Autonomous Mobile Robots

Module 8: Sensors for Mobile Robots

Sensor Characteristics

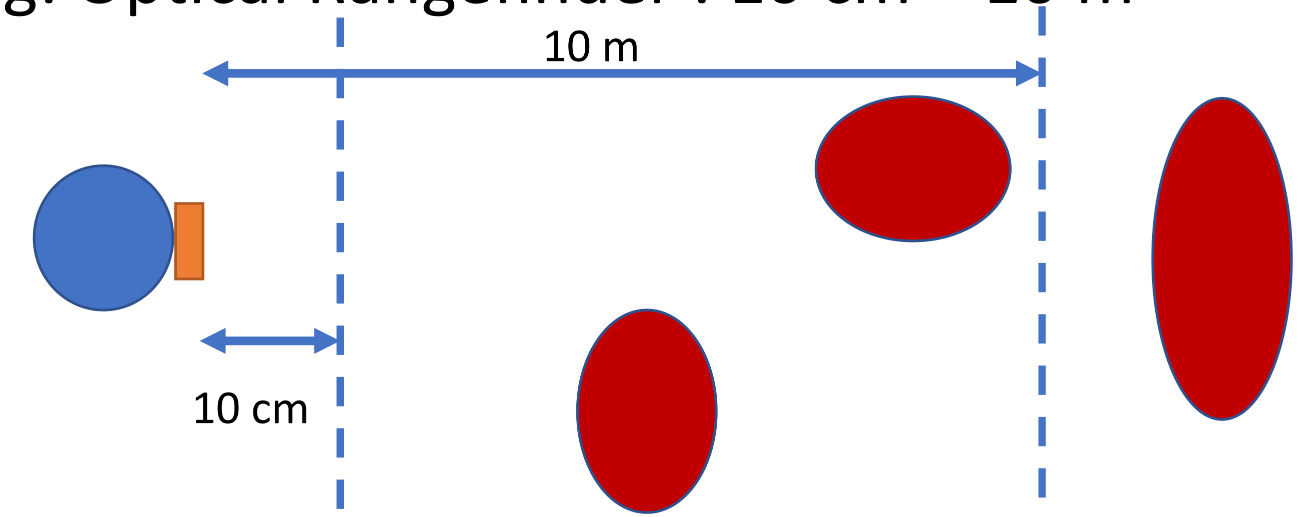
1. Dynamic Range measures the spread between the lower and upper limits of input values

Eg: Thermometer has a range from 96 – 110 F

- Range can also be expressed as a ratio of Maximum input value to the minimum input value
- This can also be expressed in decibels
  - Dynamic Range = $\frac{Maximum\ input\ value}{Minimum\ input\ value}$
  - Dynamic Range (in decibels) = $20 \log_{10}\left(\frac{Maximum\ input\ value}{Minimum\ input\ value}\right)$

Sensor Characteristics

- For thermometer example: Dynamic range = $\frac{110}{96}$
- Eg: Motor current sensor has a range : 1 mA – 20 A
  - $\frac{Maximum\ input\ value}{Minimum\ input\ value} = \frac{20}{0.001} = 20{,}000$
  - Dynamic range in dB : $20\log_{10}(20{,}000) = 86\ dB$
- Eg: Optical Rangefinder : 10 cm – 10 m



