# Topic 4: Internal Sensors for Mobility



# 4.1 Introduction

In robotics & embedded systems, sensors are used for:

**Mobility**: (Internal sensors)

- measuring system parameters (*position, velocity, acceleration)* for stable control
- detecting and avoiding failure situations
- adapting to changes that may effect system performance

**Navigation**: (External sensors)

- abstracting features & correcting errors in a world model
- monitoring the changes in robot's environments
- detecting and avoiding unexpected obstacles
- finding the location of objects or reaching a goal

# 4.1.1 Typical internal sensors for mobility

| General classification (typical use) | Sensor Sensor System |
|---|---|
| Tactile sensors (detection of physical contact or closeness; security switches) | Contact switches, bumpers<br>Optical barriers<br>Noncontact proximity sensors |
| Wheel/motor sensors (wheel/motor speed and position) | Brush encoders<br>Potentiometers<br>Synchros, resolvers<br>Optical encoders<br>Magnetic encoders<br>Inductive encoders<br>Capacitive encoders |
| Heading sensors (orientation of the robot in relation to a fixed reference frame) | Compass<br>Gyroscopes<br>Inclinometers |

# 4.1.2 Typical external sensors for navigation

| General classification (typical use) | Sensor Sensor System |
|---|---|
| Ground-based beacons (localization in a fixed reference frame) | GPS<br>Active optical or RF beacons<br>Active ultrasonic beacons<br>Reflective beacons |
| Active ranging (reflectivity, time-of-flight, and geo-metric triangulation) | Reflectivity sensors<br>Ultrasonic sensor<br>Laser rangefinder<br>Optical triangulation (1D)<br>Structured light (2D) |
| Motion/speed sensors (speed relative to fixed or moving objects) | Doppler radar<br>Doppler sound |
| Vision-based sensors (visual ranging, whole-image analy-sis, segmentation, object recognition) | CCD/CMOS camera(s)<br>Visual ranging packages<br>Object tracking packages |

# 4.1.3 A brief Sensor Comparison

| Sensor | Information | Accuracy | Adv./Disadv. |
|---|---|---|---|
| Odometry | Pose change | $\pm 1mm/m$ | cheap, simple<br>subject to drift |
| Sonar | Range | $\pm 2$ cm, $\pm 5$-$30°$ | cheap<br>rel. well understood<br>low angular res.<br>rel. low scan rate |
| Laser | Range | $\pm 1$-$5$ cm, $\approx 0.5°$ | high angular res.<br>high scan rate<br>expensive<br>transparent materials |
| IR | Range | 1-10 cm | cheap<br>material dependent |
| Radar | Range | - | long range<br>used extensively<br>outdoor |
| Inertial | Acc, vel, pos | - | easy to use<br>drift |
| Compass | Direction | - | easy to use<br>sensitive to disturb. |
| Vision | Various | - | pot. very powerful<br>difficult to use<br>not well understood |

# 4.2 Internal Position Sensors

## 4.2.1 introduction

*Contact sensors*

* Micro switch -- to measure the danger situation (*on/off output*)
* Potentiometers -- to measure position (*continuous output*)
* Strain gauges -- to measure force or position (*continuous output*)

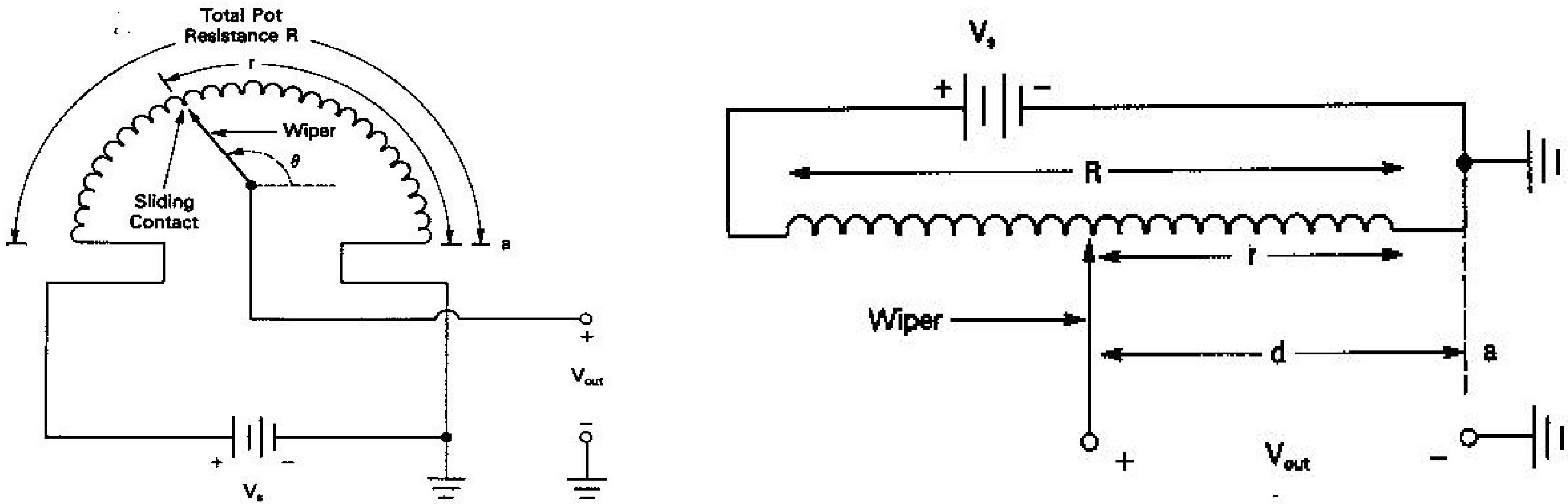
Non-contact sensors

* Optical interrupters -- to measure positions (*on/off output*)
* Incremental optical encoders -- to measure position & velocity (*digital output*)
* Absolute optical encoders -- to measure position (*digital output*)
* Synchros -- to measure angular displacement (*continuous output*)
* Resolvers -- A rotary electrical transformer for measuring degrees of rotation .

**Note**: *The resolvers and synchros are used in automatic systems as sensors and receivers for the angle remote transmission systems . They have been replaced by optical rotary encoders.*

# 4.2.2 Potentiometers

**Potentiometers:** *(pot for short) They are the simplest device to measure actuator position, e.g. the angle of the steering wheel of the robot.*




(a) rotary--output proportional to ; (b)linear--output proportional to d.

The voltage $V_{out}$ is proportional to linear or rotary distance of the sliding contact (or wiper) from the reference point *a*.

