SENSING AND ACTUATION

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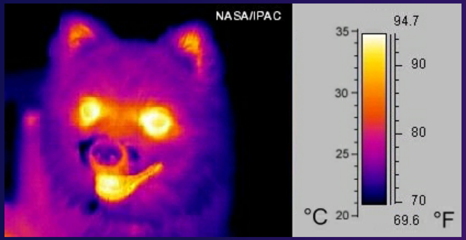
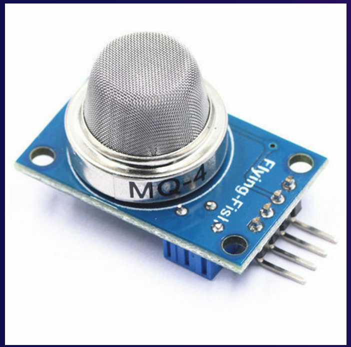
Parameters	Transducers	Sensors	Actuators
Definition	Converts energy from one form to another.	Converts various forms of energy into electrical signals.	Converts electrical signals into various forms of energy, typically mechanical energy.
Domain	Can be used to represent a sensor as well as an actuator.	It is an input transducer.	It is an output transducer.
Function	Can work as a sensor or an actuator but not simultaneously.	Used for quantifying environmental stimuli into signals.	Used for converting signals into proportional mechanical or electrical outputs.
Examples	Any sensor or actuator	Humidity sensors, Temperature sensors, Anemometers (measures flow velocity), Manometers (measures fluid pressure), Accelerometers (measures the acceleration of a body), Gas sensors (measures concentration of specific gas or gases), and others	Motors (convert electrical energy to rotary motion), Force heads (which impose a force), Pumps (which convert rotary motion of shafts into either a pressure or a fluid velocity).

SENSORS

- Sensors are devices that can measure, quantify, or respond to the ambient changes in their environment or within the intended zone of their deployment.
- Properties of Sensors:
    - They generate responses to external stimuli or physical phenomena through characterization of the input functions (which are these external stimuli) and their conversion into typically electrical signals.
    - A sensor is only sensitive to the measured property.
    - It is insensitive to any other property besides what it is designed to detect.
    - A sensor does not influence the measured property.



CLASSIFICATION OF SENSORS



POWER REQUIREMENTS

❖ Active

- Active sensors do not require external circuitry or mechanism to provide them with power

❖ Passive

- Passive sensors require an external mechanism to power them up

PROPERTY TO BE MEASURED

❖ Scalar

- Scalar sensors produce an output proportional to the magnitude of the quantity being measured.
- The output is in the form of a signal or voltage.

❖ Vector

- Vector sensors are affected by the magnitude as well as the direction and/or orientation of the property they are measuring.