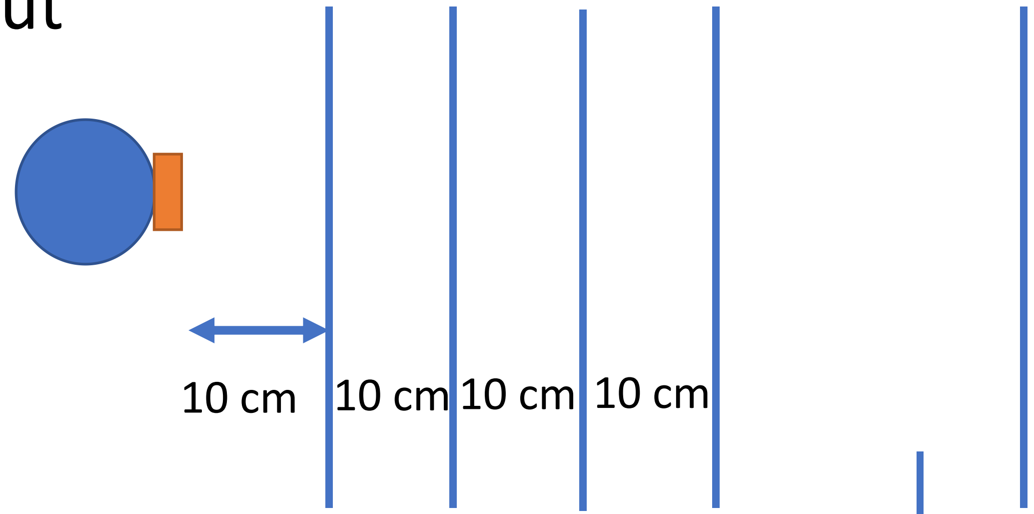
Sensor Characteristics

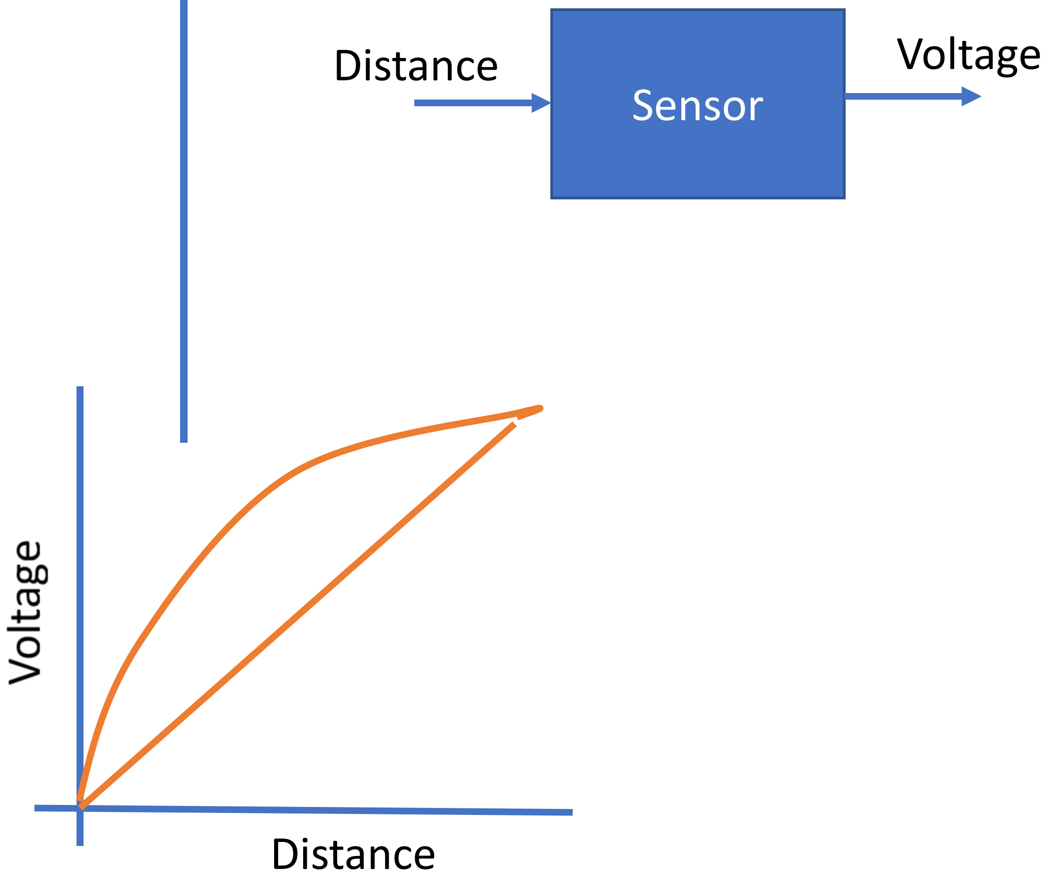
2. Resolution indicates the minimum difference between 2 values that can be detected by a sensor

Eg: Suppose laser rangefinder sensor has 1 cm resolution

Sensor Characteristics

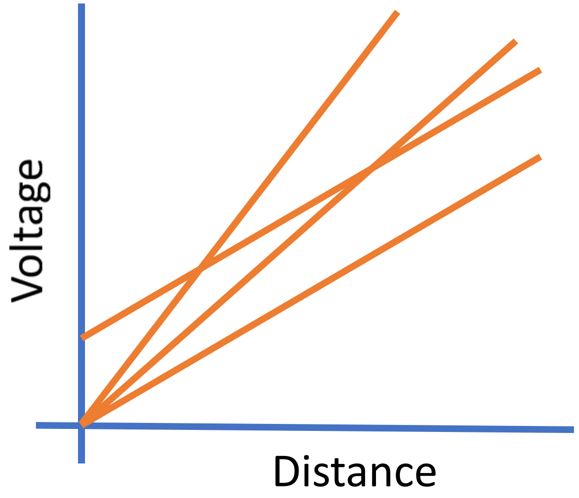
3. Linearity indicates the behavior of sensor's output with variation in input





Sensor Characteristics

3. Linearity



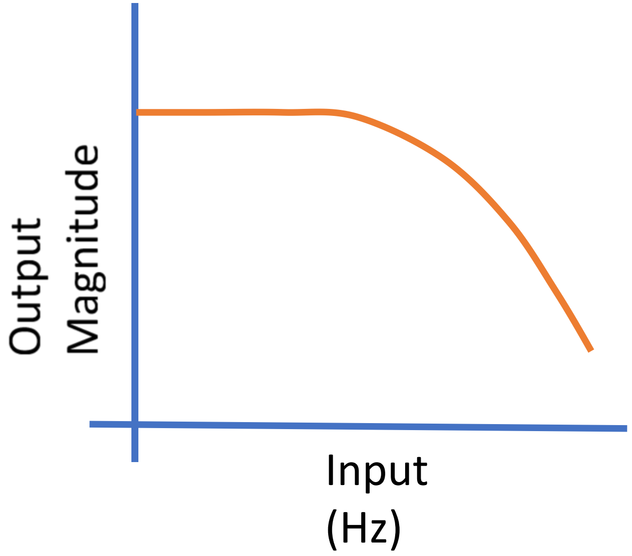
$Y = mX + C$

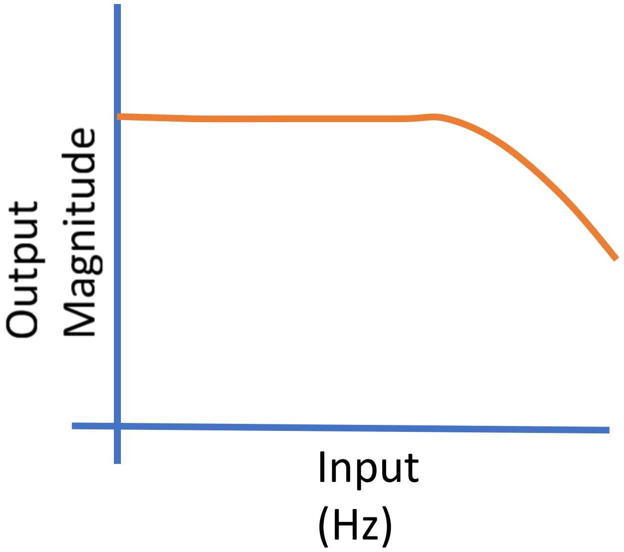
- *If input x1 results in output y1*
- *If input x2 results in output y2*
- *Then an input ax1 + bx2 will result in an output ay1 + by2*

Sensor Characteristics

4. Bandwidth/frequency indicates the range of input frequencies that can be detected by a sensor

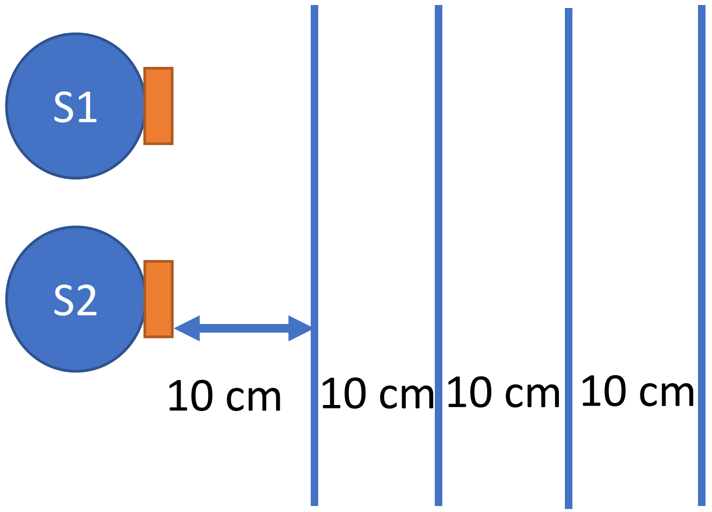
- Generally, if a robot uses a sensor with higher bandwidth, it can operate faster