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

# 4.2.2 Potentiometers

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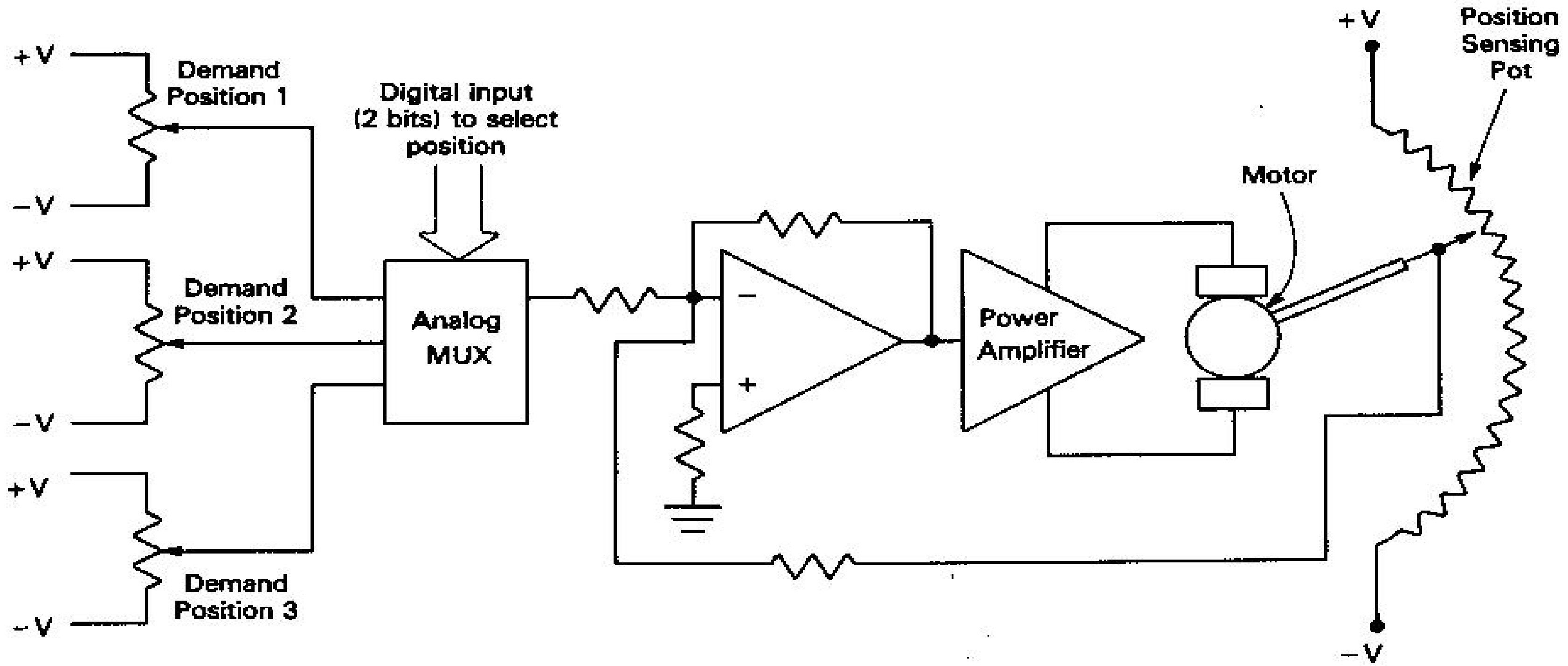
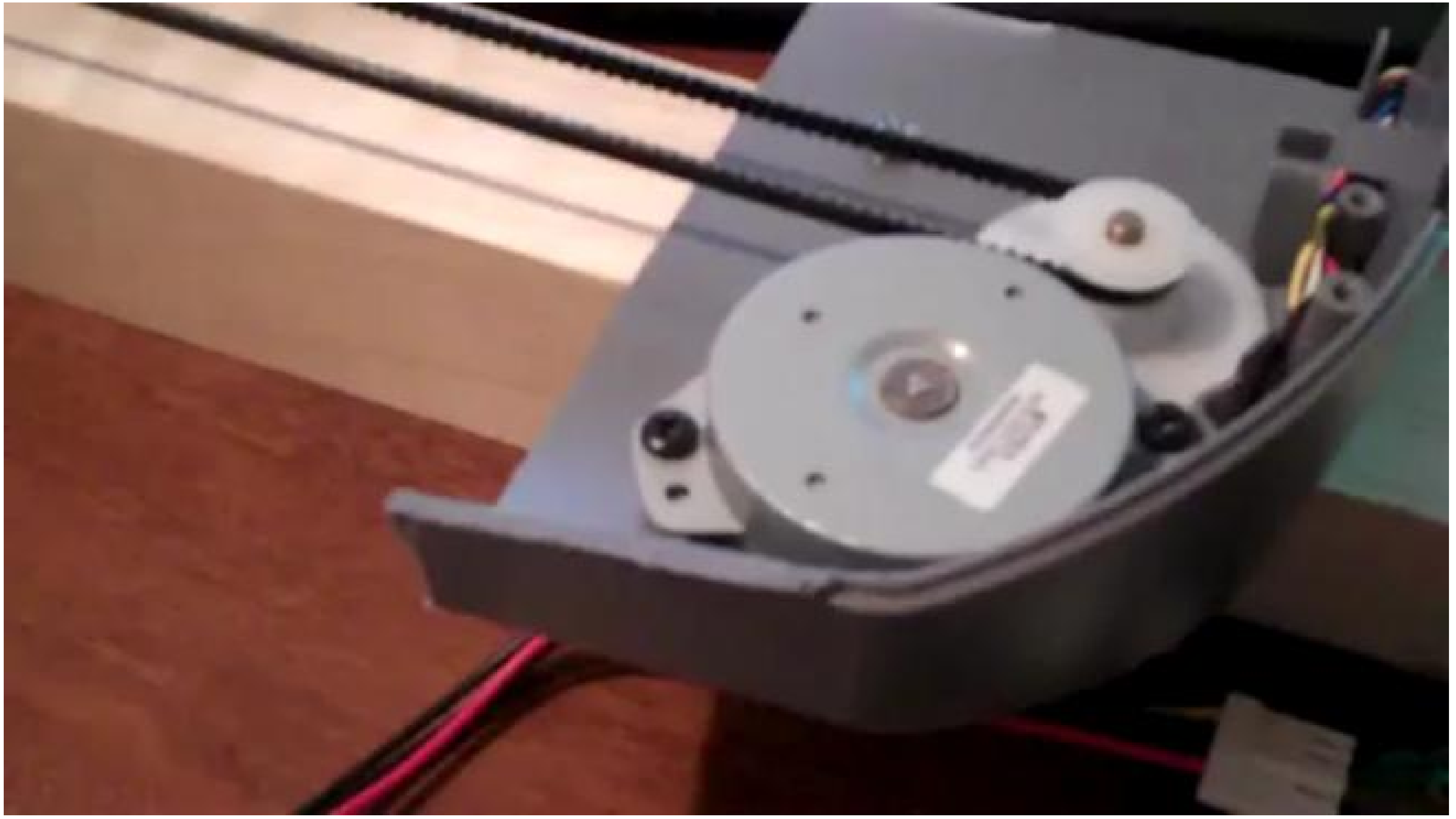
**Typical application**:

The potentiometer can be used to measure the steering angle:



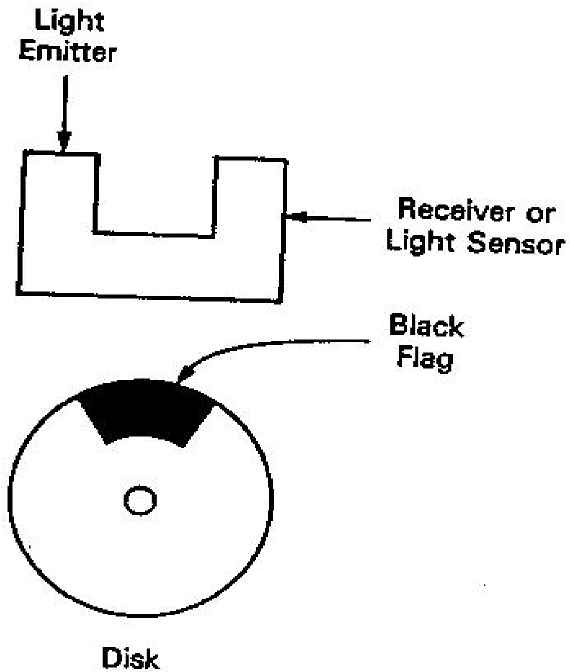

**Note:** *The potentiometer is in the feedback loop in order to provide position information for the servo control.*

# 4.2.2 Potentiometers

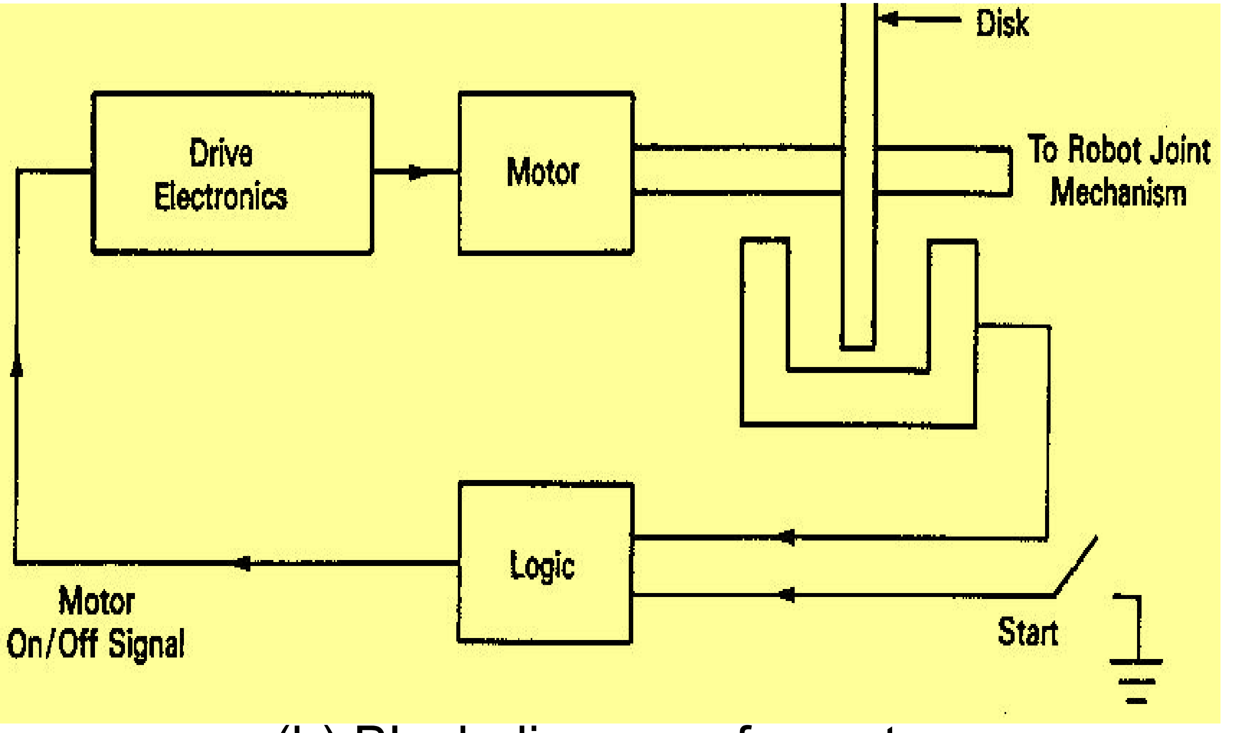


# 4.2.3 Optical Position Sensors

**1. <u>Opto-Interrupters:</u>** *Opto-interrupter* can be used to sense the and of travel for robot actuators with a long life.




(a) Light emitter-receiver and disk with black flag



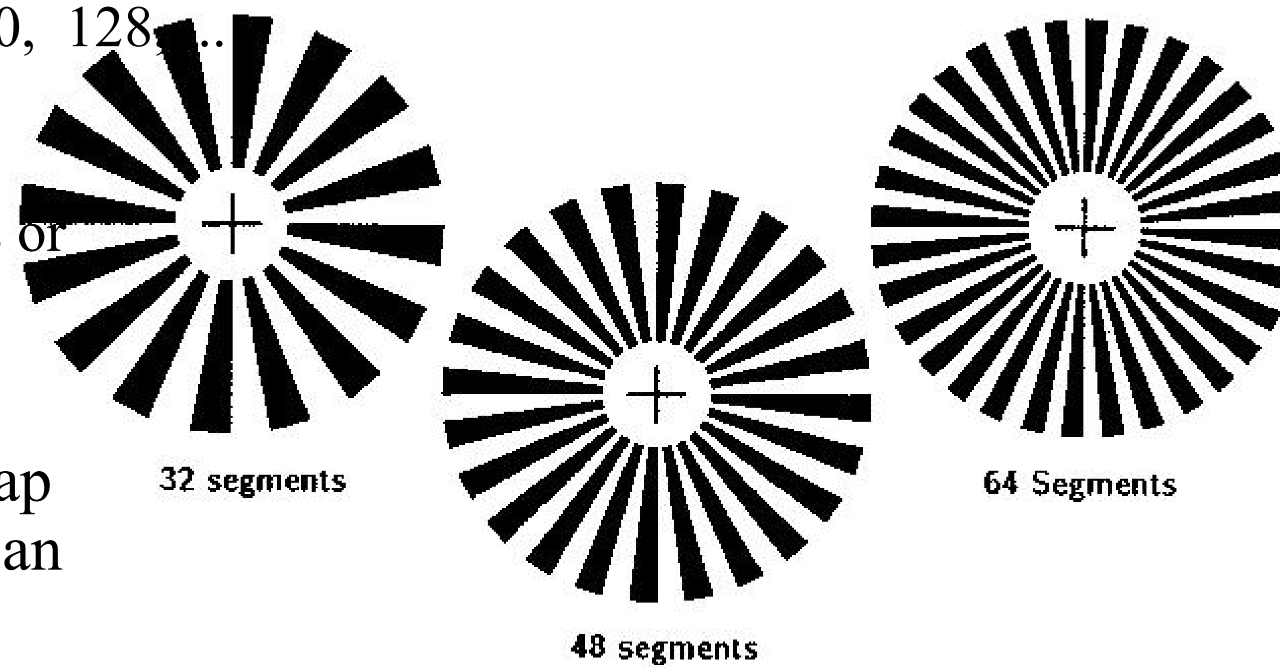

(b) Block diagram of a motor control circuit (unidirectional)