SENSOR OUTPUT

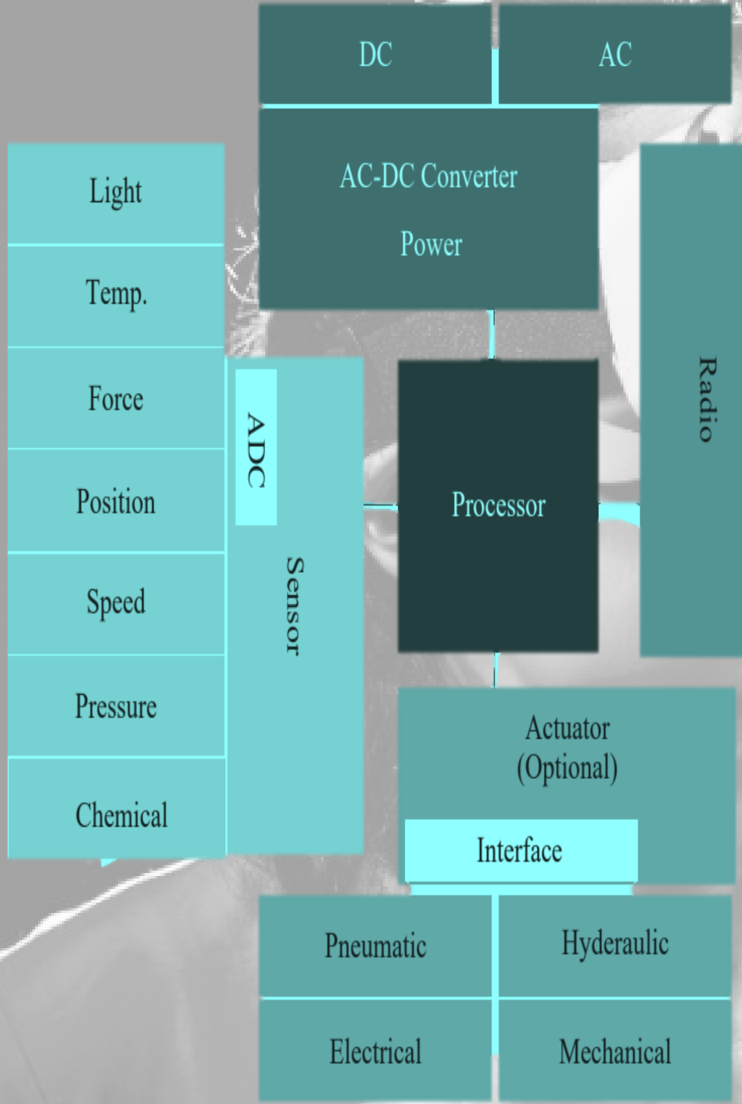
❖ Analog

- Analog sensors generate an output signal or voltage, which is proportional (linearly or non-linearly) to the quantity being measured and is continuous in time and amplitude.

❖ Digital

- These sensors generate the output of discrete time digital representation (time, or amplitude, or both) of a quantity being measured, in the form of output signals or voltages.

SENSORS



IOT SENSORS

A sensor node is made up of a combination of sensor/sensors, a processor unit, a radio unit, and a power unit.

The nodes are capable of sensing the environment they are set to measure and communicate the information to other sensor nodes or a remote server.

Typically, a sensor node should have low-power requirements and be wireless.

This enables them to be deployed in a vast range of scenarios and environments without the constant need for changing their power sources or managing wires.

The wireless nature of sensor nodes would also allow them to be freely relocatable and deployed in large numbers without bothering about managing wires

SENSOR CHARACTERISTICS

SENSOR RESOLUTION

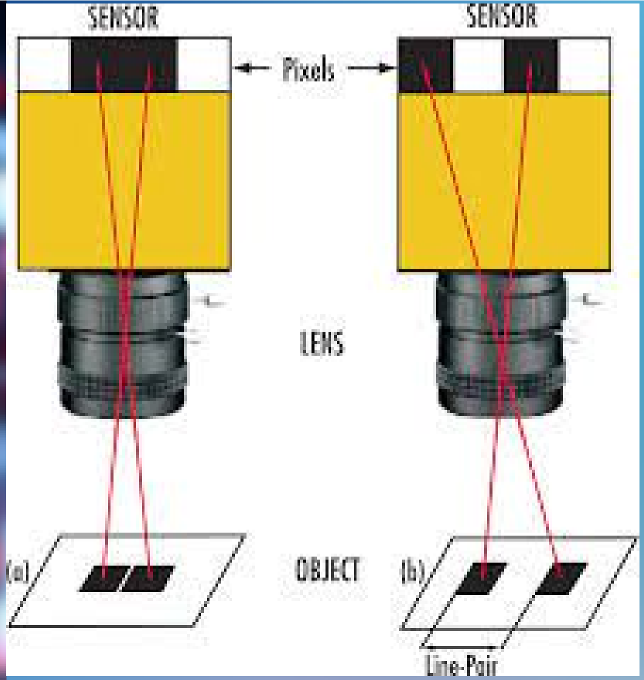
The smallest change in the measurable quantity that a sensor can detect is referred to as the resolution of a sensor.

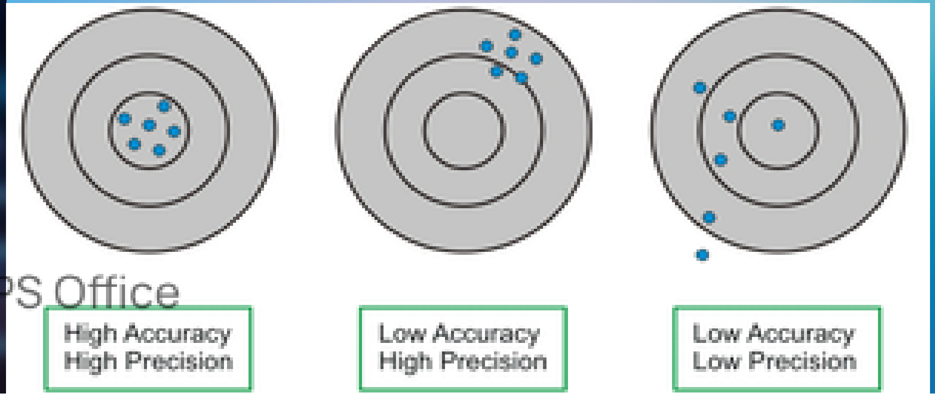
SENSOR ACCURACY

The accuracy of a sensor is the ability of that sensor to measure the environment of a system as close to its true measure as possible