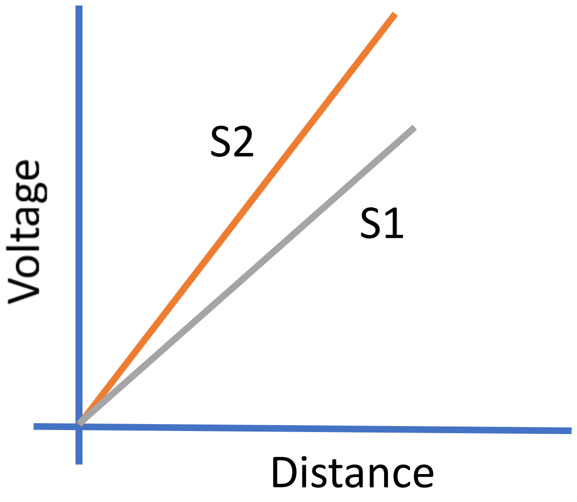




Sensor Characteristics

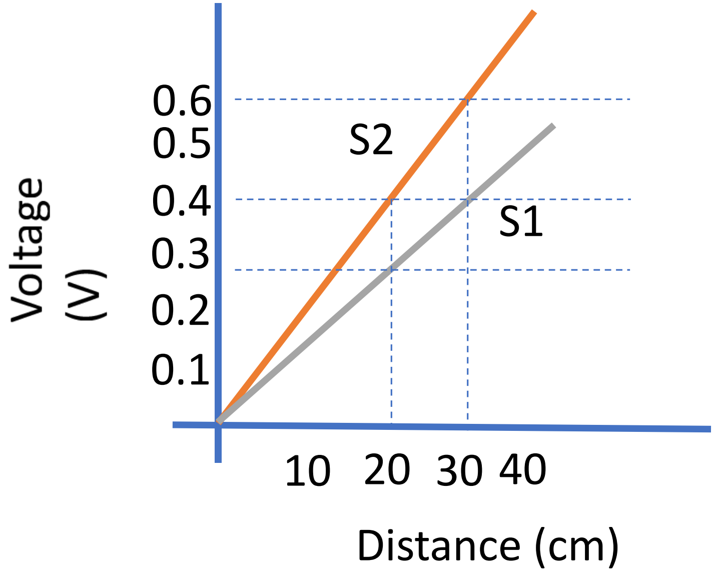
5. Sensitivity captures the ratio of change in output of sensor to change in the physical variable being measured





Sensor Characteristics

5. Sensitivity captures the ratio of change in output of sensor to change in the physical variable being measured



- *Sensitivity of S1 = 0.1/10 = 0.01 V/cm*
- *Sensitivity of S2 = 0.2/10 = 0.02 V/cm*

Sensor Characteristics

6. Error is the difference between the sensor output and the true value being measured

- *E = R – T*
- *R: reading*
- *T : True value*

Suppose laser rangefinder is measuring distance to an object

The actual distance is 1m, but the sensor records 1.01m

Error in measurement is 0.01 m or 1 cm

Sensor Characteristics

7. Accuracy is related to error and given as

$$Accuracy = 1 - \frac{|E|}{T}$$

Suppose true value is 16 cm, measurement is 12 cm

E = -4 cm

Accuracy = 1-4/16 = 1-0.25=0.75

8. Precision is related to reproducibility of sensor readings to the same quantity measured

Suppose a **sensor (S1)** measures a true distance of 10 cm and produces readings of 9.3, 9.4,9.35,9.5 and 9.4

Sensor (S2) produces readings 9.3, 9.8, 10, 9.4 and 9.2. **S1** would be more precise

Sensor Classification

- 2 popular ways to classify
  - Proprioceptive or Exteroceptive
  - Passive or Active
- Proprioceptive sensors measure values internal to the system
- Examples of such values are temperature of a chip, motor speed, joint angle of a robot arm, voltage of a battery
- Exteroceptive sensors, on the other hand, acquire info about robot’s environment
- Examples of such values are distance to an obstacle, light intensity in the room, sound amplitude

Sensor Classification : Active v/s Passive

- Passive sensors measure ambient environment energy entering the sensor.
- Examples of passive sensors include microphones, temperature probes, cameras
- Active sensors emit energy into the environment and measures the environmental reaction to the emitted energy
- Examples of active sensors include ultrasonic sensors, laser rangefinders
- An advantage of active sensing is that we can control our interaction with the environment
- A disadvantage of it is that it may suffer from interference (e.g. signal from another robot)

Sensor Classification

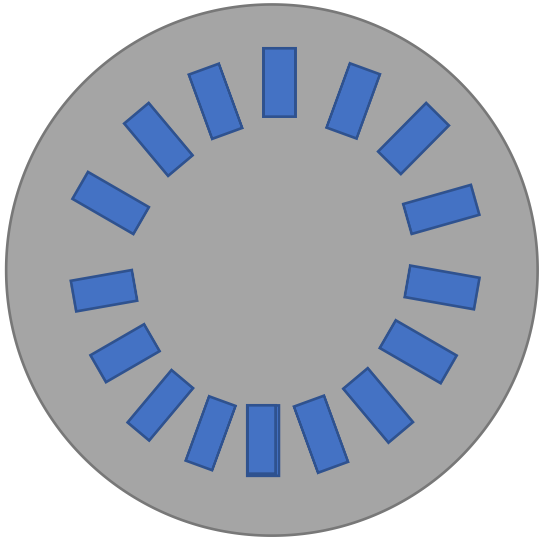
Sensor Category	Sensor		Proprioceptive /Exteroceptive	Passive/Active
Tactile Sensors	Contact Switch		EC	Passive
Wheel/Motor Sensors	Optical/Magnetic Encoders Potentiometers		PC PC	A P
Heading Sensors	Compass Inclinometers		EC EC	P P
Active Ranging	Ultrasonic & Laser rangefinders		EC EC	A A
Vision-based sensors	Cameras		EC	P

