Sensing and Perception

Lecture 3 – Thursday October 13, 2016

Objectives

When you have finished this lecture you should be able to:

- Recognize the difference between sensing and perception.
- Recognize different sensor classifications.
- Understand inner-state (interoceptive), surface-state and outer-state (exteroceptive) sensors and their usage in mobile robots.
- Recognize innovative directions in sensor technology.

Outline

- Introduction to Sensors
- Inner-State (Interoceptive) Sensors
- Surface Sensors
- Outer-State (Exteroceptive) Sensors
- Innovative Sensor Technologies
- Summary

Outline

- **Introduction to Sensors**
- Inner-State (Interoceptive) Sensors
- Surface Sensors
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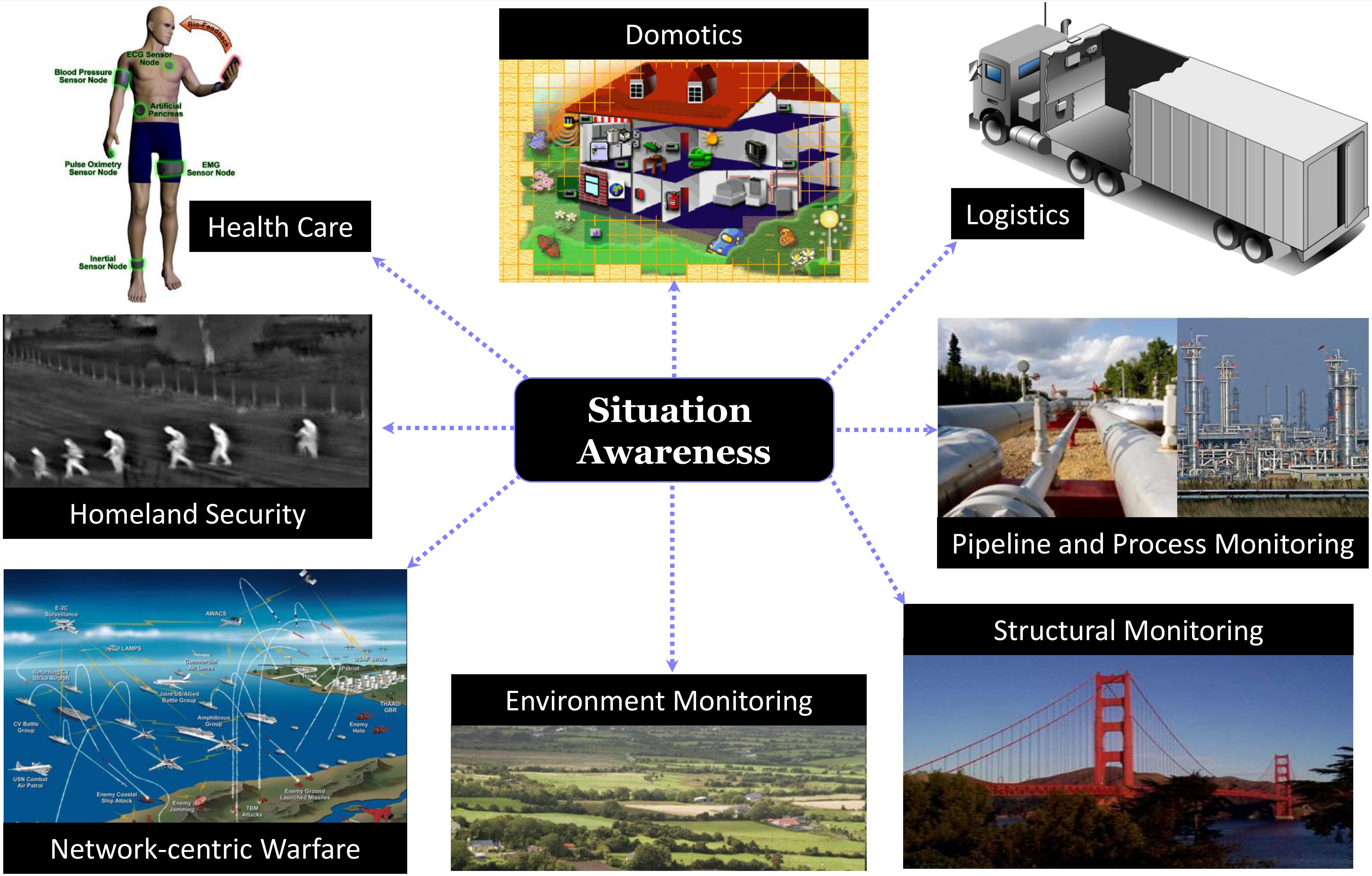
Introduction to Sensors



Introduction to Sensors

- **Situation Awareness**

Situation awareness is:

◇ the **perception** of environmental elements with respect to time and/or space,

◇ the **comprehension** of their meaning, and

◇ the **projection** of their status after some variable has changed, such as time, or some other variable, such as a predetermined event [1].

Uncertainty

- **Situation Awareness**

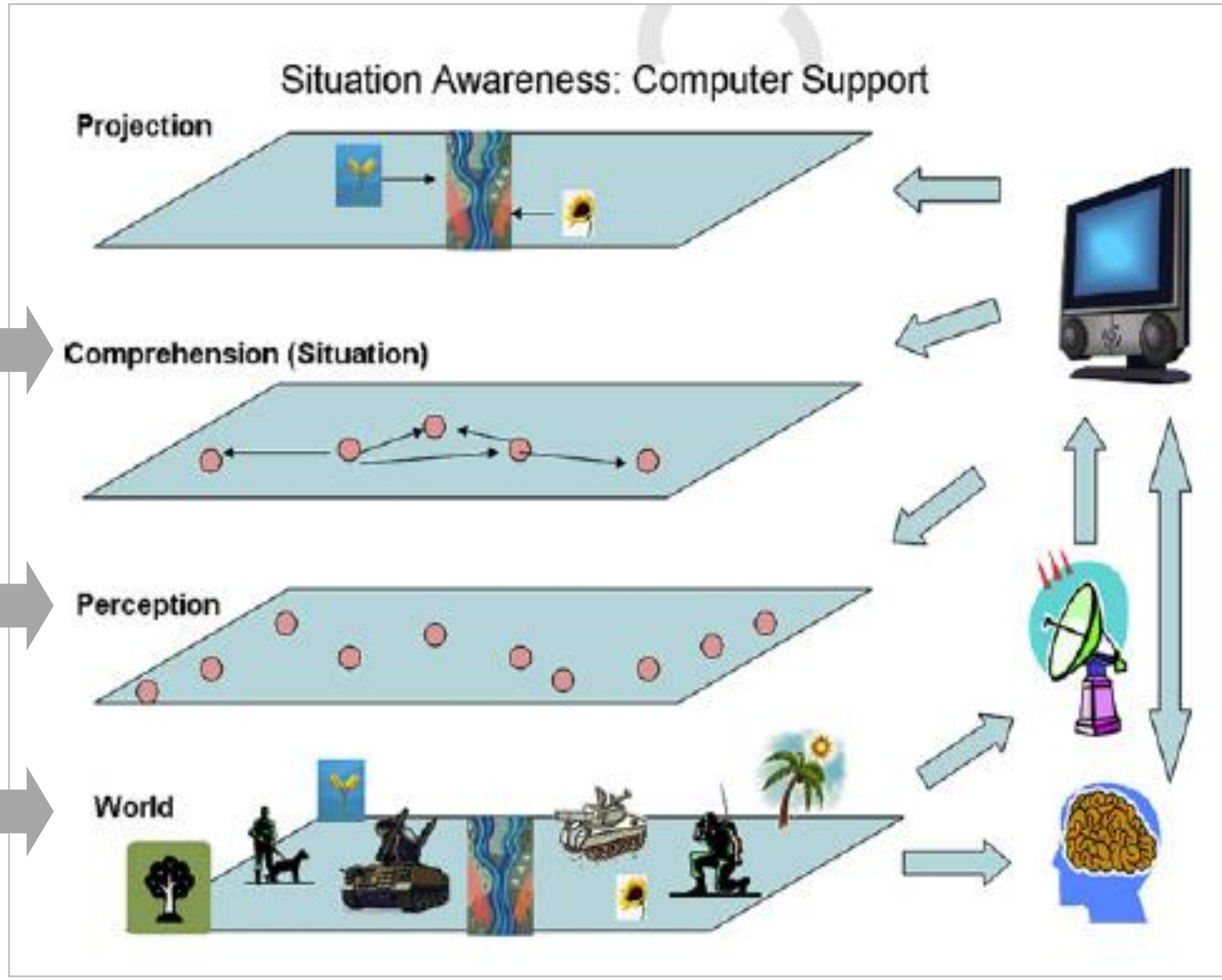
Semantic Analysis
- Thematic
- Spatio-Temporal
- Trust

Provenance

Relate Situation Entities

Identify Situation Entities

Collect Relevant Data



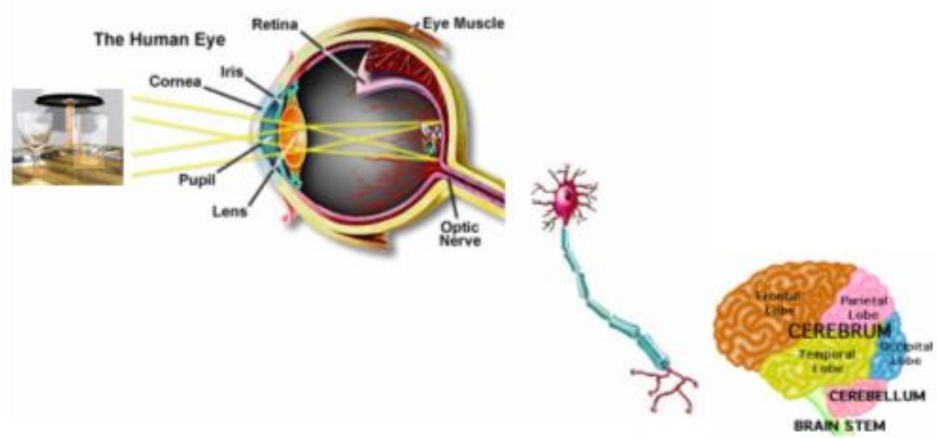
Introduction to Sensors

- **The Perception Process**

As human, we often take for granted our amazing perceptual systems. We see a cup sitting on a table, automatically reach out to pick it up and think nothing of it. At least, we are not aware of thinking much of it.

In fact, accomplishing simple task of drinking from a cup requires a complex interplay of:

- sensing,
- interpretation,
- cognition,
- and coordination.



Thus, instilling human-level performance in a robot has turned out to be tremendously difficult.

Introduction to Sensors

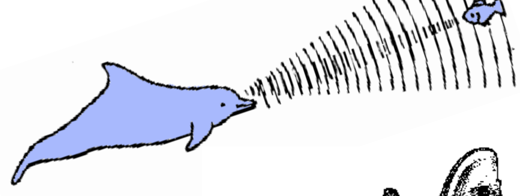
- **The Perception Process**

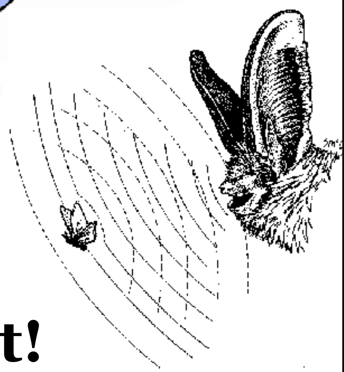
If we assign a robot some service task, the first expectation is that the robot should emulate a human in getting the task done.

Thus, the robot servant probably has arms and hands, is mobile and is sensate.

It is sensory perception that will mark the success or failure of a service robot.

Machine perception includes a vast array of transducers that can inform robots about their surroundings. Bats and dolphins use sonar, cats use whiskers and birds use magnetic fields in navigation.

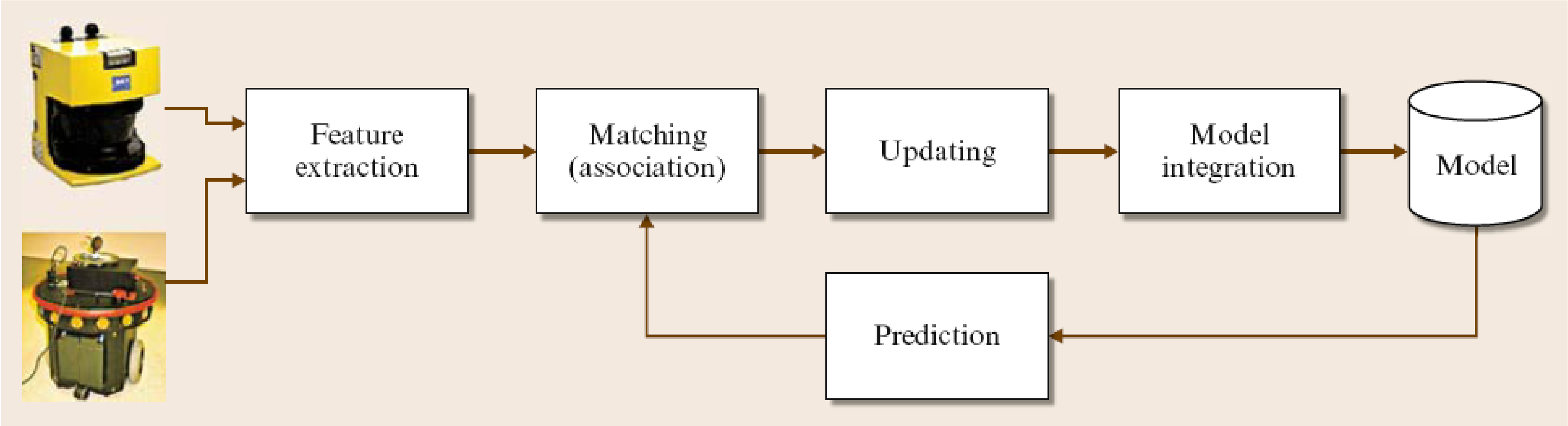




So can robot!