SENSOR PRECISION

The principle of repeatability governs the precision of a sensor. Only if, upon multiple repetitions, the sensor is found to have the same error rate, can it be deemed as highly precise.





ACTIVITY

1. What type of sensor is being used?
2. Classify the sensor
3. Mention other applications of this sensor.

SENSOR DEVIATIONS: ERRORS IN SENSORS

- In the event of a sensor's output signal going beyond its designed maximum and minimum capacity for measurement, the sensor output is truncated to its maximum or minimum value, which is also the sensor's limit.
- The measurement range between a sensor's characterized minimum and maximum values is also referred to as the full-scale range of that sensor. Under real conditions, the sensitivity of a sensor may differ from the value specified for that sensor leading to ***sensitivity error***.
- If the output of a sensor differs from the actual value to be measured by a constant, the sensor is said to have an ***offset error or bias***
- If the output signal of a sensor changes slowly and independently of the measured property, this behavior of the sensor's output is termed a ***drift.***
- If a sensor's output varies/deviates due to deviations in the sensor's previous input values, it is referred to as a ***hysteresis error.*** The present output of the sensor depends on the past input values provided to the sensor.

SENSOR DEVIATIONS: ERRORS IN SENSORS

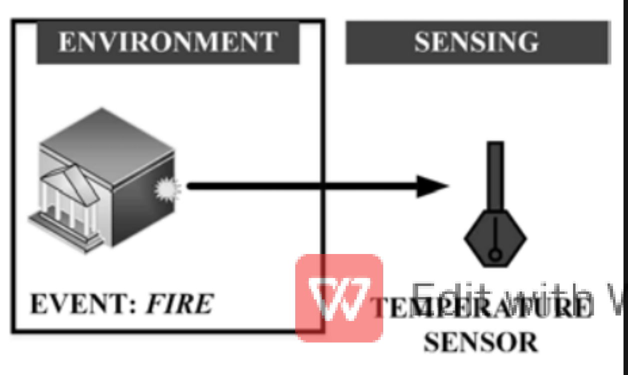
- Focusing on digital sensors, if the digital output of a sensor is an approximation of the measured property, it induces ***quantization error***. This error can be defined as the difference between the actual analog signal and its closest digital approximation during the sampling stage of the analog to digital conversion..

- ***Dynamic errors*** caused due to mishandling of sampling frequencies can give rise to aliasing errors. Aliasing leads to different signals of varying frequencies being represented as a single signal in case the sampling frequency is not correctly chosen, resulting in the input signal becoming a multiple of the sampling rate.

SENSING TYPES

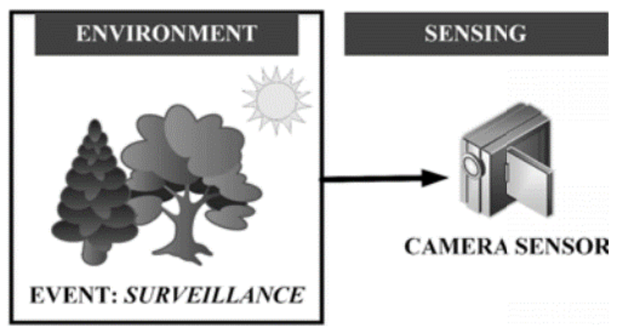
SCALAR SENSING

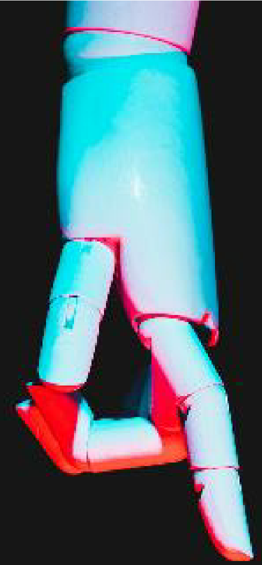
- Encompasses the sensing of features that can be quantified simply by measuring changes in the amplitude of the measured values with respect to time.
- Quantities such as ambient temperature, current, atmospheric pressure, rainfall, light, humidity, flux, and others are considered as scalar values as they normally do not have a directional or spatial property assigned with them.



