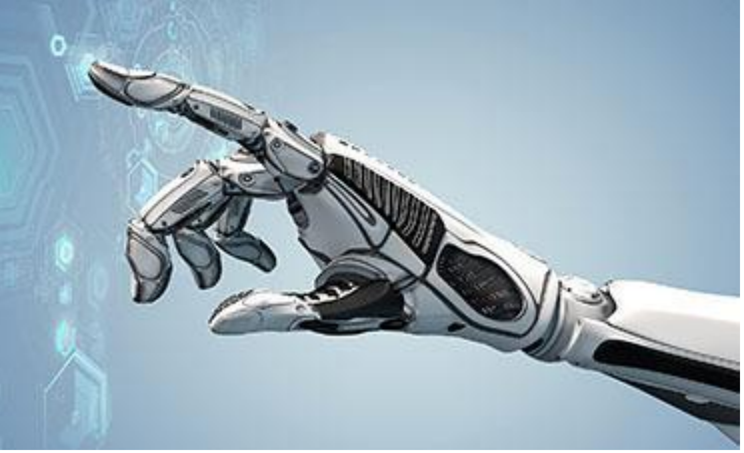
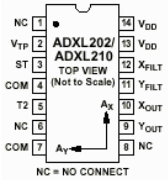
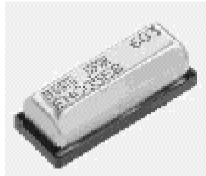


CSE444: Introduction to Robotics
Lesson 2a,3a: Working and Sensors

Summer 2019



Accelerometer

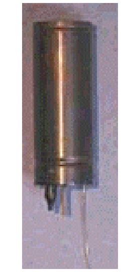

Gyro


Pendulum Resistive Tilt Sensors

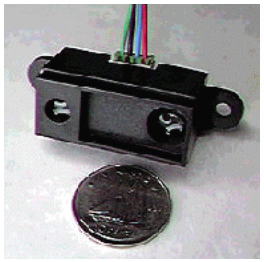

Piezo Bend Sensor


Metal Detector

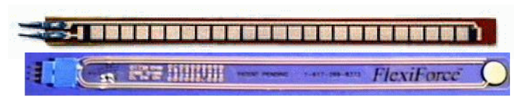
Gas Sensor


Gieger-Muller Radiation Sensor

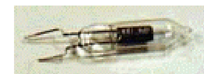

Pyroelectric Detector

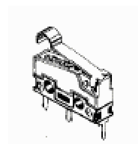

Digital Infrared Ranging


CDS Cell Resistive Light Sensor



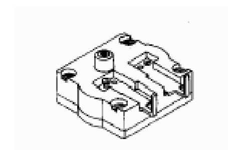
Resistive Bend Sensors

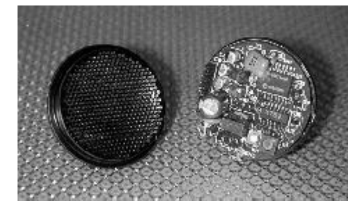

UV Detector

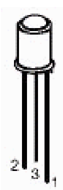

Limit Switch

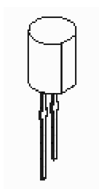

Mechanical Tilt Sensors

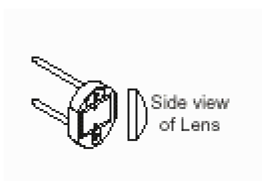

Touch Switch


Pressure Switch

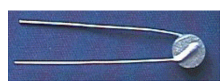

Miniature Polaroid Sensor

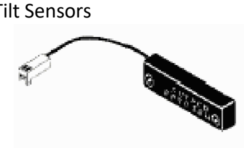


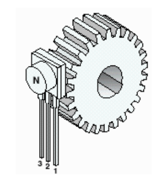

IR Pin Diode



IR Sensor w/lens


Thyristor

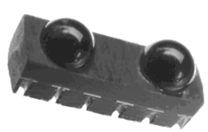

Magnetic Sensor


Hall Effect Magnetic Field Sensors

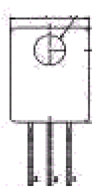

Polaroid Sensor Board

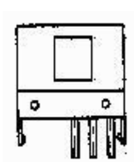

IR Reflection Sensor


IR Amplifier Sensor


IRDA Transceiver

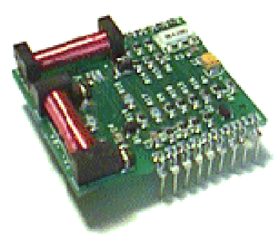

Magnetic Reed Switch

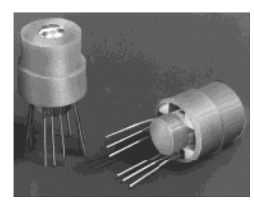

Lite-On IR Remote Receiver

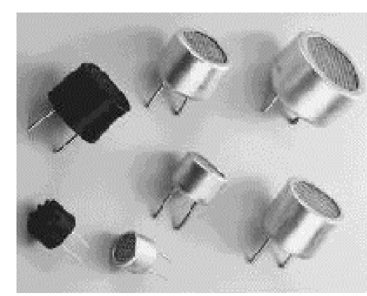

Radio Shack Remote Receiver


IR Modulator Receiver


Solar Cell


Compass


Compass


Piezo Ultrasonic Transducers

Overview

- What are Sensors?
- Detectable Phenomenon
- Physical Principles – How Do Sensors Work?
- Need for Sensors
- Choosing a Sensor
- Sensor Descriptions
  - Temperature Sensor
  - Accelerometer
  - Light Sensor
  - Magnetic Field Sensor
  - Ultrasonic Sensor
  - Photogate
  - CO_2 Gas Sensor

Sensors

Definition: a device for sensing a physical variable of a physical system or an environment