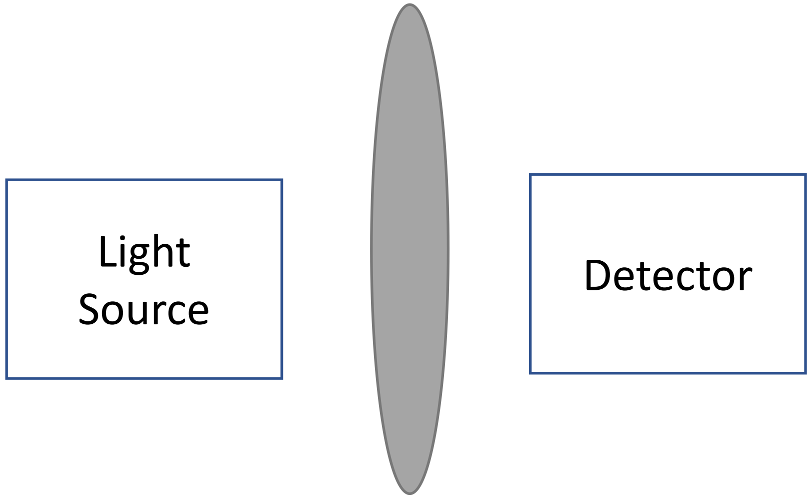
Autonomous Mobile Robots

Module 11: Different Sensors – Wheel/Motor Sensors

Wheel/Motor Sensors

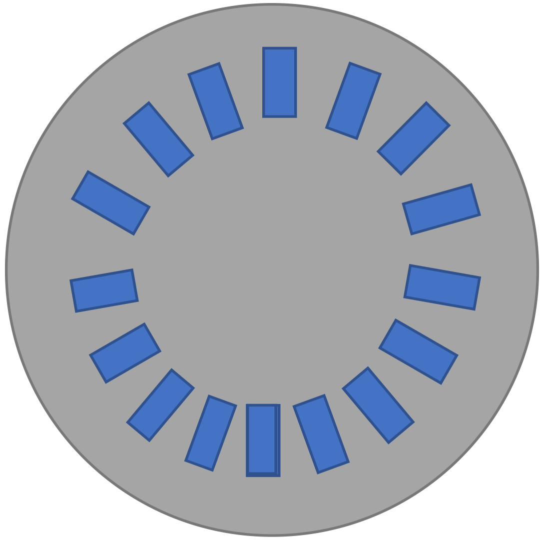
- Optical encoders are popular sensors to measure angular position of the wheel and its angular speed
- Components of an encoder system includes an Illumination source, grating on a disk, detectors
- N slots in 360°
- Angular spacing between slots is 360/N

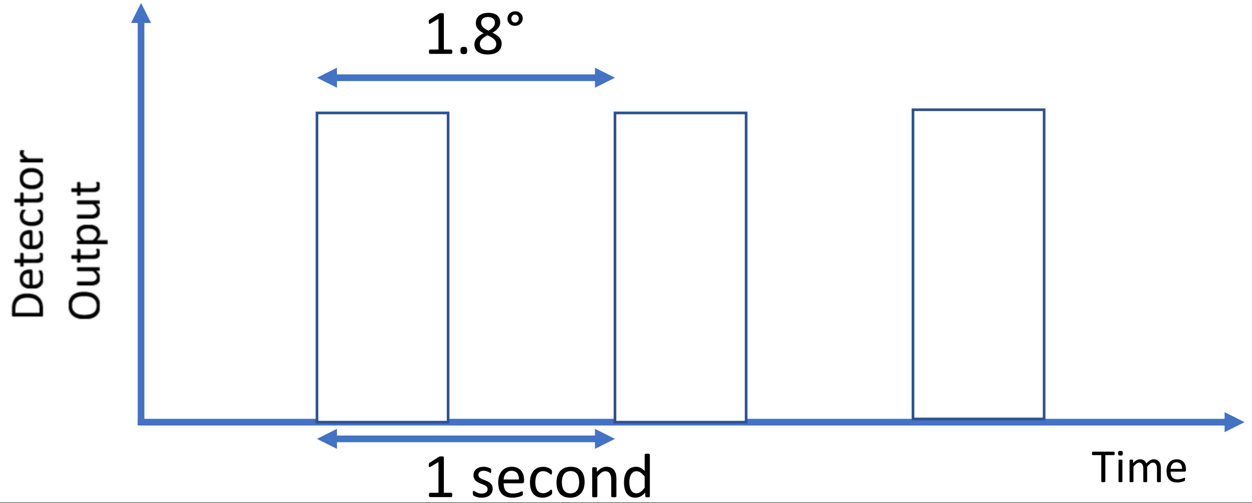




Wheel/Motor Sensors

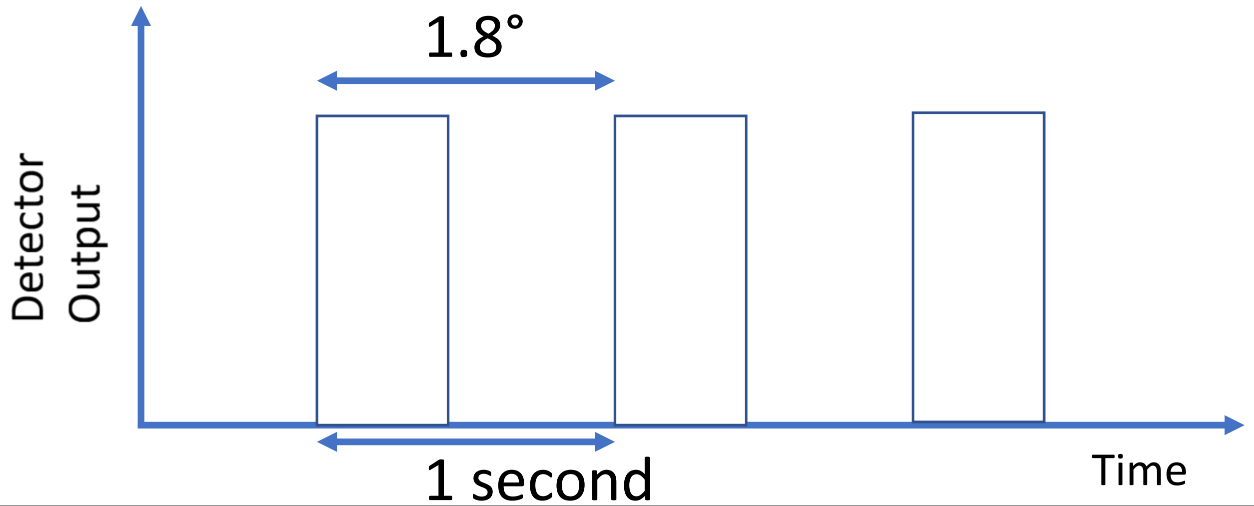
- If there are 20 slots on the disk, angular spacing is 18°
- This means that the encoder can at best detect motion with a resolution of 18°
- If there are 200 slots on the disk, angular spacing and resolution improves to 1.8°
- The output of the detector is in the form of a pulse wave where every time the slot appears between the light source and the detector, a pulse is output



