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WEEK 6: ROBOTICS

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Topic 5: Control Scheme

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Control of Motor

- A DC motor is connected at each joint of a robot, where torque is proportional of the armature current.

$$\tau_m \propto I_A$$

$$\tau = K_m \cdot I_A$$

- **Joint torque τ can be represented as follows:**

$$\tau = D(\theta)\ddot{\theta} + h(\theta, \dot{\theta}) + C(\theta)$$

where
$D(\theta)$: inertia terms
$h(\theta, \dot{\theta})$: Coriolis and centrifugal terms
$C(\theta)$: gravity terms

If we consider **friction**, then

$$\tau = D(\theta)\ddot{\theta} + h(\theta, \dot{\theta}) + C(\theta) + F(\theta, \dot{\theta})$$

where
$F(\theta, \dot{\theta})$: friction terms

Let us consider Partitioned Control Scheme

$$\tau = \alpha\tau' + \beta$$

where $\alpha = D(\theta)$

$$\beta = h(\theta, \dot{\theta}) + C(\theta) + F(\theta, \dot{\theta})$$

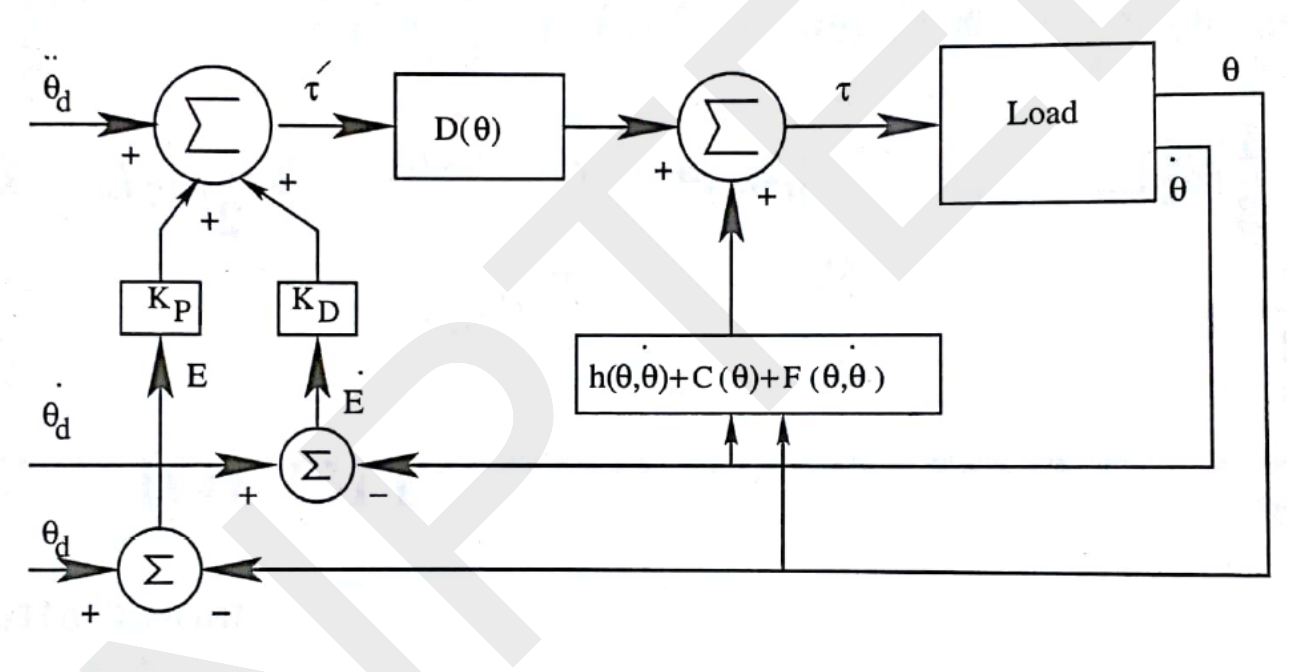
Now, τ' can be written as follows:

$$\tau' = \ddot{\theta}_d + K_P E + K_D \dot{E}$$ (for PD control law)

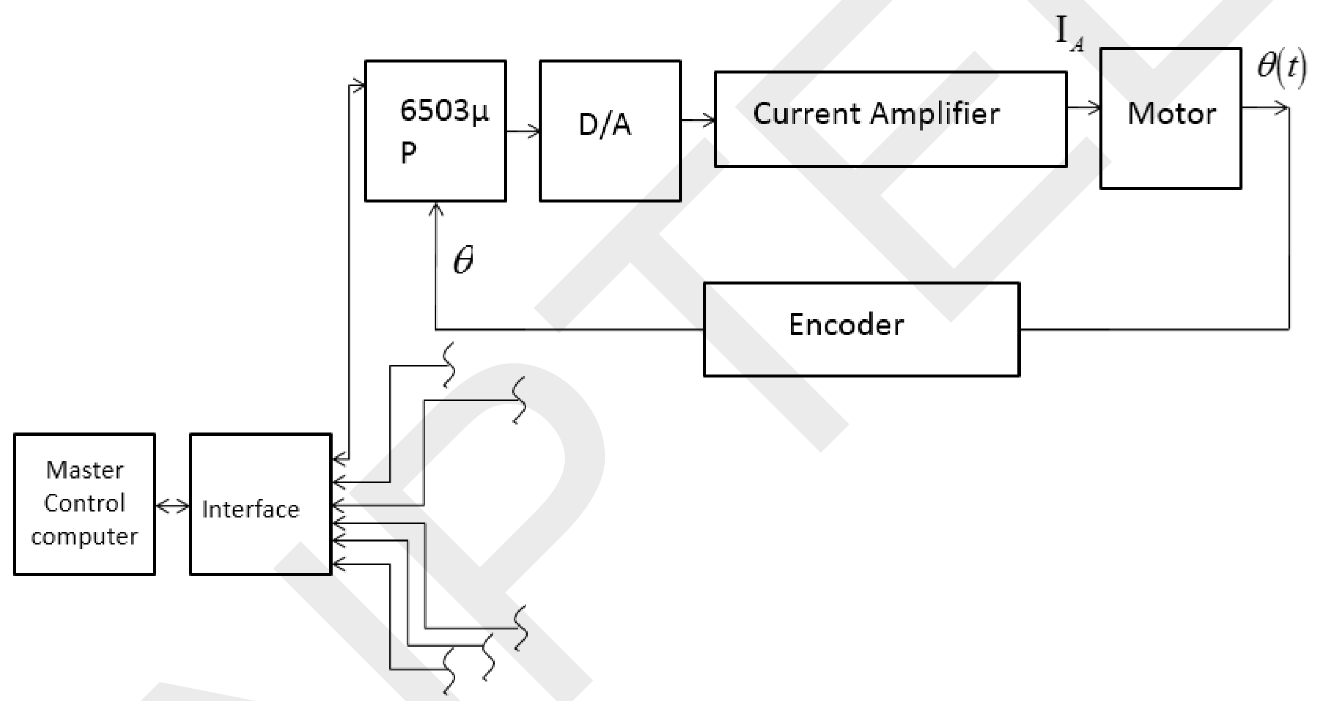
$$\tau' = \ddot{\theta}_d + K_P E + K_I \int E dt + K_D \dot{E}$$ (for PID control law)

