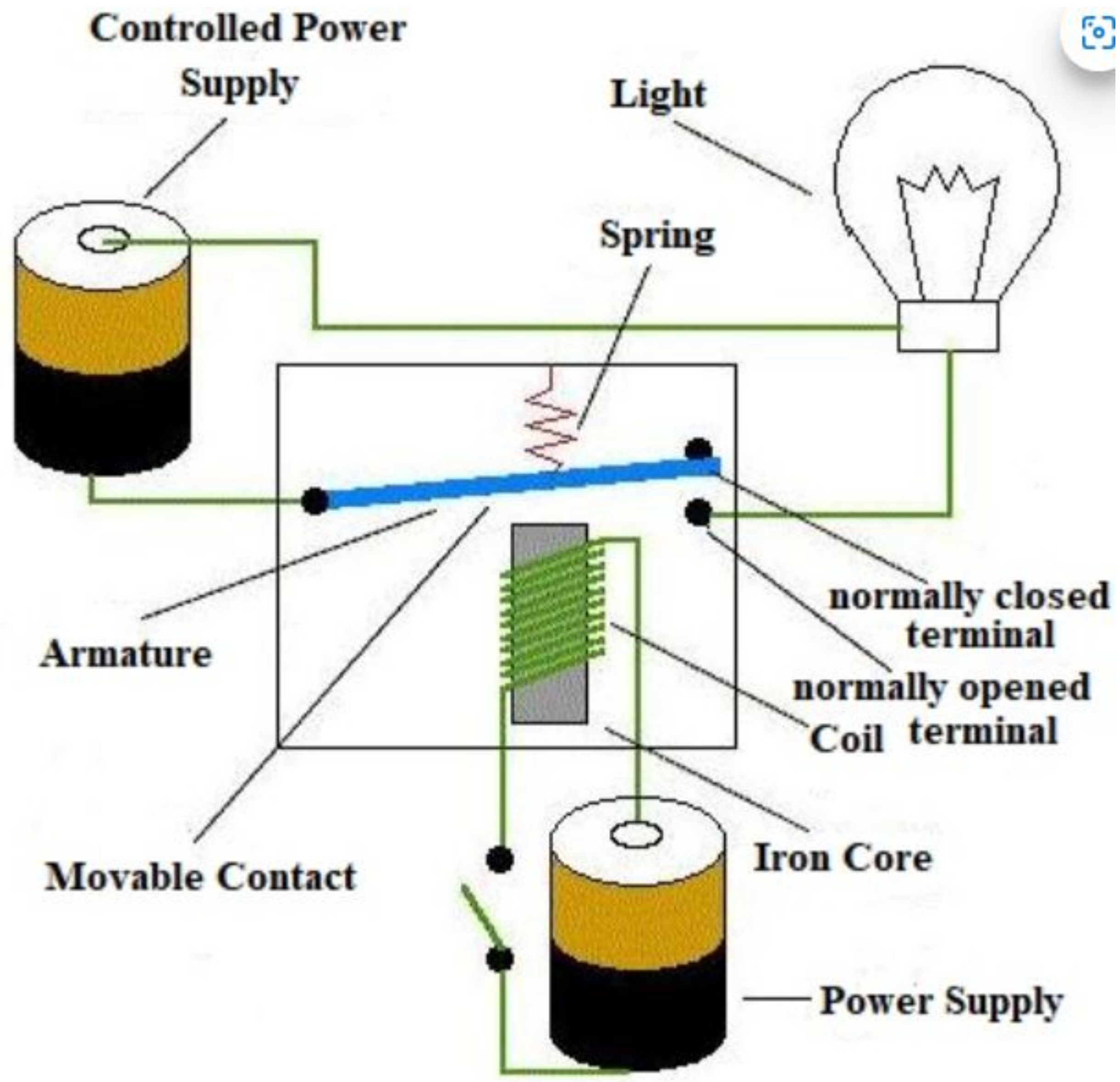

# Motor drivers for interfacing

- In motor interfacing with controllers, primary requirement for the operation of the controller is low voltage and small amount of current.
- But the motors require a high voltage and current for its operation.
- In other words we can say the output of the controller or processor is not enough to drive a motor.
- In such a case direct interfacing of controllers to the motor is not possible.
- Not only in the case of controllers, while connecting motors with 555 timer ICs etc.; they also cannot provide the large current required by the motor.
- If direct connection is given, there might be a chance of damage to the IC.
- So we use a Motor Driver Circuit or Motor Driver IC.