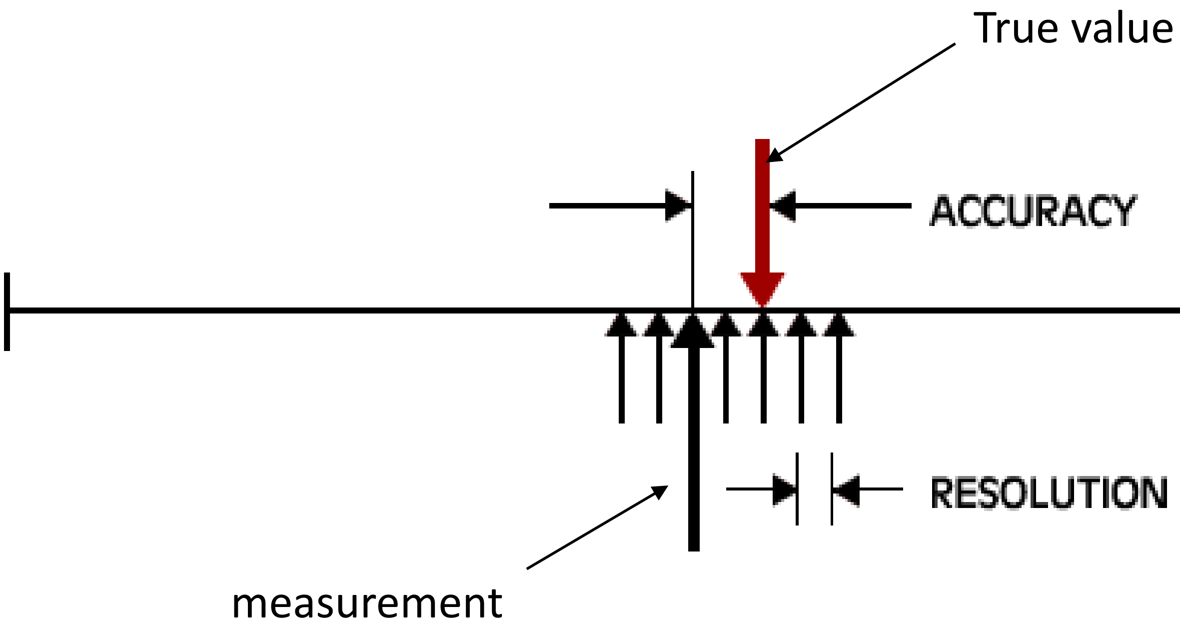
Classification of Sensors

- *Mechanical quantities*: displacement, Strain, rotation velocity, acceleration, pressure, force/torque, twisting, weight, flow
- Thermal quantities: temperature, heat.
- Electromagnetic/optical quantities: voltage, current, frequency phase; visual/images, light; magnetism.
- Chemical quantities: moisture, pH value

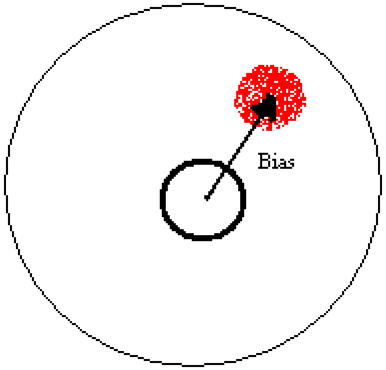
Specifications of Sensor

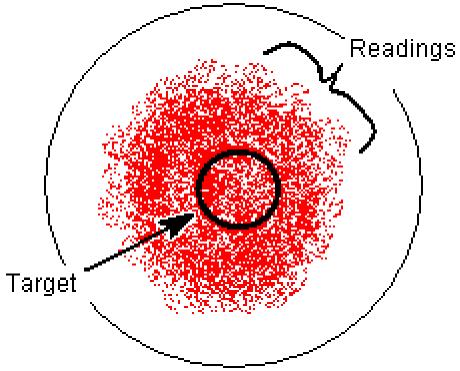
- **Accuracy:** error between the result of a measurement and the true value being measured.
- **Resolution:** the smallest increment of measure that a device can make.
- **Sensitivity**: the ratio between the change in the output signal to a small change in input physical signal. Slope of the input-output fit line.
- **Repeatability/Precision**: the ability of the sensor to output the same value for the same input over a number of trials