where E = error = $\theta_d - \theta$
where θ_d : Desired value of θ
θ : Actually obtained value of θ

Control Architecture



PUMA



6503μ P
D/A
Current Amplifier
I_A
Motor
$\theta(t)$
θ
Encoder
Master Control computer
Interface

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Topic 6: Sensors

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SENSORS

- Human-beings collect information of the surroundings using their sensors, namely eyes, ears, nose, skin etc., in order to perform various tasks.
- A sensor is used to take measurement of physical variable.
- A sensor requires calibration
- Sensors are used to build intelligent robots

Classification of Sensors

1. SENSORS

Internal Sensors
(used to operate the drive units)
Ex. Position sensors, velocity sensors, Acceleration sensors, Force/Moment sensor

External Sensors
(used to collect information of the environment)

Ex. Temperature sensors, Visual sensor, Proximity sensor, Acoustic sensor

Classification of Sensors (Cont.)

SENSORS

2.

Contact Sensors

(Physical contact between sensor mounted on robot and object)

Touch sensor/ Tactile sensor/ Binary sensor

(indicates presence or absence of an object)

Ex. Micro-switch, Limit switch

Force sensor/ Analog sensor (not only the contact is made but also the force is measured)

Ex. Sensors using strain gauges

Non-Contact Sensors

(No physical contact)

Proximity sensor

Visual sensor

Acoustic sensor

Range sensor

Characteristics of Sensors

- **Range :** Difference between the maximum and minimum values of the input that can be measured.
- **Response :** should be capable of responding to the changes in minimum time.
- **Accuracy :** deviation from exact quantity
- **Sensitivity** = change in output/ change in input
- **Linearity :** constant sensitivity
- **Repeatability :** Deviation from reading to reading, when these are taken for a number of times under identical conditions.
- **Resolution**

Touch Sensor

- Used to indicate whether contact has been made between two objects
- Does not determine the magnitude of contact force
- Ex. : Micro-switch, Limit switch

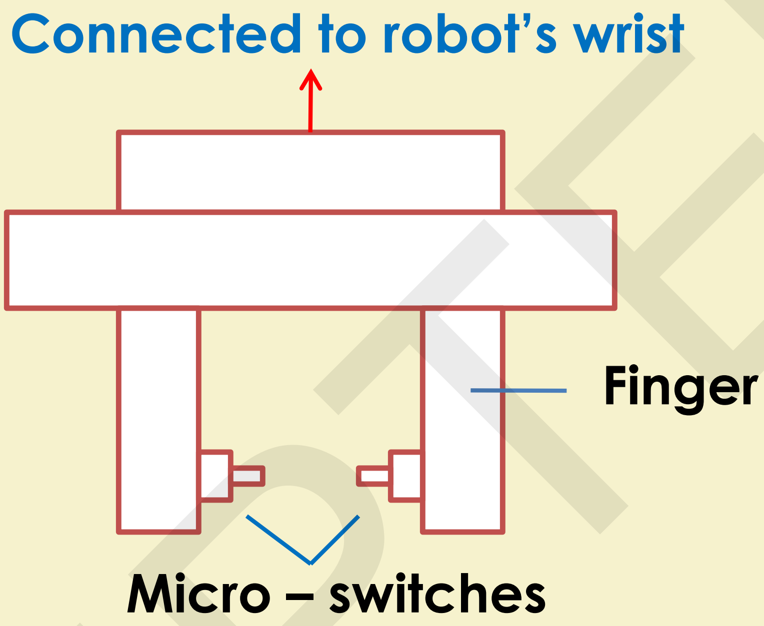


Figure: Micro – switches placed on two fingers of a robotic hand

Position sensor

1. Potentiometer
   - Linear Potentiometer
   - Angular Potentiometer

Angular Potentiometer

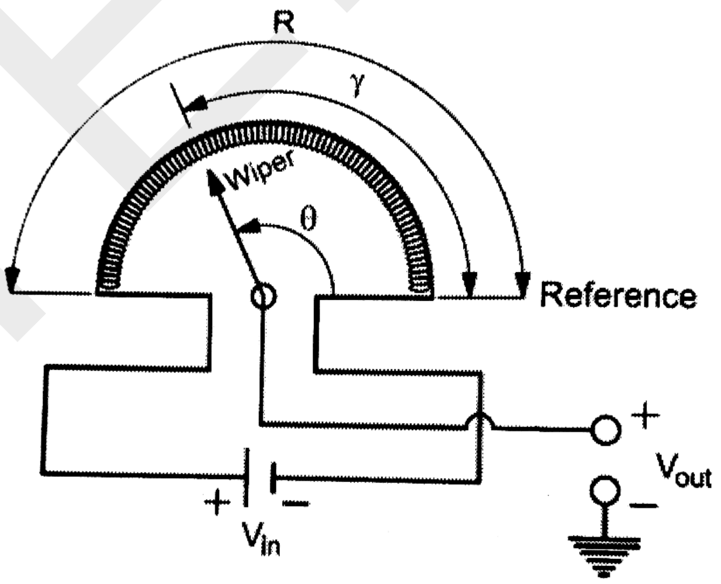
Θ: Angular displacement of the wiper with respect to the reference

R: Total resistance

r : Resistance of the coil between the wiper and the reference

V_{in} : Input voltage

V_{out} : Output voltage



Angular Potentiometer (contd.)

$$\frac{V_{out}}{r} = \frac{V_{in}}{R}$$

$$\Rightarrow V_{out} = \frac{r}{R} V_{in}$$

For the known values of V_{in} ,R; $V_{out} = f(r)$

By measuring V_{out} , r can be determined and hence, angular displacement θ.