Introduction to Sensors

- **The Perception Process**



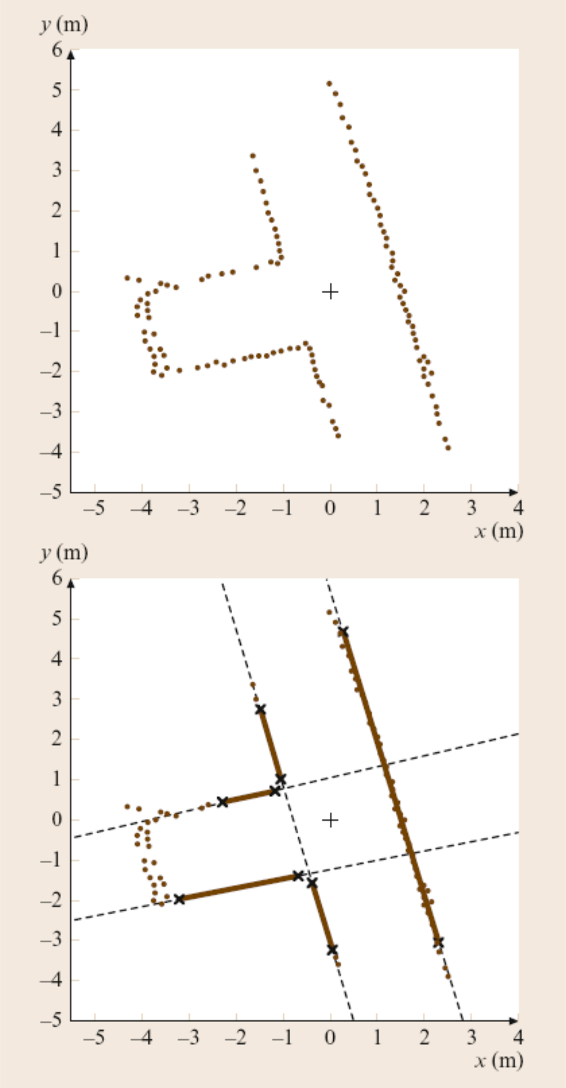
The input to the perception process is typically twofold:

1. **digital data** from a number of sensors/transducers,
2. **a partial model** of the environment (a world model) that includes information about the state of the robot and other relevant entities in the external world.

[2]

Introduction to Sensors

- **The Perception Process: Feature Extraction**
  - The initial problem in sensory processing is data preprocessing and feature extraction.
  - The role of **preprocessing** is to reduce noise from the transducer, to remove any systematic errors, and to enhance relevant aspects of the data.
  - A One common approach for feature extraction is model fitting.



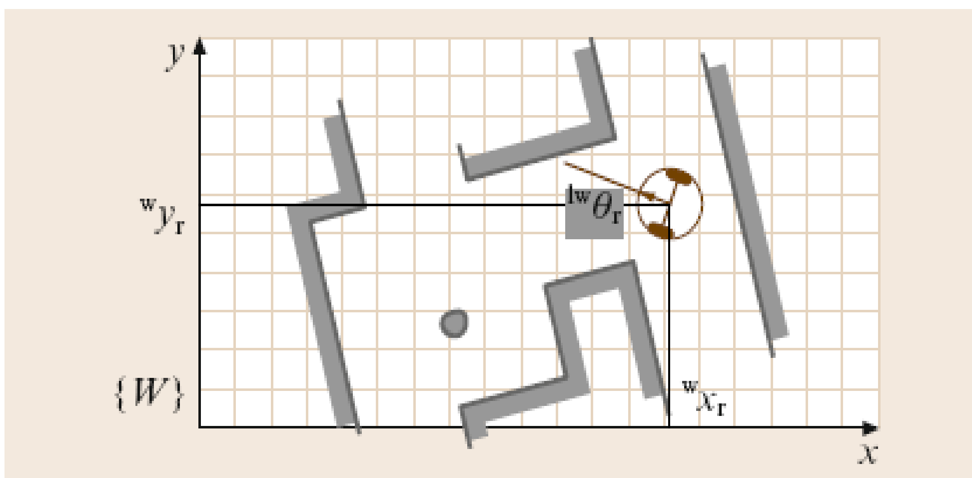
An example of feature extraction from a laser scan

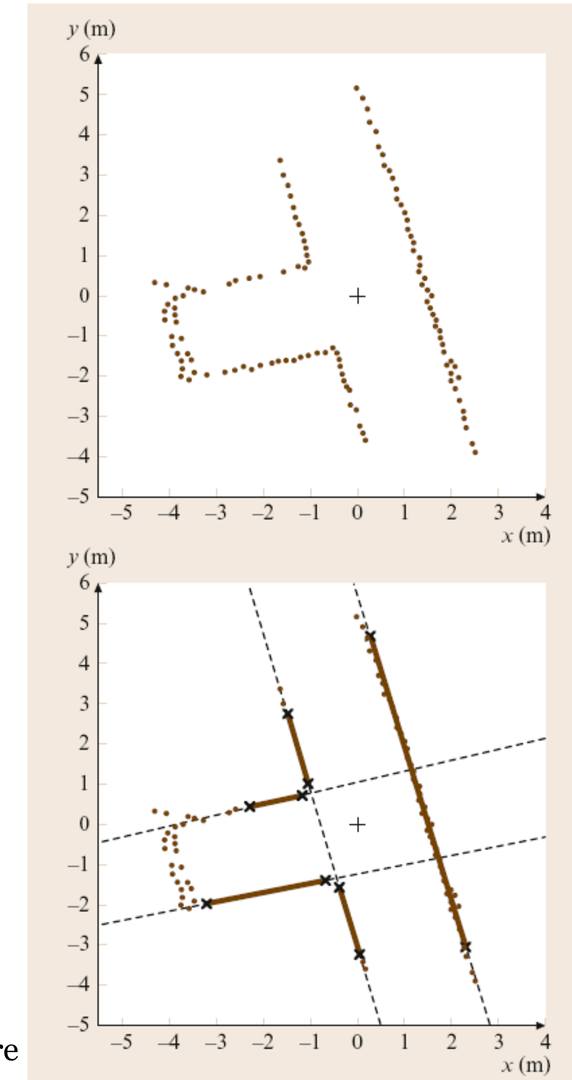
[2]

Introduction to Sensors

- **The Perception Process: Model Matching**
  - In **model fitting**, once sensor information is available, it is often necessary to match the data with an existing model.

An example environmental model for mobile robot localization



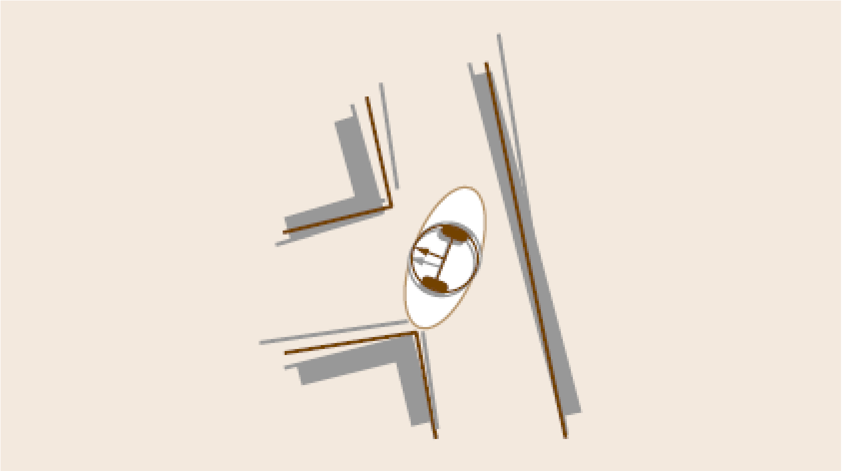


An example of feature extraction from a laser scan

[2]

Introduction to Sensors

- **The Perception Process: Model Updating**
  - Once sensory data has been matched against the world model it is possible to **update the model** with new information contained in the sensor data.



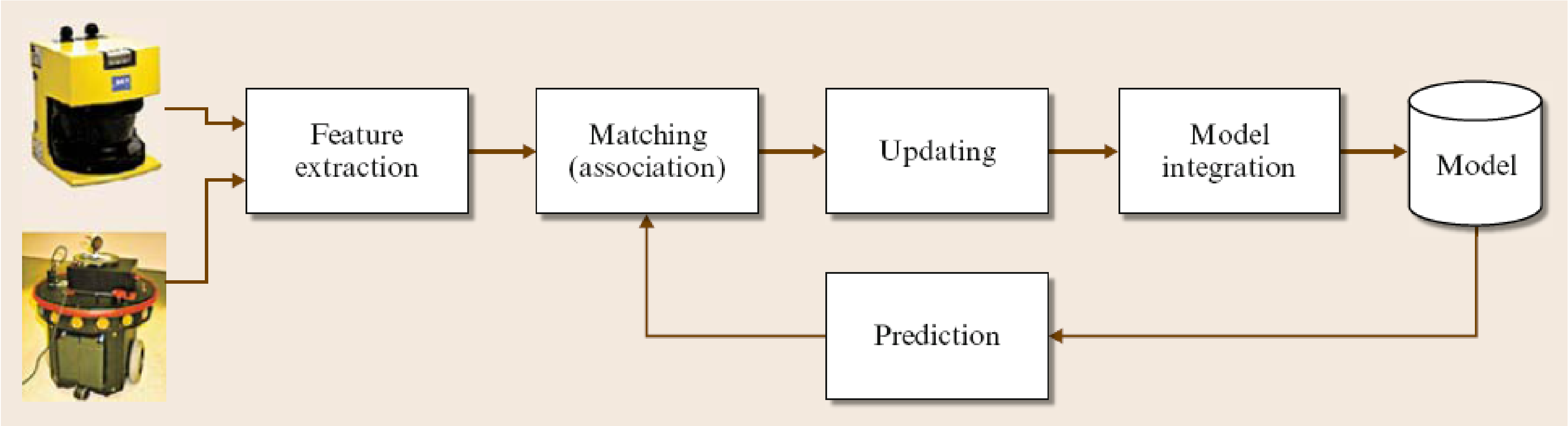
Estimation of position and orientation for the example mobile robot

  - In the example, the orientation and position of the robot relative to the world model can be updated (as shown in the figure) from the matched line segments.

[2]

Introduction to Sensors

- **The Perception Process: Model Building**



- It may be possible to develop a **dynamical system model** of the underlying state being estimated. Using such a system model, it is possible to predict how the world changes over time until new sensory data is acquired.

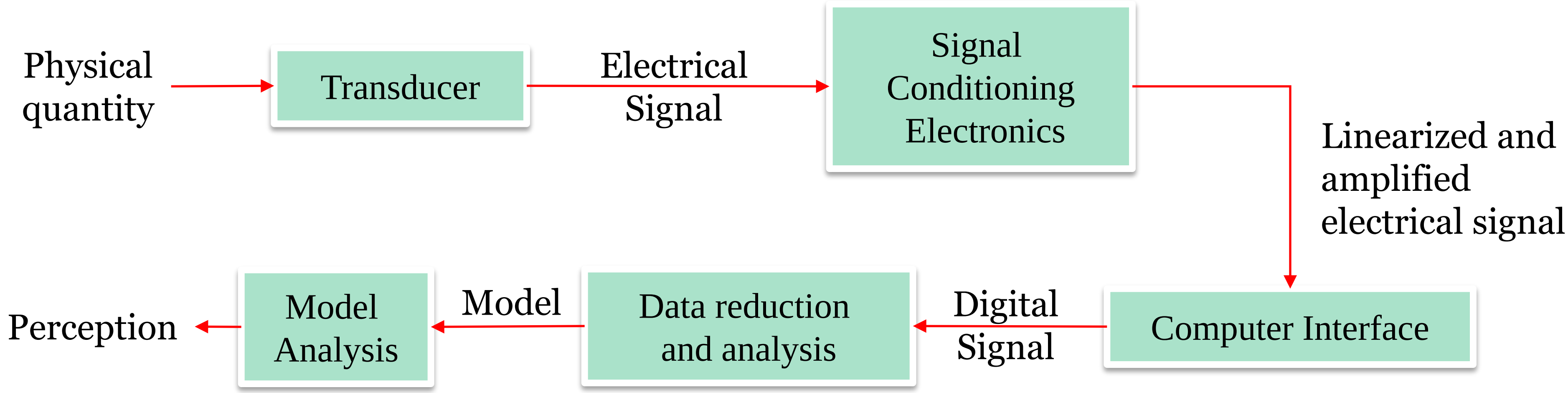
[2]

Introduction to Sensors

- **What is a Sensor?**

A sensor consists of a transducer and an electronic circuit.