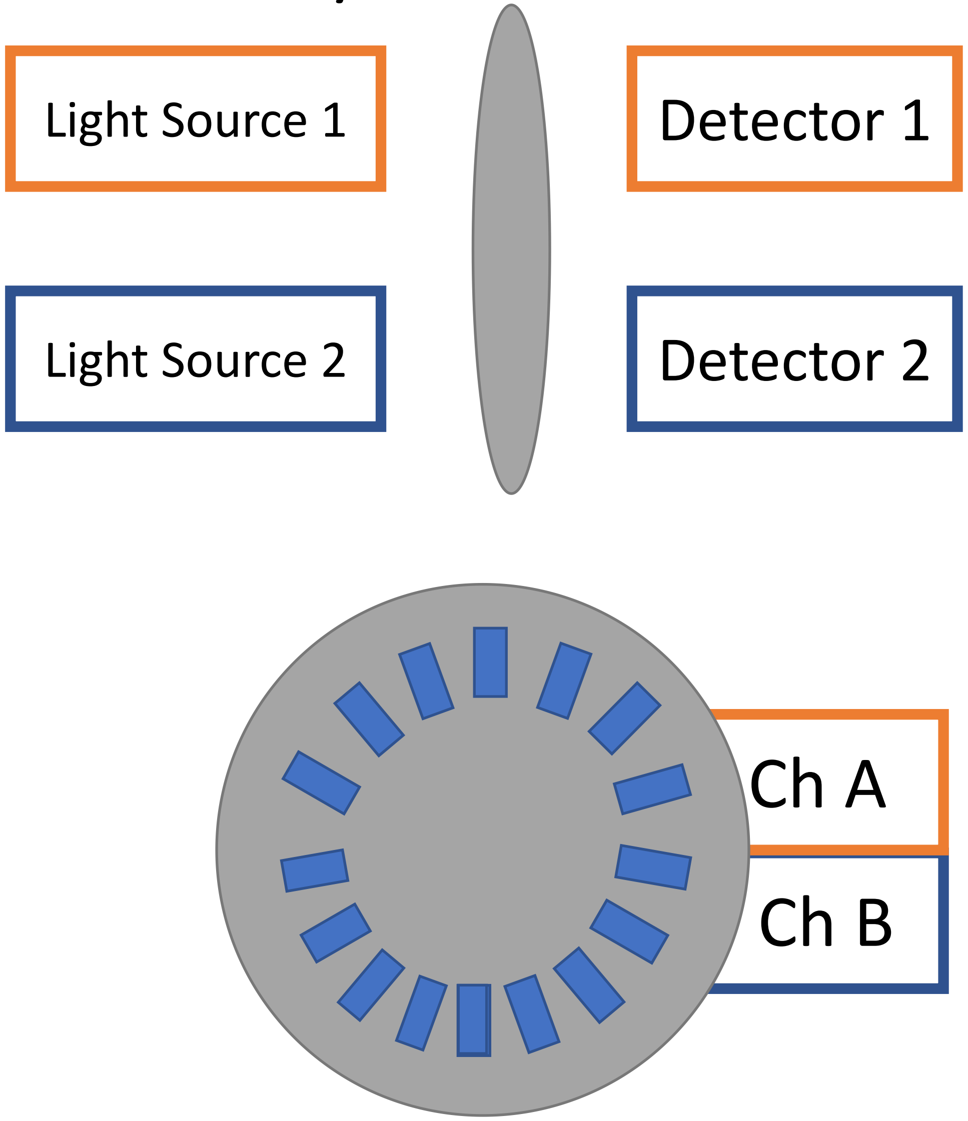


Wheel/Motor Sensors

- Counting the number of rising edges provides an indication of the total angle rotated by the wheel
- *Total angle rotated = Angular resolution * no. of rising edges*
- Angular speed can be determined by dividing angle by time
- Such an encoder cannot indicate the direction of rotation, however
- To determine direction of rotation, we need one more pair of illumination source and detector and this is called as a quadrature encoder