Demerit

- Resistance of the wire is temperature dependent.

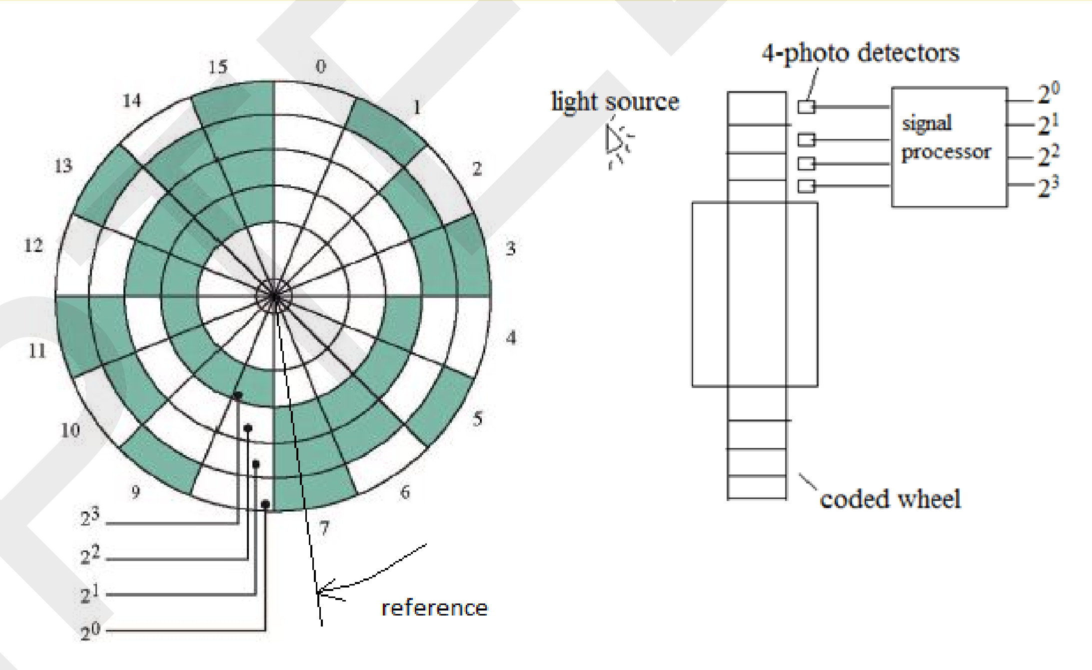
Potentiometer is temperature sensitive.

2. Optical Encoder

- Absolute Optical Encoder
- Incremental Optical Encoder

Absolute Optical Encoder

- It is mounted on the shaft a rotary device
- To generate digital word identifying actual position of the shaft measured from zero position



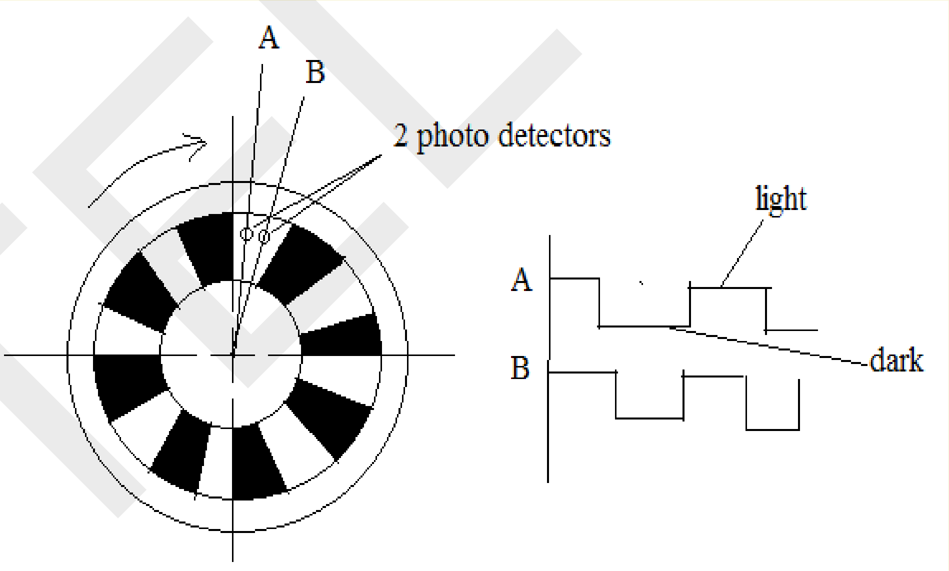
Absolute Optical Encoder (contd.)

Resolution : 1 part in 2^n, where n : number of concentric rings (tracks)

2^3	2^2	2^1	2^0		DV
0	0	0	0	$\longrightarrow$	0
0	0	0	1	$\longrightarrow$	1
0	0	1	0	$\longrightarrow$	2
	:	:			
	:	:			
1	1	1	0	$\longrightarrow$	14
1	1	1	1	$\longrightarrow$	15

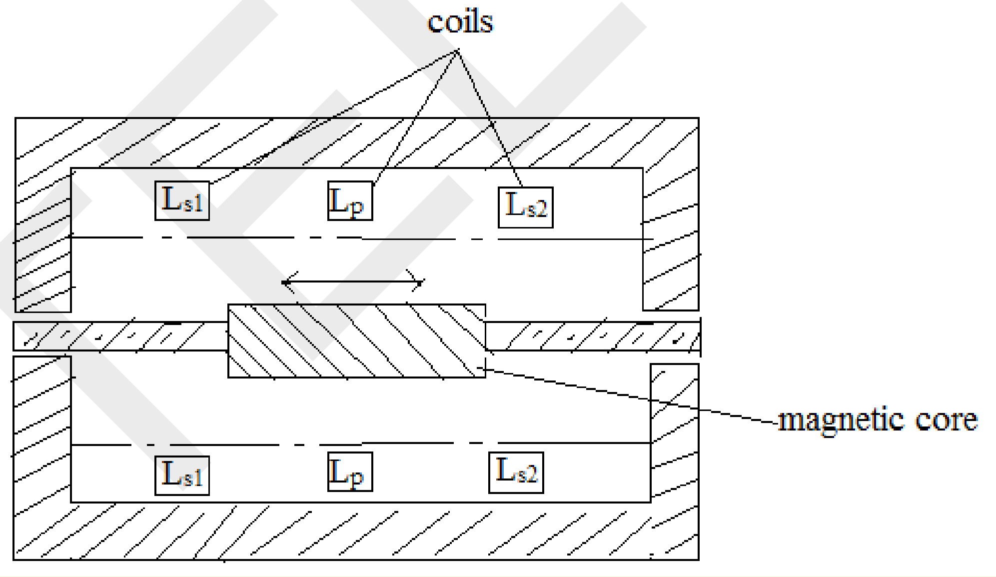
Incremental optical encoder

- Consists of one coded disc and two photo-detectors
- By counting the number of light and dark zones, angular displacement can be measured with respect to known starting position.
- It can determine the direction of rotation also
- It is construction-wise simpler, less accurate and less expensive.