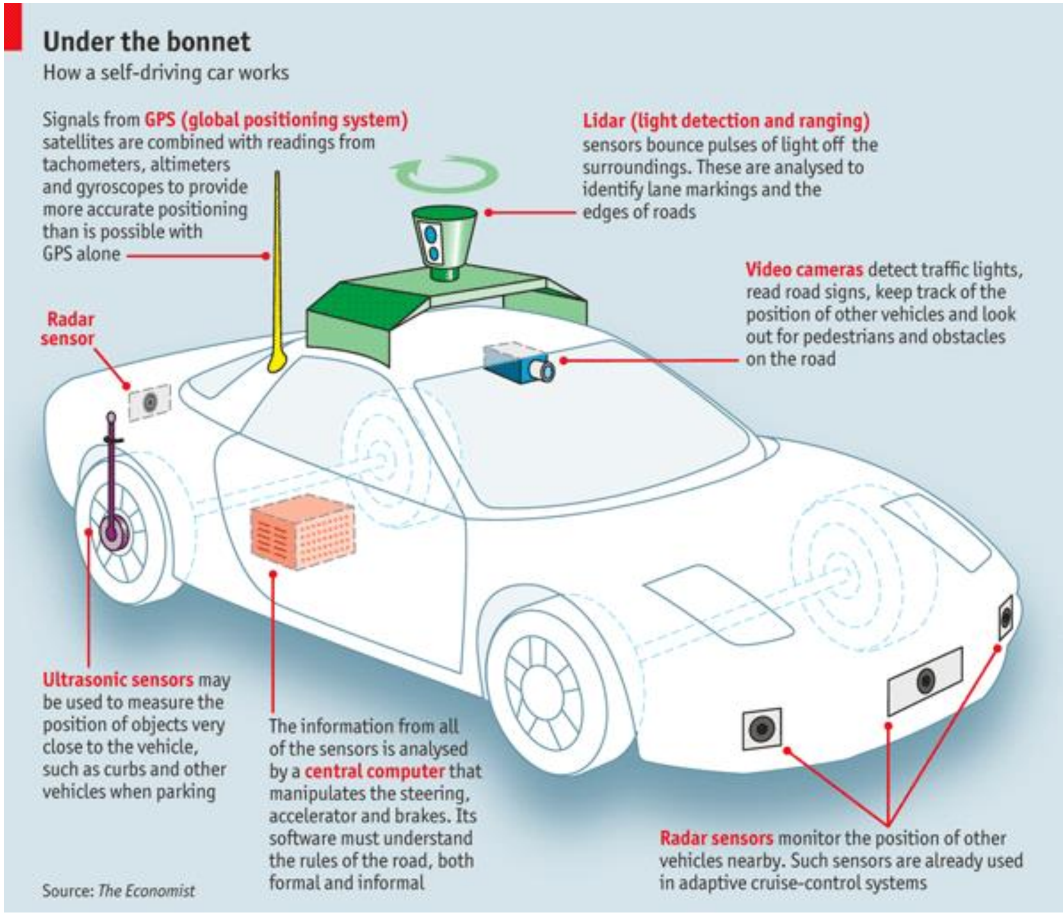
A transducer is a device, usually electrical, electronic, or electro-mechanical, that converts one type of energy to another for various purposes including measurement or information transfer. In a broader sense, a transducer is sometimes defined as any device that converts a signal from one form to another.

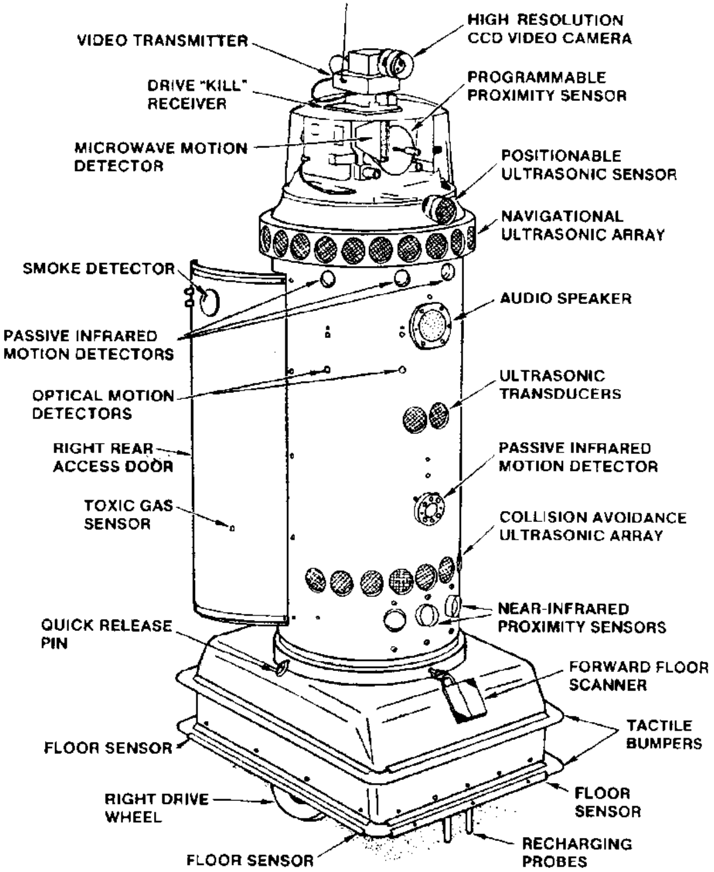


Introduction to Sensors

- **Why do we need sensors?**

Measurement of robot and environment parameters is fundamental to the successful application of robots.





Introduction to Sensors

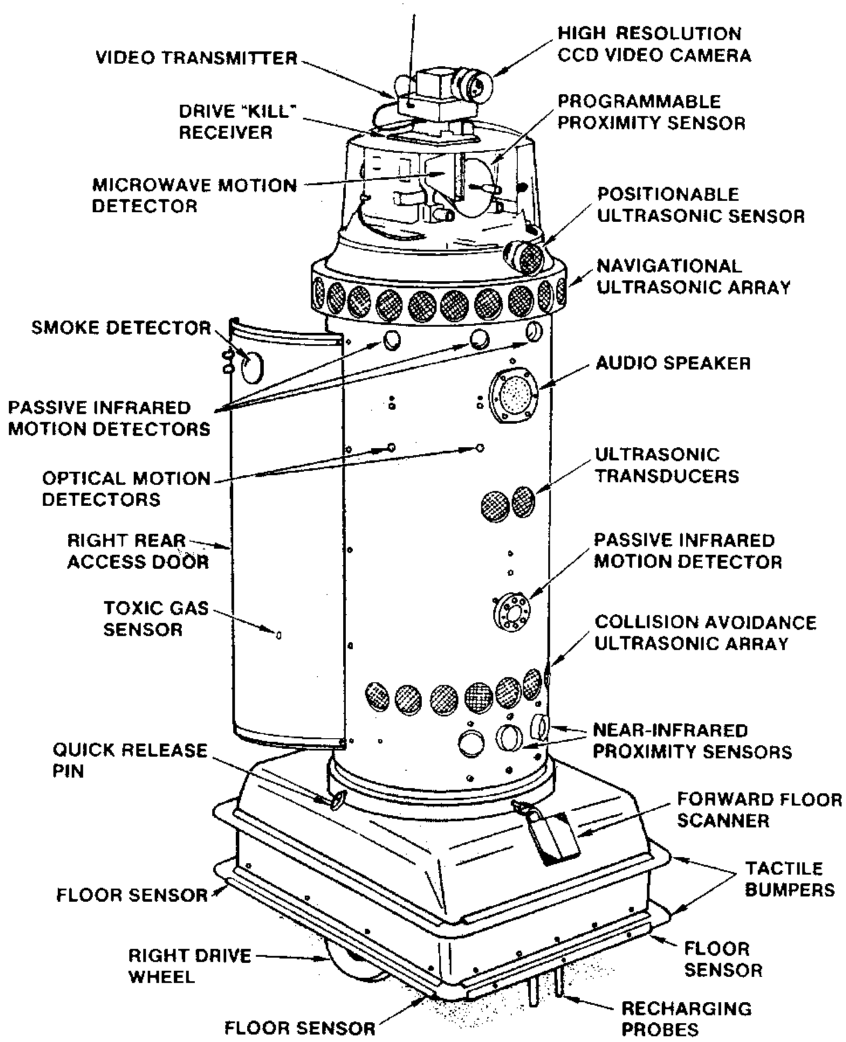
- **Why do we need sensors?**
  - Measuring robot parameters for control loops,
  - Finding the location of objects,
  - Correcting for errors in the robot's models of itself and of the world,
  - Detecting and avoiding failure situations,
  - Detecting and avoiding collisions,
  - Monitoring interaction with the environment such as forces during complaint motion,
  - Monitoring the environment for changes (such as temperature) that may affect the task,
  - Inspecting the results of processes.

Introduction to Sensors

- **Sensor Classifications**
  - The physical or chemical quantity the sensor is to measure such as, velocity, viscosity, color;
  - The physical principle the sensor is based on such as, magnetostriction, memory metal, Hall effect;
  - The technology that is used such as silicon, electro-mechanical, fiber optic;
  - The type of energy involved such as electrical, mechanical, solar;
  - The type of the output signal such as discrete and analogy;
  - The spatial relationship between the sensor and the object it is sensing such as, contact, non-contact and remote or process-monitoring.

Introduction to Sensors

- **Other Classifications**
  - **Internal Sensors:** measure variables within the robot – for example, position, velocity, torque and acceleration sensors.
  - **External Sensors:** measure the environment – for example tactile, proximity, range, vision, and voice.



Introduction to Sensors

- **Other Classifications**

Classification of sensors frequently used in robotics according to sensing objective [proprioception (PC) /exteroception (EC)] and method (active/passive)

Classification	Sensor type	Sens	A/P
Tactile sensors	Switches/bumpers	EC	P
	Optical barriers	EC	A
	Proximity	EC	P/A
Haptic sensors	Contact arrays	EC	P
	Force/torque	PC/EC	P
	Resistive	EC	P
Motor/axis sensors	Brush encoders	PC	P
	Potentiometers	PC	P
	Resolvers	PC	A
	Optical encoders	PC	A
	Magnetic encoders	PC	A
	Inductive encoders	PC	A
	Capacity encoders	EC	A
Heading sensors	Compass	EC	P
	Gyroscopes	PC	P
	Inclinometers	EC	A/P
Beacon based (postion wrt an inertial frame)	GPS	EC	A
	Active optical	EC	A
	RF beacons	EC	A
	Ultrasound beacon	EC	A
	Reflective beacons	EC	A

Classification	Sensor type	Sens	A/P
Ranging	Capacitive sensor	EC	P
	Magnetic sensors	EC	P/A
	Camera	EC	P/A
	Sonar	EC	A
	Laser range	EC	A
	Structures light	EC	A
Speed/motion	Doppler radar	EC	A
	Doppler sound	EC	A
	Camera	EC	P
	Accelerometer	EC	P
Identification	Camera	EC	P
	Radio frequency identification		
	RFID	EC	A
	Laser ranging	EC	A
	Radar	EC	A
	Ultrasound	EC	A
	Sound	EC	P

[2]

Introduction to Sensors

Sensors for Mobile Robots

Inner-State (Interoceptive) Sensors

- ◇ Position Sensors
- ◇ Heading Sensor
- ◇ Acceleration Sensor
- ◇ Force and Torque Sensor
- ◇ Temperature Sensor
- ◇ Battery-Level Sensors
- ◇ Stall Current Sensor

Surface State Sensors

- ◇ Push Buttons and Limit Switches
- ◇ Tactile Sensors/Artificial Skin

Outer-State (Exteroceptive) Sensors

- ◇ Proximity sensors
- ◇ Range Sensors (SONAR, LIDAR, RADAR)
- ◇ Ground Penetrating Radar (GPR)
- ◇ Vision Systems

LIDAR (LIght Direction And Ranging)

RADAR (RAdio Direction And Ranging)

Outline

- Introduction to Sensors
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Inner-State (Interoceptive) Sensors

Inner-state or Proprioceptive Sensors measure values internally to the system (robot), e.g. motor speed, wheel load, heading of the robot, battery status.

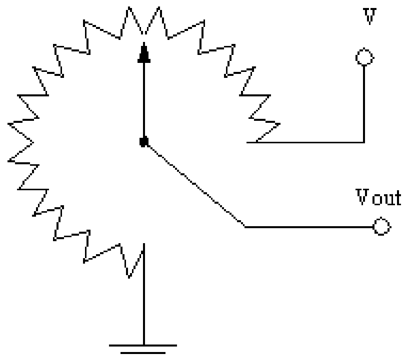
Examples:

- ◇ Position Sensors
- ◇ Heading Sensor
- ◇ Acceleration Sensor
- ◇ Force and Torque Sensor
- ◇ Temperature Sensor, Battery-Level Sensors, Stall Current Sensor, etc.

