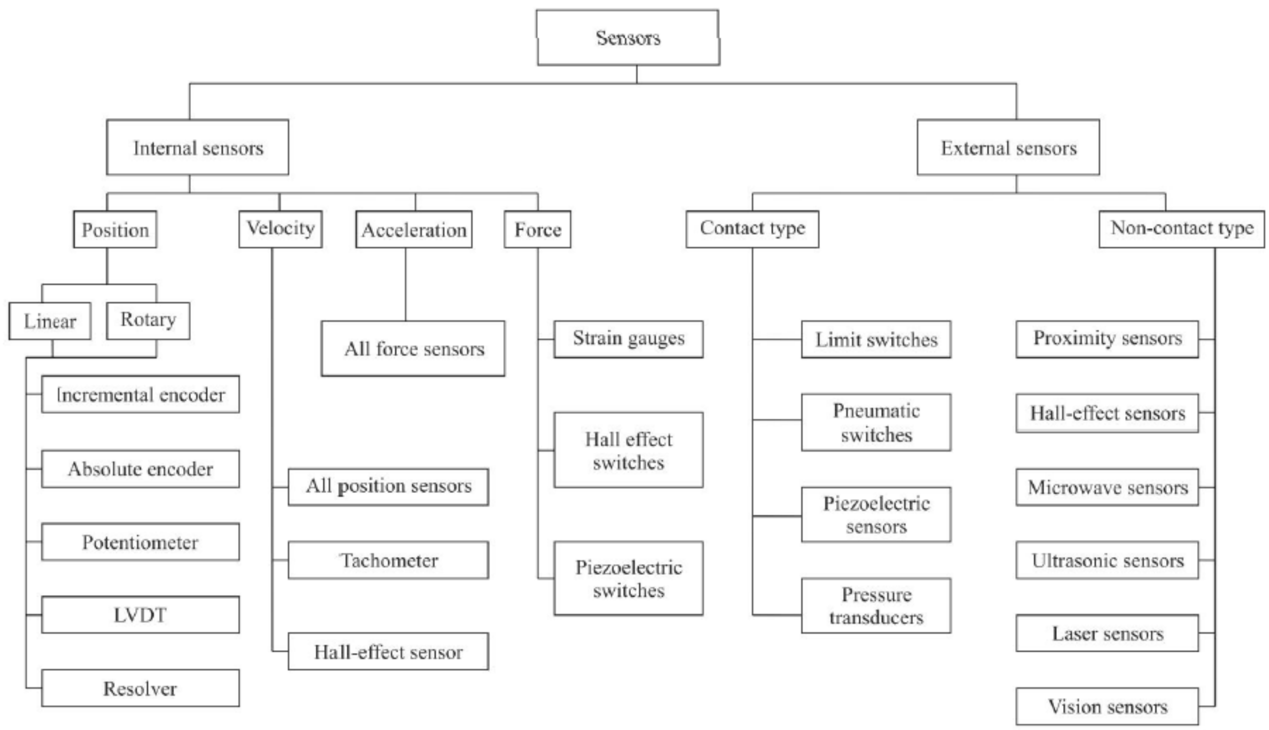
Chapter 1 - Robotic Sensors

Define Sensor - Sensor is a device that detects a change in a physical stimulus and turns it into a signal which can be measured or recorded.

Classification of Sensors

- **Simple Touch** - The presence or absence of an object.
- **Taction or Complex Touch -** The presence of an object plus some information on its size and shape.
- **Simple Force** - Measured force along a single axis.
- **Complex Force** - Measured force along two or more axes.
- **Proximity** - Noncontact detection of an object.
- **Simple Vision** - Detection of edges, holes, corners, and so on.
- **Complex Vision** -Recognition of shapes.