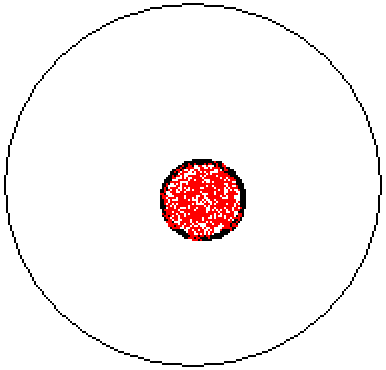
Accuracy vs. Resolution



Accuracy vs. Precision







Precision without accuracy

Accuracy without precision

Precision and accuracy

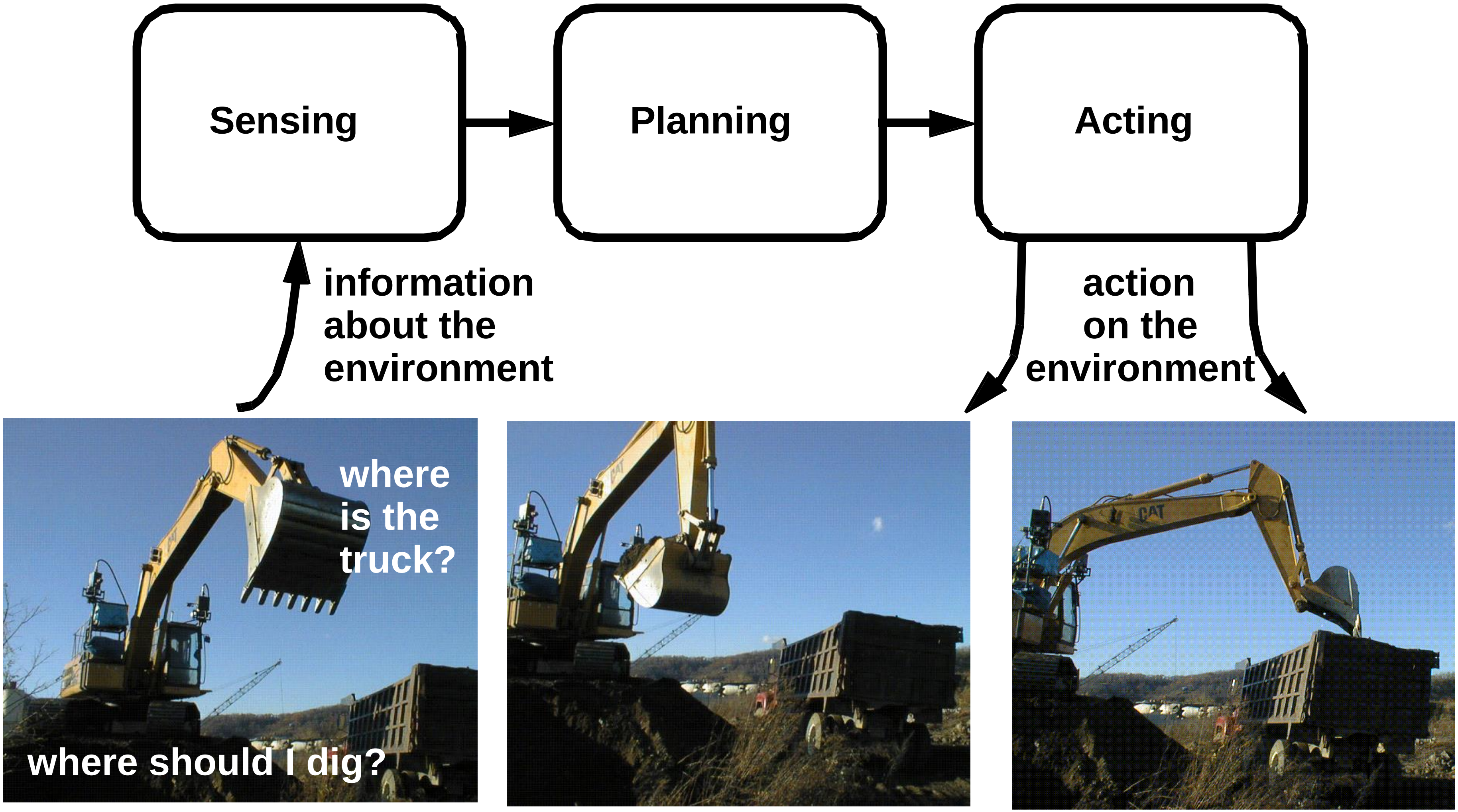
Specifications of Sensor

- **Dynamic Range**: the ratio of maximum recordable input amplitude to minimum input amplitude, i.e. D.R. = 20 log (Max. Input Ampl./Min. Input Ampl.) dB
- **Linearity**: the deviation of the output from a best-fit straight line for a given range of the sensor
- **Transfer Function** (Frequency Response): The relationship between physical input signal and electrical output signal, which may constitute a complete description of the sensor characteristics.
- **Bandwidth**: the frequency range between the lower and upper cutoff frequencies, within which the sensor transfer function is constant gain or linear.
- **Noise**: random fluctuation in the value of input that causes random fluctuation in the output value

Attributes of Sensors

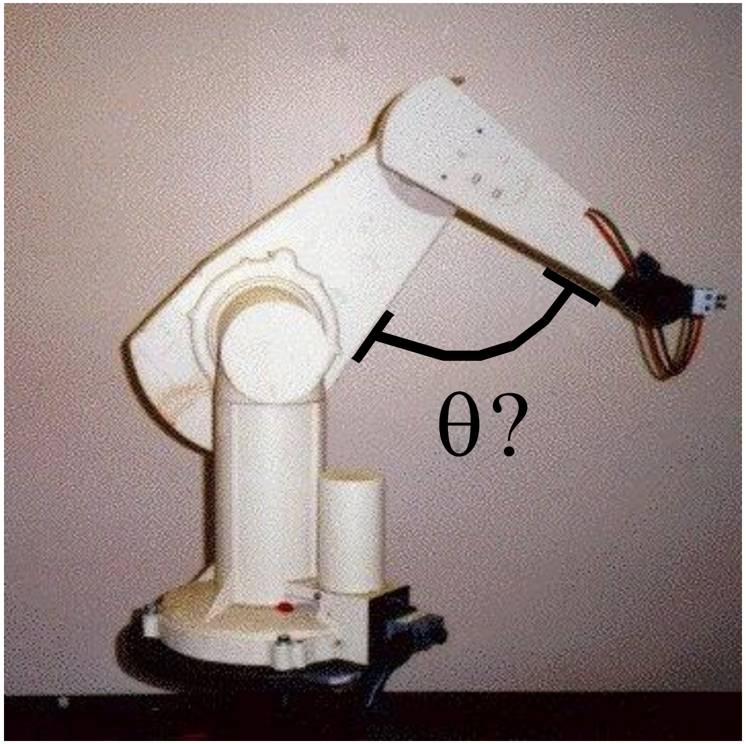
- **Operating Principle**: Embedded technologies that make sensors function, such as electro-optics, electromagnetic, piezoelectricity, active and passive ultraviolet.
- **Dimension of Variables**: The number of dimensions of physical variables.
- **Size**: The physical volume of sensors.
- **Data Format**: The measuring feature of data in time; continuous or discrete/analog or digital.
- **Intelligence**: Capabilities of on-board data processing and decision-making.
- **Active versus Passive Sensors**: Capability of generating vs. just receiving signals.
- **Physical Contact**: The way sensors observe the disturbance in environment.
- **Environmental durability**: will the sensor robust enough for its operation conditions

What makes a machine a robot?



Why do robots need sensors?

What is the angle of my arm?



internal information

What is Sensing ?

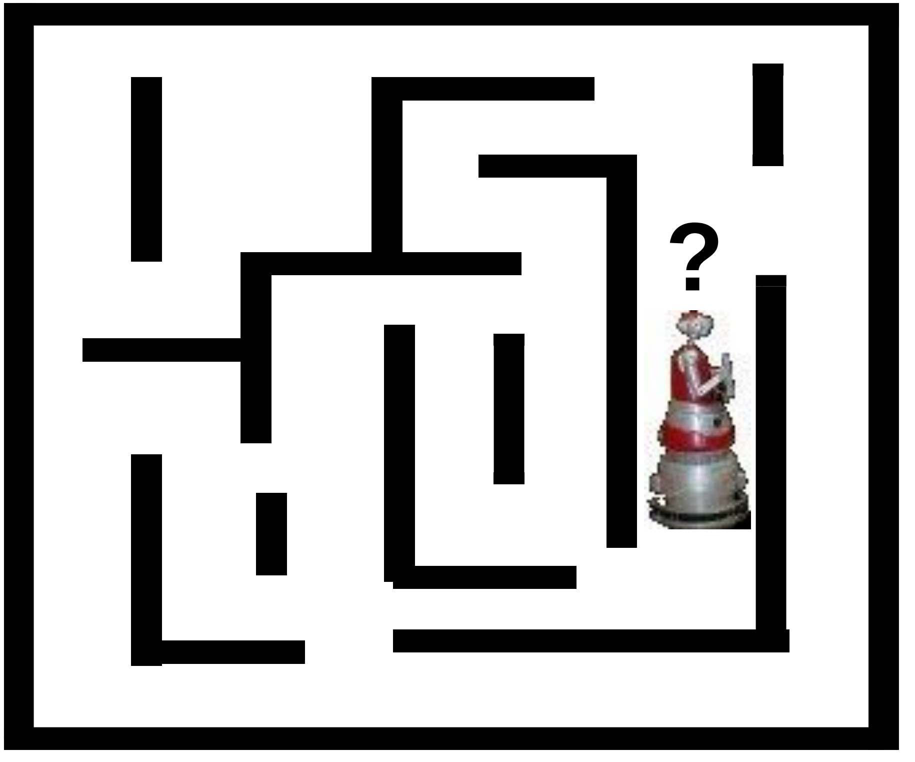
- Collect information about the world

- Sensor - an electrical/mechanical/chemical device that maps an environmental attribute to a quantitative measurement
  - attribute mixtures - often no one to one map
  - hidden state in environment

- Each sensor is based on a *transduction principle* - conversion of energy from one form to another
- Also known as transducers

Why do robots need sensors?