# 4.2.3 Optical Position Sensors

## 2. Incremental optical encoder:

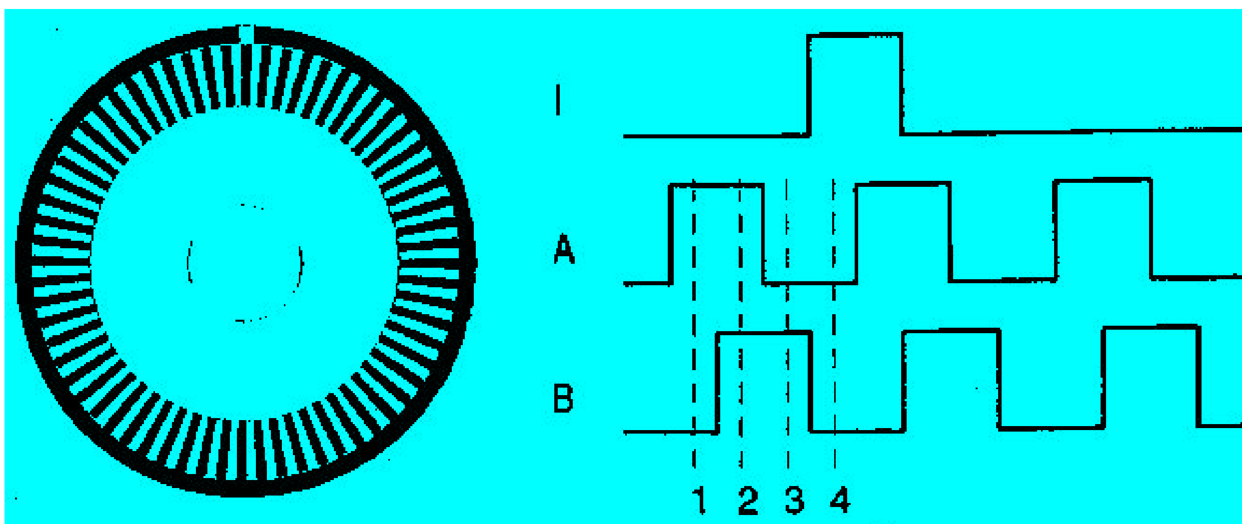
- An rotating disk with N radial grating lines, e.g., 100, 128, …
- An LED light source.
- A set of light receivers or phototransistors.

***Single channel:*** Cheap and easy to use, but can not determine the direction of rotation.



# 4.2.3 Optical Position Sensors

***Two/Three channels of Incremental optical encoder:***
Able to determine the direction of rotation, as shown in the next figure.




| State | Ch A | Ch B |
|---|---|---|
| $S_1$ | High | Low |
| $S_2$ | High | High |
| $S_3$ | Low | High |
| $S_4$ | Low | Low |

# 4.2.3 Optical Position Sensors

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**4. Absolute optical encoder:**

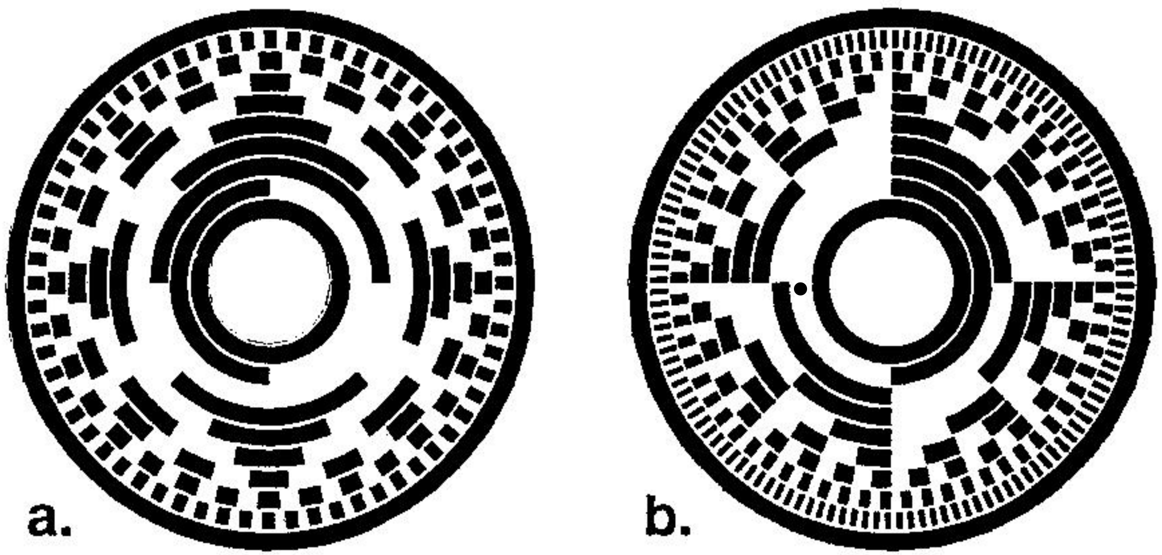
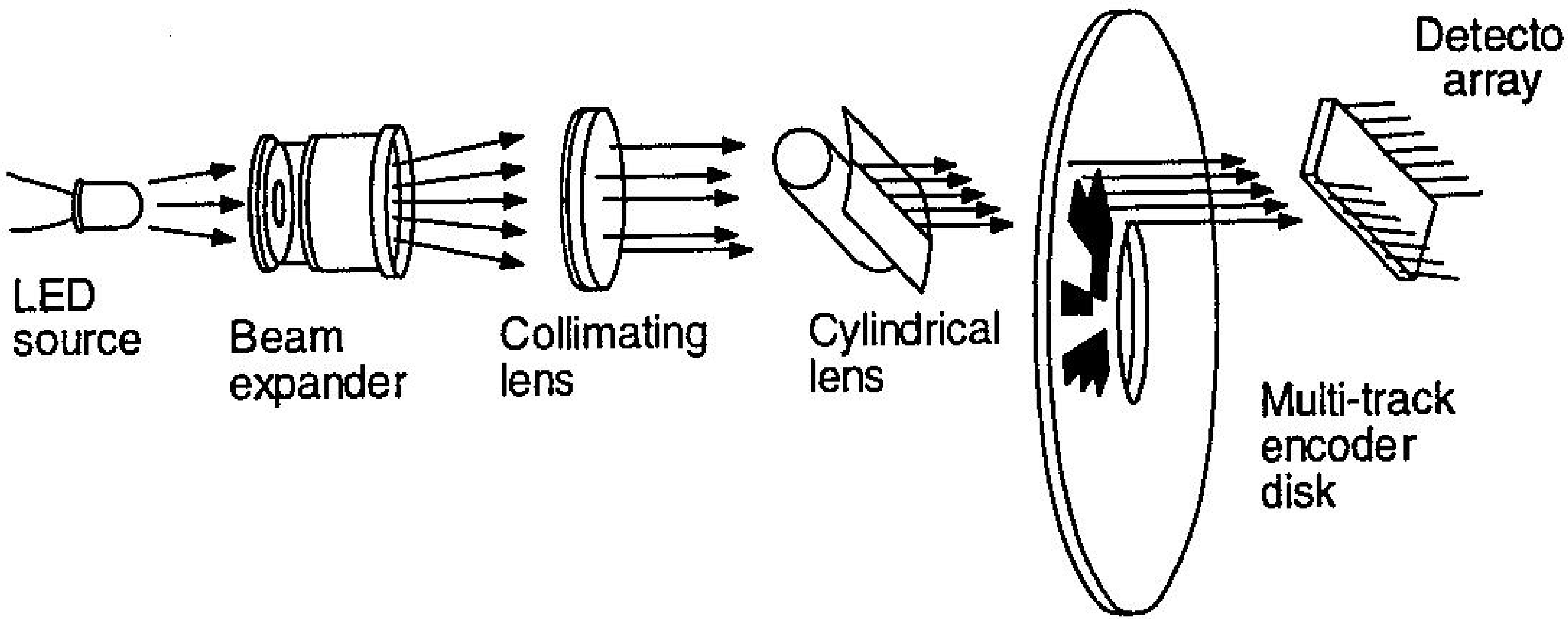