Inner-State (Interoceptive) Sensors

- **Position Sensors: Potentiometers**

Potentiometer is an instrument used for measuring an unknown voltage by comparison to a standard voltage.



$$V_{out} = V\left(\frac{\theta}{\theta_{max}}\right)$$

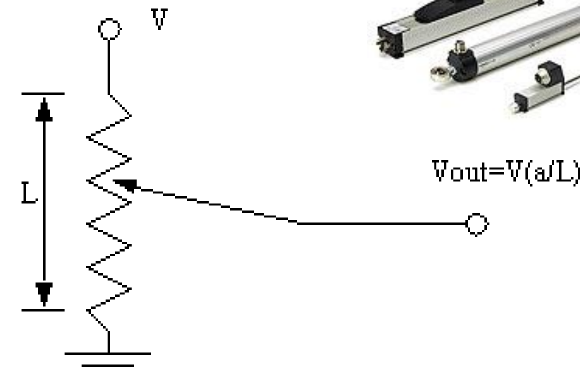
$$V_{unknown} = \frac{R_2}{R_1 + R_2} * V_{known}$$

Rotary Position Sensor

V = F^{n}(R)

R=F^{n}(slider position)

Slider position can be obtained by measuring V

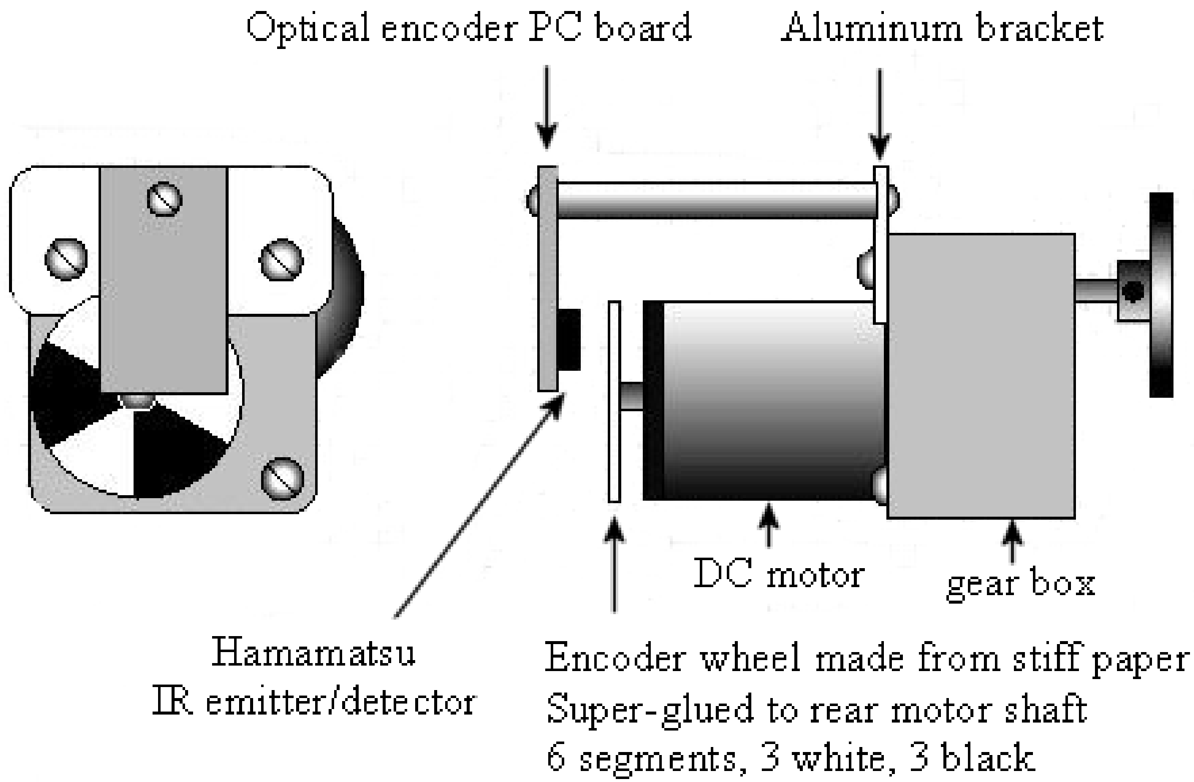


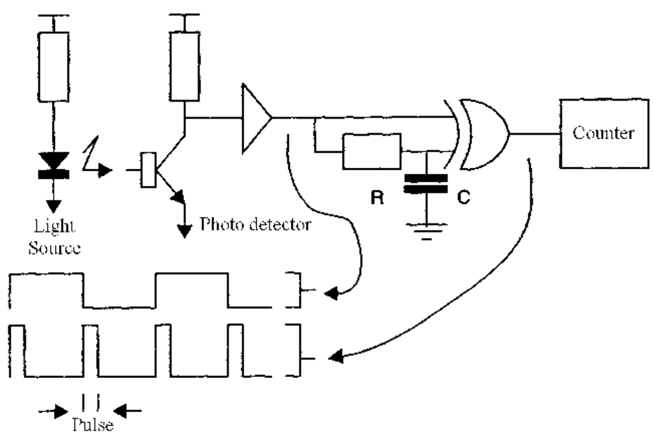
Linear Position Sensor

Inner-State (Interoceptive) Sensors

- **Position Sensors: Encoders**

A rotary encoder is a sensor for converting rotary motion or position to a series of electronic pulses.

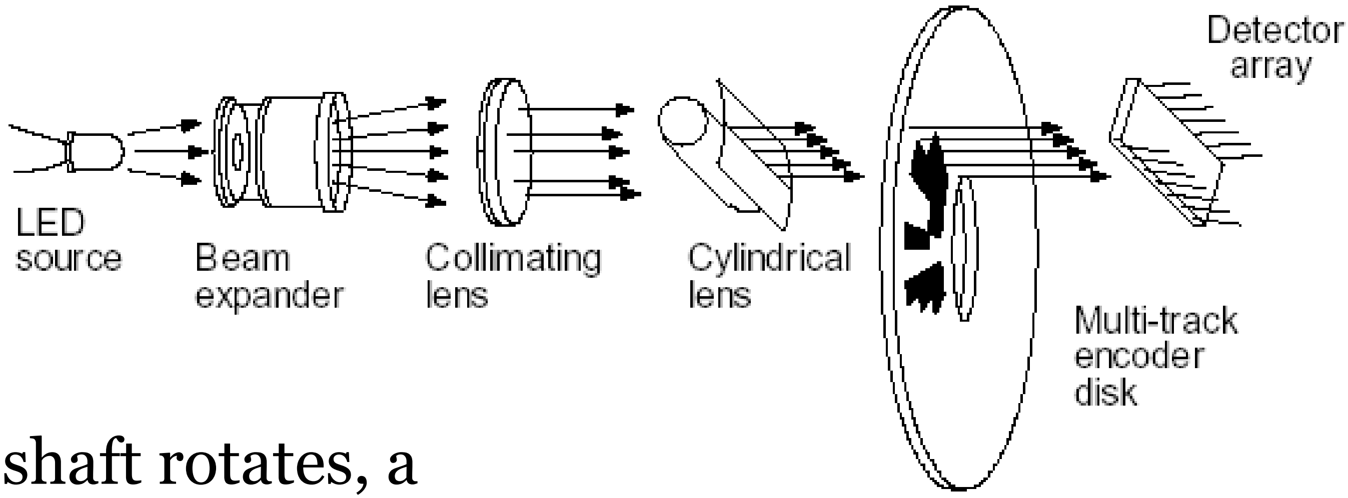




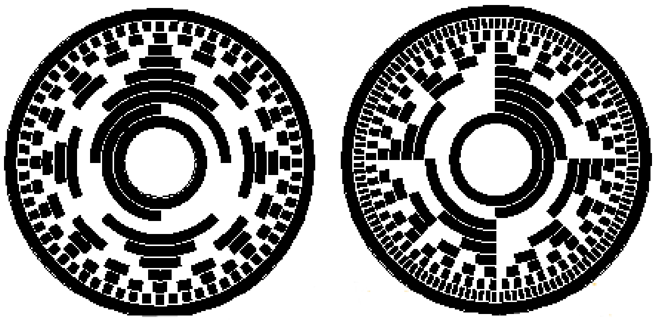
The number of signals per turn defines the resolution of the device

Inner-State (Interoceptive) Sensors

- **Position Sensors: Absolute Optical Encoders**



As the shaft rotates, a pulse train is generated. Counting the number pulses gives the angle of rotation.

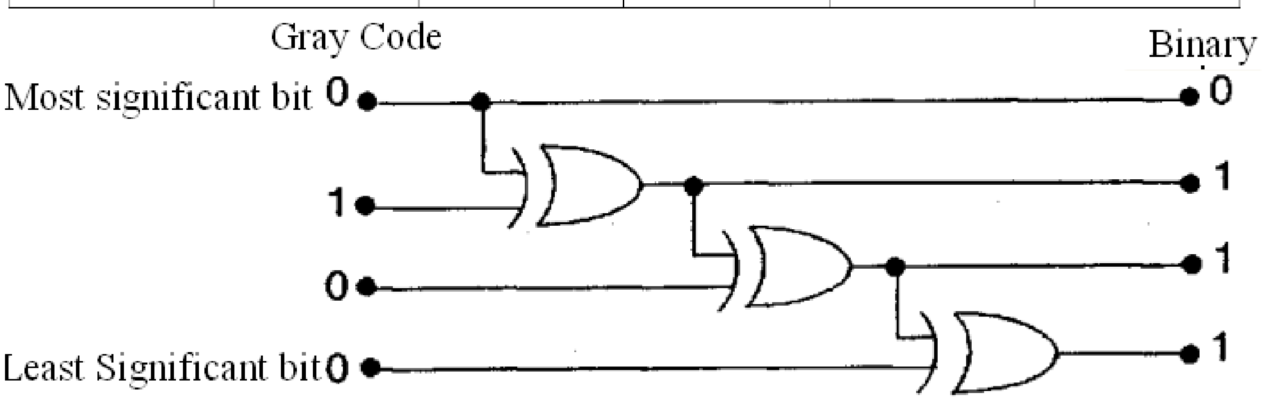


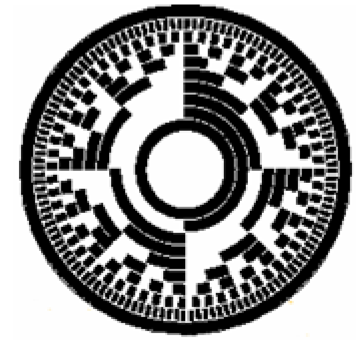
Gray Code   Binary Code

Inner-State (Interoceptive) Sensors

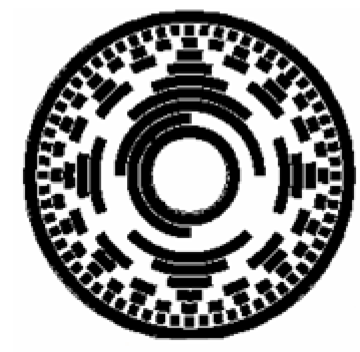
- **Position Sensors: Absolute Optical Encoders**

Decimal Number	Binary Code	Gray Code	Decimal Number	Binary Code	Gray Code
0	0000	0000	8	1000	1100
1	0001	0001	9	1001	1101
2	0010	0011	10	1010	1111
3	0011	0010	11	1011	1110
4	0100	0110	12	1101	1010
5	0101	0111	13	1101	1011
6	0110	0101	14	1110	1001
7	0111	0100	15	1111	1000