Based on the type of signals a sensor or transducer receives and processes, it can be classified as analog or digital. In analog sensors, with the variation of input there is a continuous variation of output, whereas in case of digital sensors, the output is of digital or discrete nature. For example, potentiometers, tacho-generators located at the joints and strain-gauge-based sensors located at the end-effector of a robot fall in the category of analog sensors, whereas encoders, located at the robot's joints, are digital sensors. In this book, sensors are, however, classified based on what they sense, i.e., internal or external state of the robots, etc.,



Types of Sensors

Touch Sensor

The touch sensors gather the information established b the contact between the parts to be handled and the fingers in the manipulator end effectors. The signals of touch informations are useful in

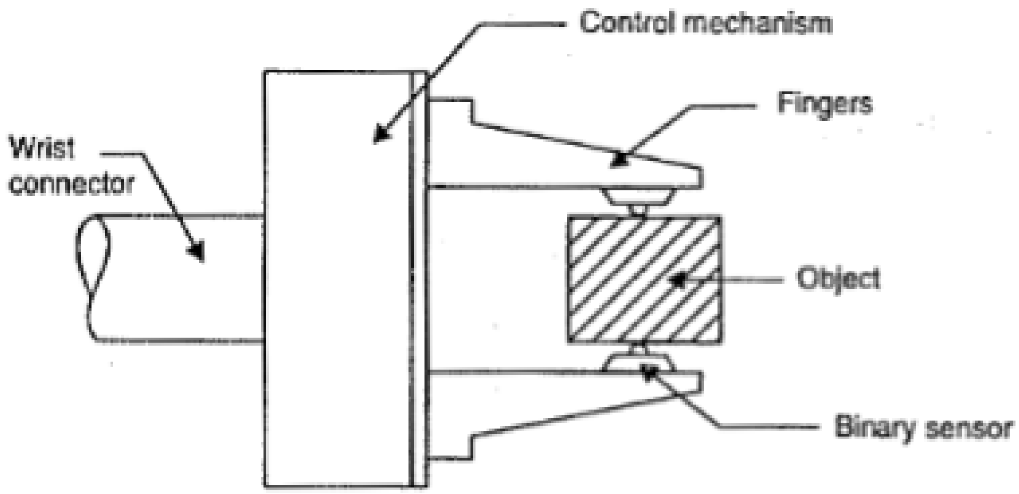
- Locating the objects
- Recognizing the object type
- Force and torque control needed for task manipulation.

The types of Touch Sensors are:-

1. **Binary Sensor :**

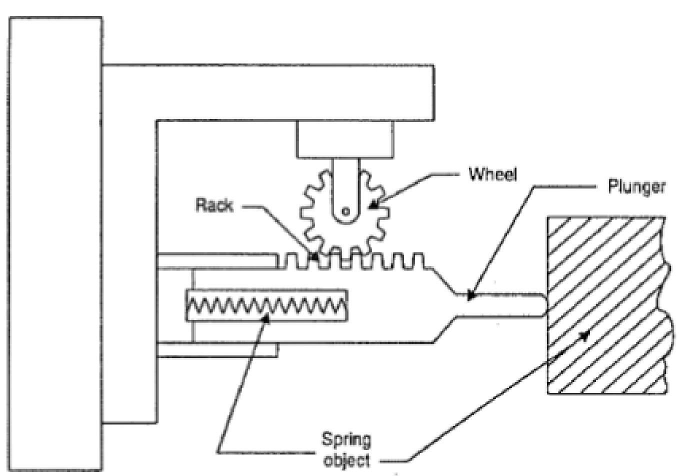
- The devices that deliver sensing signals by contact at two gripping points are termed the binary sensors.
- The fingers in the fig below shows accommodate the binary sensors.
- The contact with the parts results in defection and this information is sufficient to determine the presence of the object between the fingers.

- The proper grasping and manipulation of the object in the work envelope can be easily achieved through centering of the fingers assisted by the information given by binary.



2. **Analog Sensor**

- This type of sensors are featured by spring actuated plunger connected to a code wheel,
- The defection of the plunger rod by the action of constant force, results in rotation of the wheel which gives an output proportional to the sensors force.
- The schematic representation of analog sensor is shown below.



Force Sensor

Force sensor is a type of transducer, specifically a force transducer. It converts an input mechanical force such as load, weight, tension, compression or pressure into another physical variable.

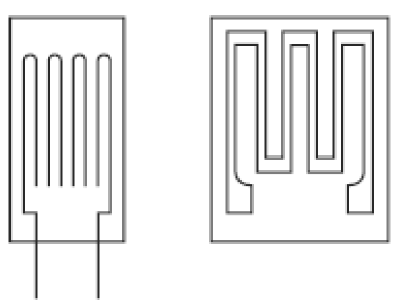
1. **Strain-gauge Based :**

The principle of this type of sensors is that the elongation of a conductor increases its resistance. Typical resistances for strain gauges are 50– 100 ohms.

