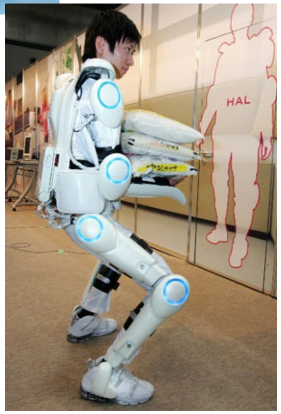
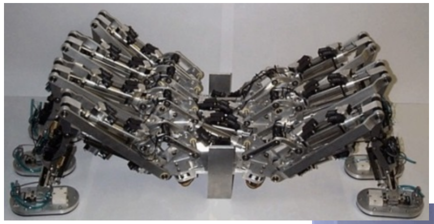
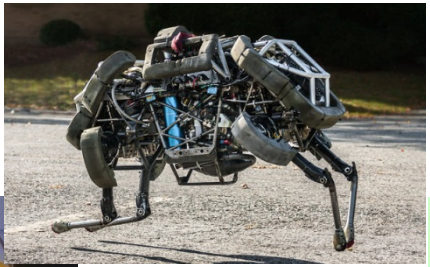
Sensors and actuators







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Introduction to sensors

- **“Getting the world into our programs”**
  - **World ⇒ Sensors ⇒ Decision making ⇒ Action**

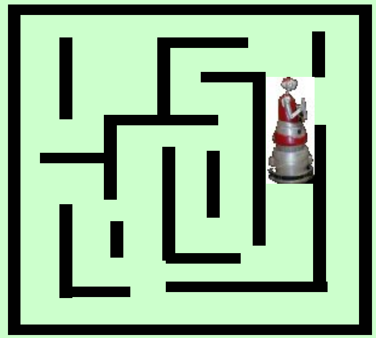
- **Basic stages are:**
  - **Sensors and transducers**
    - **Convert one physical phenomenon to another**
  - **Signal conditioning**
    - **Match sensor output to µP range of input**
  - **Intelligence**
    - **Software program that performs the planning, etc**
  - **Action**

Why do robots need sensors?

What is the angle of my arm?

Internal information

Where am I?



Localisation

Will I hit anything?

Obstacle detection

Where is the cropline?

Autonomous harvesting

Where is the face?

Face detection and tracking

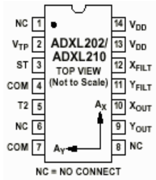
Choosing a sensor

The main factors to consider in choosing a sensor are:

- **Cost: sensors can be expensive, especially in bulk.**
- **Environment: there are many sensors that work well and predictably inside, but that fail outdoors.**
- **Range: Most sensors work best over a certain range of distances. If something comes too close, they bottom out, and if something is too far, they cannot detect it. Choose a sensor that will detect obstacles in the range you need.**
- **Field of View: depending upon what you are doing, you may want sensors that have a wider cone of detection. A wider "field of view" will cause more objects to be detected per sensor, but it also will give less information about where exactly an object is when one is detected**
- **Are sensors safety rated, eg. Comply to IEC 61496 (Safety of machinery – Electro sensitive protective equipment)**

Sensors list

- Contact: switches, whiskers
- Distance: infrared, radar, ultrasound, laser, lidar
- Light level: photocells, cameras
- Sound level: microphone
- Rotation: encoders and potentiometers
- Force: load cells
- Acceleration: gyroscopes, accelerometers
- Magnetism: compass
- Smell: chemical
- Temperature: thermal (thermistor, platinum), infra-red
- Inclination: Inclinometers, gyroscopes
- Pressure: pressure gauges
- Altitude: altimeters
- Strain: strain gauges
- etc.