Linear Variable Differential Transformer (LVDT)

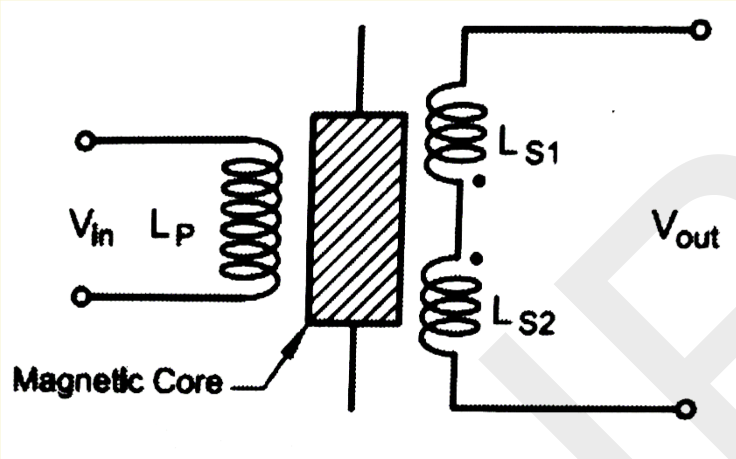
- It consists of two parts: fixed casing and moving magnetic core
- In-between the fixed casing and magnetic core, there are one primary(LP) and two secondary (L_{s1}, Ls_2) coils
- Produced voltage output is proportional to the displacement of moving part relative to the fixed one



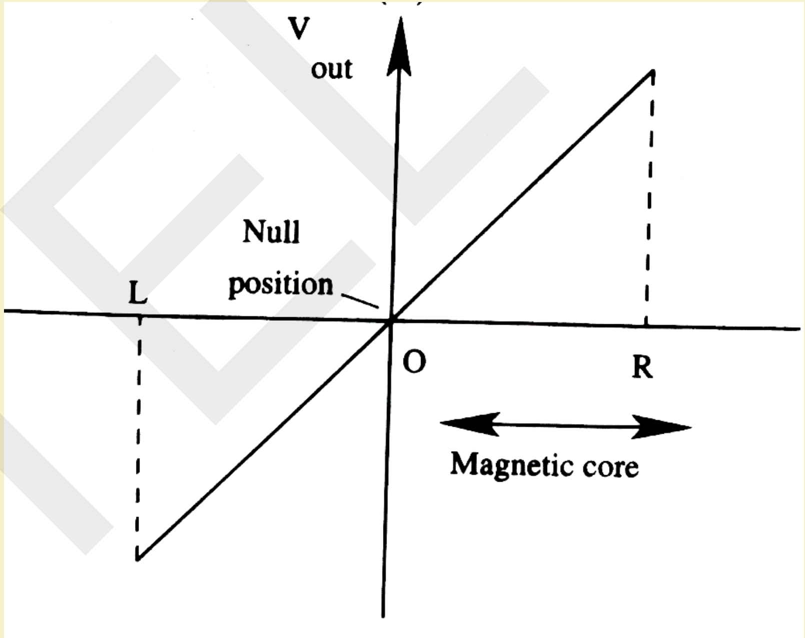
LVDT (contd.)

- AC voltage is applied to L_p
- L_{s1} and L_{s2} are connected in series.

$$V_{out} = V_{L_{s2}} - V_{L_{s1}}$$

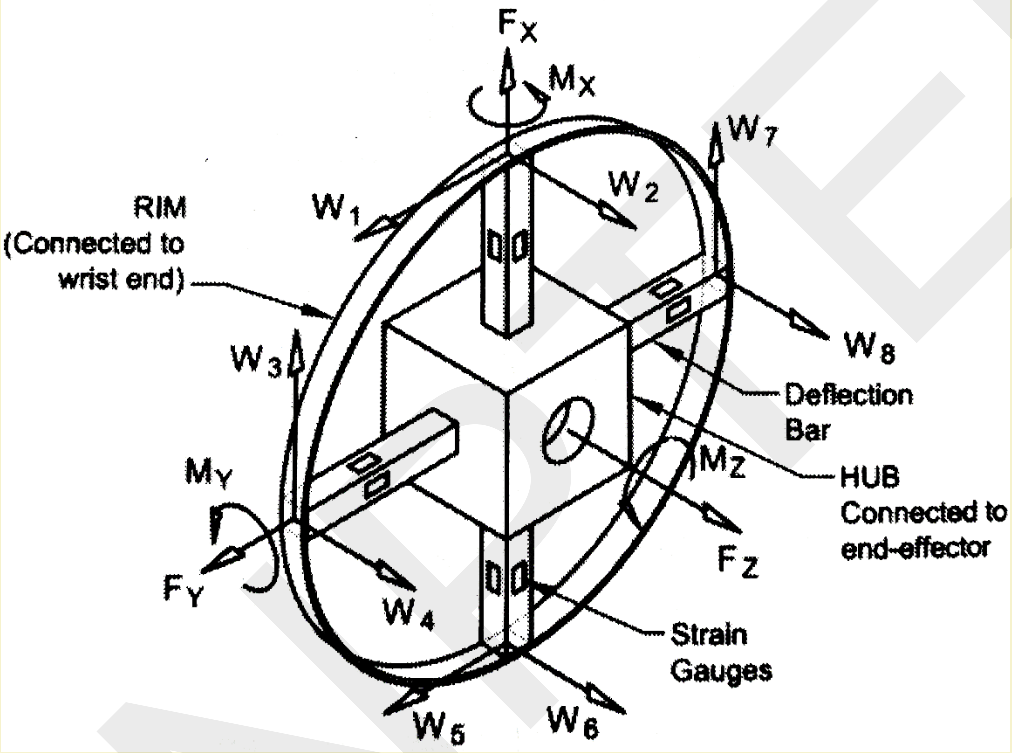


LVDT: equivalent electrical circuit



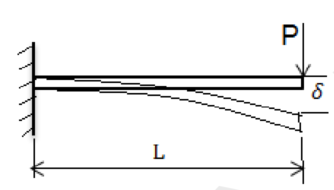
Calibration curve

Force/Moment sensor



Force/Moment sensor (contd.)