**Figure 1.3:** Rotating an 8-bit absolute Gray code disk.
a. Counterclockwise rotation by one position increment will cause only one bit to change.
b. The same rotation of a binary-coded disk will cause all bits to change in the particular case (255 to 0) illustrated by the reference line at 12 o'clock.
[Everett, 1995].

- A multiple-track (or channel) light source
- A multiple-channel light receiver
- A multiple-track rotary disk
- Grey code -- one bit changes at a time.
- Binary code --- multiple bit changes
- Binary-coded decimal -- possible multiple bit changes each time.

# 4.2.3 Optical Position Sensors

**4. Absolute optical encoder:**

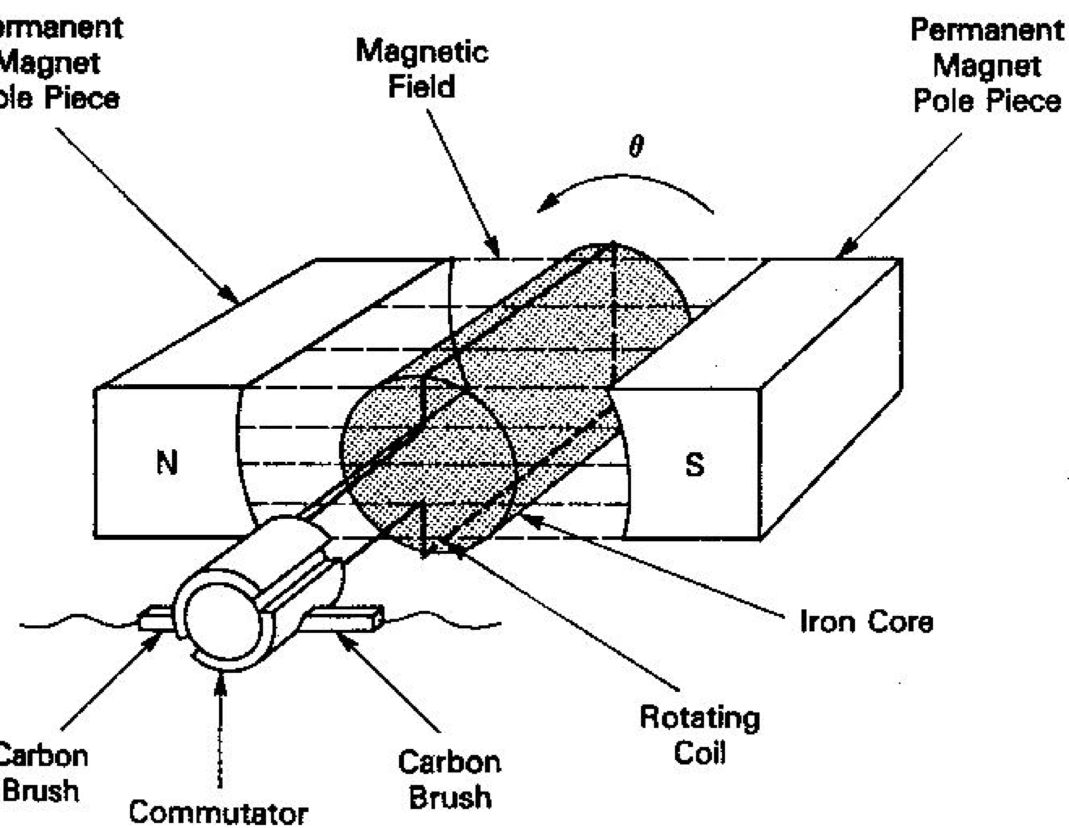


# 4.2.3 Optical Position Sensors

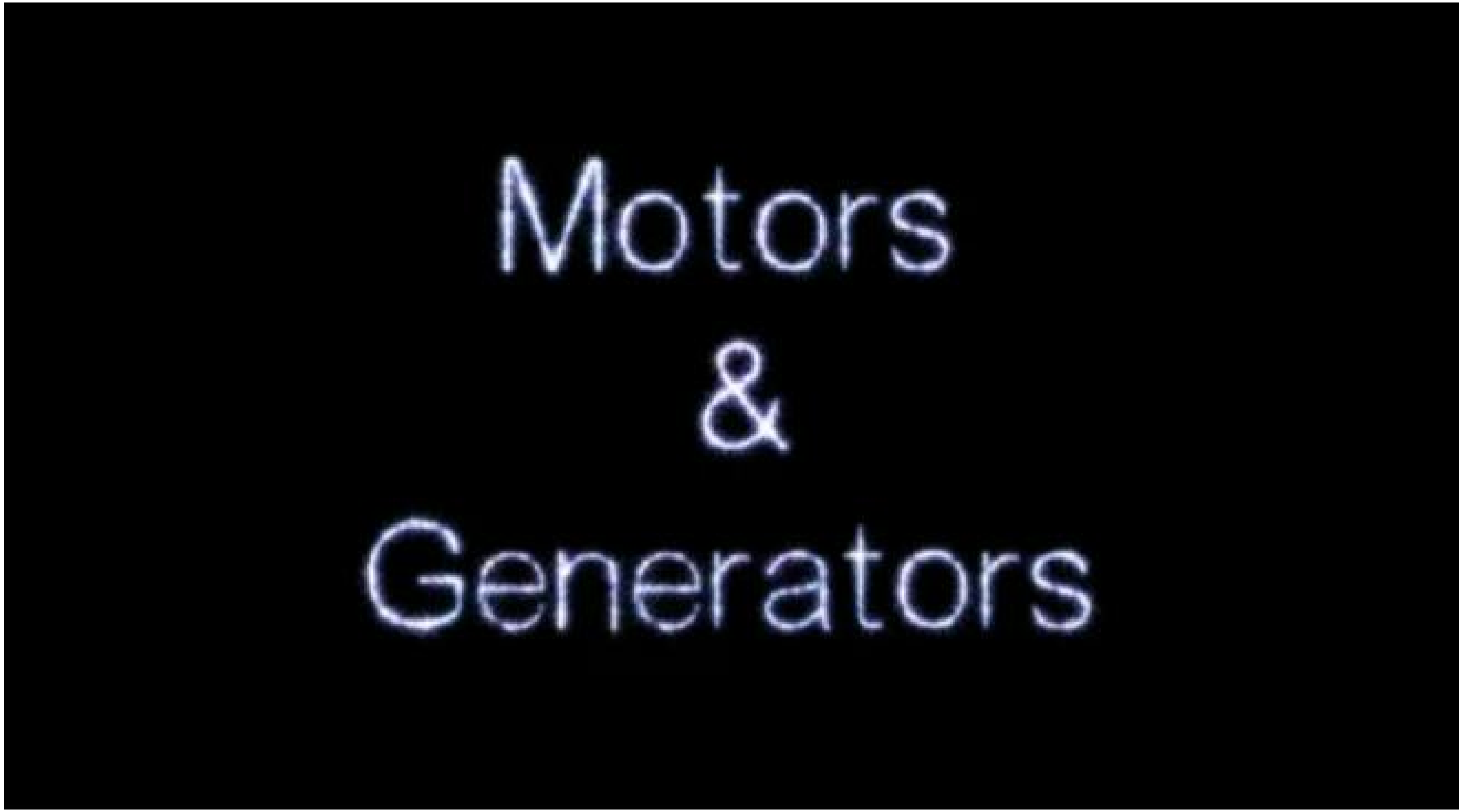
# 4.3 Internal State Sensors

**1. Velocity sensors --** DC Tachometers (Tacho *for short*):

Analog tacho showing only one coil mounted on an iron core. Note that there are many coils in practice.



# 4.3 Internal State Sensors



# 4.3.1 Velocity Sensors

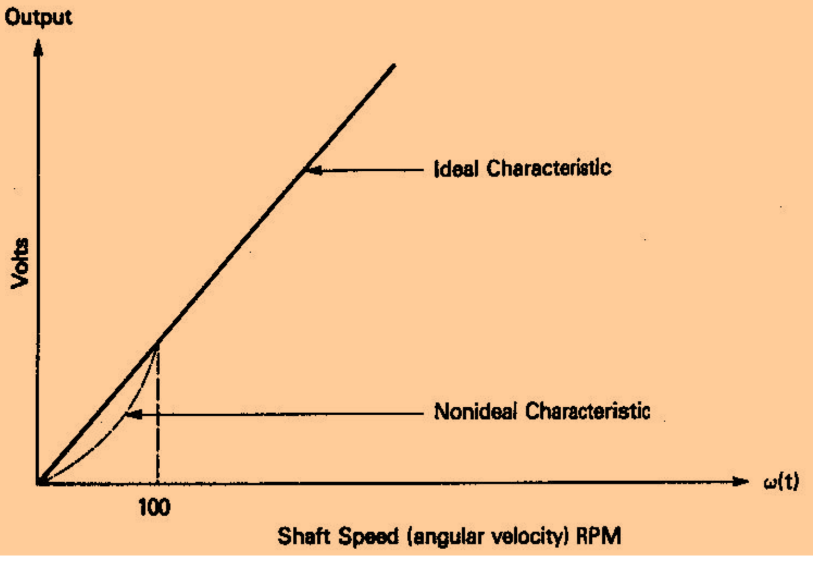
A Tacho sensor has the following features:

- Able to produce a dc voltage proportional to the shaft speed.
- Output voltage versus speed is linear over the operation range.
- Being relatively free of voltage ripple in the operating.
- Being small size, very light, and low costs (about $50/unit).

- Let ω be the angular velocity, θ the rotating angle of coil plane, *K* the tacho's parameter. Then the output voltage of a tacho is:

$$V_{out} = K\omega \sin\theta$$

- Output voltage versus speed transfer characteristic of an analogue tacho. It usually becomes non-linear at low speed.



# 4.3.2 Accelerometers

**There are two kinds of acceleration**:

- Angular acceleration
- Linear acceleration.

**Two methods to measure**:

- ***Software implementation***

  we can calculate acceleration by differentiating velocity, i.e,

  $$A=\Delta V \quad \Delta T$$

  -- This is normally done by software subroutine.

- ***Hardware implementation***

  -- using different accelerometers.