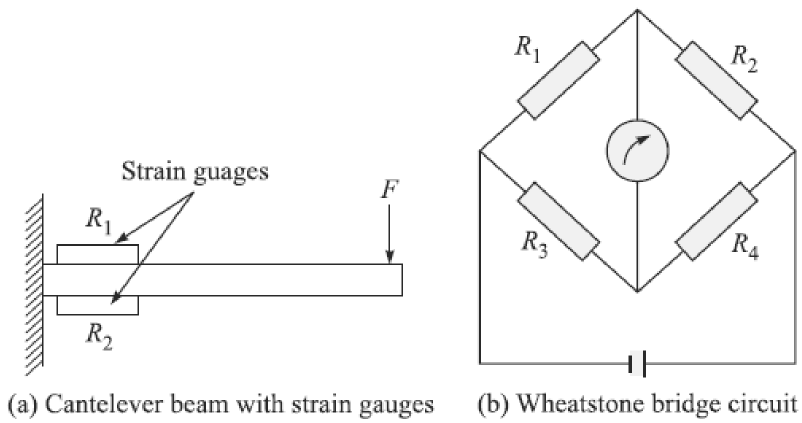
The increase in resistance is due to

- Increase in the length of the conductor; and
- Decrease in the cross-section area of the conductor.

Strain gauges are made of electrical conductors, usually wire or foil, etched on a base material, as shown in Fig. 1.2. They are glued on the surfaces where strains are to be measured, e.g., R1 and R2 of Fig. 1.3(a). The strains cause changes in the resistances of the strain gauges, which are measured by attaching them to the Wheatstone bridge circuit as one of the four resistances, R1 . . . R4 of Fig. 1.3(b). It is a cheap and accurate method of measuring strain. But care should be taken for the temperature changes. In order to enhance the output voltage and cancel away the resistance changes due to the change in temperature, two strain gauges are used, as shown in Fig. 1.3(a), to measure the force at the end of the cantilever beam.

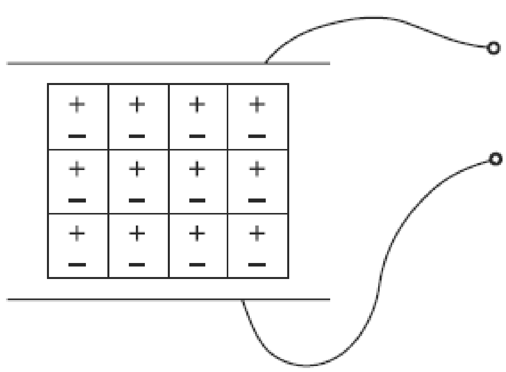


1.2 - Strain Gauges



1.3 - Strain Measurement

2. **Piezoelectric sensor**
   A piezoelectric material exhibits a phenomenon known as the piezoelectric effect. This effect states that when asymmetrical, elastic crystals are deformed by a force, an electrical potential will be developed within the distorted crystal lattice, as illustrated in Fig. 1.4. This effect is reversible. That is, if a potential is applied between the surfaces of the crystal, it will change its physical dimensions. The magnitude and polarity of the induced charges are proportional to the magnitude and direction of the applied force. The piezoelectric materials are quartz, tourmaline, Rochelle salt, and others. The range of forces that can be measured using piezoelectric sensors are from 1 to 20 kN and at a ratio of 2 × 105. These sensors can be used to measure an instantaneous change in force (dynamic forces).



1.4 - Piezoelectric sensor

Proximity sensors :

The output of the proximity sensors gives an indication of the presence of an object with in the vicinity job operation. In robotics these sensors are used to generate information of object grasping and obstacle avoidance. This section deals with some of the important proximity sensors used in robotics.

• Inductive Sensors

** Principle*

The ferromagnetic material brought close to this type of sensor results in change in position of the flux lines of the permanent magnet leading to change in inductance of the coil. The induced current pulse in the coil with change in amplitude and shape is proportional to rate of change of flux line in magnet.