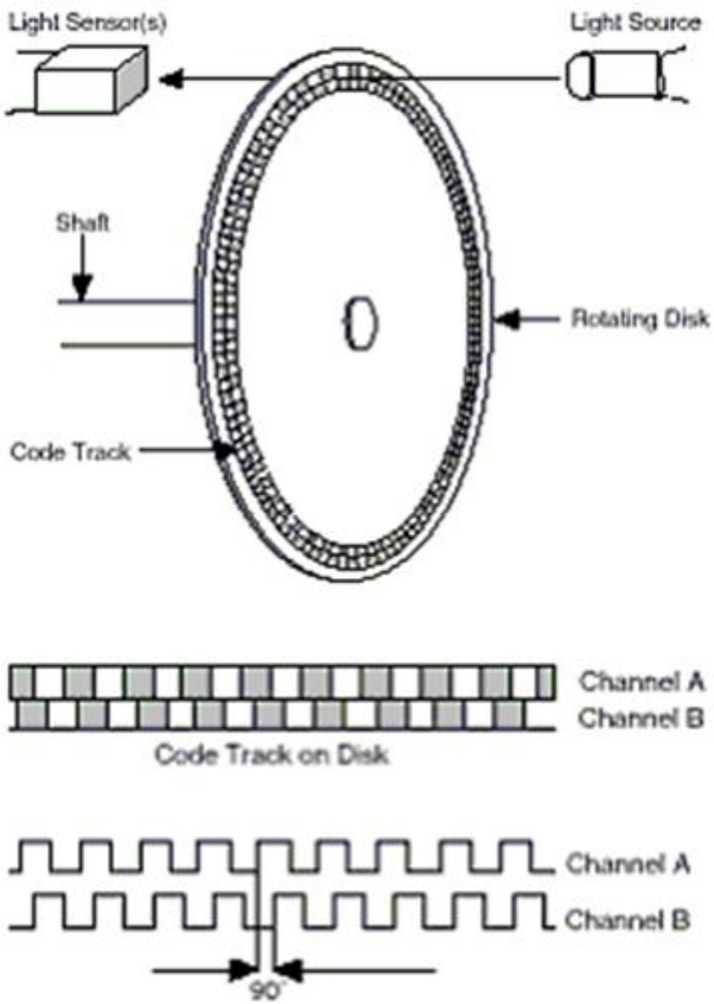
Binary Code



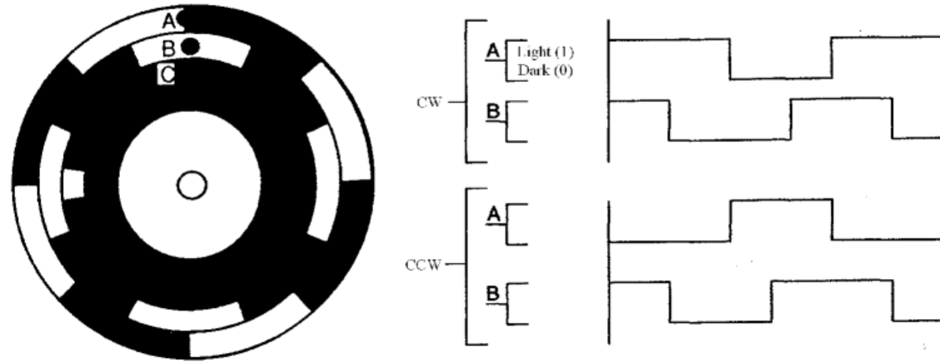
Gray Code

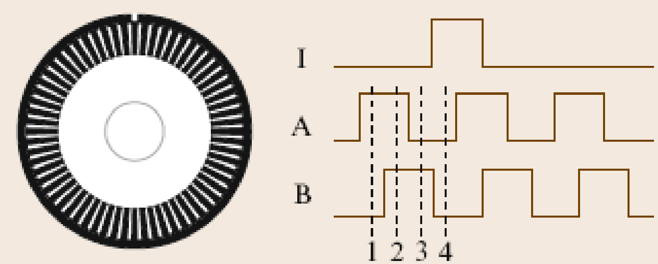
Inner-State (Interoceptive) Sensors

- **Position Sensors: Incremental Optical Encoders**



Two-Channels Encoder



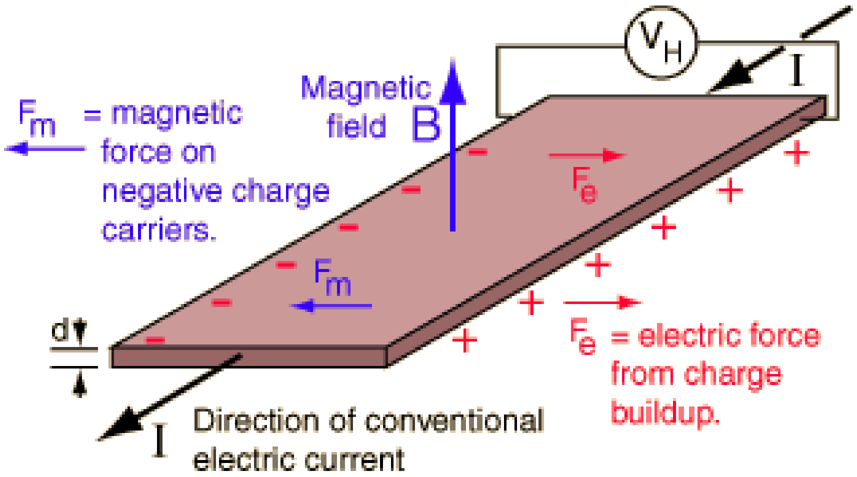


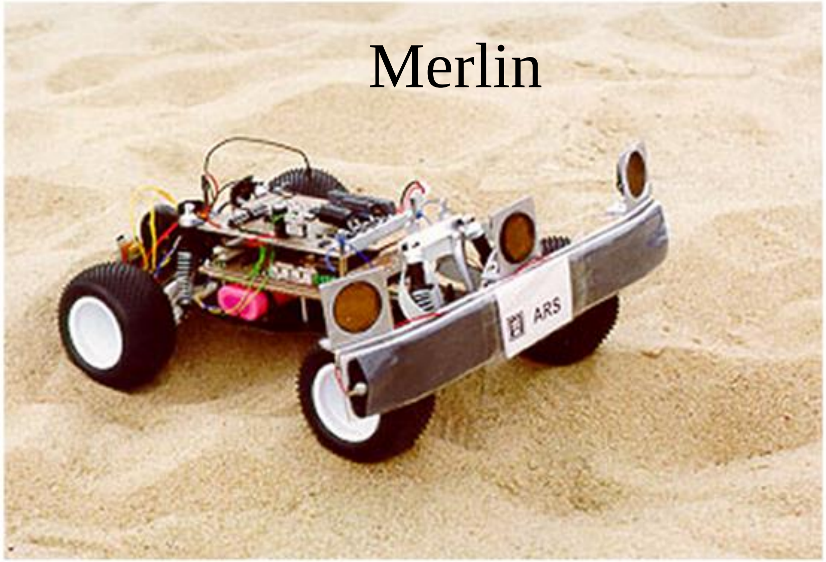
State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Sketch of the quadrature encoder disc, and output from photodetectors placed over each of the two pattern. The corresponding state changes are shown on the *right*

Inner-State (Interoceptive) Sensors

- **Position Sensors: Hall-effect Sensor**

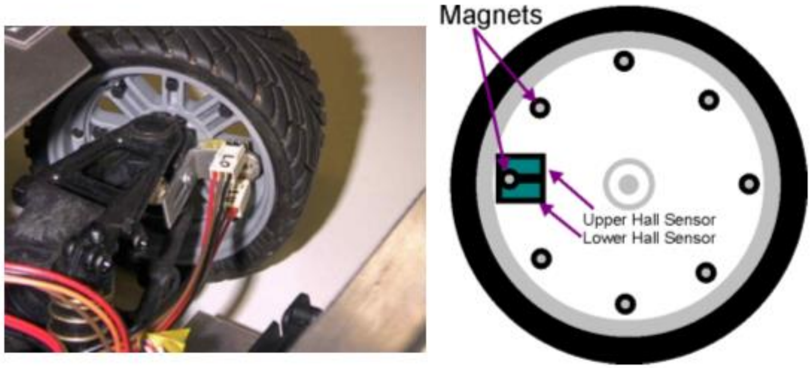




$$V_H = \frac{I.B}{n.e.d}$$

n=density of charge carriers

e=electron charge



Inner-State (Interoceptive) Sensors

- **Orientation Sensors**

Gyroscopes and gyrocompasses rely on the principle of the conservation of angular momentum.

Angular momentum is the tendency of a rotating object to keep rotating at the same angular speed about the same axis of rotation in the absence of an external torque.

$$L = I \times \omega$$

L: the angular momentum

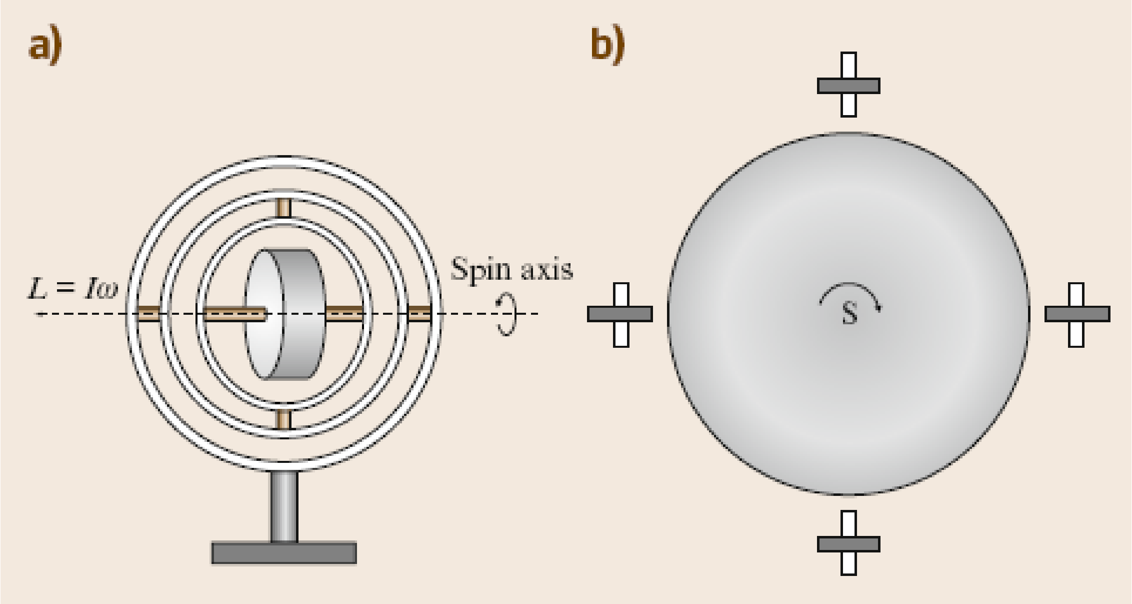
I: moment of inertia

ω : angular speed

[4]

Inner-State (Interoceptive) Sensors

- **Orientation Sensors**



Mechanical gyroscope

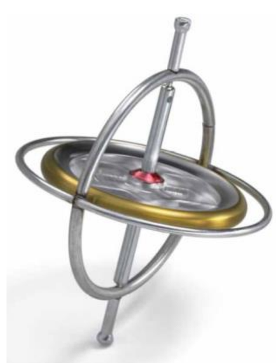
(a) Traditionally gimballed gyroscope. The gimbal provides the gyroscope the freedom to rotate about its axis as the base of the gyroscope is rotated.

(b) A gyroscope. as it is rotated around the planet. The wheel of the gyroscope (grey) remains in the same orientation as it revolves with the planet. To an observer on the planet the gyroscope will appear to rotate.

[4]

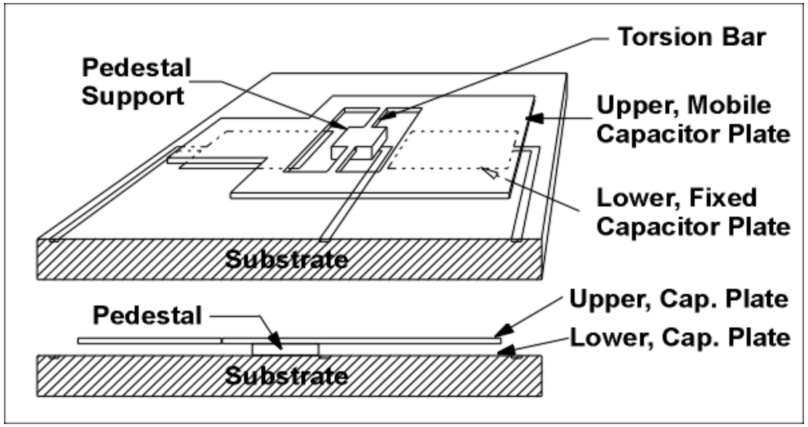
Inner-State (Interoceptive) Sensors

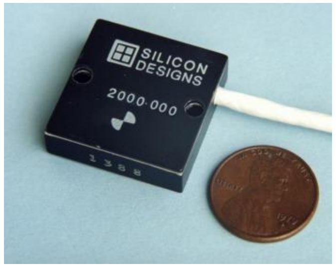
- **Heading Sensor**
  - Heading sensors can be proprioceptive (gyroscope, inclinometer) or exteroceptive (compass).
  - Used to determine the robots orientation and inclination.
  - Allow, together with an appropriate velocity information, to integrate the movement to an position estimate.
  - This procedure is called dead reckoning (ship navigation)

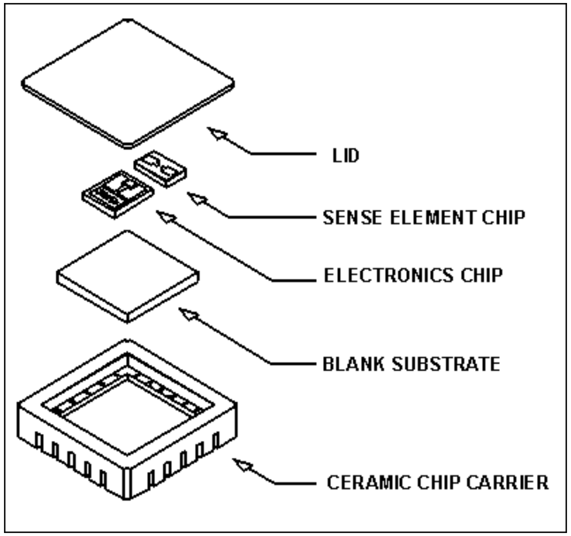


Inner-State (Interoceptive) Sensors

- **Acceleration Sensor**







Inner-State (Interoceptive) Sensors

- **Inertial Measurement Units (IMU)**

An IMU typically includes both accelerometers and gyros.

◇ **Accelerometers** are sensitive to all types of acceleration, which implies that both translation motion and rotation (centripetal forces) are measured in combination.

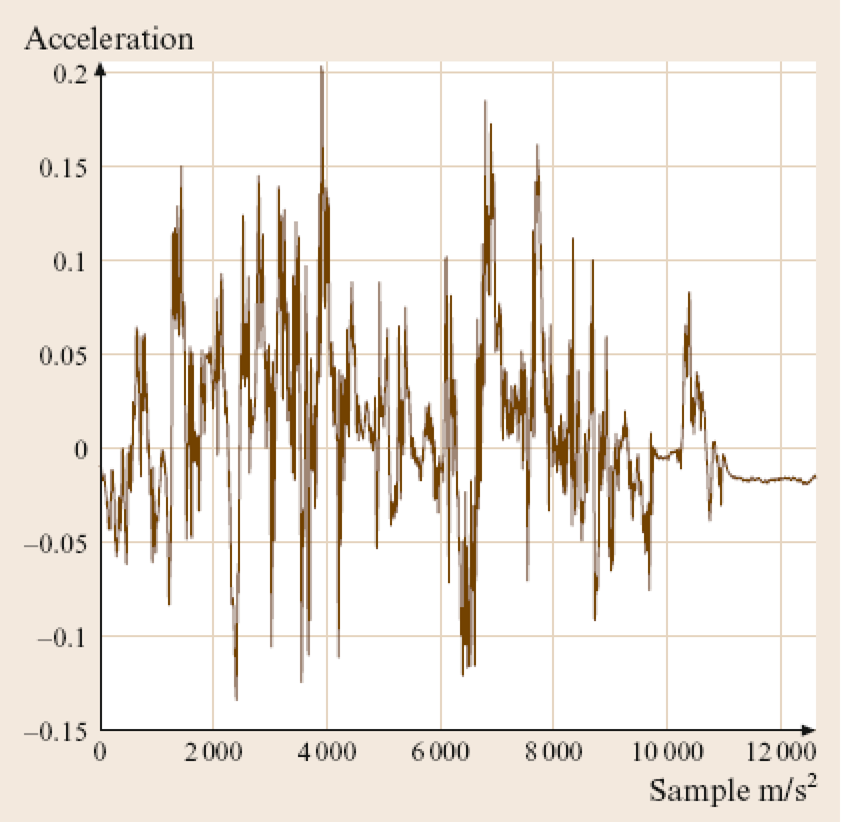
◇ **Joint IMU** units allow the estimation of rotation and translation, and allow for **double integration** to estimation the velocity, orientation, and position of a system.

MPU-6050: 6-DOF (3-axis gyroscope, 3-axis accelerometer)

[2]

Inner-State (Interoceptive) Sensors

- **Inertial Measurement Units (IMU)**
  - ◇ One of the problems associated with the use of an IMU is the need for **double integration**.
  - ◇ Small biases and noise can result in significant divergence in the final estimate, which calls for use of detailed models and careful calibration and identification of sensor characteristics.