MULTIMEDIA SENSING

- Encompasses the sensing of features that have a spatial variance property associated with the property of temporal variance.
- Quantities such as images, direction, flow, speed, acceleration, sound, force, mass, energy, and momentum have both directions as well as a magnitude
- They might have different values in different directions for the same working condition at the same time.

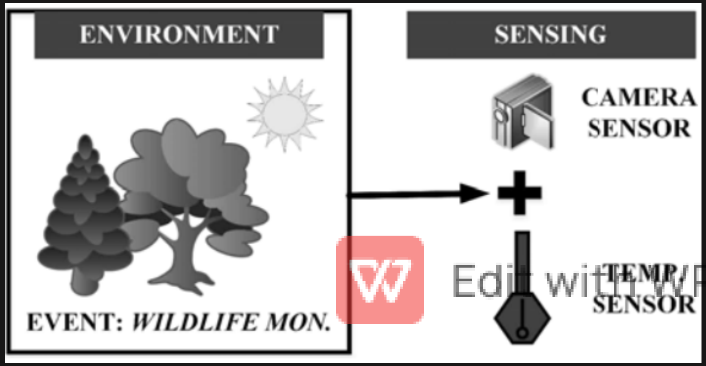




SENSING TYPES

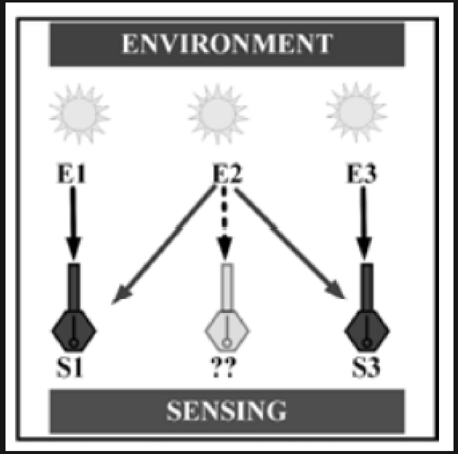
HYBRID SENSING

- The act of using scalar as well as multimedia sensing at the same time is referred to as hybrid sensing
- A range of various sensors are employed (from the collection of scalar as well as multimedia sensors) to measure the various properties of that environment at any instant of time, and temporally map the collected information to generate new information.



VIRTUAL SENSING

- Many a time, there is a need for very dense and large-scale deployment of sensor nodes spread over a large area for monitoring of parameters. One such domain is agriculture



ACTIVITY

Code for PIR Motion Sensor

```
//the time we give the sensor to calibrate (10-60 secs according to the datasheet)
int calibrationTime = 30;

//the time when the sensor outputs a low impulse
long unsigned int lowIn;

//the amount of milliseconds the sensor has to be low
//before we assume all motion has stopped
long unsigned int pause = 5000;

boolean lockLow = true;
boolean takeLowTime;

int pirPin = 3;    //the digital pin connected to the PIR sensor's output
int ledPin = 13;
```

```
/////////////////////////////
//SETUP
void setup(){
  Serial.begin(9600);
  pinMode(pirPin, INPUT);
  pinMode(ledPin, OUTPUT);
  digitalWrite(pirPin, LOW);

  //give the sensor some time to calibrate
  Serial.print("calibrating sensor ");
    for(int i = 0; i < calibrationTime; i++){
      Serial.print(".");
      delay(1000);
      }
    Serial.println(" done");
    Serial.println("SENSOR ACTIVE");
    delay(50);
  }
```