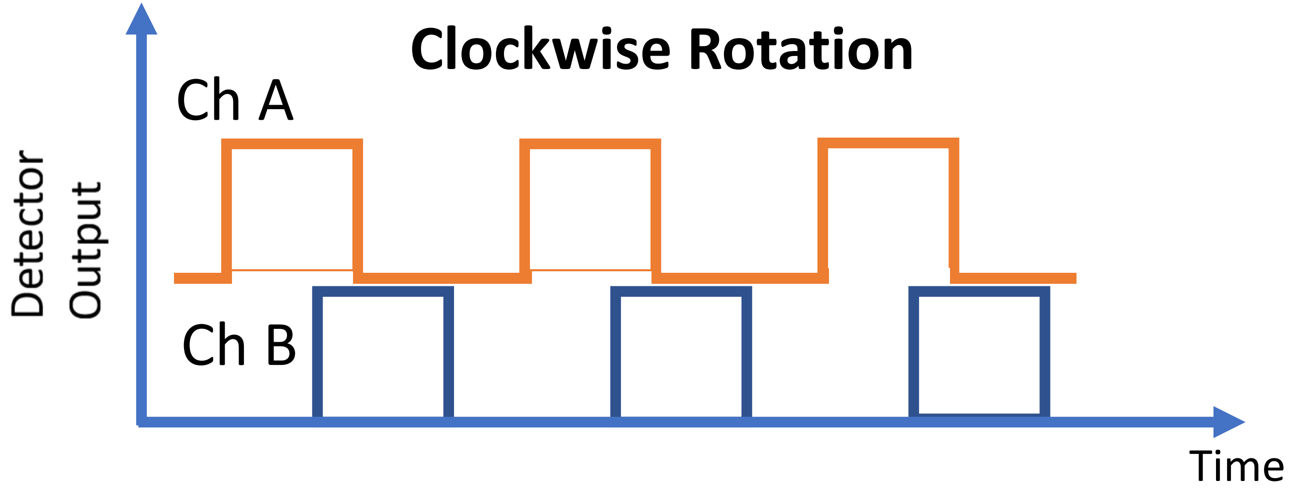
Wheel/Motor Sensors



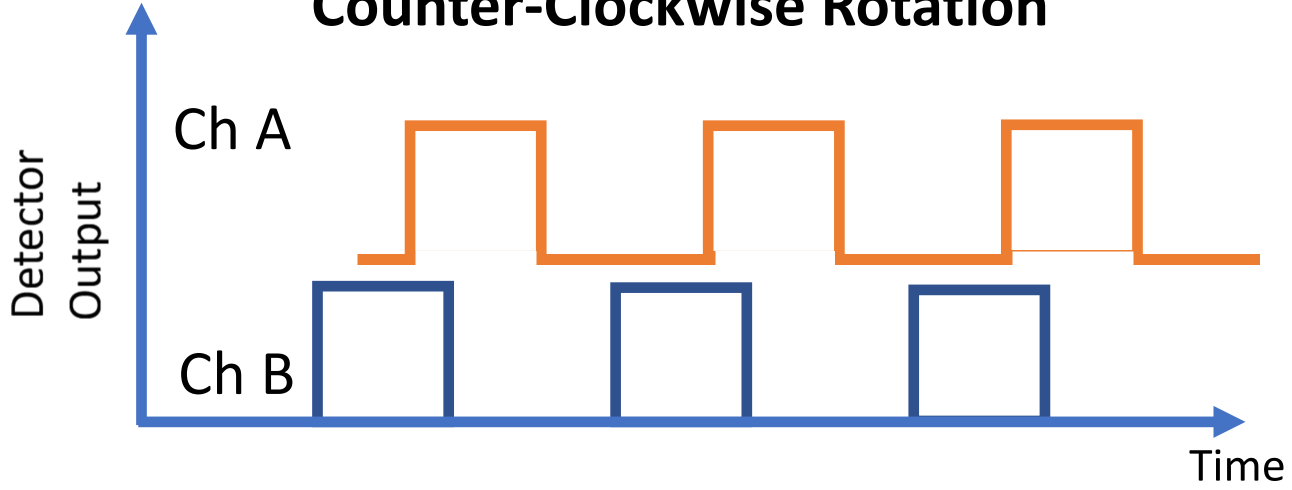
- Two sets of illumination sources and detectors are made use of
- The sources and detectors are placed at an offset with respect to each other
- Depending on the position of the grating, light may fall on one detector and not on the other
- As the wheel rotates, this pattern will change

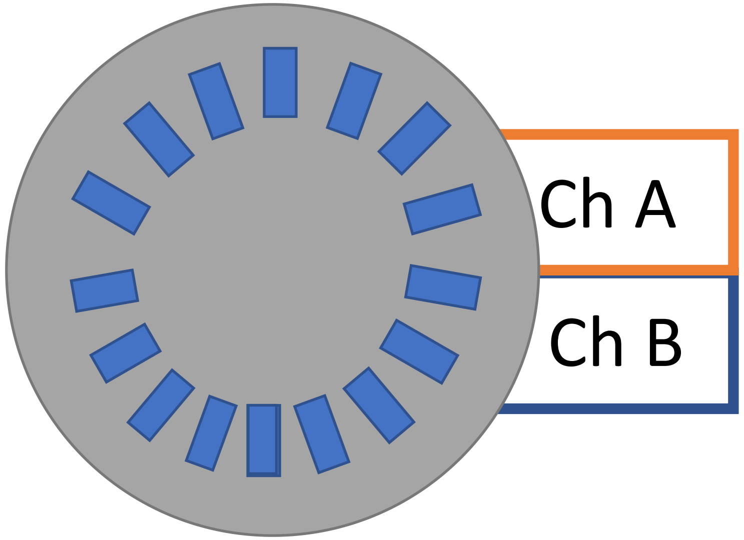
Wheel/Motor Sensors

Clockwise Rotation



Counter-Clockwise Rotation





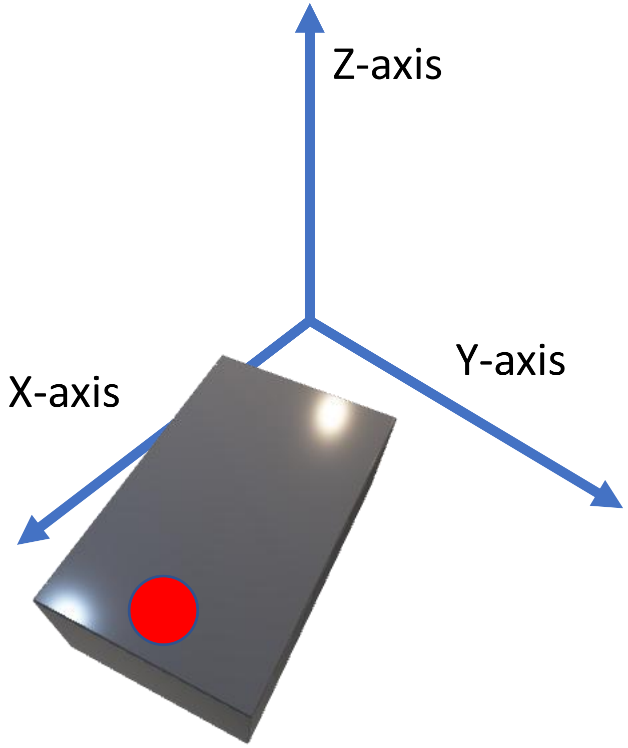
The direction of rotation is inferred from the relative phases of the two signals