Example data from an IMU unit for driving on an unpaved road

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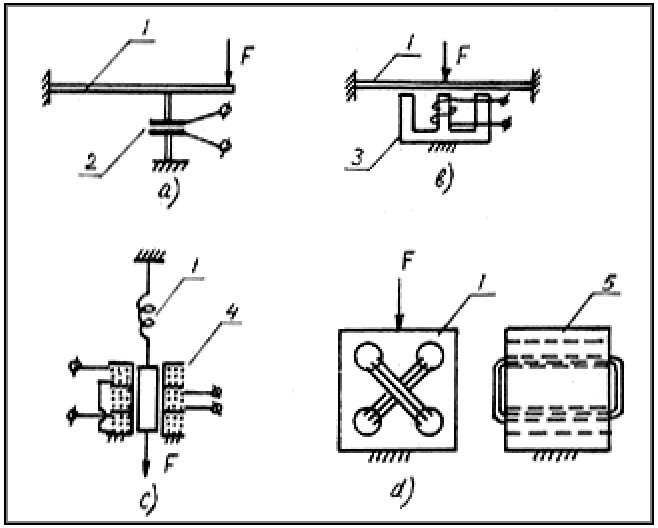
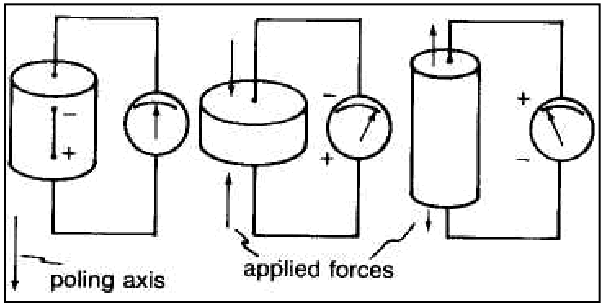
Inner-State (Interoceptive) Sensors

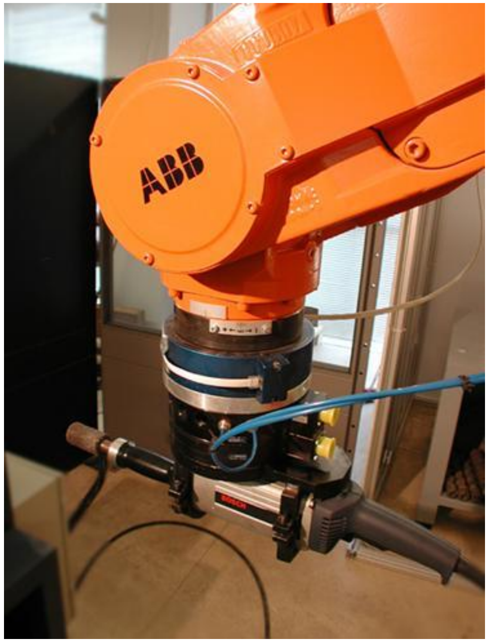
- **Force and Torque Sensor**



Variable Reluctance



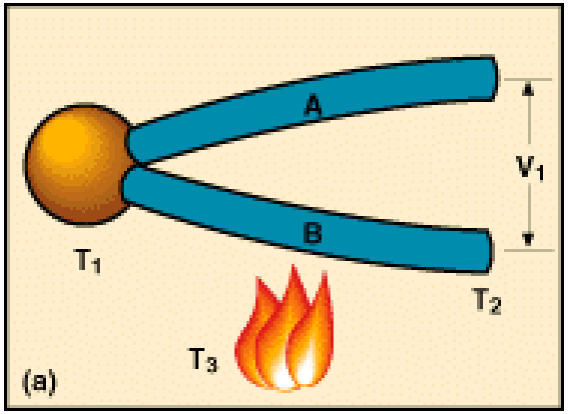
Piezoelectric



For more information: http://robotics.dem.uc.pt/norberto/jr3pci/ft_sensors.htm

Inner-State (Interoceptive) Sensors

- **Temperature Sensor**
  - Peltier-Seebeck Effect

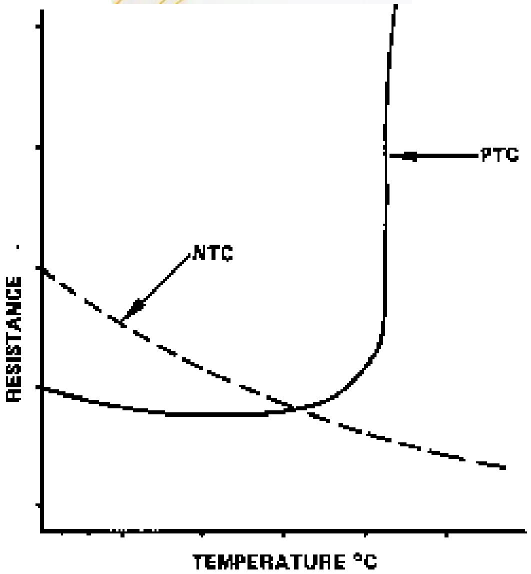


$V_1 \approx k\ (t_1 - t_2)$

The Peltier–Seebeck effect, or thermoelectric effect, is the direct conversion of thermal differentials to electric voltage and vice versa. Related effects are the Thomson effect and Joule heating.

  - Thermistors

[therm(al) + (res)istor.]



Inner-State (Interoceptive) Sensors

- **Other sensors**
  - **Battery-Level Sensing:** By sensing its battery voltage, a robot can determine when it is time to return to the charging station or curtail power-draining operations. Only a voltage divider is needed to design a battery-level indicator.
  - **Stall Current Sensing:** One reliable way to determine if a robot is stuck is to monitor the current being used to drive the motors. If all other sensors fail to detect an imminent collision, the robot will, in short order, come to rest against the obstacle. In this situation, the wheels will stop rotating while current to the motors will go to a maximum. Thus, motor current serves as a collision detector of last resort.

Outline

- Introduction to Sensors
- Inner-State (Interoceptive) Sensors
- **Surface Sensors**
- Outer-State (Exteroceptive) Sensors
- Innovative Sensor Technologies
- Summary

Surface Sensors

Surface Sensors provide information from the robot's surface.

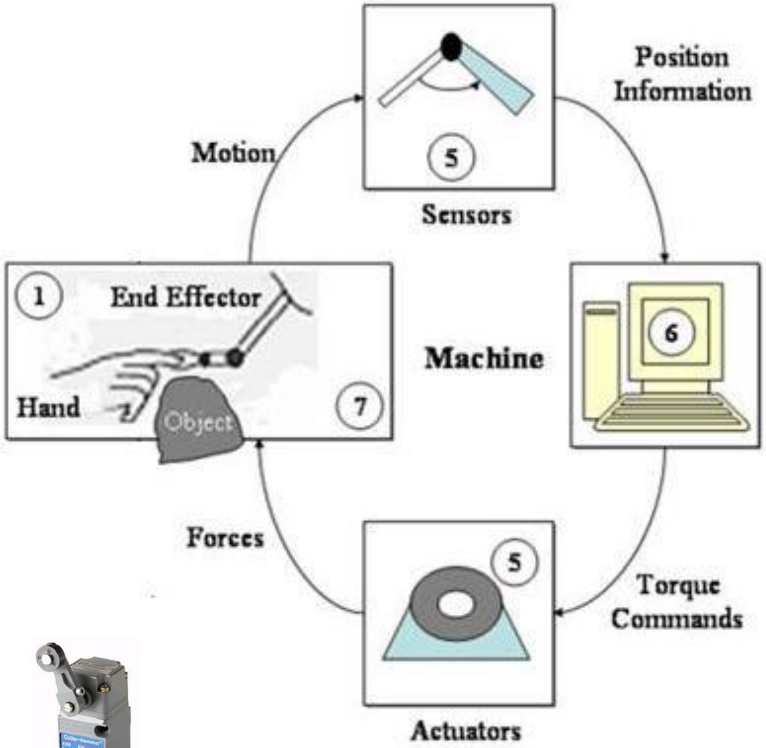
Examples:

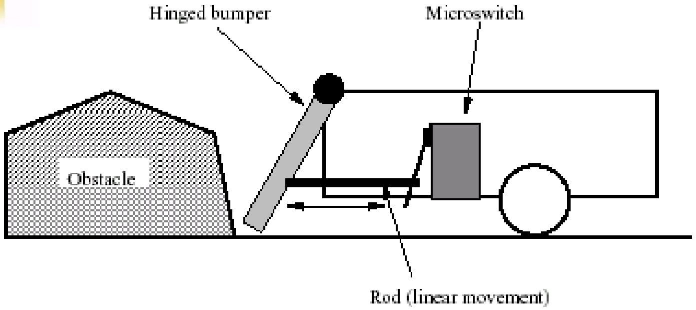
◇ Push Buttons and Limit Switches

◇ Tactile Sensors/Artificial Skin

Surface Sensors

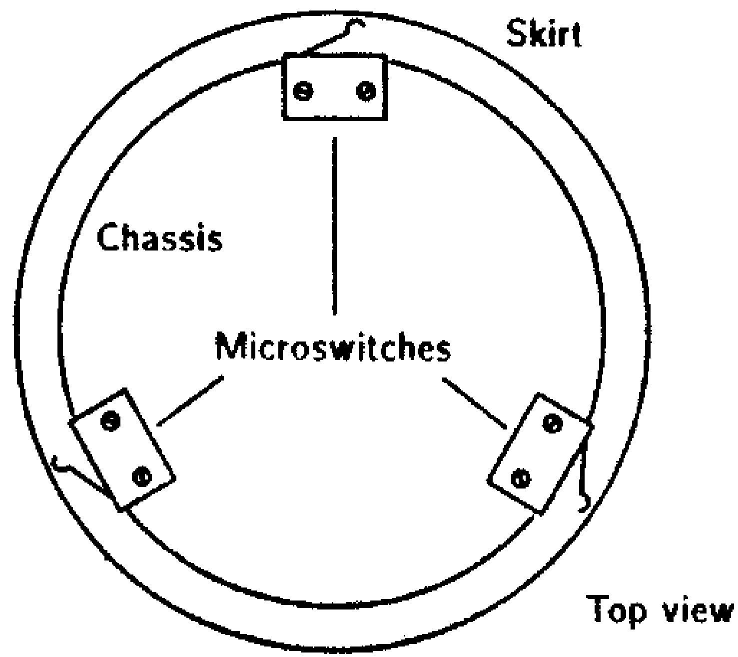
- **Limit Switches / Push Buttons**
  - ◇ A contact sensor must physically touch an object before the sensor is activated.
  - ◇ When the switch is pressed the circuit is closed and current flows, and when it is released the circuit is open and no current flows.
  - ◇ Thus the output of these sensors is a **binary value**.
    - ➢Push buttons detect operator input
    - ➢Limit switches detect collisions.





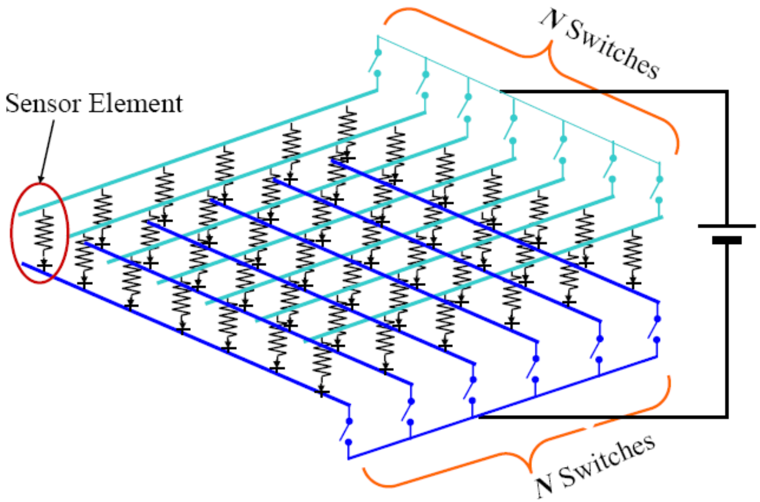
Surface Sensors

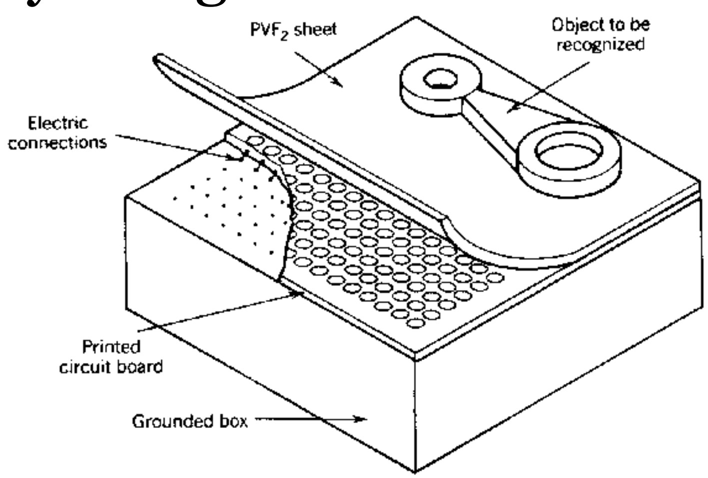
- **Limit Switches / Push Buttons**
  - ◇ The using of micro Limit switches in a Robot is shown in the following figure.
  - ◇ It’s used to detect if the robot touches any obstacle in its environment while operating.



Surface Sensors

- **Tactile Sensors/Artificial Skin**
  - ◇ Tactile sensors are able to detect an object and recognize its shape.
  - ◇ Artificial skin can be formed by aggregating multiple sensing points in form of digital sensor array using VLSI.