Accelerometer

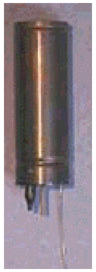

Gyro

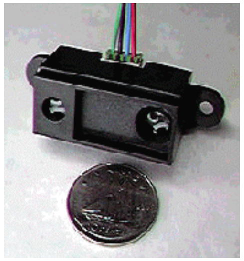

Pendulum Resistive
Tilt Sensors

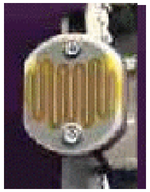

Piezo Bend Sensor

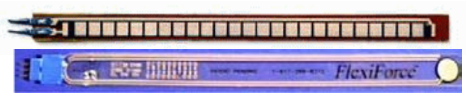

Metal Detector

Gas Sensor

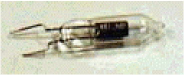

Gieger-Muller
Radiation Sensor

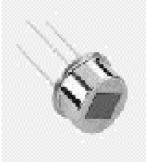

Digital Infrared Ranging

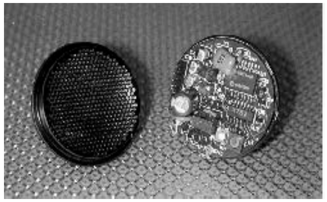

CDS Cell
Resistive Light Sensor

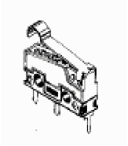


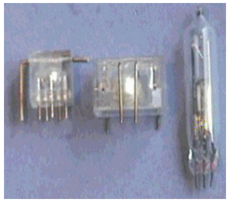
Resistive Bend Sensors

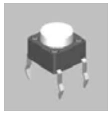

UV Detector

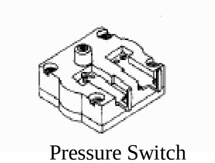

Pyroelectric Detector

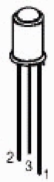

Miniature Polaroid Sensor

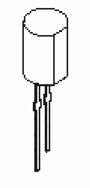

Limit Switch

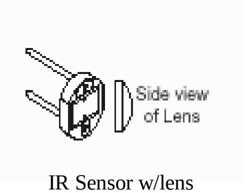

Mechanical Tilt Sensors


Touch Switch

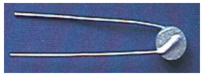

Pressure Switch

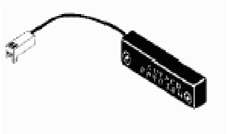


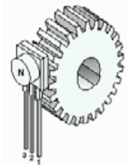

IR Pin
Diode

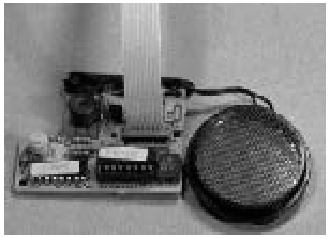


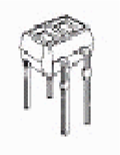
IR Sensor w/lens

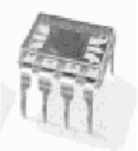

Thyristor


Magnetic Sensor


Hall Effect
Magnetic Field
Sensors

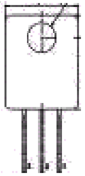

Polaroid Sensor Board

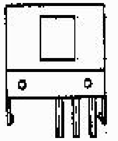

IR Reflection
Sensor


IR Amplifier Sensor

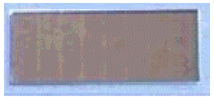

IRDA Transceiver

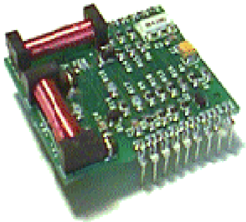

Magnetic Reed Switch

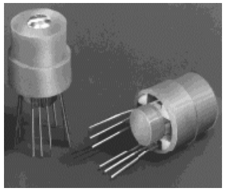

Lite-On IR
Remote Receiver

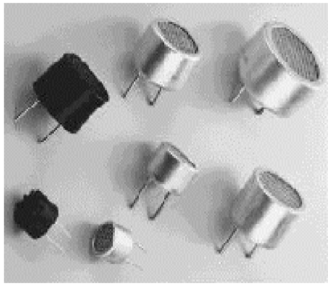

Radio Shack
Remote Receiver


IR Modulator
Receiver


Solar Cell


Compass


Compass


Piezo Ultrasonic Transducers

Getting answers from sensors

- Given a sensor reading, what should robot do?
  - Deals with actions in the world
- Given a sensor reading, what was the world like when the reading was taken?
  - Deals with reconstruction of the world
- Simple sensors can answer the first question
  - Their output can be used directly
- Complex sensors can answer both questions
  - Their information needs to be processed (electronics and/or software (signal processing))

Sensor fusion

A man with a watch knows what time it is;

a man with two watches isn't so sure

- **Combining multiple sensors to get better information about the world**
- **Sensor fusion is a complex process**
  - **Different sensor accuracy**
  - **Different sensor complexity**
  - **Contradictory information**
  - **Asynchronous perception**

Sensor Fusion: Why?

- **One sensor is (usually) not enough**
  - **Real sensors are noisy and have limited accuracy**
  - **Unreliable - Failure/redundancy**
  - **Limited point of view of the environment**
  - **The sensor of choice may be expensive - might be cheaper to combine two inexpensive sensors**
- **General Pre-processing**
  - **“Cleanup” the sensor readings before using them**
  - **Noise reduction – filtering**
  - **Recalibration to keep readings accurate**
  - **Usually unique processes for each sensor, eg. Edge detection in vision**

Sensor/ Data Fusion: How?

- **Combine data from different sources**
  - **Measurements from different sensors which do not depend on each other but are complementary to each other, e.g. cover different ranges. Could be competitive technology so effects of errors can be reduced**
  - **Measurements from different positions**
  - **Measurements from different times**