ACTIVITY

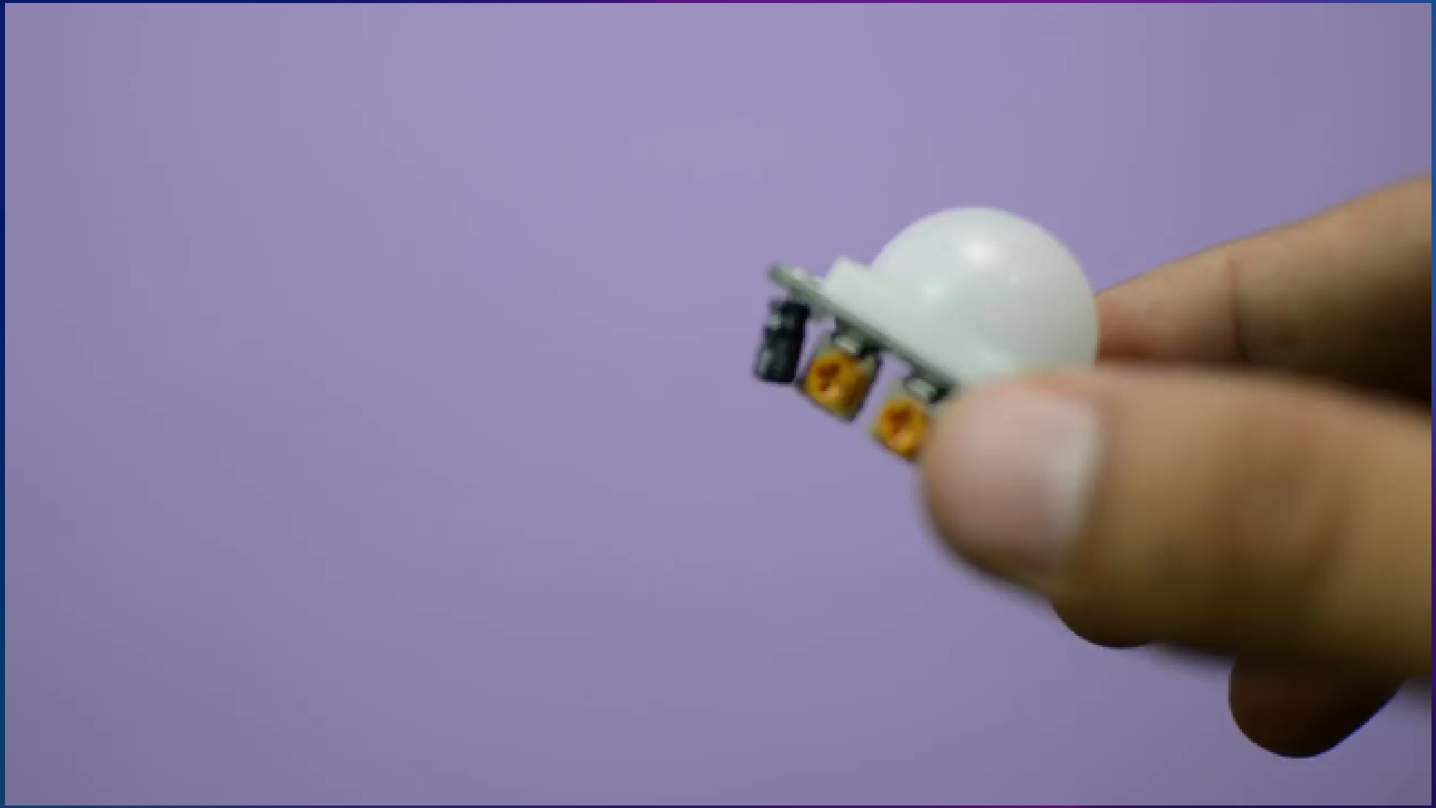
Code for PIR Motion Sensor

```
//LOOP
void loop(){

    if(digitalRead(pirPin) == HIGH){
      digitalWrite(ledPin, HIGH);   //the led visualizes the sensors output pin state
      if(lockLow){
        //makes sure we wait for a transition to LOW before any further output is made:
        lockLow = false;
        Serial.println("---");
        Serial.print("motion detected at ");
        Serial.print(millis()/1000);
        Serial.println(" sec");
        delay(50);
        }
        takeLowTime = true;
      }
```

```
    if(digitalRead(pirPin) == LOW){
      digitalWrite(ledPin, LOW);  //the led visualizes the sensors output pin state

      if(takeLowTime){
       lowIn = millis();          //save the time of the transition from high to LOW
       takeLowTime = false;       //make sure this is only done at the start of a LOW phase
       }
      //if the sensor is low for more than the given pause,
      //we assume that no more motion is going to happen
      if(!lockLow && millis() - lowIn > pause){
          //makes sure this block of code is only executed again after
          //a new motion sequence has been detected
          lockLow = true;
          Serial.print("motion ended at ");      //output
          Serial.print((millis() - pause)/1000);
          Serial.println(" sec");
          delay(50);
          }
      }
}
```