- It is placed between the wrist and end-effector end
- It consists of 4 deflection bars. Two pairs of strain gauges are mounted on each deflection bar. One end of each deflection bar is rigidly supported by a hub, which is connected to the end-effector end. The other ends of the deflection bars are supported by a common rim, which is connected to the wrist end.
- External forces cause deflection of the mechanical structure, which are measured using strain gauges.



Cantilever beam

$$\delta = \frac{PL^3}{3EI}$$

Force/Moment sensor (contd.)

- Strain gauge is connected to potentiometer circuit, whose output voltage is proportional to the deflection and hence, force.
- Three components of force (F) and moment (M) each are determined by adding and subtracting the respective components of force. $\mathbf{F} = \mathbf{C_M}\,\mathbf{W}$

Calibration matrix

Forces/ moments

$$\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} C_{11} C_{12} C_{13} -- -C_{18} \\ C_{21} C_{22} C_{23} -- -C_{28} \\ . \\ . \\ . \\ C_{61} C_{62} C_{63} -- -C_{68} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ . \\ . \\ . \\ W_8 \end{bmatrix}$$

Readings of the strain gauges

$$F_X = W_3 C_{13} + W_7 C_{17}$$

$$F_Y = W_1 C_{21} + W_5 C_{25}$$

$$F_Z = W_2 C_{32} + W_4 C_{34} + W_6 C_{36} + W_8 C_{38}$$

$$M_X = W_4 C_{44} + W_8 C_{48}$$

$$M_Y = W_2 C_{52} + W_6 C_{56}$$

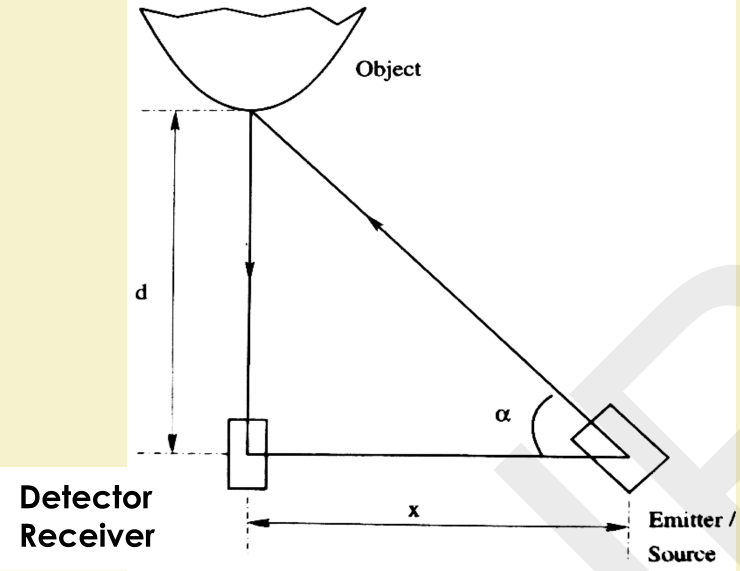
$$M_Z = W_1 C_{61} + W_3 C_{63} + W_5 C_{65} + W_7 C_{67}$$

Precautions

- **Strain gauges are to be properly mounted on the deflection bars**
- **Sensor should be operated within the elastic limit of its material (deflection bars).**

Range Sensor

- It measures the distance between the sensor (detector) mounted on the robot's body and the object



Triangulation method

$$\frac{d}{a} = \tan\theta$$

$$d = a\tan\theta$$

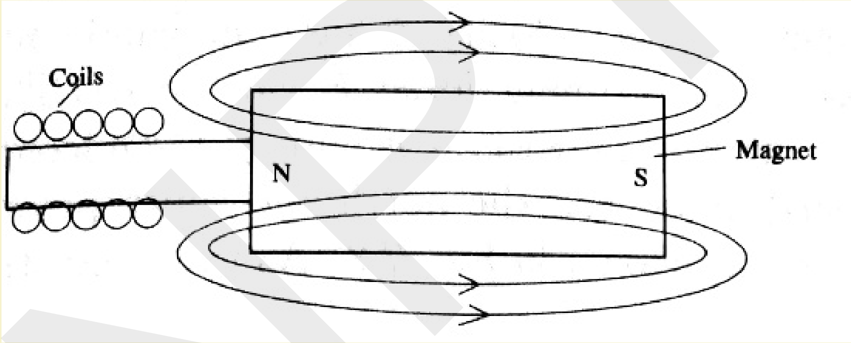
Knowing the values of a and θ, d can be calculated.