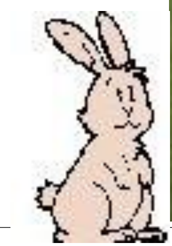
Where am I?



localization

Why do robots need sensors?

Will I hit anything?



obstacle detection

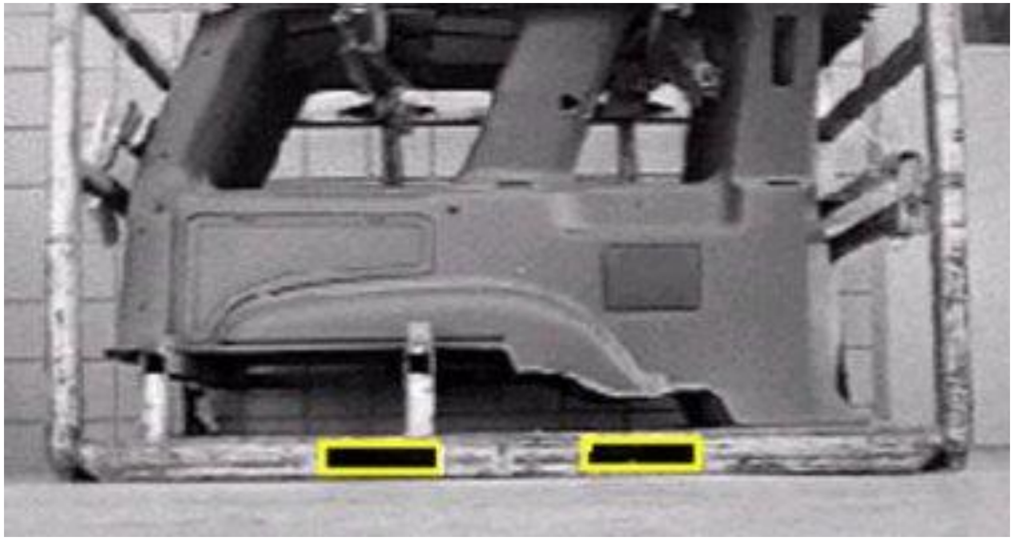
Sensing for specific tasks

Where is the cropline?

Autonomous harvesting

Sensing for specific tasks

Where are the forkholes?



Autonomous material handling

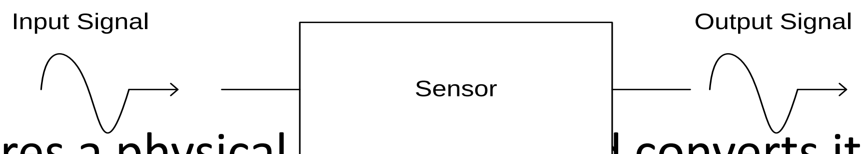
Sensing for specific tasks

Where is the face?

Face detection & tracking

What are Sensors?

- American National Standards Institute (ANSI) Definition
  - A device which provides a usable output in response to a specified measurand



- A sensor acquires a physical parameter and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical)

- A transducer
  - Microphone, Loud Speaker, Biological Senses (e.g. touch, sight,…ect)

Detectable Phenomenon

Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Physical Principles

- Amperes's Law
  - A current carrying conductor in a magnetic field experiences a force (e.g. galvanometer)
- Curie-Weiss Law
  - There is a transition temperature at which ferromagnetic materials exhibit paramagnetic behavior
- Faraday's Law of Induction
  - A coil resist a change in magnetic field by generating an opposing voltage/current (e.g. transformer)
- Photoconductive Effect
  - When light strikes certain semiconductor materials, the resistance of the material decreases (e.g. photoresistor)

Need for Sensors

- Sensors are omnipresent. They embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications.

- Without the use of sensors, there would be no automation !!
  - Imagine having to manually fill Poland Spring bottles

Choosing a Sensor

Environmental Factors	Economic Factors	Sensor Characteristics
Temperature range	Cost	Sensitivity
Humidity effects	Availability	Range
Corrosion	Lifetime	Stability
Size		Repeatability
Overrange protection		Linearity
Susceptibility to EM interferences		Error
Ruggedness		Response time
Power consumption		Frequency response
Self-test capability		

Types of Sensors

- Active
  - send signal into environment and measure interaction of signal w/ environment
  - e.g. radar, sonar
- Passive
  - record signals already present in environment
  - e.g. video cameras

Types of Sensors

- Classification by medium used
  - based on electromagnetic radiation of various wavelengths
  - vibrations in a medium
  - concentration of chemicals in environment
  - by physical contact

Types of Sensors

- Exteroceptive: deal w/ external world
  - where is something ?
  - how does is look ? (camera, laser rangefinder)
- Proprioceptive: deal w/ self
  - where are my hands ? (encoders, stretch receptors)
  - am I balanced ? (gyroscopes, INS)

Types of Sensors

- Interoceptive
  - what is my thirst level ? (biochemical)
  - what is my battery charge ? (voltmeter)