ACTIVITY

1. What is Arduino Uno?



SENSING CONSIDERATIONS

SENSING RANGE:

- The sensing range of a sensor node defines the detection exactness of that node.
- Typical approaches to optimize the sensing range in deployments include ***fixed k-coverage*** and ***dynamic k-coverage***.
- A lifelong ***fixed k-coverage*** tends to usher in redundancy as it requires a large number of sensor nodes, the sensing range of some of which may also overlap.
- In contrast, ***dynamic k-coverage*** incorporates mobile sensor nodes post-detection of an event, which, however, is a costly solution and may not be deployable in all operational areas and terrains
- Additionally, the sensing range of a sensor may also be used to signify the upper and lower bounds of a sensor's measurement range
- As the complexity of the sensor and its sensing range goes up, its cost significantly increases.

ACCURACY AND PRECISION

- The accuracy and precision of measurements provided by a sensor are critical in deciding the operations of specific functional processes.
- Typically, off-the-shelf consumer sensors are low on requirements and often very cheap.
- However, their performance is limited to regular application domains

SENSING CONSIDERATIONS

ENERGY

- The energy consumed by a sensing solution is crucial to determine the lifetime of that solution and the estimated cost of its deployment.
- If the sensor or the sensor node is so energy inefficient that it requires replenishment of its energy sources quite frequently, the effort in maintaining the solution and its cost goes up; whereas its deployment feasibility goes down

DEVICE SIZE

- Modern-day IoT applications have a wide penetration in all domains of life.
- Most of the applications of IoT require sensing solutions that are so small that they do not hinder any of the regular activities that were possible before the sensor node deployment was carried out.
- Larger the size of a sensor node, the larger the obstruction caused by it, the higher is the cost and energy requirements, and the lesser is its demand for the bulk of the IoT applications

ACTIVITY

1. What type of sensor is being used?
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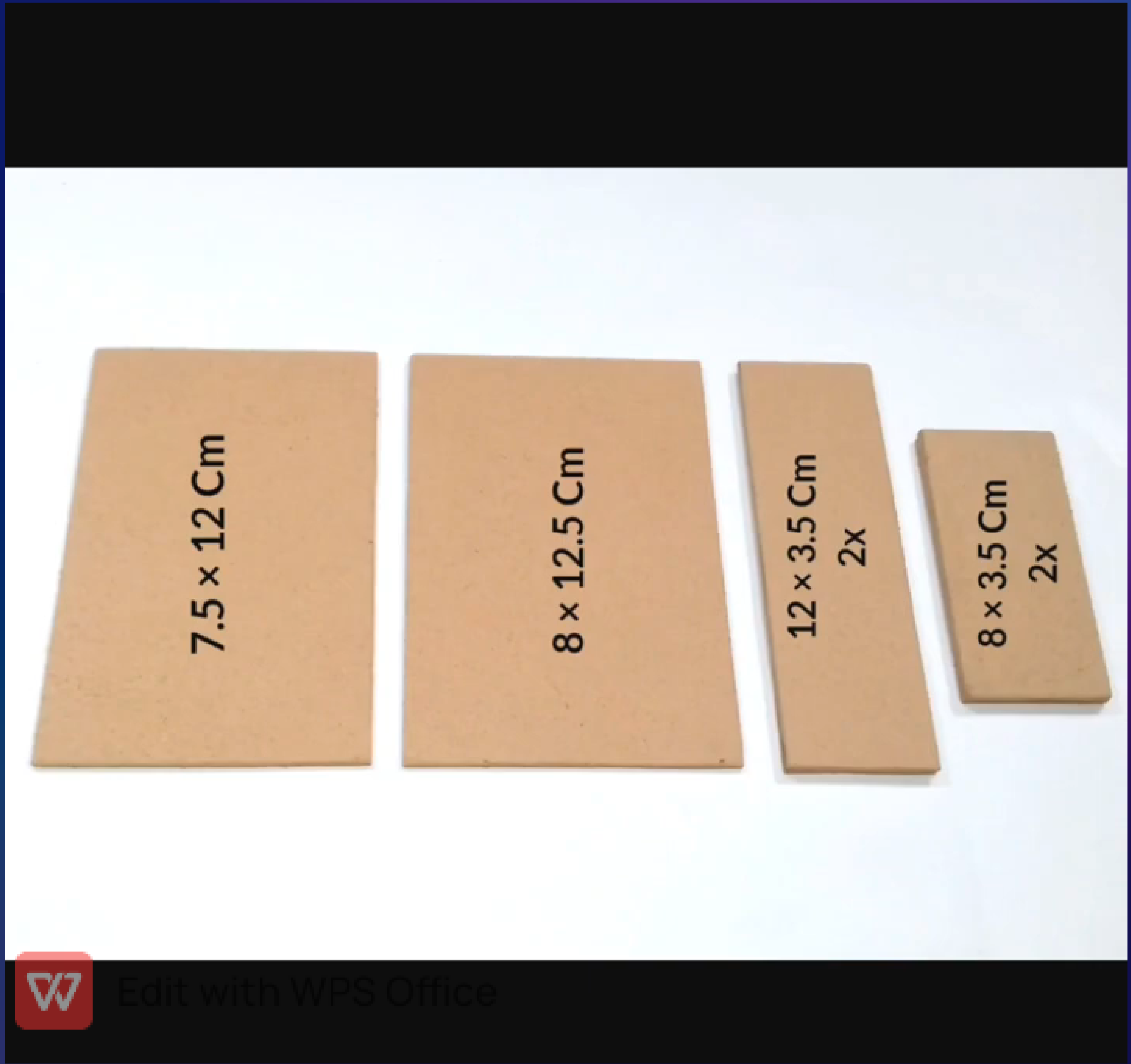