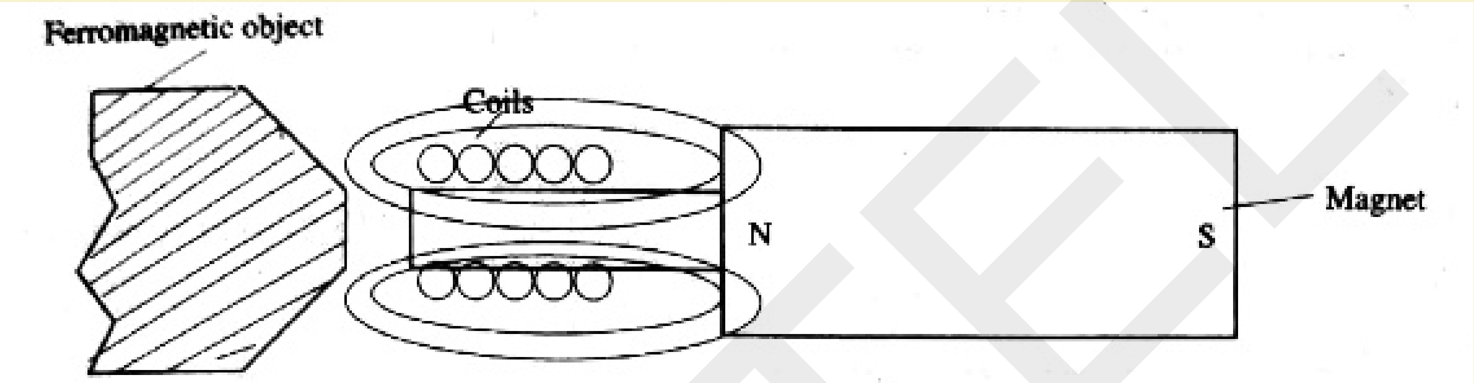
Proximity Sensors

Inductive Sensor | Hall-effect Sensor | Capacitive Sensor

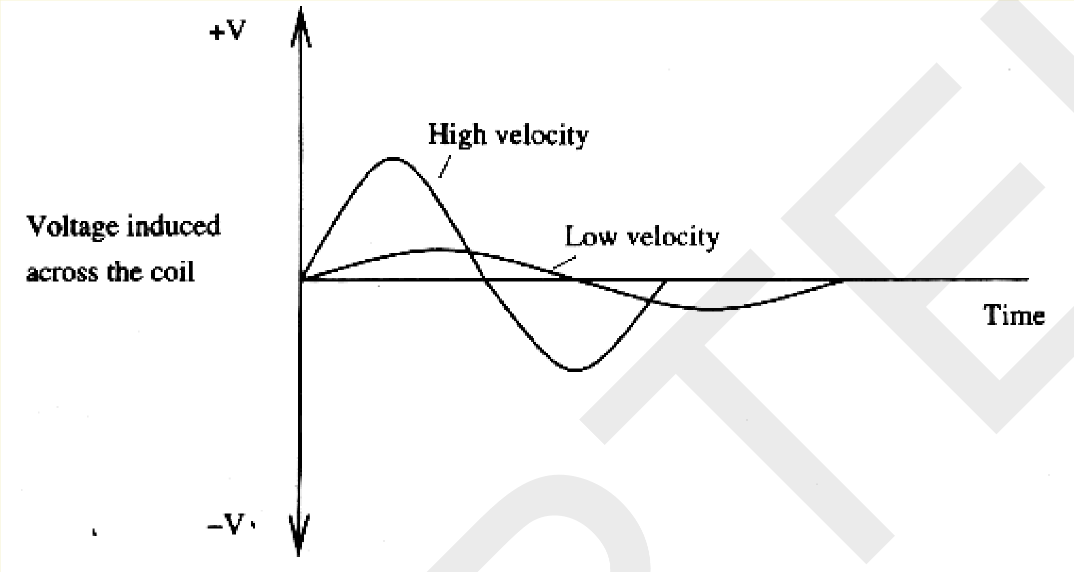
Inductive Sensor

- It consists of a permanent magnet and a wound coil placed next to it.



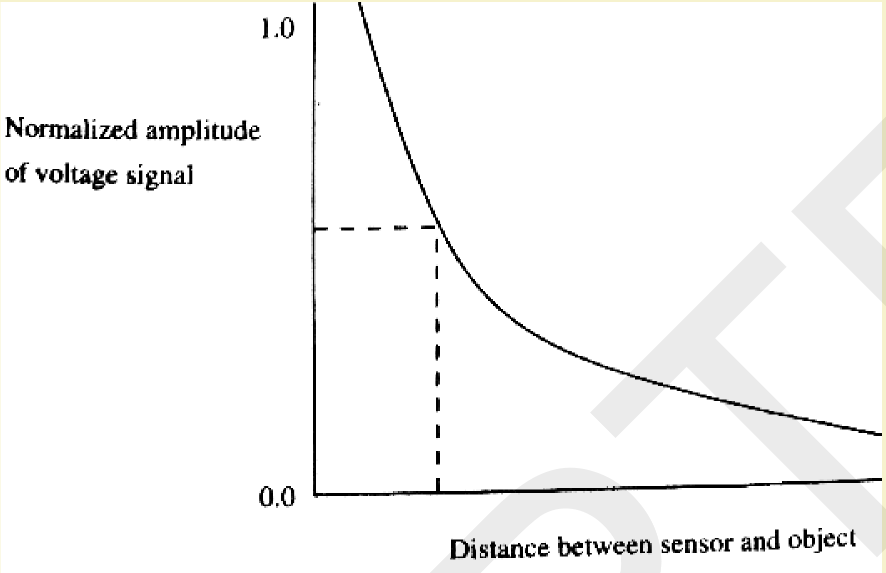


- The nature of flux lines changes, as the sensor comes closer to a ferromagnetic object.
- The flux lines change, as the ferromagnetic object either enters or leaves the field of the magnet.
- Rate of change of the magnetic flux is proportional to induced current (voltage)



Inductive sensor:
induced voltage vs. time

- Voltage induced across the coil depends on the speed at which the object either enters or leaves the magnetic field
- Polarity of the voltage depends on whether the object enters or leaves the field.



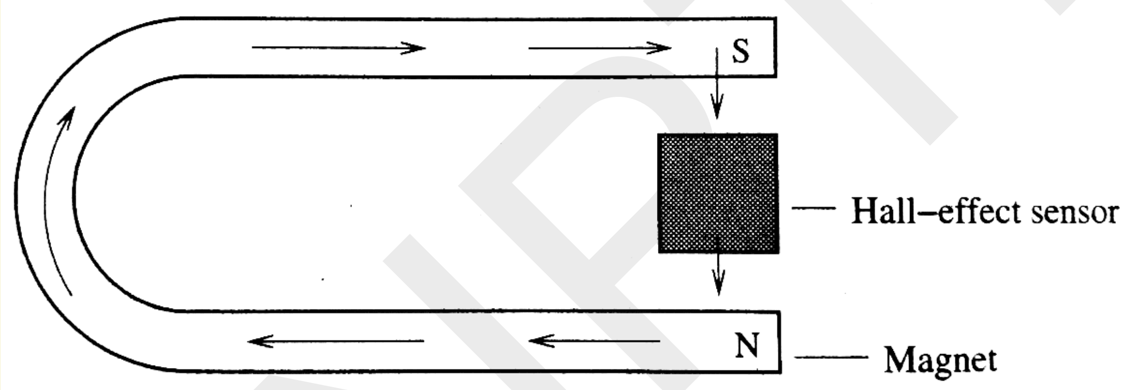
Calibration curve

- The figure shows the calibration curve corresponding to the measured amplitude of voltage signal, the distance between the sensor and object can be determined.