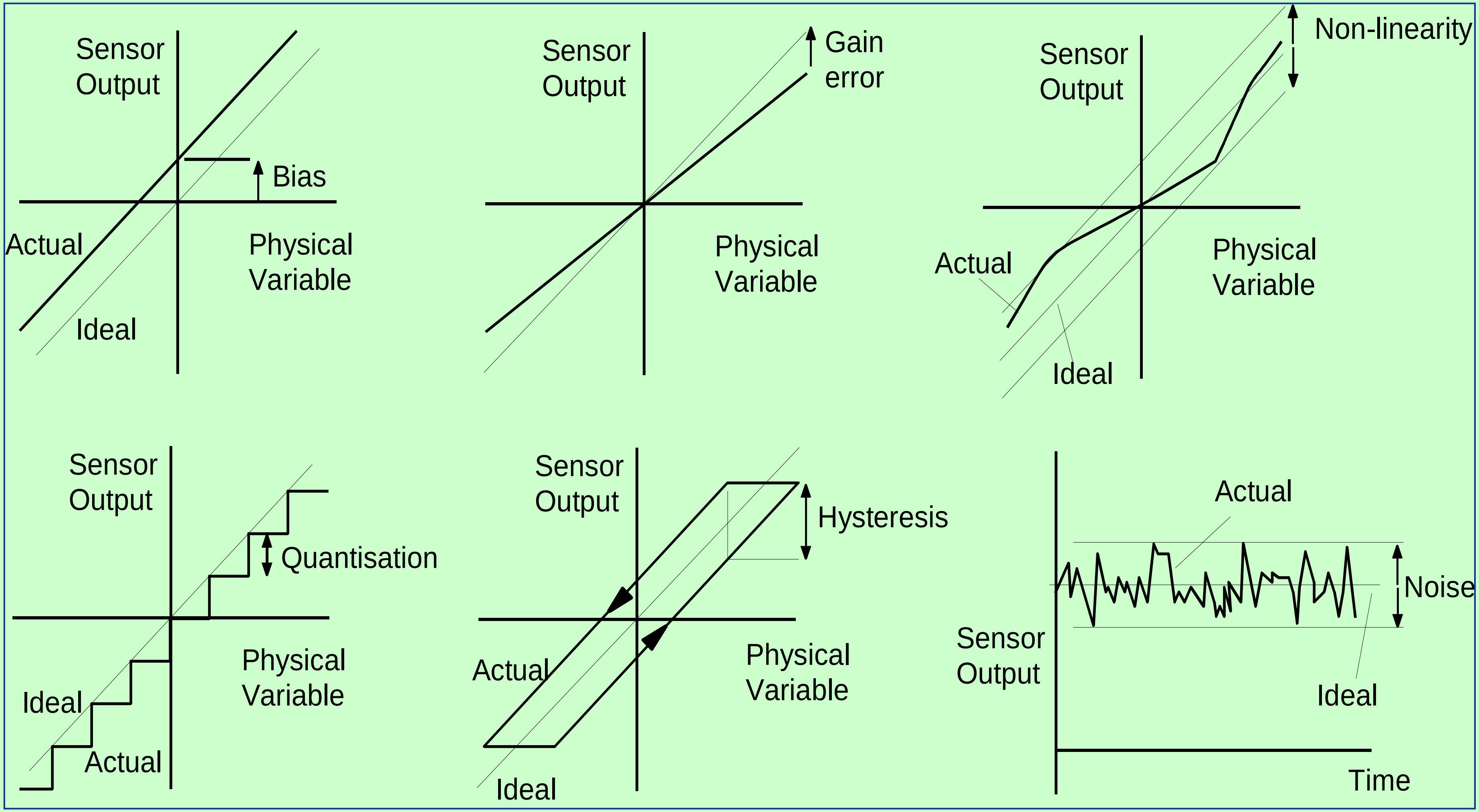
- **Often a mathematical technique that takes into account uncertainties in data sources**
  - **Discrete Bayesian methods**
  - **Neural networks**
  - **Kalman filtering**