Autonomous Mobile Robots

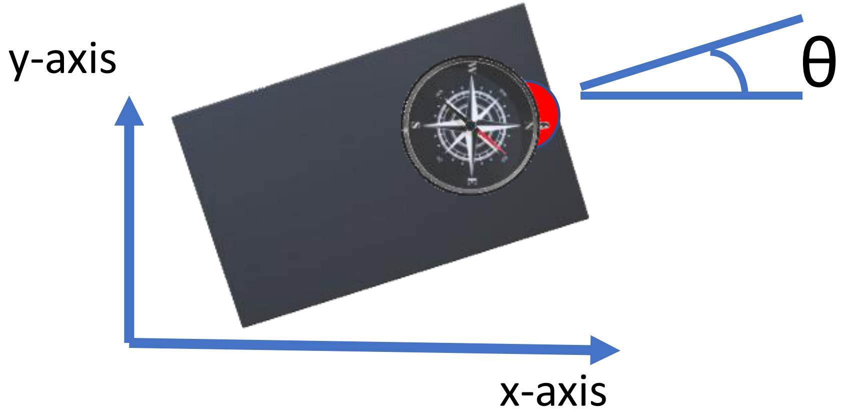
Module 12: Heading Sensors

Heading Sensors

- Heading sensors are used to determine the robot's orientation (in which direction is the robot heading) and inclination
- This can be treated as a proprioceptive or exteroceptive sensor
- Heading sensors can be of two types: Compasses and Gyroscopes
- Robot can have rotation about x-axis, y-axis or z-axis



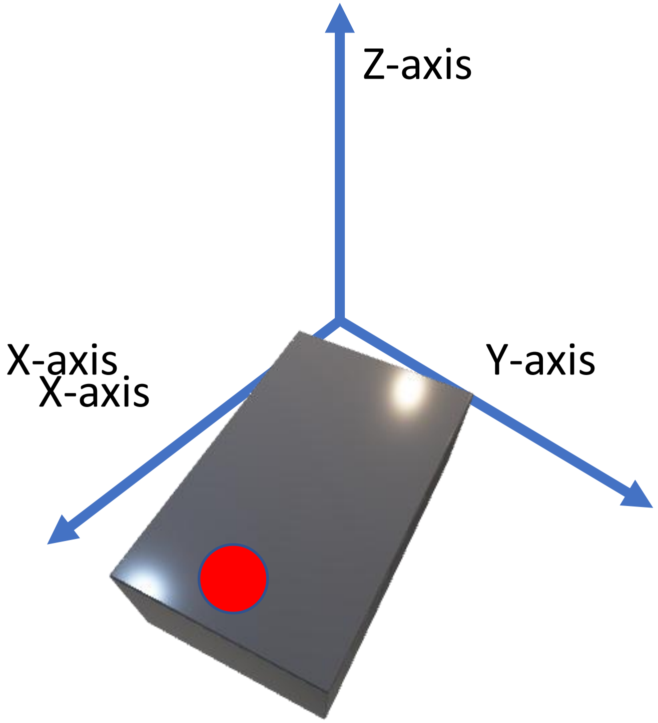
Top-view: rotation about z-axis



Side-view: rotation about x-axis

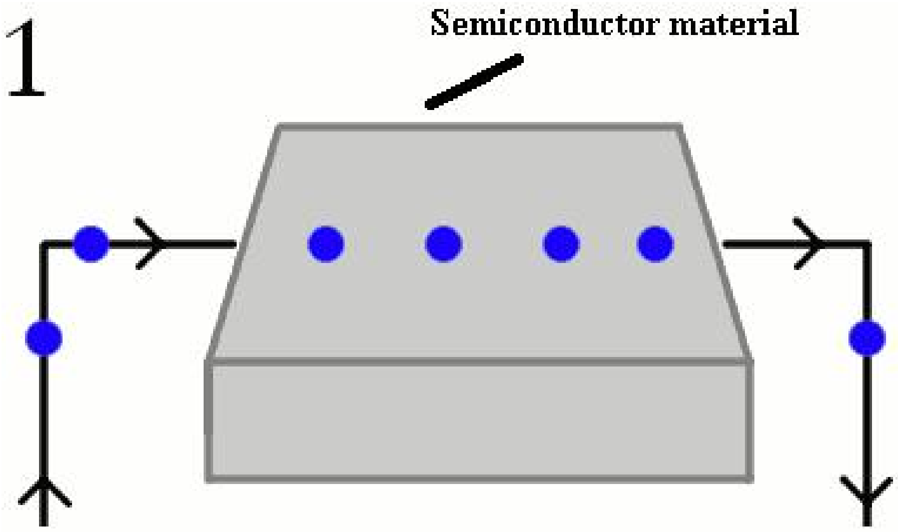
Heading Sensors - Compass

- A compass measures the direction of the magnetic field and uses this measurement to determine the orientation of the robot
- Two common sensors for measuring direction of magnetic field are
  - Hall-effect compasses
  - Flux-gate compasses

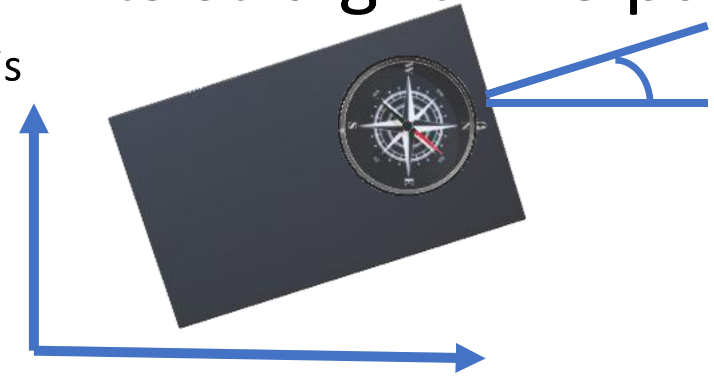


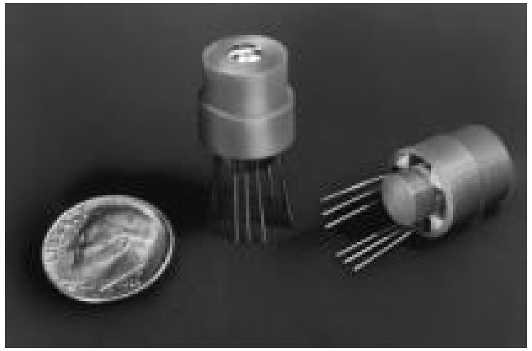
Heading Sensors – Compass – Hall Effect

- Hall effect describes the behavior of electric potential in a semiconductor when it is placed in a magnetic field
- When a beam of charge particles passes through a magnetic field, forces act on the particles and the current beam is deflected from its straight-line path.