** Construction*

The proximity inductive sensor basically consists of a wound coil located infront of a permanent magnet encased inside a rugged housing. The leads from the coil, embedded in resin is connected to the display through a connector. The schematic is as shown in Fig. 7.4.

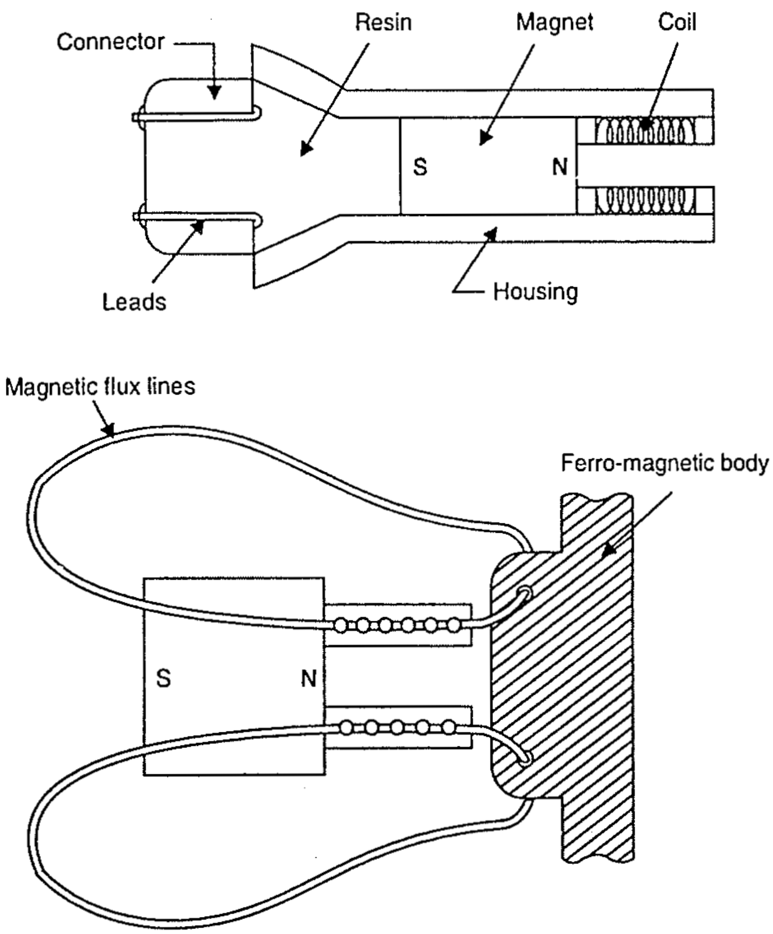


Fig. 7.4. Inductive Sensor.

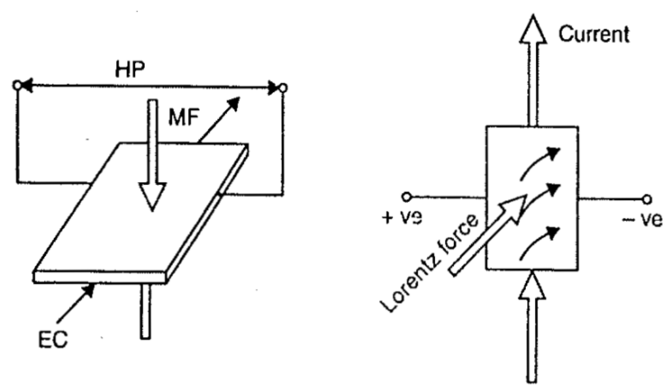
• Hall-Effect Sensors

* *Principle*

Hall-Effect deals with the voltage between the two points in a conductor which changes by the near field of the magnetised or ferromagnetic material. The sensor experiences a weakened magnetic field in the close proximity of a ferromagnetic materials, due to the bending of the flux lines of the magnet through approaching object.

E.R. Hall in 1879 discovered Hall Effect, which states that "A beam of charged particles passing through a magnetic field experiences a force that deflect the beam from the straight line path".

Electrons (negative charged particles) are made to pass through a plate rectangular in shape and a magnetic field is applied at right angle to the plane of plate as shown in Fig. 7.5(*a*). The electrons are deflected towards one side of the plate making that side negatively charged and other side positively charged. The force due to applied magnetic field is known as Lorentz force. The mechanism of deflection is governed by the balance of Lorentz force and force on the beam of electrons.