- **Produces a merged data set (as though there was one ‘virtual sensor’)**

Sensor errors

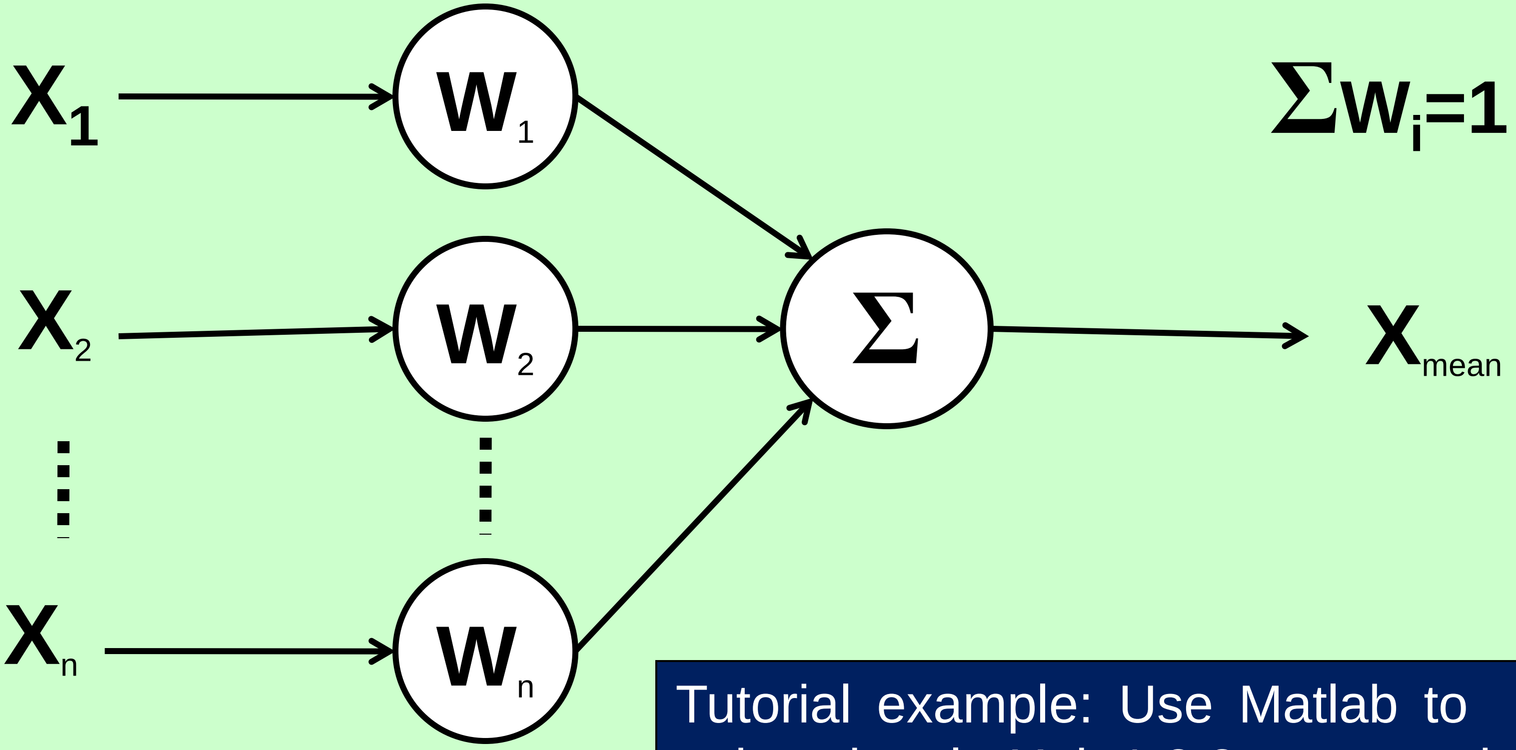
- **Systematic error → deterministic errors**
  - **Caused by factors that can (in theory) be modelled and so they can be predicted, eg. Calibration of a laser sensor or of the distortion caused by the optic of a camera**
- **Random error → non-deterministic errors**
  - **No prediction possible but these errors can be described probabilistically and their effect minimised**
- **Hence sensors take measurements of “parameters with unknown values” which can be modelled as well as “noise” as $y_i=A_i\theta+v_i$, where y_i, is the sensor “information” needed, A_i are the sensor measurements, θ is the sensor model parameters and v_i is the noise in the sensor readings**

Errors in measured signals



Simple sensor fusion

- **Sensor fusion by weighted fusion algorithm**



Tutorial example: Use Matlab to show that noisy signals X_i i=1,2,3,…,n can be fused to reduce the level of the noise in X_{mean} (use rand function in Matlab file)

Learning from nature

- **Our brain process information from multiple sensory modalities**
  - **Vision, touch, smell, hearing, sound**
- **Individual sensory modalities use separate regions in the brain (sight, hearing, touch)**
- **Evolved sensors have specific *geometric* and *mechanical* properties**
- **Examples**
  - **Flies: complex facetted eyes**
  - **Birds: polarized light sensors**
  - **Bugs: horizon line sensors**
  - **Humans: complicated auditory systems**
- **Biology uses clever designs to maximize the sensor’s perceptual properties, range and accuracy**

How would you detect people?

- **Use the interaction with the world, keep in mind the task**
- **Camera: great deal of processing**
- **Movement: if everything else is static: movement means people**
- **Colour: If you know the particular colour people wear**
- **Temperature: can use sensors that detect the range of human body heat**
- **Distance: If any open-range becomes blocked**

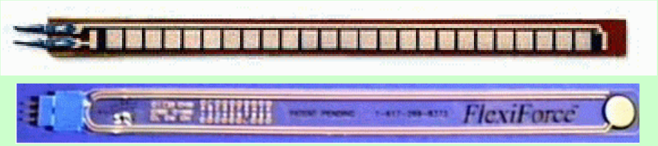
How would you measure distance?

- **Ultrasound sensors (sonar) provide distance measurement directly (time of flight)**
- **Infra red sensors provide return signal intensity**
- **Two cameras (i.e., stereo) can be used to compute distance/depth**
- **A laser and a camera: triangulate distance**
- **Laser-based structured light: overlay grid patterns on the world, use distortions to compute distance**

Resistive sensors

Bend Sensors

- Resistance = 10k to 35k
- Force to produce 90deg = 5 grams



Resistive Bend Sensor

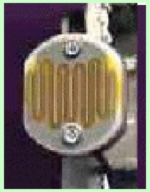
Potentiometers

- Fixed Rotation Sensors
- Easy to find, easy to mount

Potentiometer

Light Sensor

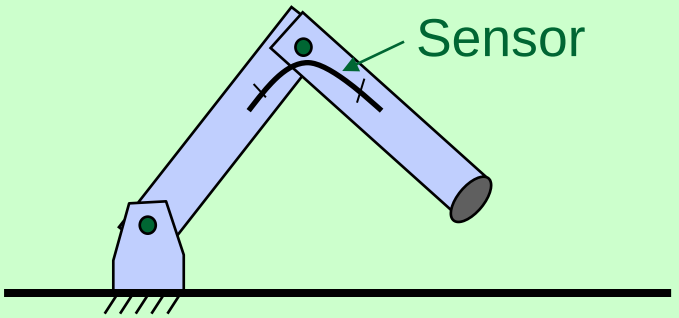
- Good for detecting direction/presence of light
- Non-linear resistance
- Slow response