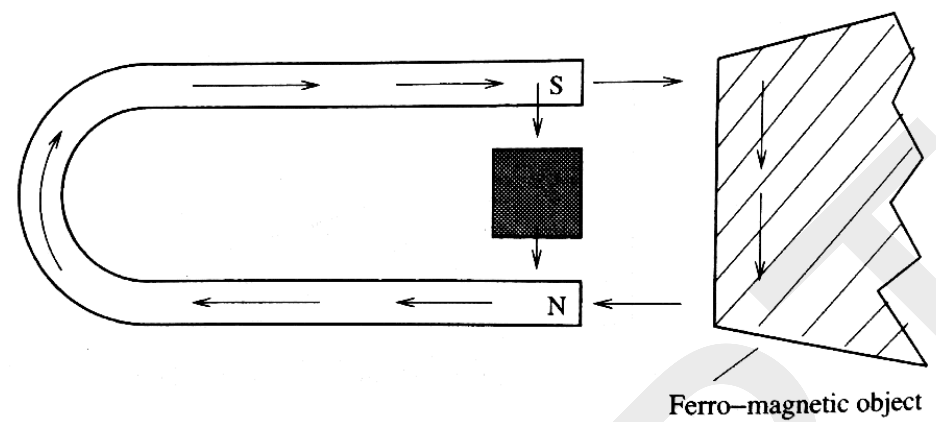
Hall-Effect Sensors (for Ferro-magnetic object)

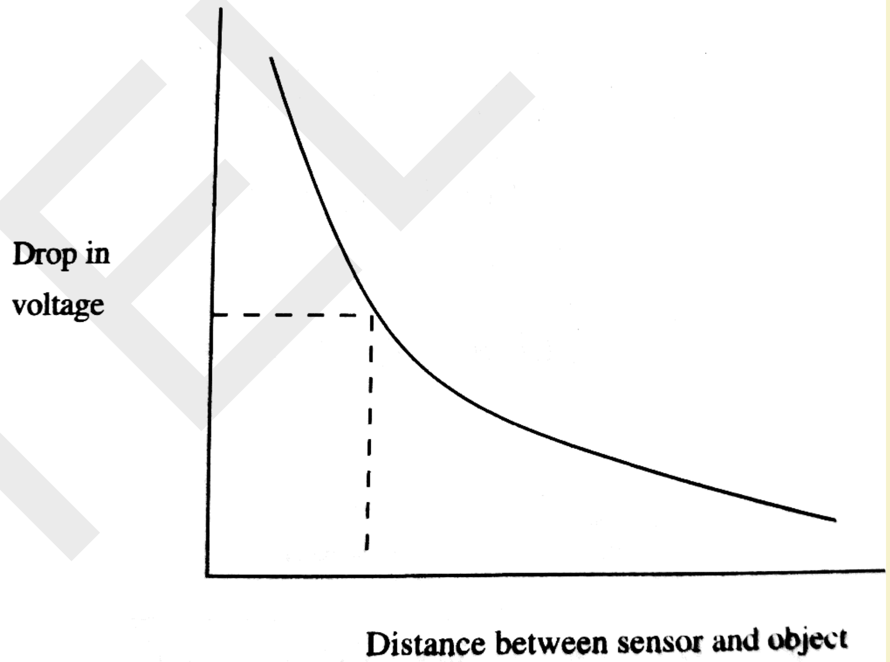
- It works based on the principle of Lorentz force
- If a charge of amount q is moving with velocity $\vec{v}$ in a magnetic field of strength $\vec{B}$, then the Lorentz force

$$\vec{F} = q(\vec{v} \times \vec{B})$$



Hall-Effect Sensors (cont.)