Measuring 2-D pressure distribution

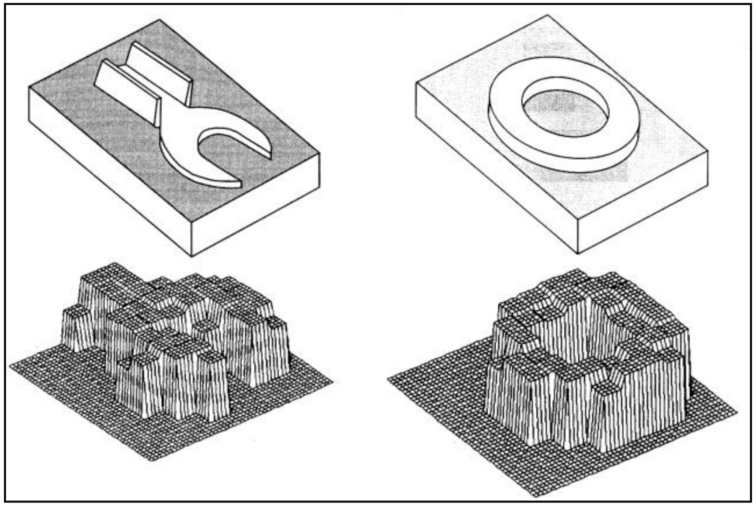
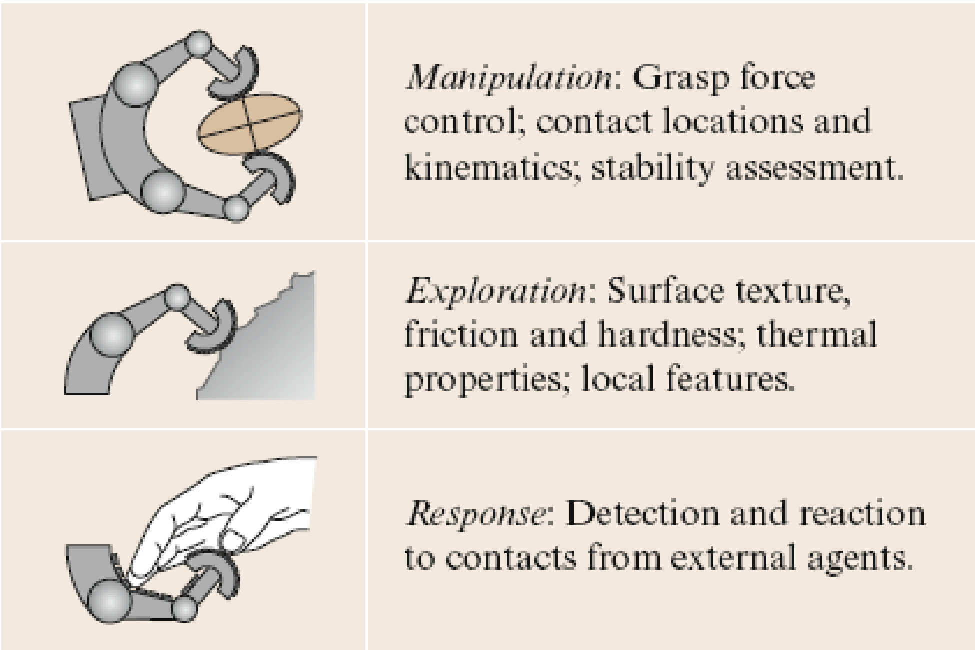


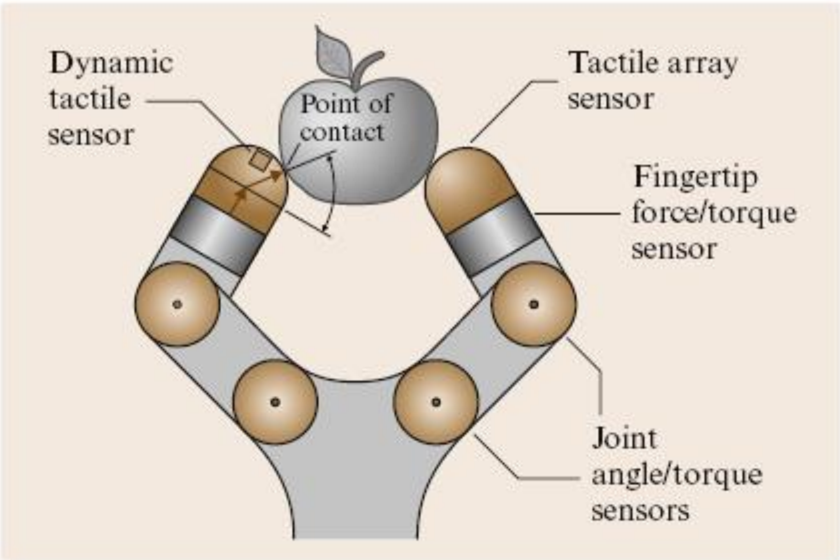
Image formation from tactile sensor data

Surface Sensors

- **Tactile Sensors/Artificial Skin**



Uses of tactile sensing in robotics



Robot hand with fingertip force and tactile sensing. Information from the force sensors can be combined with knowledge of fingertip geometry to estimate contact location, referred to as intrinsic tactile sensing

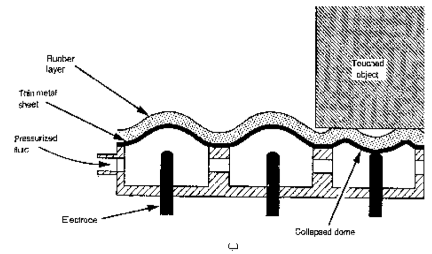
[3]

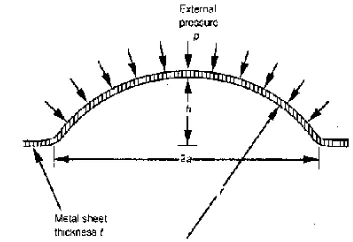
Surface Sensors

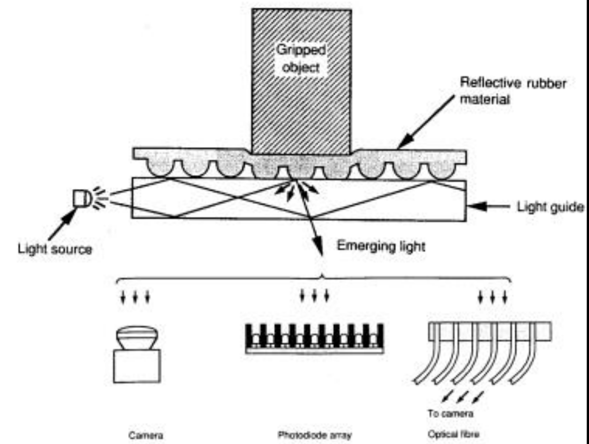
• **Tactile Sensors/Artificial Skin**

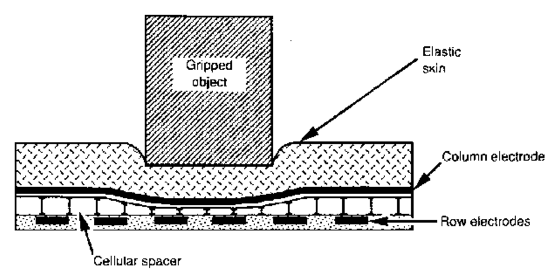
Other types of artificial skin include:

- Piezoresistive sensors (conductive elastomers, carbon felt carton fibers, piezoelectric polymers);
- Optical sensors (frustrated internal reflection, opto-mechanical);
- Ultrasonic sensors;
- Capacitive sensors;
- Electrochemical sensors.









For more details: R. Russell. *Robot Tactile Sensing*. Prentice Hall Australia, 1990.

Surface Sensors

- **Tactile Sensors/Artificial Skin**

Sensor modality	Sensor type and attributes	Advantages	Disadvantages
Normal pressure			
	Piezoresistive array [19.3–8]		
	• Array of piezoresistive junctions • Embedded in an elastomeric skin • Cast or screen printed	• Simple signal conditioning • Simple design • Suitable for mass production	• Temperature sensitive • Frail • Signal drift and hysteresis
	Capacitive array [19.9–13]		
	• Array of capacitive junctions • Row and column electrodes separated by elastomeric dielectric	• Good sensitivity • Moderate hysteresis, depending on construction	• Complex circuitry
	Piezoresistive MEMS array [19.14, 15]		
	• Silicon micromachined array with doped silicon strain-gauged flexures	• Suitable for mass production	• Frail
	Optical [19.16]		
	• Combined tracking of optical markers with a constitutive model	• No interconnects to break	• Requires PC for computing applied forces

[For reading]

[3]

Surface Sensors

- **Tactile Sensors/Artificial Skin**

Skin deformation

Optical [19.17]		
• Fluid-filled elastomeric membrane • Tracking of optical markers inscribed on membrane coupled with energy minimization algorithm	• Compliant membrane • No electrical interconnects to be damaged	• Complex computations • Hard to customize sensor
Magnetic [19.18]		
• Array of Hall-effect sensors		• Complex computations • Hard to customize sensor
Resistive tomography [19.19]		
• Array of conductive rubber traces as electrodes	• Robust construction	• Ill-posed inverse problems
Piezoresistive (curvature) [19.20]		
• Employs an array of strain gauges	• Directly measure curvature	• Frailty of electrical interconnects • Hysteresis

[For reading]

[3]

Surface Sensors

- **Tactile Sensors/Artificial Skin**

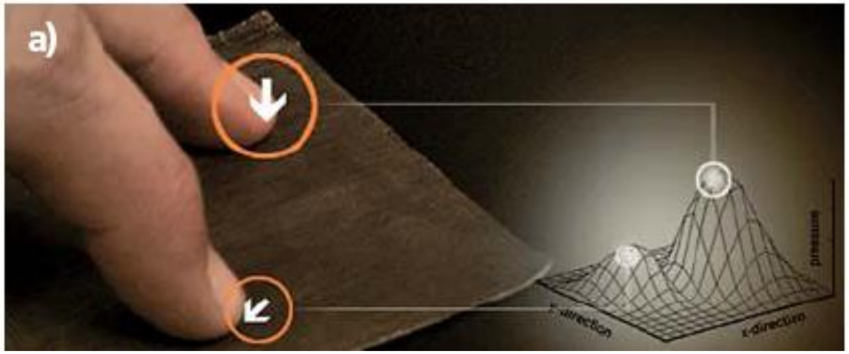
Dynamic tactile sensing		
Piezoelectric (stress rate) [19.21–23]		
• PVDF (polyvinylidene difluoride) embedded in elastomeric skin	• High bandwidth	• Frailty of electrical junctions
Skin acceleration [19.23, 24]		
• Commercial accelerometer affixed to robot skin	• Simple	• No spatially distributed content • Sensed vibrations tend to be dominated by structural resonant frequency

[For reading]

[3]

Surface Sensors

- **Tactile Sensors/Artificial Skin**



(a) TactArray, a flexible capacitive array tactile sensor from Pressure Profile Systems, Inc., is appropriate for sensing contact locations and areas under sliding conditions.

(b) Conformable TactArray sensors can fit on a human or robotic hand (courtesy Pressure Profile Systems, Inc.)

[2]

Outline

- Introduction to Sensors
- Inner-State (Interoceptive) Sensors
- Surface Sensors
- **Outer-State (Exteroceptive) Sensors**
- Innovative Sensor Technologies
- Summary

Outer-State (Exteroceptive) Sensors

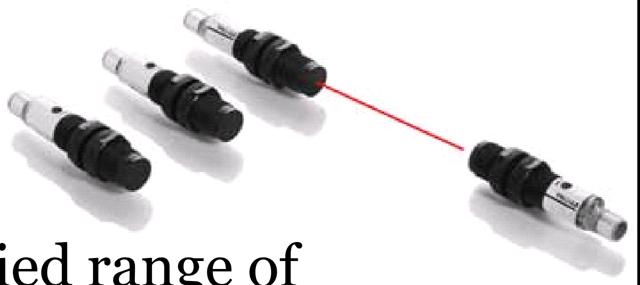
Outer-state or external-state or Exteroceptive Sensors provide information from the robots environment such as distances to objects, intensity of the ambient light, unique features.

Examples:

- ◇ Proximity sensors
- ◇ Range Sensors (SONAR, LIDAR, RADAR)
- ◇ Ground Penetrating Radar (GPR)
- ◇ Vision Systems

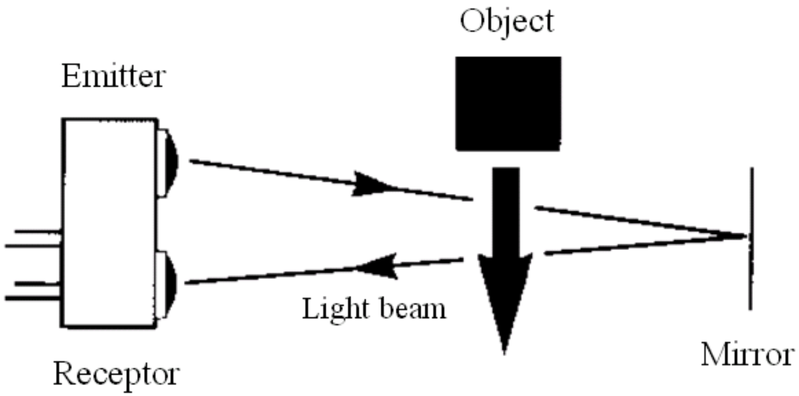
Outer-State (Exteroceptive) Sensors

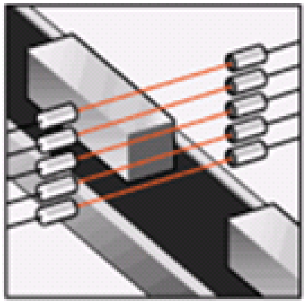
- **Proximity Sensors**



Proximity sensors detect the presence of an object when the object comes within a specified range of the sensor **without physically touching** it.

- **Optical Proximity Sensors**
  - ◇ They consist of a light emitter and receiver.
  - ◇ They detect the presence of an object by reflection. If the object is in sensitive range, it will reflect the emitted beam back to a receptor.