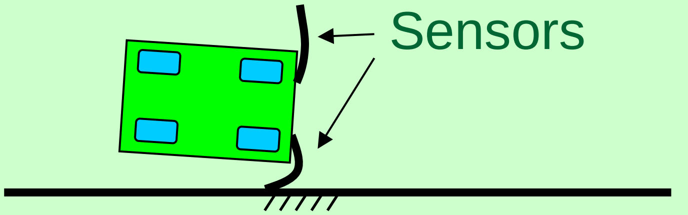
Cadmium Sulfide Cell

Applications

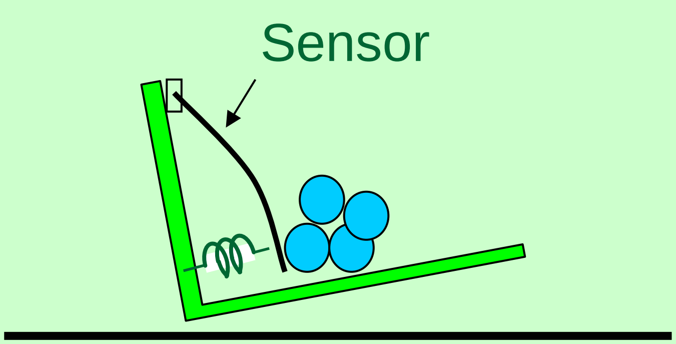
- Measure bend of a joint



- Wall Following or
- Collision Detection



- Weight Sensor



Range sensors

- **Why needed?: To provide distance measurement which is key for localisation and environment modelling; cheap and relatively accurate**
- **How?: Time of flight (sound, light)**
  - **Time delay of arrival: triangulation**
  - **Distance=velocity × time**
  - **Limitations: Need to wait for last package to arrive before sending next one; speed of propagation determines maximum range**
    - **Speeds: Sound (0.3m/ms); Light/Laser (0.3m/ns)**
    - **3 metres takes: Sound (10ms); Light (10ns)**
    - **Time measurement: Exact time of arrival of reflected signal**
      - **Opening angle of beam (Ultrasonic), multiple reflections, variation of propagation speed, speed of mobile robot**

Ultrasonic (sonar) sensors

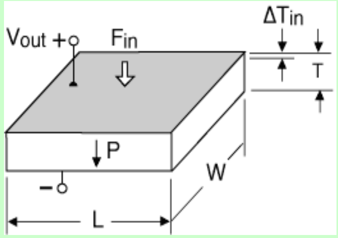
- **Transmit a packet of US pressure waves (50kHz), (human hearing 20Hz-20kHz)**
- **Measure the elapsed time until receiver indicates that an echo is detected**
- **Determine how far away nearest object is**
- **The speed of sound c (0.34 m/ms) in air is**

$$c = \sqrt{\gamma . R . T}$$

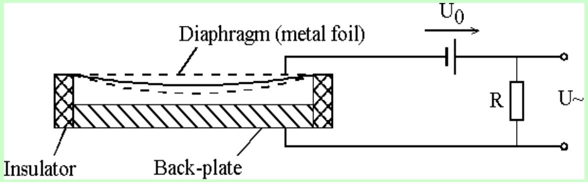
  - γ: **Adiabatic index (Ratio of specific heats)**
  - R: **Gas constant**
  - T: **Temperature in degree Kelvin**

Ultrasonic Sensor

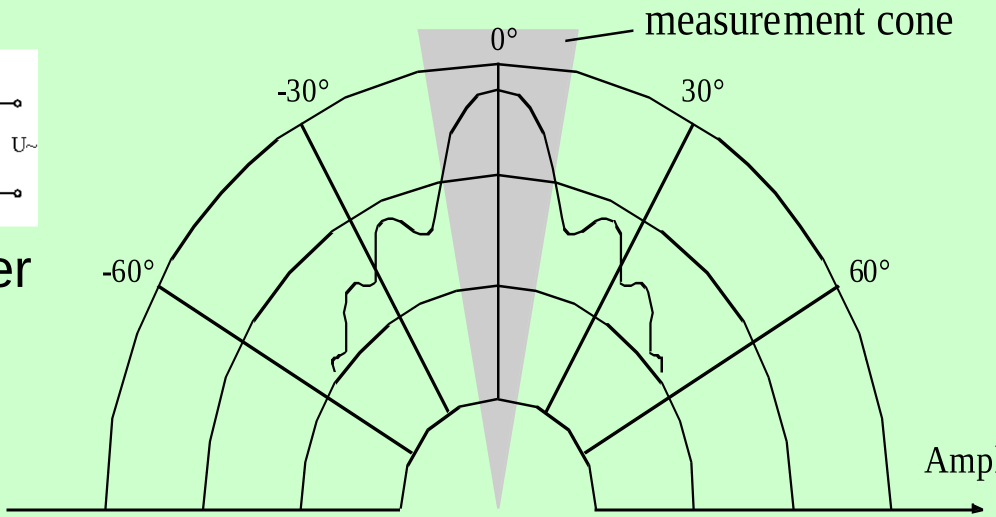
- **Frequencies: 40 - 180 kHz**
- **Sound source: piezo/electrostatic transducer**
  - **transmitter and receiver separated or not separated**
- **Propagation: cone**
  - **Opening angles around 20 to 40 degrees**
  - **Regions of constant depth**
  - **Segments of an arc (sphere for 3D)**