HP = Hall Potential ; MF = Magnetic Field ; EC = Electric Current

Fig. 7.5 (*a*) Hall Effect Principle.

* *Construction*

A sensor element is stationed between the poles of a horse shoe magnet constructed inside a container. The principle of operation is as depicted in Fig. 7.5 (*b*).

The decrease in the strength of the magnetic field resulting due to the proximity of the object field reduces the voltage across the sensor. The sensor gives binary output for the decision making devices of control for further actions. The silicon makes the ideal selection for a semiconductor interms of size, strength and capacity to electrical interference prevention.

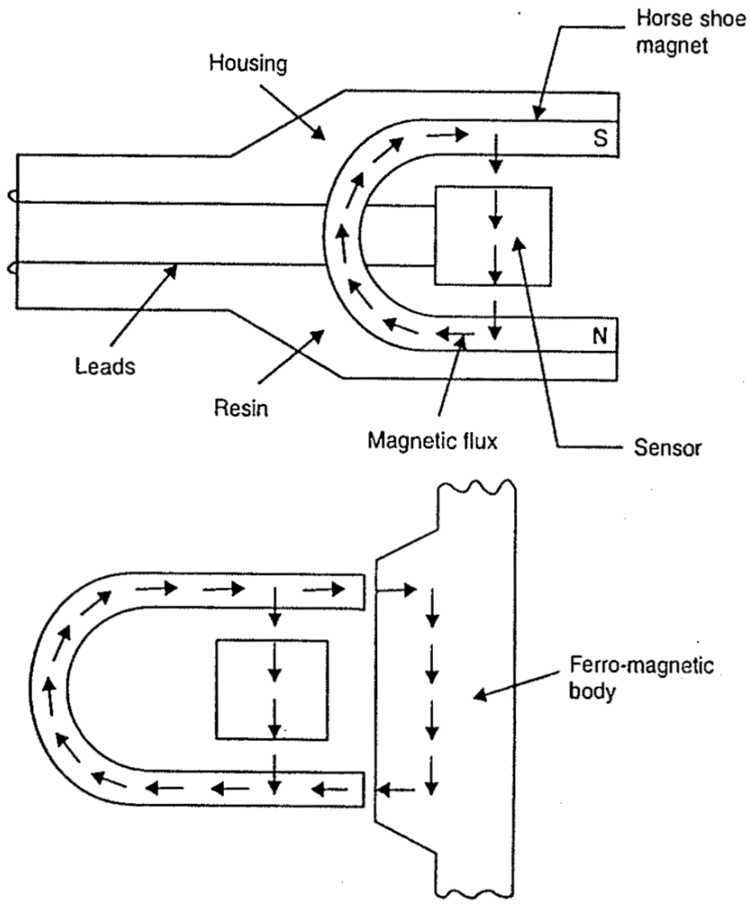


Fig. 7.5 (*b*) Hall-Effect Sensor.

- Advantages of Hall Effect Sensors :
  - ✓ They can operate as switches at high frequency.
  - ✓ They cost less than electromechanical devices.
  - ✓ They are free from contact bounce problem.
  - ✓ They can be used under severe environmental service conditions as they are immune to environmental contaminations.
  - ✓ They can be used as proximity, position and displacement sensors.

Tactile Sensors:

An array of touch sensors arranged systematically to provide information about the contact of the fingers with the object is called the tactile sensors. The special tactile sensors also provide additional informations like shape, size and the type of material of the objects.

Each element in an array (tactile sensor) there are three functional parts : A plunger, a LED and a light sensing device. The schematic is as shown in Fig. 7.3. The movement of the plunger opens/blocks the LED, and the light sensor gives output signal accordingly.