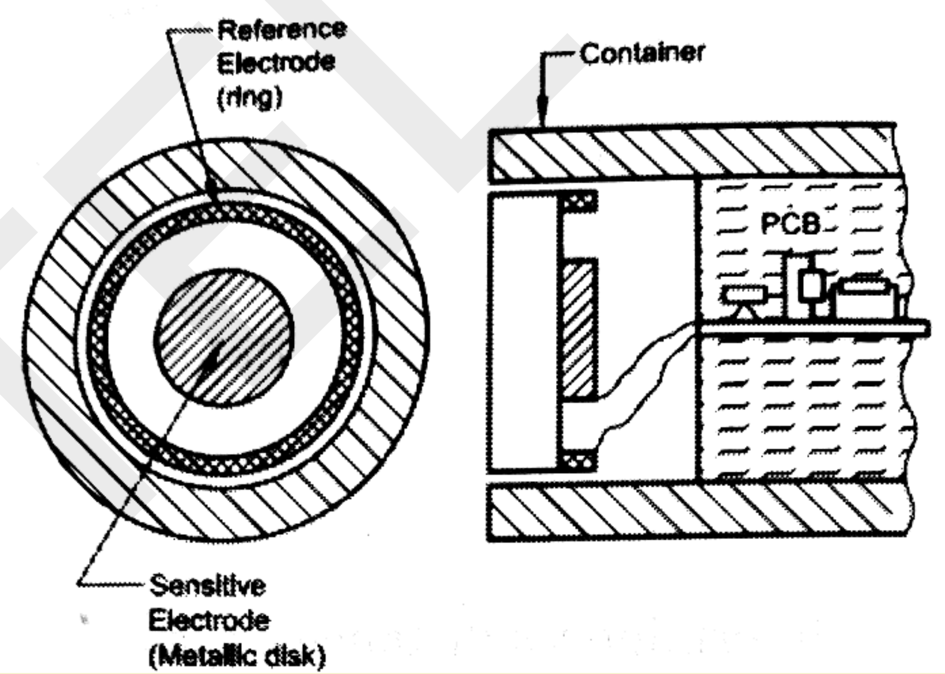


Calibration curve for Hall-effect sensor

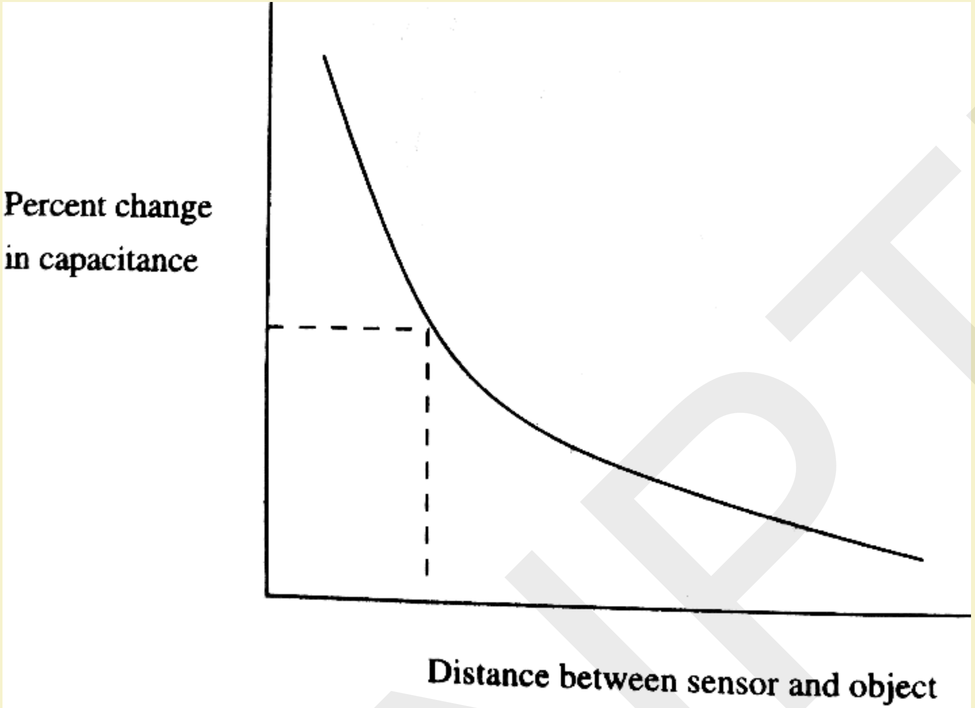
- Voltage across the semiconductor will be reduced

Capacitive Sensor (suitable for any material)

- When an object is brought near to the sensitive electrode, there will be accumulation of charge and consequently, its capacitance changes.
- When the capacitance of the sensor exceeds a predefined threshold value, oscillation starts.
- Oscillations are converted into output voltage through PCB.



Capacitive sensor(contd.)



Calibration curve

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Topic 7: Robot Vision

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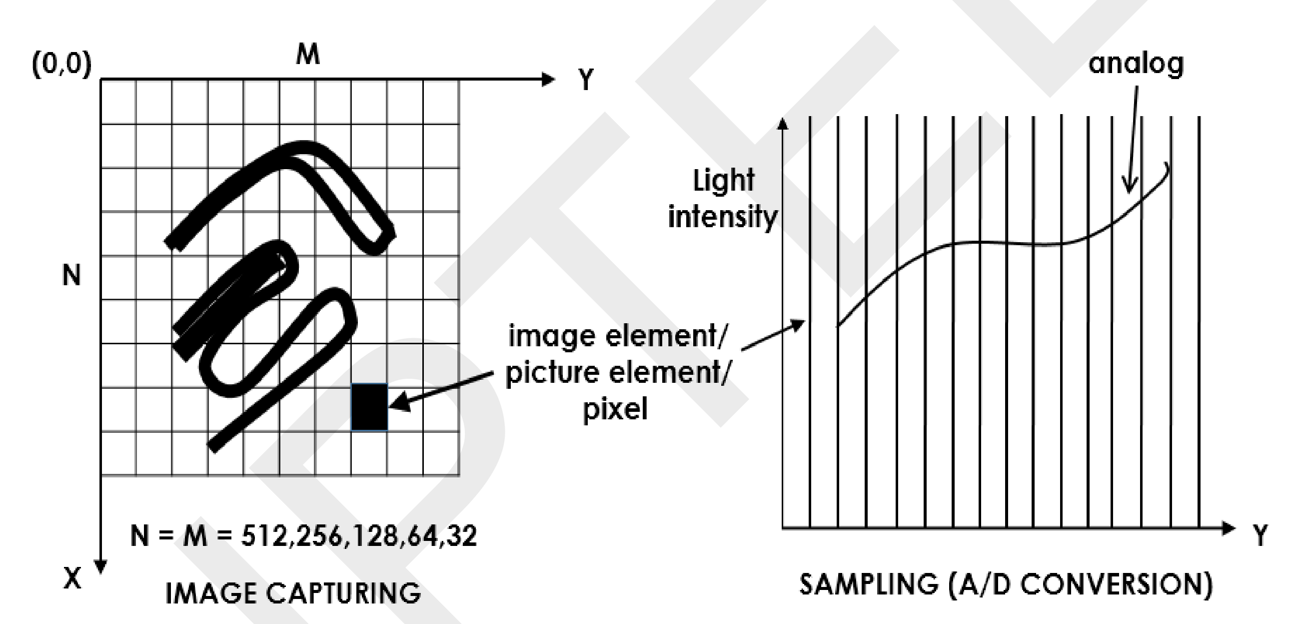
Robot Vision

- **To extract, characterize and interpret objects present in an image/photograph captured using a camera.**

Steps to be Followed

- *Step 1:* Capturing image of the environment using CCD camera.
- *Step 2:* Light intensity is measured along a particular direction say Y using Electron Beam Scanner (in which the charge accumulated in photo-sites is proportional to light intensity). Analog plot of light intensity is digitized and it is known as A/D conversion or digitizing.

Robot Vision



Steps to be Followed (contd.)

- *Step 3:* Image is stored as an array of pixels (each pixel may have different light intensity values). It is known as frame grabbing.

- *Step 4:* Preprocessing of the data collected in *Step 3* is done for noise reduction, restoration of lost information etc.

Frame Grabbing

$$
\begin{bmatrix}
f(0,0) & f(0,1) & \text{-------------} & f(0,M-1) \\
f(1,0) & f(1,1) & \text{--------------} & f(1,M-1) \\
\vdots & \vdots & & \vdots \\
f(N-1,0) & f(N-1,1) & \text{--------------} & f(N-1,M-1)
\end{bmatrix}
$$

$f(x,y)$: Light intensity of image at the point (x,y)