Piezo transducer

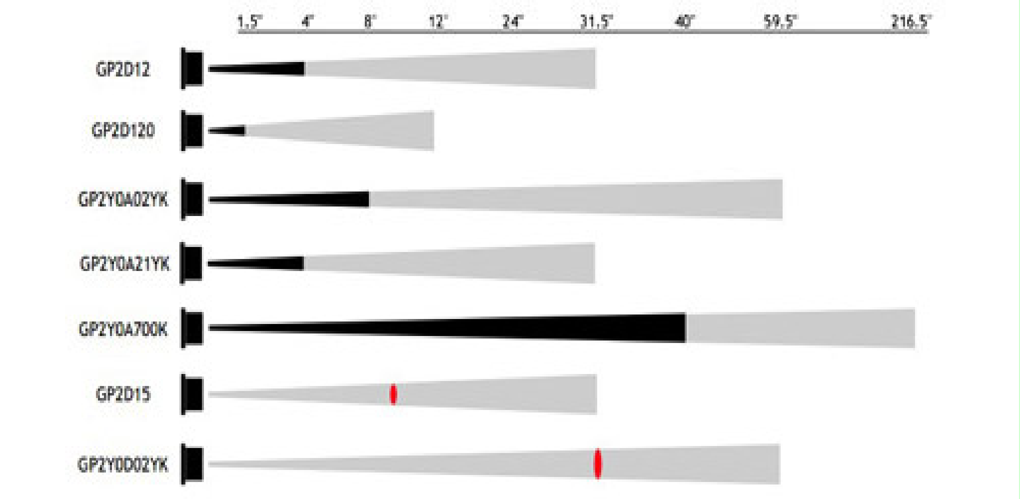


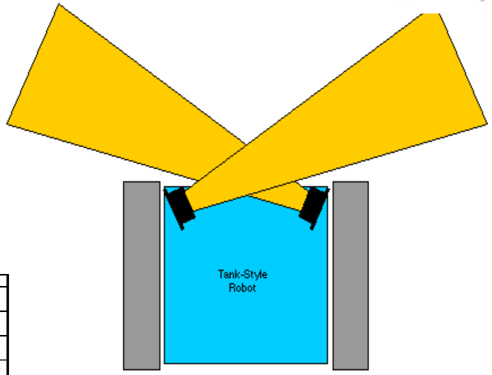
Electrostatic transducer

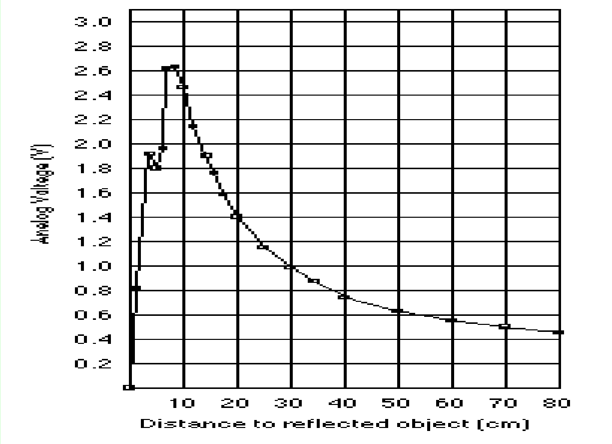


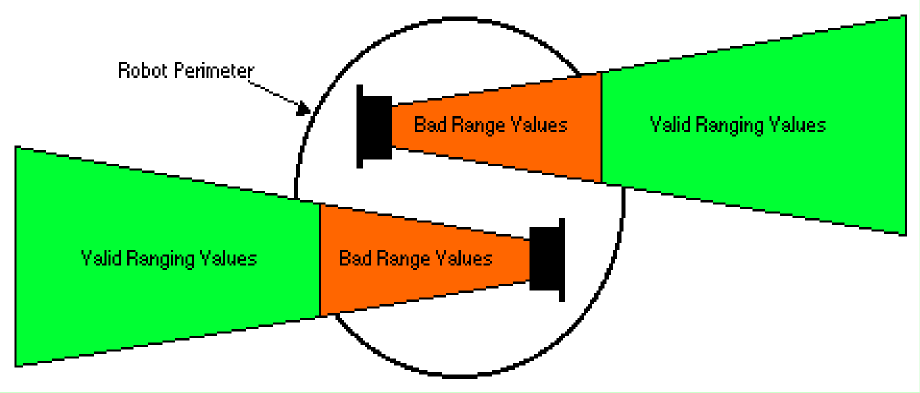
Typical intensity distribution of an ultrasonic sensor