- For the most part we’ll ignore these in this class

Simple Practical Sensors that we can purchase

- Touch sensors
- Tilt sensors

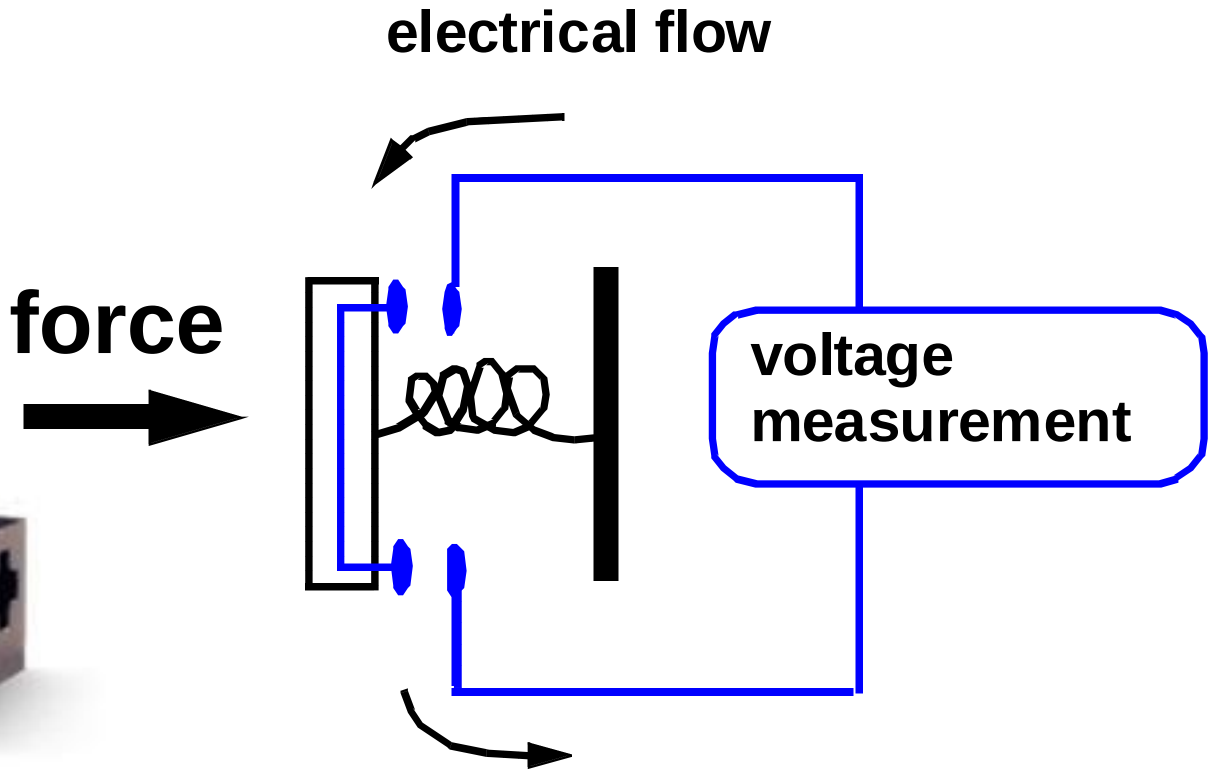
- Encoders

- Bend sensors
- Light sensors
- Temperature sensors
- Potentiometers

- Laser rangefinders
- Cameras

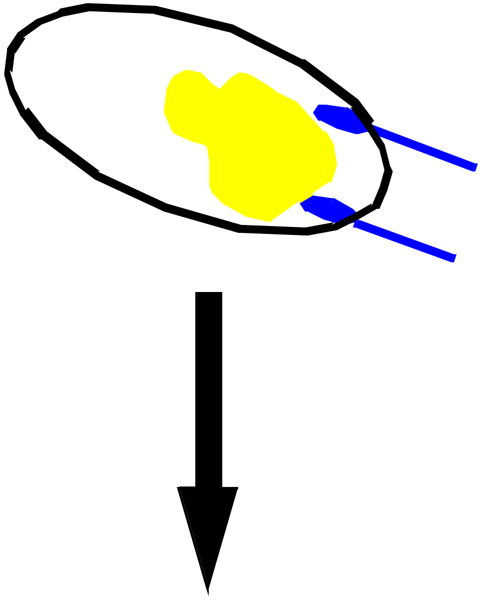
Touch sensors

a simple switch



Tilt sensors

another simple switch

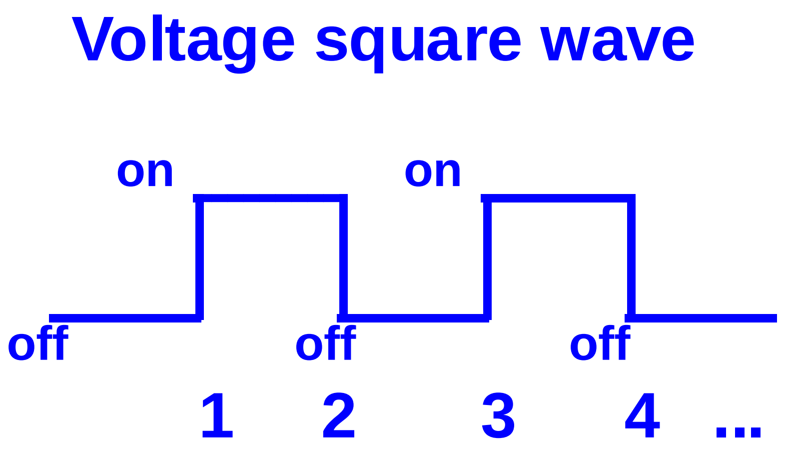


gravity

Encoders

- Encoders measure rotational motion.
- They can be used to measure the rotation of a wheel.
- **Servo motors:** Used in conjunction with an electric motor to measure the motor's position and, in turn, control its position.

Encoders

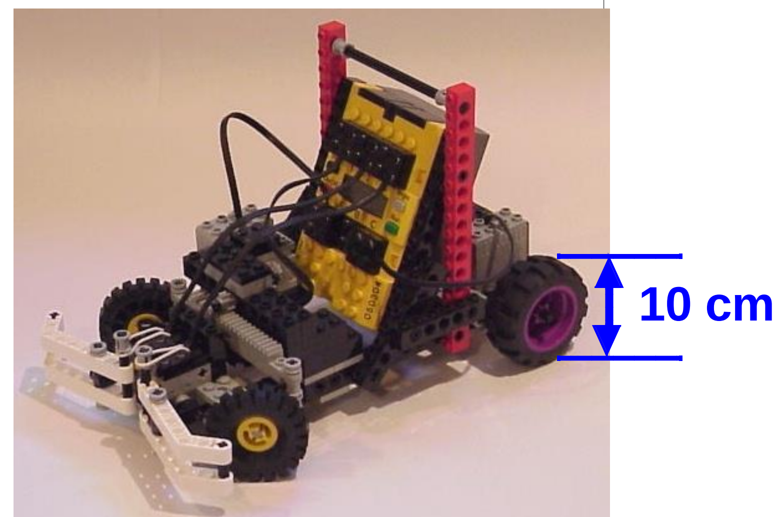


Important spec:
Number of counts per revolution

Sample problems

Sensor Analysis

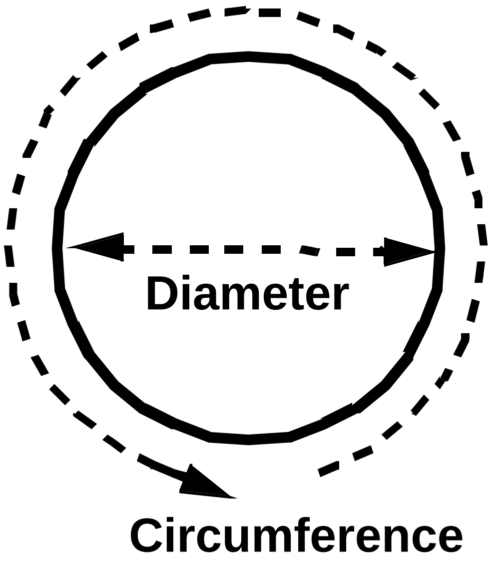
16 counts per rev.



10 cm wheel diameter

- How far does the wheel travel for 1 encoder count?
- What happens if we change the wheel diameter?
- How many counts are there per meter of travel?

Sample problems



$$C = \pi D$$

$$C = 10\pi \text{ cm}$$

$$\frac{10\pi \text{ cm}}{1 \text{ rev}} \times \frac{1 \text{ rev}}{16 \text{ counts}} = \frac{1.96 \text{ cm}}{\text{count}}$$

Sample problems

Suppose I want 1.0 cm / count.