ACTUATORS

- An actuator can be considered as a machine or system component that can affect the movement or control of the said mechanism or the system.
- Control systems affect changes to the environment or property they are controlling through actuators.
- The system activates the actuator through a control signal, which may be digital or analog. It elicits a response from the actuator, which is in the form of some form of mechanical motion.
- The control system of an actuator can be a mechanical or electronic system, a software-based system (e.g., an autonomous car control system), a human, or any other input.
- A remote user sends commands to a processor.
- The processor instructs a motor-controlled robotic arm to perform the commanded tasks accordingly. The processor is primarily responsible for converting the human commands into sequential machine-language command sequences, which enables the robot to move.
- The robotic arm finally moves the designated boxes, which was its assigned task.

ACTIVITY

1. How many actuators are used in this experiment? list them.
2. Principle of actuation.

ACTUATOR CHARACTERISTICS

The physical weight of actuators limits their application scope.

WEIGHT

The power rating defines the minimum and maximum operating power an actuator can safely withstand without damage to itself.

POWER RATING

Generally, it is indicated as the power-to-weight ratio for actuators

The ratio of torque to the weight of the moving part of an instrument/device is referred to as its torque/weight ratio.

This indicates the sensitivity of the actuator.

TORQUE-TO-WEIGHT RATIO

Higher is the weight of the moving part; lower will be its torque to weight ratio for a given power.

STIFFNESS AND COMPLIANCE

The resistance of a material against deformation is known as its stiffness, whereas compliance of a material is the opposite of stiffness.

Stiffness can be directly related to the modulus of elasticity of that material.

Stiff systems are considered more accurate than compliant systems as they have a faster response to the change in load applied to it.

ACTIVITY

1. What is the principle of working these actuators?
2. Mention the property of operation of the actuators.
3. Mention the uses of these actuators.
4. Differences between pneumatic, hydraulic, electrical, and mechanical actuators

1. Hydraulic Actuator
2. Pneumatic Actuator
3. Electric Actuator
4. Thermal or magnetic actuators
5. Mechanical actuators
6. Soft actuators
7. Shape memory polymers

SUMMARY

- The first part of this chapter discusses sensors, sensing characteristics, considerations of various sensorial deviations, and the sensing types possible in a typical IoT-based implementation of a sensing solution.
- This part concludes with a discussion on the various considerations to be thought of while selecting sensors for architecting a viable IoT-based sensing solution.
- The second part of this chapter focuses on actuators and the broad classes of actuators available.
- This part concludes with a discussion on the various considerations to be thought of while selecting actuators for architecting a viable IoT-based control solution using actuators.

THANK YOU

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