# 4.3.2 Accelerometers

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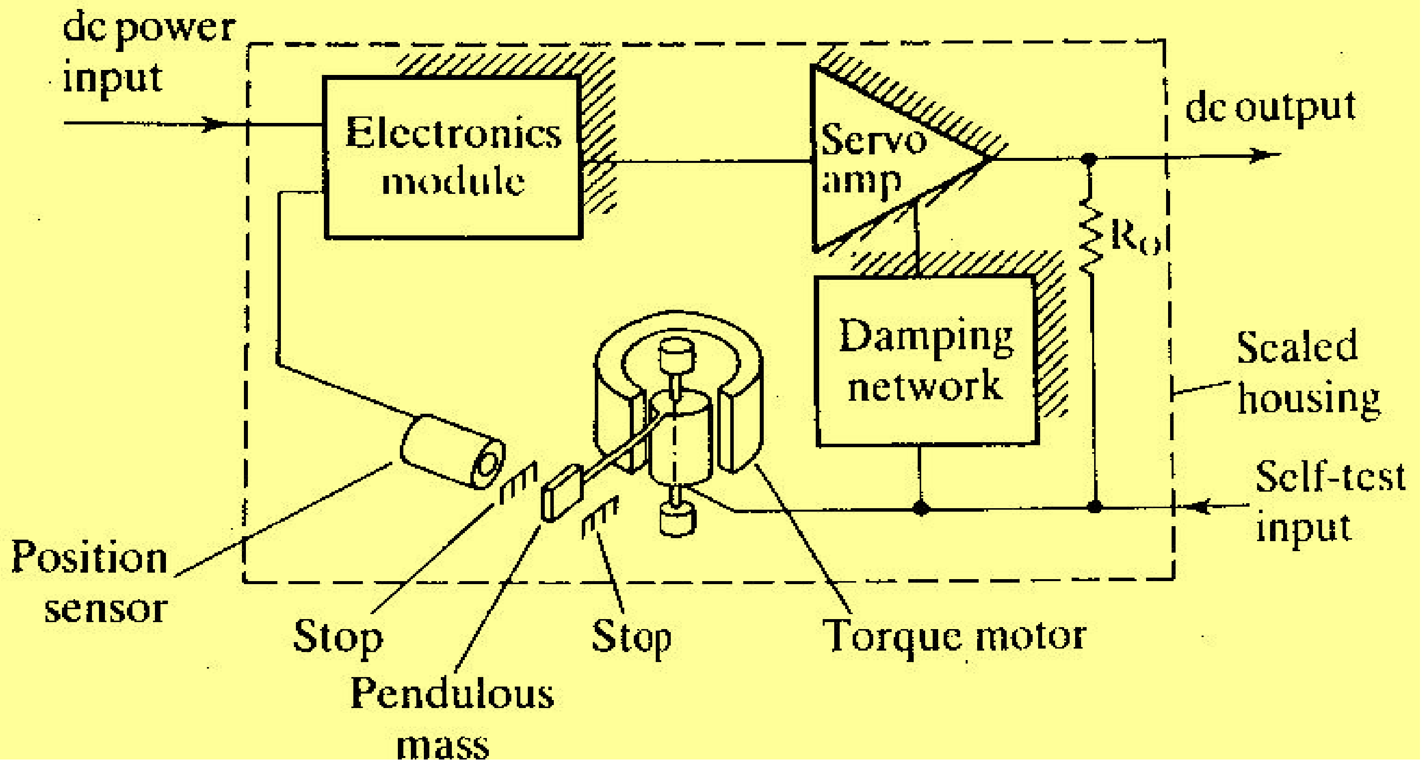
## 1. Angular accelerometer:

It is a closed-loop torque balance system, namely a servo accelerometer, for measuring angular acceleration based on Newton's second law: α=F M.



# 4.3.2 Accelerometers

## Main features of Angular accelerometer :

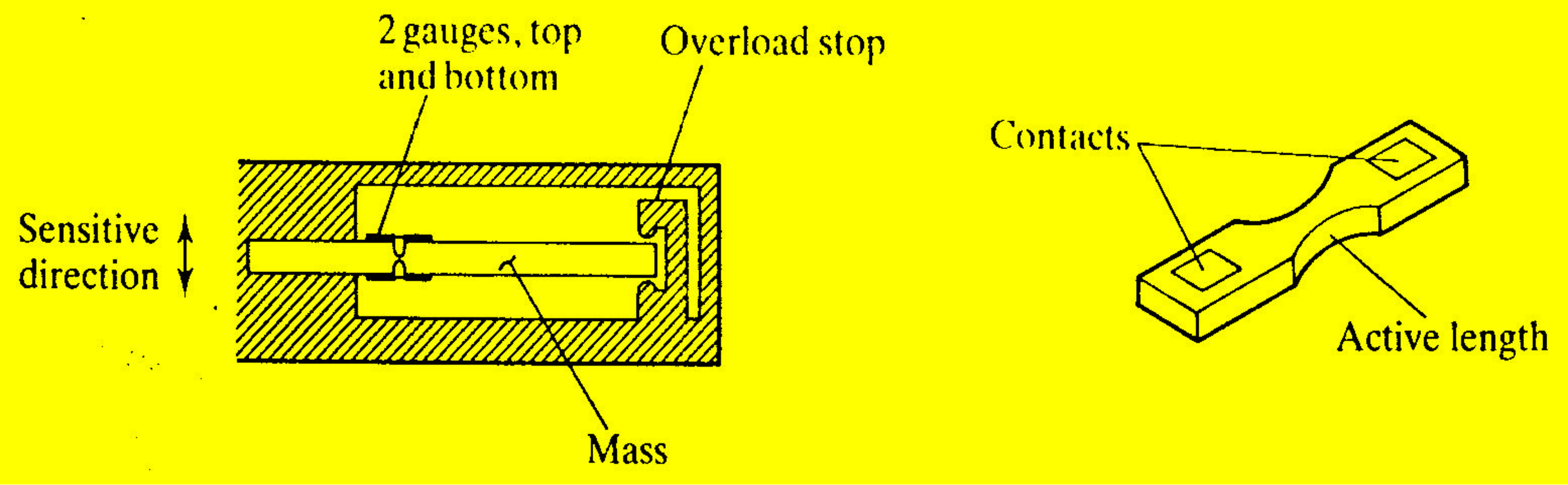
- A pendulous mass develops a torque proportional to the product of its mass unbalance and applied acceleration.
- The motion of the mass is detected with a position sensor.
- Position signal is compared to a fixed reference by a servo amplifier.
- The applied torque stops the motion of the mass at a position proportional to acceleration.
- The current through the torque motor produces a voltage across the output resistor, which is proportional to acceleration.
- The performance of accelerometers available on the market:

*Range: ±200 - ±1500 radians/s²;* *Linearity: ±0.05% of full scale;*
*Resolution: 0.0005% of full scale;* *Hysteresis: 0.02% of full scale.*

# 4.3.2 Accelerometers

## 2. **Linear accelerometers** -- a piezo-resistive accelerometer

- t is constructed by placing strain gauges on a cantilevered beam as follows




*(a) Accelerometer design using cantilever beam with overload stop & 2 semiconductor strain gauges*

*(b) semiconductor strain gauge with large mounting pads & narrow active neck*

# 4.3.2 Accelerometers

***Sensing principle*:**

- The gauges are placed across a slit in the beam. The outboard end of the beam forms a rigid mass & narrow slit forms a flexible member.
- The beam motion is concentrated in the slit, with the strain forces across the slit.
- Inertial forces cause the beam to bend when acceleration is applied to the sensor along the sensitive direction.
- Of two gauges attached to the beam, one measures tension and one measures compression when the beam bends.
- Strain gauges form two arms of a Wheatstone bridge, and imbalance causes an output voltage proportional to beam bending.