What should my wheel diameter be?

$$\frac{1.0\ \text{cm}}{\text{count}} \times \frac{16\ \text{counts}}{1\ \text{rev}} = \frac{16\ \text{cm}}{\text{rev}}$$

$$C = 16\ \text{cm}$$

$$D = \frac{C}{\pi} = \frac{16}{\pi} = 5.09\ \text{cm}$$

Sample problems

For my 10 cm wheel, how many encoder counts will there be for 1 meter of travel?

$$\frac{1.96\ \text{cm}}{\text{count}} \times \frac{1\ \text{meter}}{100\ \text{cm}} = \frac{0.0196\ \text{m}}{\text{count}}$$

$$\frac{1}{0.0196\ \text{m/ct}} = 51\ \text{counts/m}$$

Physics 101

Ohm's Law

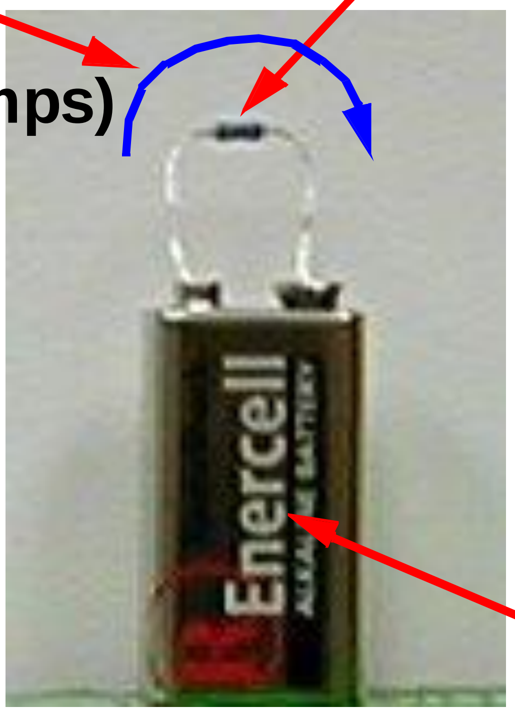
V = I x R

voltage current resistance

9 = 0.009 x 1000

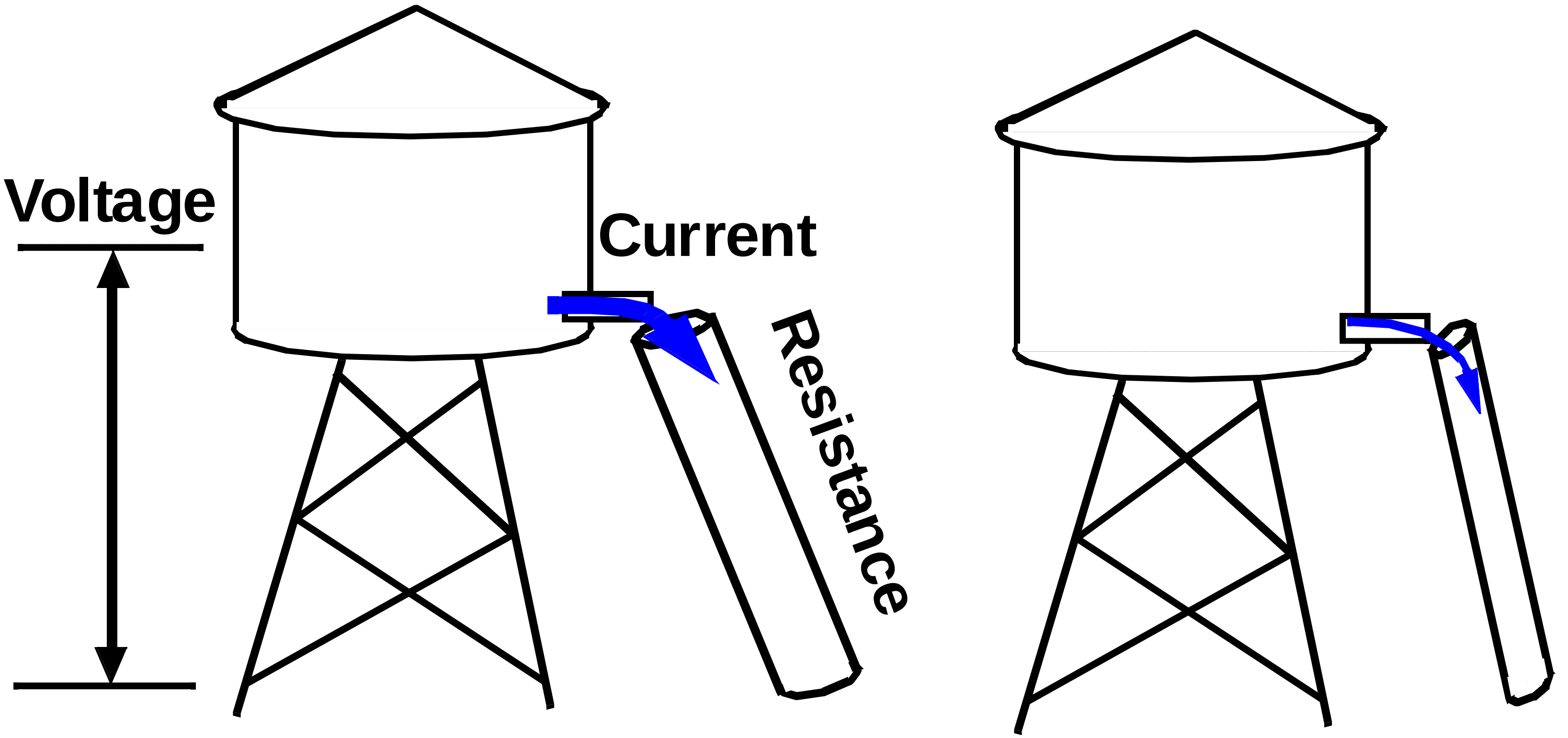
I
(0.009 Amps)

R (1000 Ohms)



V
(9 Volts)