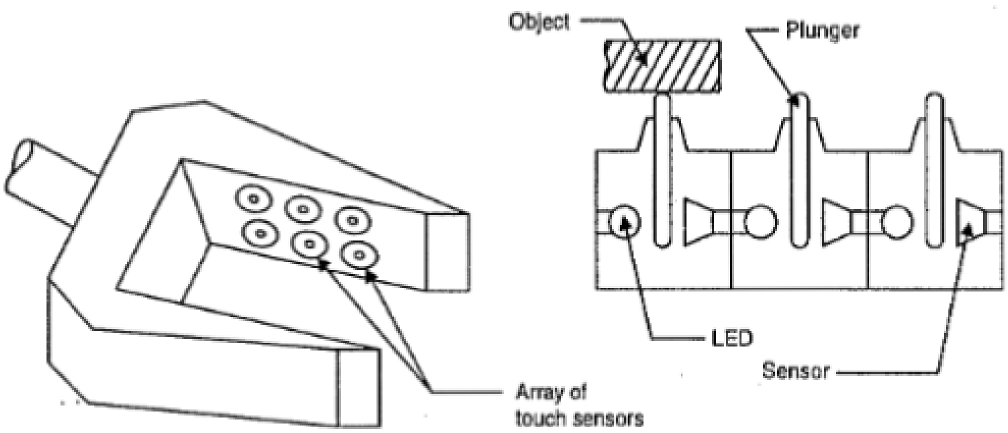


Fig. 7.3. Tactile Sensors.

Range Sensors:

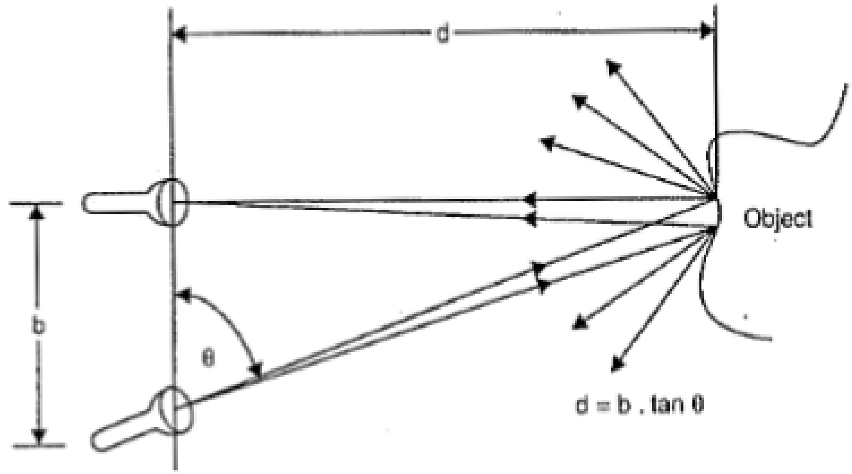
The distance between the object and the robot hand is measured using the range sensors within it is range of operation. The calculation of the distance is by visual processing. Range sensors find use in robot navigation and avoidance of the obstacles in the path. The exact location and the general shape characteristics of the part in the work evelope of the robot is done by special applications for the range sensors. There are several approaches like, triangulation method, structured lighting approach and time-of-flight ránge finders etc. In these cases the source of illumination can be light-source, laser beam or based on ultrasonics.

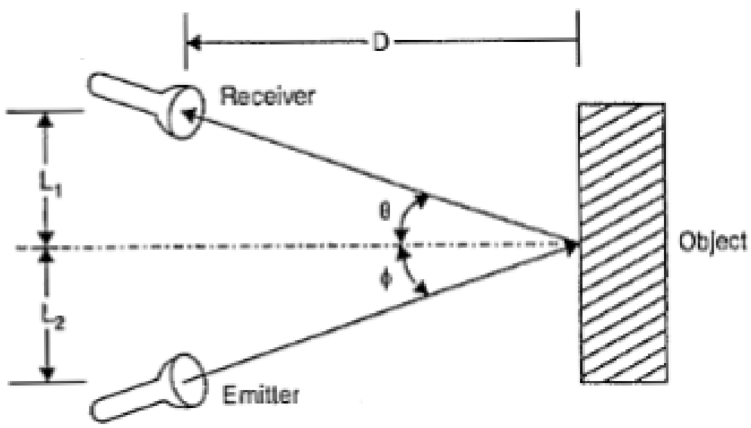
** Triangulation Method*

This is the simplest of the techniques, which is easily demonstrated in the Fig. 7.8. The object is swept over by a narrow beam of sharp light. The sensor focussed on a small spot of the object surface detects the reflected beam of light. If 'θ' is the angle made by the illuminating source and 'b' is the distance between source and the sensor, the distance 'd' of the sensor on the robot is given as

$$d = b \cdot \tan\theta \qquad \text{...(7.2)}$$

The distance 'd' can be easily transformed into 3D-co-ordinates





$$D = \frac{(L_1 + L_2)\tan\theta \,.\, \tan\phi}{\tan\theta + \tan\phi}$$

Tilt Sensors:

The tilt sensor helps to find if an object tilts accurately. In a typical tilt sensor, a small amount of mercury is present in a glass bulb. If tilted, the mercury automatically flows to one of the ends, turning the switch off to indicate the tilt.

Navigation Sensors:

The Navigation sensors are also called positioning sensors. The position sensors in robots are used to detect their positions. The commonly used position sensors are:

GPS - It is beneficial for outdoor robots. It analyses the maps received from the GPS satellites.

Localisation - This sensor helps a robot recognise elements externally and process the data to locate their positions. It considers both natural and artificial landmarks to achieve the task.

Compass - Like a magnetic compass, the digital version also helps a robot detect directions. They are very cheap in comparison to GPS.

Acceleration Sensors:

This sensor helps to measure the tilt as well as the acceleration. The two primary forces that can affect the functioning of an accelerometer are static forces and dynamic forces.

The static force is friction between two objects. This force is used to understand how exactly a robot tilts.

The dynamic force is the amount of force needed to move an object. Hence, dynamic force calculates the required acceleration.

Gyroscope:

With the help of angular momentum, this sensor is used to quantify the orientation. It is used when we want our robot to be independent of the earth's gravity to maintain the right orientation.

IMU (Inertial Measurement Unit):

To measure velocity, orientation, and gravitational forces together, an IMU is used to combine all the required sensors to determine the results accurately.

Voltage Sensors:

These sensors are mainly used to convert a lower voltage to a higher one or vice versa. For example, take a simple Op-Amp that intakes a low voltage, amplifies, and creates a higher output. They are also used to determine the potential difference between two ends, like a voltage comparator.

Current Sensors:

These sensors are made to monitor the flow of current in a circuit. The output is either the same current or the corresponding voltage. Most of the voltage outputs of current sensors are in the range of 0V to 5V. The obtained current, if required, can be modified by a microcontroller.

Characteristics/ Features of Sensors:

1. Range / span
2. Errors and accuracy
3. Nonliearity
4. Hysteresis
5. Dead band and Saturation
6. Output impedance
7. Repeatability
8. Reliability
9. Sensitvity
10. Resolution
11. Frequency Response
12. Response time
13. Calibration

Range and Span

• Range: lowest and highest values of the stimulus
• Span: the arithmetic difference between the highest and lowest values of the input that being sensed.
• Input full scale (IFS) = span
• Output full scale (OFS): difference between the upper and lower ranges of the output of the sensor.
• Dynamic range: ratio between the upper and lower limits and is usually expressed in db

Example: a sensors is designed for: −30°C to +80°C to output 2.5V to 1.2V
• Range: −30°C and +80°C
• Span: 80−(−30)=110°C
• Input full scale = 110°C
• Output full scale = 2.5V-1.2V=1.3V

• Dynamic range=20log(140/30)=13.38db

Errors and Accuracy

• **Errors**: is the difference between the result of the measurement and the true value of the quantity being measured

error= measured value –true value

• As a percentage of full scale (span for example) error is calculated as;
e =Δt/(tmax-tmin)*100 where tmax and tmin are the maximum and minimum values the device is designed to operate at.

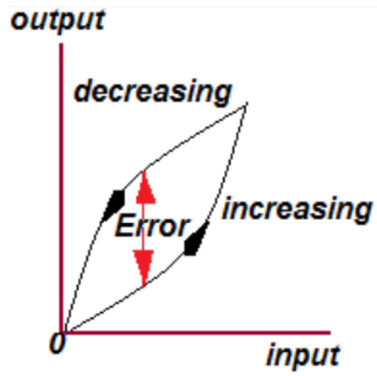
Accuracy: is the extent to which the measured value might be wrong and normally expressed in percentage

• Example: A thermistor is used to measure temperature between –30 and +80°C and produce an output voltage between 2.8V and 1.5V. Because of errors, the accuracy in sensing is ±0.5
°C. so the measured value may be high than or lower than by 0.5°C

• a. In terms of the input as ±0.5°C
• b. Percentage of input: error = 0.5/(80+30)*100 = 0.454%
• c. In terms of output. From the transfer function:
error= ±0.059V. ?