***Main features*:**

Small size, low output impedance, zero phase shaft, One direction only, wide frequency response -0.1 Hz to 5kHz, measuring range: 10g to 50Kg

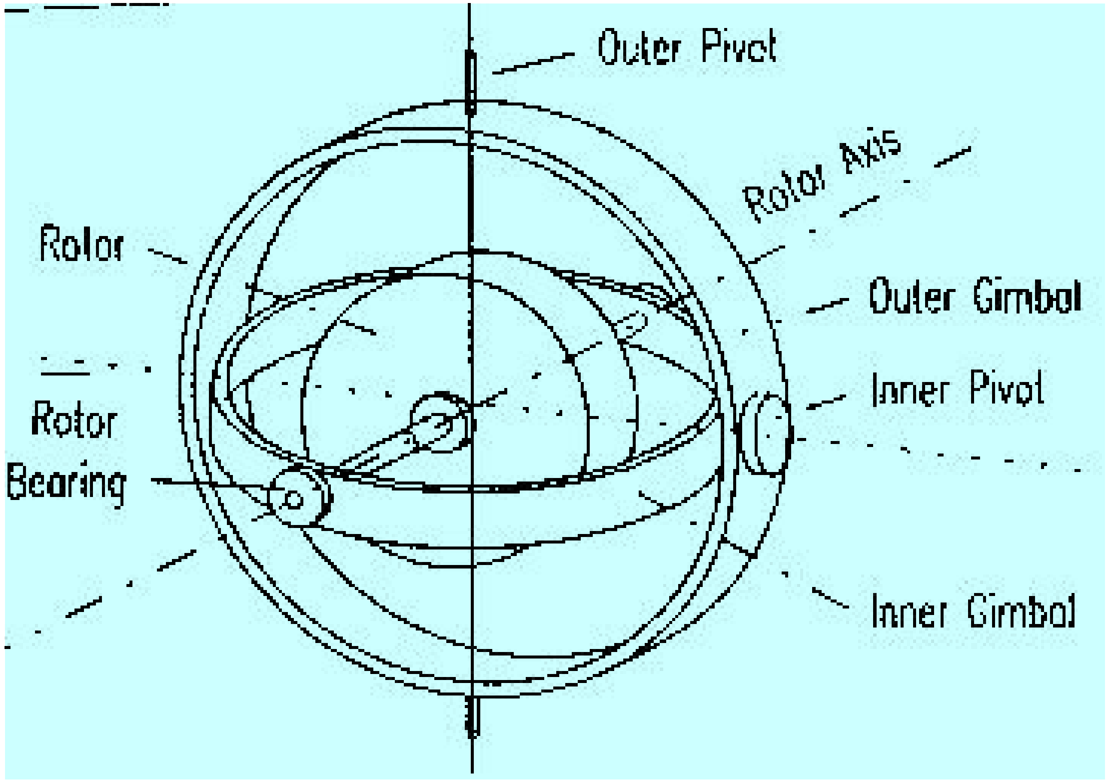
# 4.3.3 Gyroscope Sensors

**Gyroscopes**

-- measures a robot's attitude relative to an inertial frame of reference, including

*mechanical & optical*

**Mechanical gyroscopes** -- operate by sensing the change in direction of some actively sustained angular or linear momentum, including flywheel gyroscopes and vibrating structure gyroscopes.



# 4.3.3 Gyroscope Sensors

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**Optical gyroscopes** -- have little or no moving parts, and are virtually maintenance free. Five general configurations of optical gyros are:

(i) active optical resonators;

(ii) passive optical resonators;

(iii) open-loop fibre optic;

(iv) closed-loop fibre optic;

(v) fibre optical resonators.

# 4.3.3 Gyroscope Sensors

# 4.3.4 Tilt Sensors

**Simple LED tilt sensor**

# 4.3.4 Tilt Sensors

Mercury Tilt Switch

# 4.4 Inertial Measurement Units

9-axis IMU (Inertial measurement units)

- 3D orientation, 3D acceleration, 3D earth-magnetic field.
- *Platform*: Windows 2000/XP.
- *Range*: acceleration: +/- 2 G's;
  rate of turn: +/- 900 deg/s;
  magnetic field: +/- 750 mG.
- *Power supply*: 5.5 V; 40 mA.
- *Outline Size*: 39 X 54 X 28 mm.
- *Weight*: 35 g.

# 4.4 Inertial Measurement Units

Track human motion-XSEN Inertial Sensor Suit, 2008

# 4.4 Inertial Measurement Units

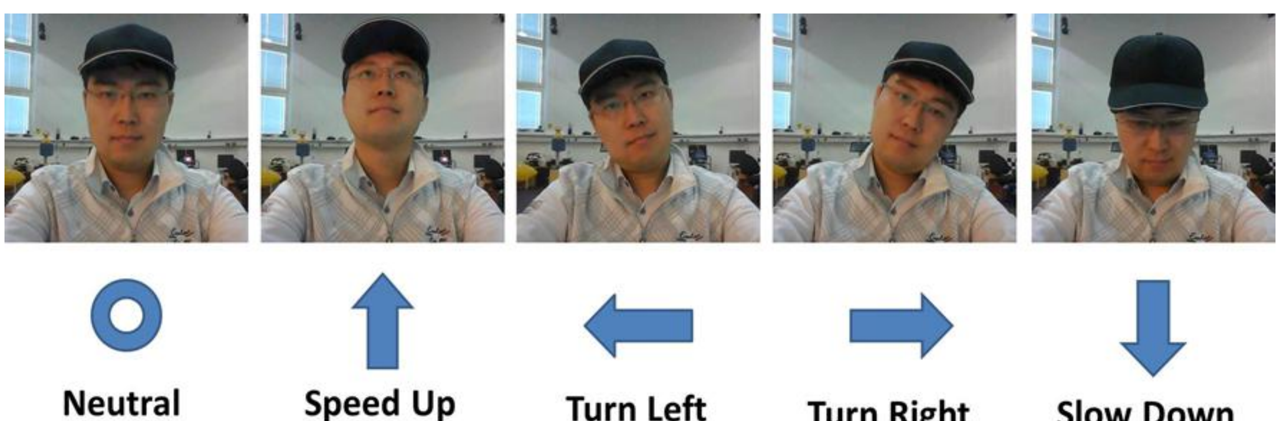
## Hand Gesture for Robotic arm control

# 4.4 Inertial Measurement Units

Wireless IMU in a Baseball Cap

- ❑ Detect head motion for wheelchair control
- ❑ Minimum user head motion required
- ❑ Adapt to people with weak neck abilities
- ❑ Obstacle avoidance with laser scanner
- ❑ Totally replace joystick control interface





# 4.4 Inertial Measurement Units

# 4.5 Conclusion

Sensors in mobile robots can be grouped into two classes:

- ***Internal sensors*** that measure variables within the robot

  e.g. robot velocity, position, acceleration, etc.

- ***External sensors*** that deal with the unknown or dynamic environment

  e.g., range, gap, road width, object features, wall, etc.

In this lecture, we focus on the internal sensors.

- ***For motion control***

  They are mainly used to implement the low level feedback motion control of the mobile robots to achieve stability & good performance.

- ***For relative positioning***

  They can also be used to calculate the robot position in order to travel from one position to another, which will be reviewed in the later topics.