Sharp Infrared Rangers



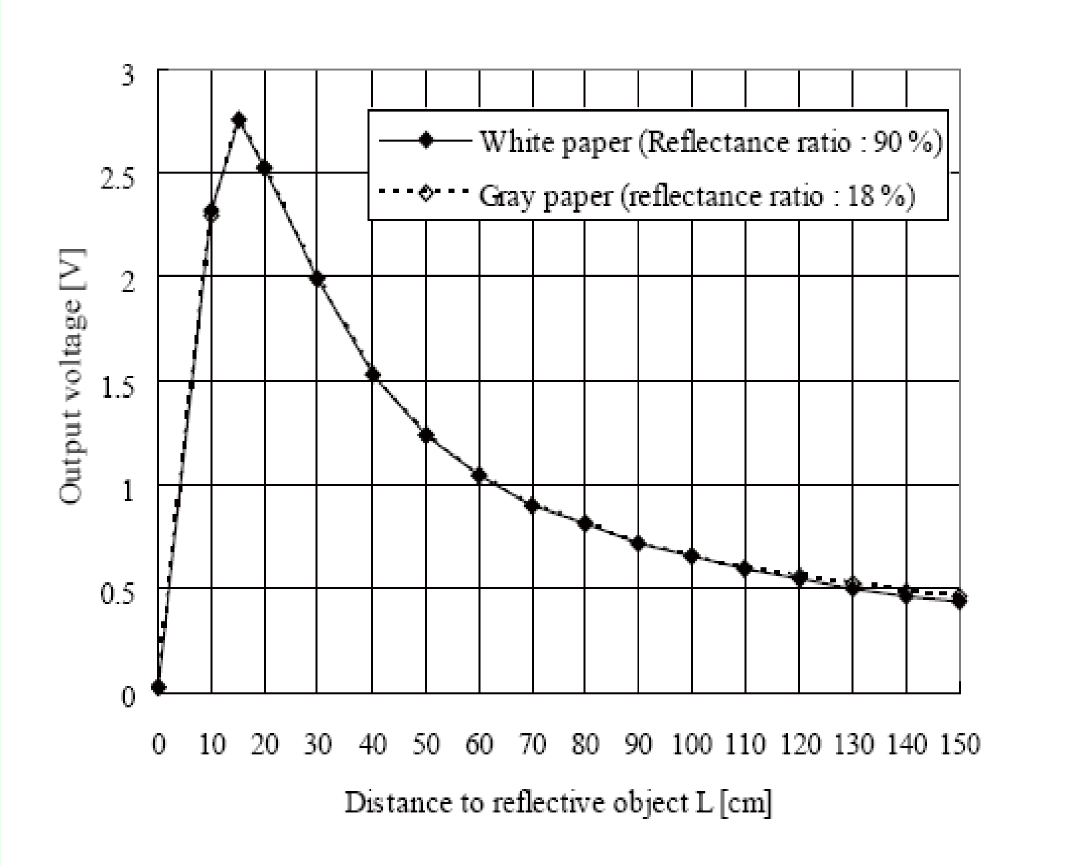






Infrared Distance Sensor (Sharp)

- **GP2Y0A02YK0F**
- **Analog O/P**
- **Range=20-150 cm**
- **Supply 5V**



Laser ranger sensor

- Range 2-500 meters
- Resolution : 10 mm
- Field of view : 100 - 180 degrees
- Angular resolution : 0.25 degrees
- Scan time : 13 - 40 msec.
- These lasers are more immune to Dust and Fog