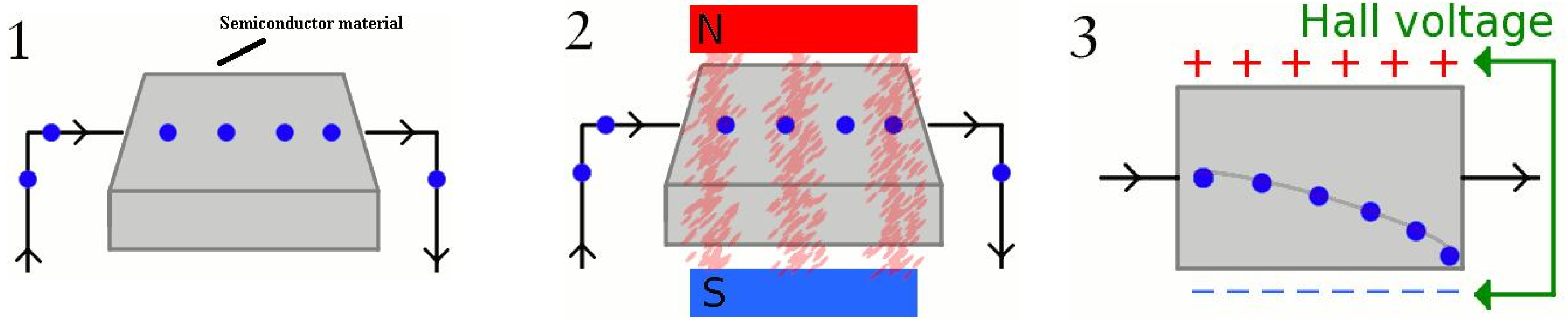
https://www.explainthatstuff.com/hall-effect-sensors.html





Reproduced from: Siegwart, Roland, Illah Reza Nourbakhsh, and Davide Scaramuzza. Introduction to autonomous mobile robots. MIT press, 2011.

Heading Sensors – Compass – Hall Effect

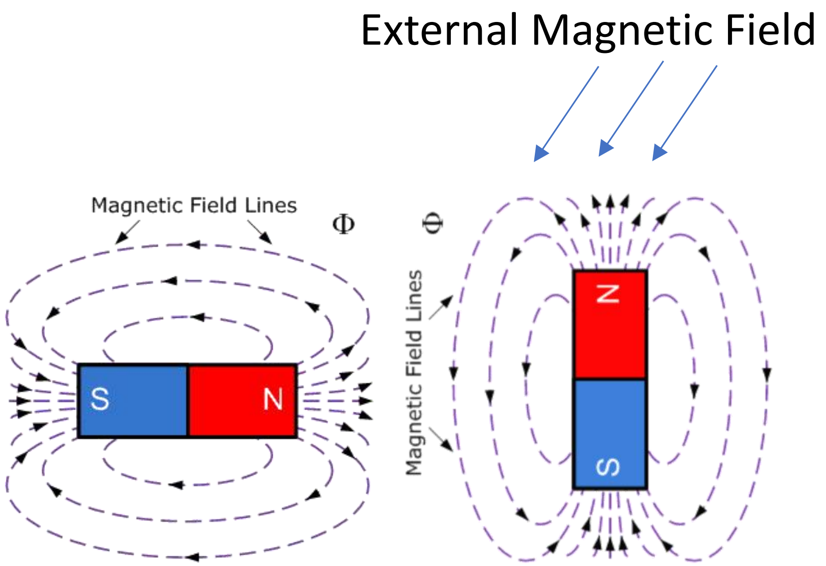


- Thus one side of the material will become negatively charged and the other side will be of positive charge. This charge separation generates a potential difference.
- The voltage potential depends on the relative orientation of the semiconductor to magnetic flux lines
- Sensor is compact, light
- Resolution can be poor, filtering may be necessary

https://www.explainthatstuff.com/hall-effect-sensors.html

Heading Sensors – Fluxgate Compass

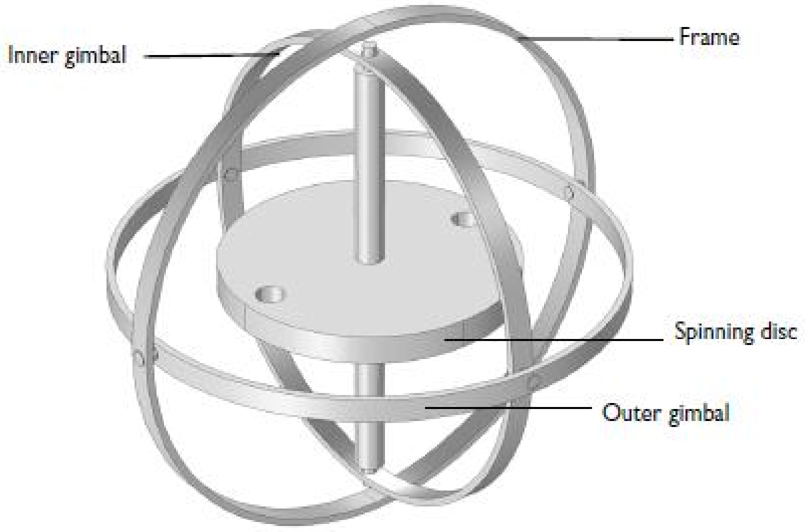
- Two small coils are wound on ferrite cores and fixed perpendicular to each other
- When AC current is passed through both coils, external magnetic field causes shifts in the phase depending on the relative alignment with each coil
- By measuring both phase shifts, direction of the magnetic field in two dimensions can be computed
- FGC has improved accuracy and resolution compared to Hall Effect compass
- FGC is larger and more expensive, however



https://www.electronics-tutorials.ws/electromagnetism/magnetism.html

Heading Sensors - Gyroscopes

- Gyroscopes are heading sensors that preserve their orientation in relation to a fixed reference frame
- It provides an absolute measure for heading of a mobile robot
- It consists of a fast-spinning rotor, which will try to maintain its orientation to conserve angular momentum
- The spinning axis of gyroscope is to be selected based on the desired axis of orientation
- By arranging the spinning wheel along desired axis of rotation, no torque will be transmitted from the outer pivot to wheel axis
- Using the relative displacement between the fixed wheel axis and rotating outer pivot, the orientation angle of the robot can be determined.



https://www.comsol.com/blogs/modeling-the-dynamics-of-a-gyroscope/

Thanks!