Hysteresis

• Hysteresis is the deviation of the sensor's output at any given point when approached
from two different directions
• Caused by electrical or mechanical systems
– Magnetization
– Thermal properties
– Loose linkages
• If temperature is measured, at a rated temperature of 50°C, the output might be 4.95V
when temperature increases but 5.05V when temperature decreases.
• This is an error of ±0.5% (for an output full scale of 10V in this idealized example).



Nonlinearity

• Nonlinearity is defined as the maximum deviation from the ideal linear transfer function.

Deadband

• Deadband: the lack of response or insensitivity of a device over a specific range of the input.
• In this range which may be small, the output remains constant.
• A device should not operate in this range unless this insensitivity is acceptable

Output impedance

Output impedance: ratio of the rated output voltage and short circuit current of the port (i.e. current when the output is shorted)

Repeatability

• Also called reproducibility: failure of the sensor to represent the same value under identical
conditions when measured at different times.
– usually associated with calibration
– given as percentage of input full scale of the maximum difference between two readings
taken at different times under identical input conditions.

$$\text{Repetability} = \frac{\text{Max – Min values given}}{\text{Full range}} \times 100$$

Reliability

• Reliability: a statistical measure of quality of a device which indicates the ability of the device to perform its stated function, under normal operating conditions without failure for a stated
period of time or number of cycles.
• Given in hours, years or in MTBF
• Usually provided by the manufacturer
• Based on accelerated lifetime testing

Sensitivity

• Sensitivity of a sensor is defined as the change in output for a given change in input, usually a unit change in input. Sensitivity represents the slope of the transfer function.
• Also is used to indicate sensitivity to other environment that is not measured.

Resolution

• Resolution: the minimum increment in stimulus to which the sensor can respond. It is the magnitude of the input change which results in the smallest observable output.
• Example: a digital voltmeter with resolution of 0.1V is used to measure the output of a
sensor. The change in input (temperature, pressure, etc.) that will provide a change of 0.1V on the voltmeter is the resolution of the sensor/voltmeter system.

Frequency response

• Frequency response: The ability of the device to respond to a harmonic (sinusoidal) input.
• A plot of magnitude (power, displacement, etc.) as a function of frequency

Response time

• Response time: indicates the time needed for the output to reach steady state for a step change in input.

Typically the response time will be given as the time needed to reach 90% of steady state output upon exposure to a unit step change in input.

• The response time of the device is due to the inertia of the device (both "mechanical" and "electrical").

• Fast response time is usually desirable

• Slow response times tend to average readings

Calibration

• Calibration: the experimental determination of the transfer function of a sensor or actuator.

• Typically, needed when the transfer function is not known or,

• When the device must be operated at tolerances below those specified by the manufacturer.

7.7 DESIRABLE FEATURES FOR SENSORS AND TRANSDUCERS

Features	*Functions*
• Precision	→ Should be as high as possible. → Deviation in measurement reading should be minimum.
• Accuracy	→ Should be as high as possible. → Error between sensed value and actual value should approach zero.
• Speed of response	→ Time taken to respond to variation should be minimum. → Response to be instaneous.
• Operating range	→ Range operating to be wide. → Accuracy over the range to be acceptable.
• Reliability	→ The life to be high. → Frequent failures are not acceptable.
• Calibration	→ Should be easy to calibrate. → Drift to be minimum. → Should take less time to calibrate without much trouble.
• Cost and ease	→ The cost of purchase should be low. → The installation and operation should be easy and less costly.

Expected Questions:

- State functions of proximity sensor
- Describe working principle, construction and working of Inductive type proximity sensor with neat sketch.
- Define Sensor
- State any four sensor commands.
- State functions of range sensor
- Explain the working of range sensor with neat sketch.
- Explain tactile sensor with neat sketch
- Explain repeatability and resolution.
- Characteristics/ Features of Sensors
- Explain Force Sensors.
- Explain Touch Sensors