Electrical analogy

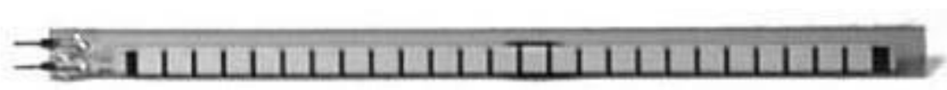


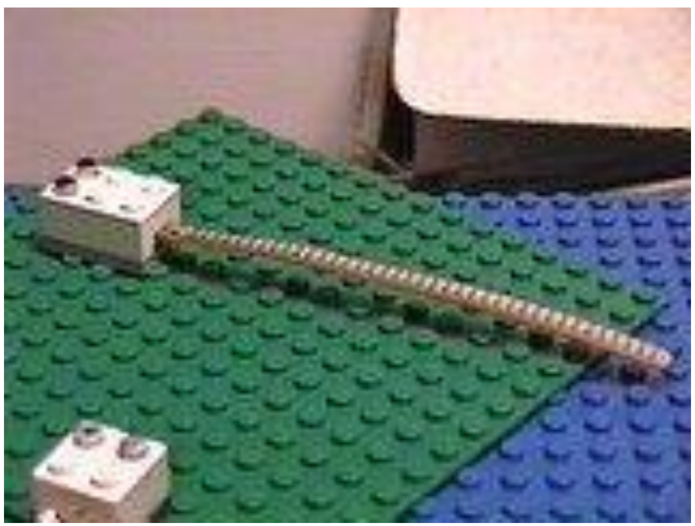
a larger pipe is less resistance so more water

a smaller pipe is more resistance so less water

Bend sensor

a variable resistor





resistance changes as it bends

$$V = I \times R$$

assuming constant current, the measured voltage changes with resistance

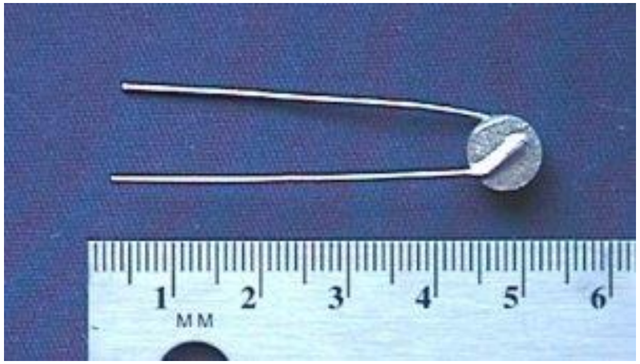
Light sensor

photo-resistor

resistance changes with light intensity

Temperature sensor

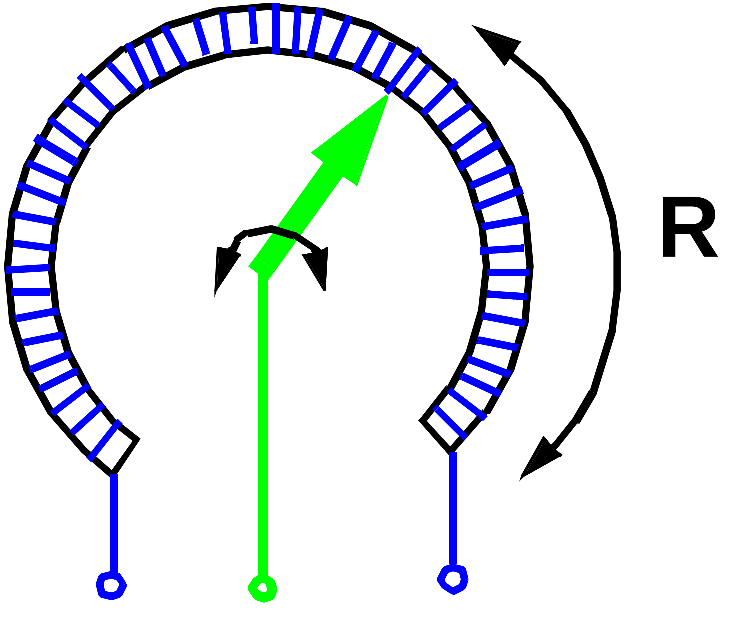
thermal resistor
"thermistor"



resistance changes with temperature

Potentiometer

another rotational sensor



resistance changes with position of dial

Sample problem

Bend sensor specs:

100 Ω when straight
1000 Ω when bent

$$V = I \times R$$

$$I = \frac{V}{R}$$

Given a 5 V source, what is the min. and max. current that is drawn?

$$\text{min} = \frac{5}{1000} = 5\ \text{mA}$$

$$\text{max} = \frac{5}{100} = 50\ \text{mA}$$

Sensors Based on EM Spectrum

- Basically used for ranging
- Light sensitive
  - eyes, cameras, photocells etc.
- Operating principle
  - CCD - charge coupled devices
  - photoelectric effect
- IR sensitive - FLIR
  - sense heat differences and construct images
  - night vision application

EM Spectrum

- Radio and Microwave
  - RADAR: **Ra**dio **D**etection **a**nd **R**anging
  - Microwave radar: insensitive to clouds
- Coherent light
  - all photons have same phase and wavelength
  - LASER: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
  - LASER RADAR: LADAR - accurate ranging

The SICK Laser Rangefinder

EM Spectrum

- Nuclear Magnetic Resonance (NMR)
  - heavy duty magnetic field lines up lines up atoms in a body
  - now expose body to radio signals
  - different nuclei resonate at different frequencies which can be measured leading to an image

Local Proximity Sensing in EM

- Infrared LEDs
  - cheap, active sensing
  - usually low resolution - normally used for presence/absence of obstacles rather than ranging
  - operate over small range

Sensors Based on Sound

- SONAR: **So**und **N**avigation **a**nd **R**anging
  - bounce sound off of something
  - measure time for reflection to be heard - gives a range measurement
  - measure change in frequency - gives the relative speed of the object (Doppler effect)
  - bats and dolphins use it with amazing results
  - robots use it w/ less than amazing results

Sonar and IR Proxmity

Odor Sensors

- Detection of chemical compounds and their density in an area
  - spectroscopy - mostly lab restricted
  - fibre-optic techniques - recently developed
  - chemical detection - sniffers aand electronic noses via “wet chemistry on a chip”

- No major penetration in robotics yet applications are vast (e.g. mine detection)

Touch Sensors

- Whiskers, bumpers etc.
  - mechanical contact leads to
    - closing/opening of a switch
    - change in resistance of some element
    - change in capacitance of some element
    - change in spring tension
    - ...

Proprioceptive Sensors

- Encoders, Potentiometers
  - measure angle of turn via change in resistance or by counting optical pulses
- Gyroscopes
  - measure rate of change of angles
  - fiber-optic (newer, better), magnetic (older)
- Compass
  - measure which way is north
- GPS: measure location relative to globe

Propriceptive Sensors

Problem: Sensor Choice

- What sensors to employ ?
- E.g. mapping
  - ranging - laser, sonar, IR, stereo camera pair
  - salient feature detection - doors using color
- Factors
  - accuracy, cost, information needed etc etc.