http://www.sick.de/de/products/categories/safety/

Time of flight measurement methods

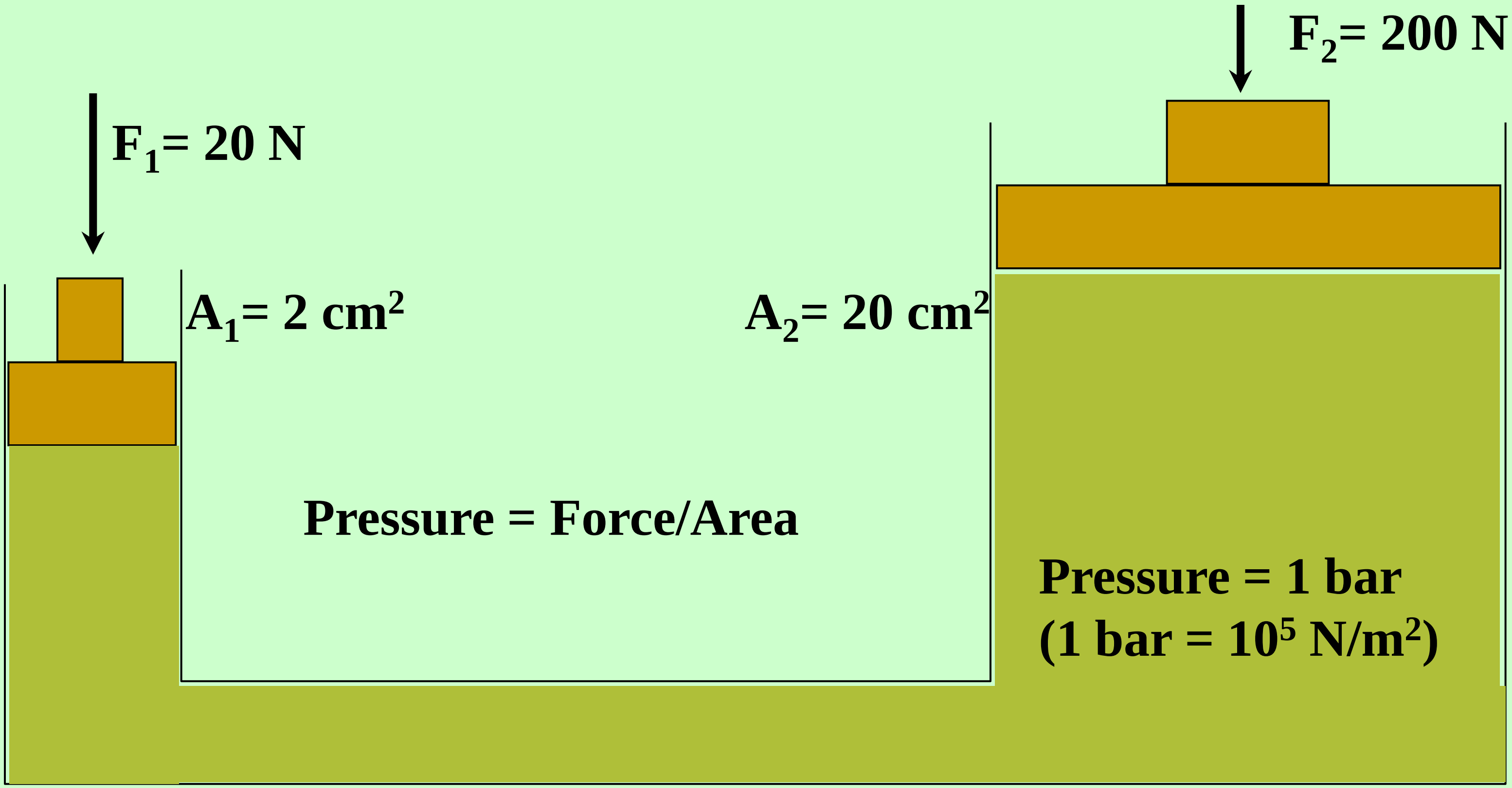
- **Pulsed laser**
  - **Direct measurement of elapsed time**
  - **Receiver: Picoseconds accuracy**
  - **Accuracy: centimeters**
- **Beat frequency between a frequency modulated continuous wave and its received reflection**
- **Phase shift measurement**
  - **Technically easier than the above two methods**

Output modules: Actuators

- Actuators are devices for altering or generating a mechanical property, usually a force or torque or motion. Those which are designed to accurately generate any desired force, displacement, velocity etc. within a given range are called servo-actuators.
- Electromagnetic actuators (DC, Permanent magnet, Stepper, AC, Brushless, etc)
- Hydraulic actuated robots have the advantage of mechanical simplicity (few moving parts), as well as physical strength and high speed
- Pneumatic drives systems are normally reserved for small, limited sequence pick and place applications. Lack of stiffness (air compressibility) and control problems associated with stiction prevent their use if good accuracy is required.
- Others: Piezo, direct fuel, chemical, etc

- Other output modules are for user interfaces (displays, haptic devices, etc)

Properties of liquids: Equal Pressure



Pros and cons of hydraulic systems

- **Advantages**
  - Convenient and smooth method of power transmission over long distances
  - Higher Power to weight ratios
  - Great flexibility
  - Variable speed control
  - Safety and reliability
- **Disadvantages**
  - Need for positive confinement
  - Reliability (leaks): Fire hazard if leaks occur (for oil)
    - failure due to oil contamination
  - Leaks in high pressure systems pose a safety hazard
  - Maintenance needed: adequate oil filtration must be maintained
  - Size/expense of hydraulic power supply
  - More difficult to control accurately than electromagnetic actuators

Most applies to pneumatic systems as well

Electro-pneumatic actuators

- **In pneumatic systems power is transmitted by the flow of air under pressure.**
- **Due to problems with sealing there can be significant leakage of air and this limits the maximum air pressure which can be used; 6 to 10 bar gauge pressures are typical.**
- **Air is compressible; difficult to position precisely**
- **In pneumatic systems a distinction must be made between:**
  - **absolute pressure (denoted bar a when measured in bar) &**
  - **gauge pressure (denoted bar g when measured in bar).**

Other types of actuators

- Pneumatic muscles: “balloon” using pneumatic, shortens by 25-30%

- Shape Memory Alloy (SMA) actuators. SMA is an alloy which is malleable when cold, allowing deformations of up to 10%. When heated it returns to its pre-formed shape, and can do useful work in the process. There is a delay while it cools before the process can be repeated.
- Piezo-electric actuators. These use a piezo-electric material which will deform when electrically charged. Linear actuators of up to 1mm stroke and 1kN force output have been constructed, and rotary actuators have been designed producing continuous rotation.

Summary

- **Introduction to the need for sensors in robots**
- **Overview of sensors**
- **Broad list of sensors introduced**

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