Problem: Sensor Placement

- Where do you put them ?
- On/off board (e.g. localization using odometry vs. localization using beacons)
- If onboard - where ?
  - Reasonable arrangements - heuristic
  - Optimal arrangements - mathematically rigorous

Temperature Sensor

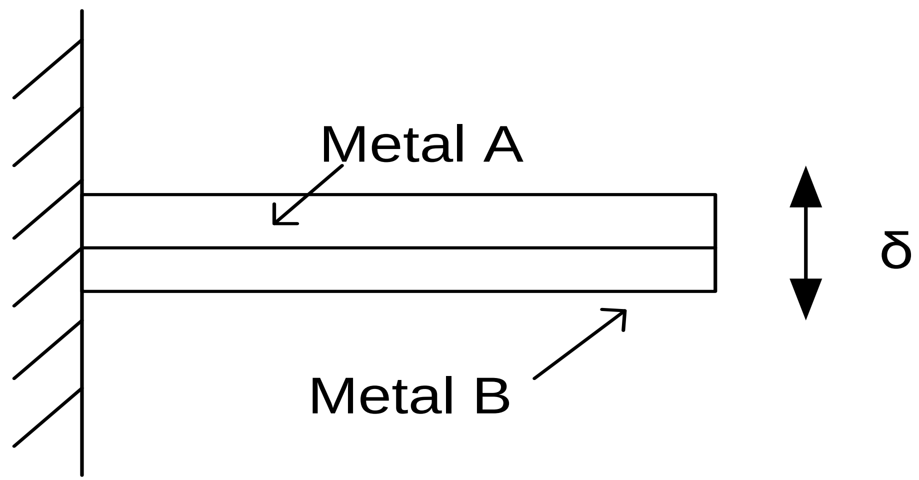
- Temperature sensors appear in building, chemical process plants, engines, appliances, computers, and many other devices that require temperature monitoring
- Many physical phenomena depend on temperature, so we can often measure temperature indirectly by measuring pressure, volume, electrical resistance, and strain

Temperature Sensor

- Bimetallic Strip

$$L = L_0[1 + \beta(T - T_0)]$$

- Application
  - Thermostat (makes or breaks electrical connection with deflection)



Temperature Sensor

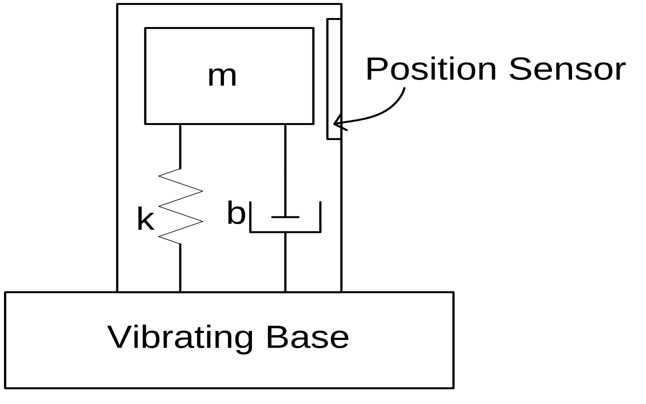
- Resistance temperature device.

$$R = R_0[1 + \alpha(T - T_0)]$$

$$R = R_0 e^{\gamma\left[\frac{1}{T} - \frac{1}{T_0}\right]}$$

Accelerometer

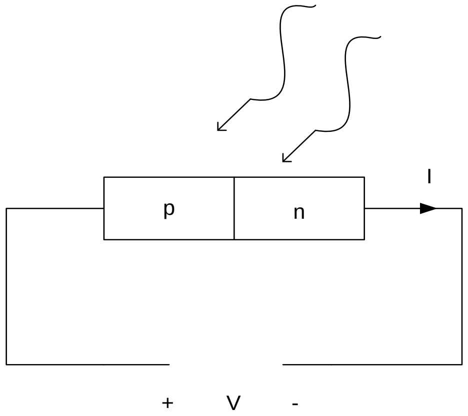
- Accelerometers are used to measure along one axis and is insensitive to orthogonal directions
- Applications
  - Vibrations, blasts, impacts, shock waves
  - Air bags, washing machines, heart monitors, car alarms
- Mathematical Description is beyond the scope of this presentation. See me during lunch if interested



Light Sensor

- Light sensors are used in cameras, infrared detectors, and ambient lighting applications

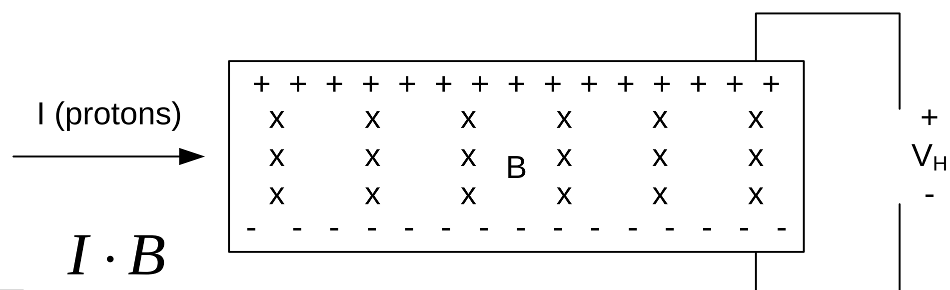
- Sensor is composed of photoconductor such as a photoresistor, photodiode, or phototransistor



Magnetic Field Sensor

- Magnetic Field sensors are used for power steering, security, and current measurements on transmission lines

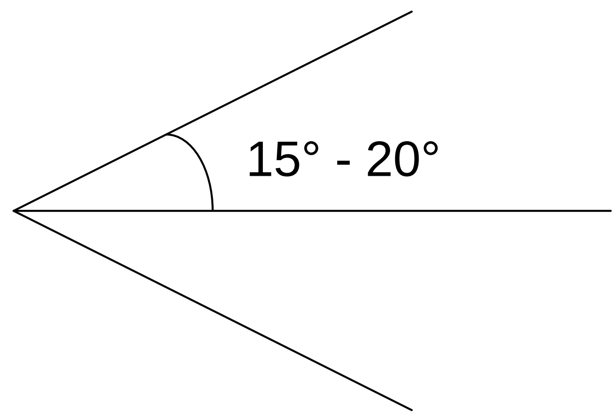
- Hall voltage is proportional to magnetic field



$$V_H = \frac{I \cdot B}{n \cdot q \cdot t}$$

Ultrasonic Sens

- Ultrasonic sensors are used for position measurements
- Sound waves emitted are in the range of 2-13 MHz
- **So**und **N**avigation **A**nd **R**anging (SONAR)
- **Ra**dio **D**ection **A**nd **R**anging (RADAR) – ELECTROMAGNETIC WAVES !!



Photogate

- Photogates are used in counting applications (e.g. finding period of period motion)
- Infrared transmitter and receiver at opposite ends of the sensor
- Time at which light is broken is recorded

CO_2 Gas Sensor

- CO_2 sensor measures gaseous CO_2 levels in an environment
- Measures CO_2 levels in the range of 0-5000 ppm
- Monitors how much infrared radiation is absorbed by CO_2 molecules