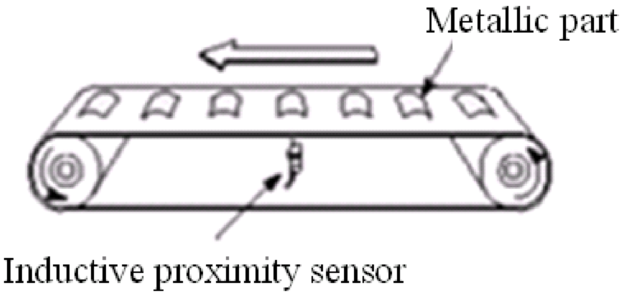


Light Barrier

Outer-State (Exteroceptive) Sensors

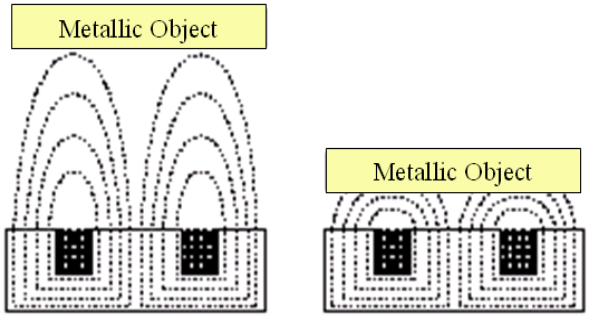
- **Inductive Proximity Sensors**

Inductive sensors use electro-magnetic induction to sense **metal objects**, typically iron and steel, by inducing a current in them.



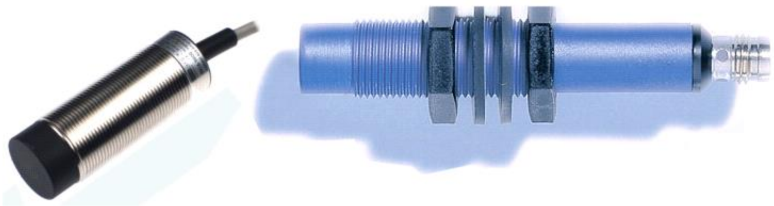
$$V = -N \frac{dBA}{dt}$$

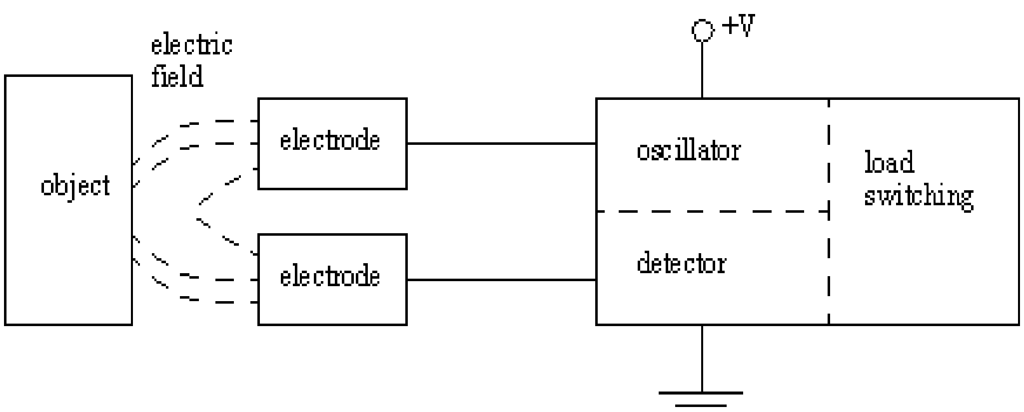
where
N-- is the number of turns,
B-- is the amplitude of magnetic field
A-- is the area of the circuit where is in the magnetic field.

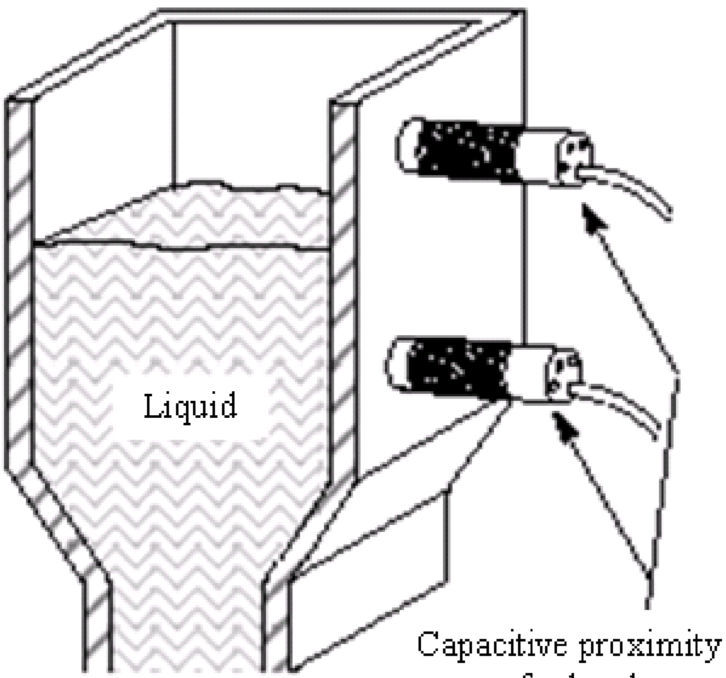


Outer-State (Exteroceptive) Sensors

- **Capacitive Proximity Sensors**
  - ◇ Capacitive proximity sensors reliably detect non-metallic objects, liquid, powder & granular materials.
  - ◇ They can also detect materials through glass or plastic walls.







Capacitive proximity sensor for level detection

Outer-State (Exteroceptive) Sensors

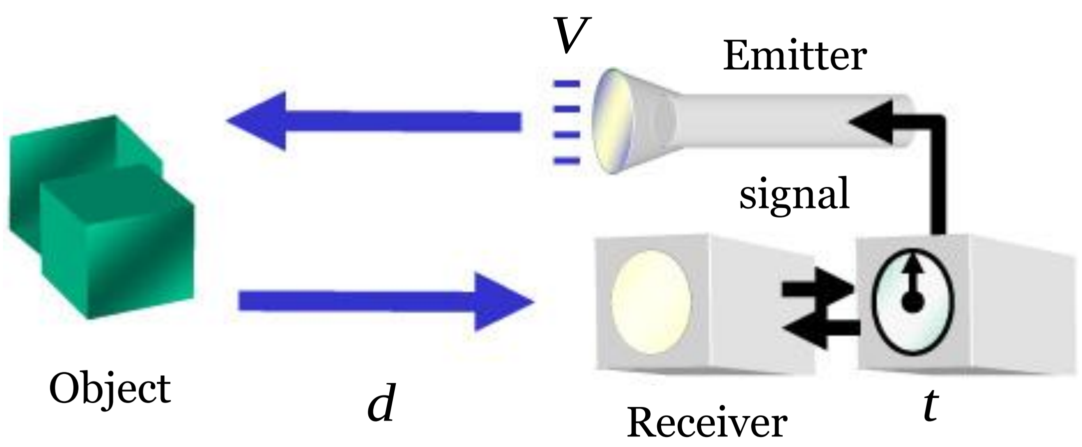
- **Range Sensors**
  - ◇ Sensors for distance measurements are among the most important ones in robotics.
  - ◇ Mobile robots are equipped with various sensor types for measuring distances to the nearest obstacle around the robot for navigation purposes.

Range Sensors

- Sonar Sensors — Sound Navigation & Ranging
- Laser Sensors — LIDAR (LIght Direction And Ranging)
- Infrared Sensors — RADAR (RAdio Direction And Ranging)

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Time-of-Flight (ToF)**
  - ◇ Time-of-flight range sensors compute distance by measuring the time that a pulse of light takes to travel from the source to the observed target and then to the detector (usually collocated with the source) [5].

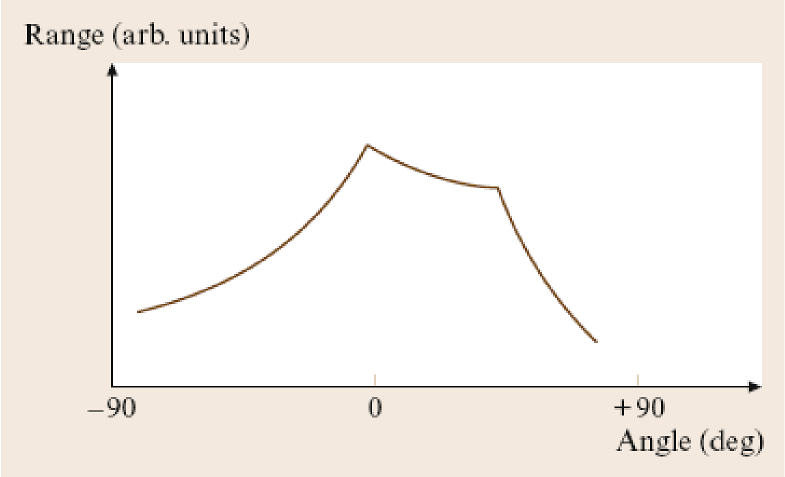


$$d = \frac{1}{2} * Vt$$

where V = speed of signal and t is the time of travel

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Time-of-Flight (ToF)**
  - ◇ Most time-of-flight sensors transmit only a single beam, thus range measurements are only obtained from a single surface point. Robotics applications usually need more information, so the range data is usually supplied as a vector of range to surfaces lying in a plane or as an image.



Ideal one-dimensional range image of sample distance versus angle of measurement

Range image where closer is darker

[5]

Outer-State (Exteroceptive) Sensors

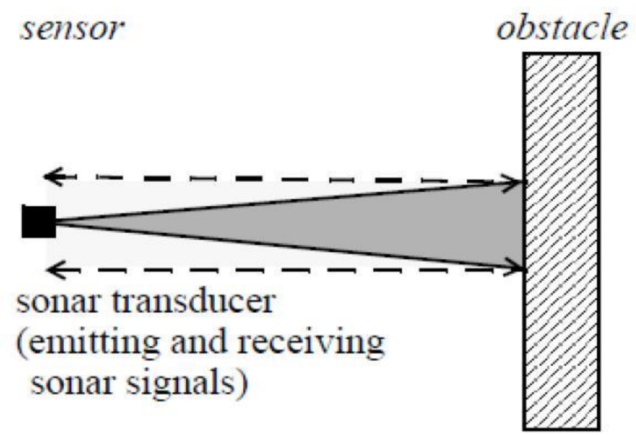
- **Range Sensors: Sonar**

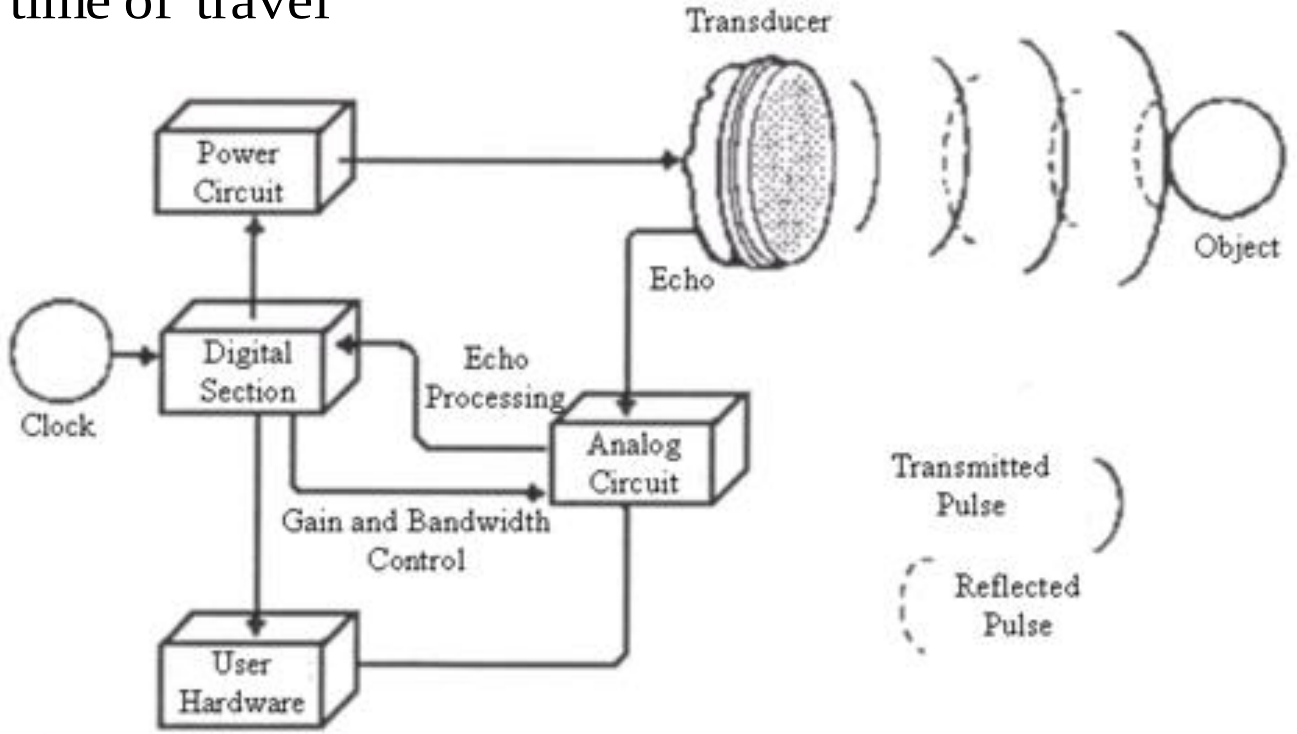
$$d = \frac{1}{2} * Vt$$

$\mathrm{V} = \text{speed of sound} = 331 + 0.6\mathrm{T}$ m/s

T is the temperature in ^{o}C

t is the time of travel

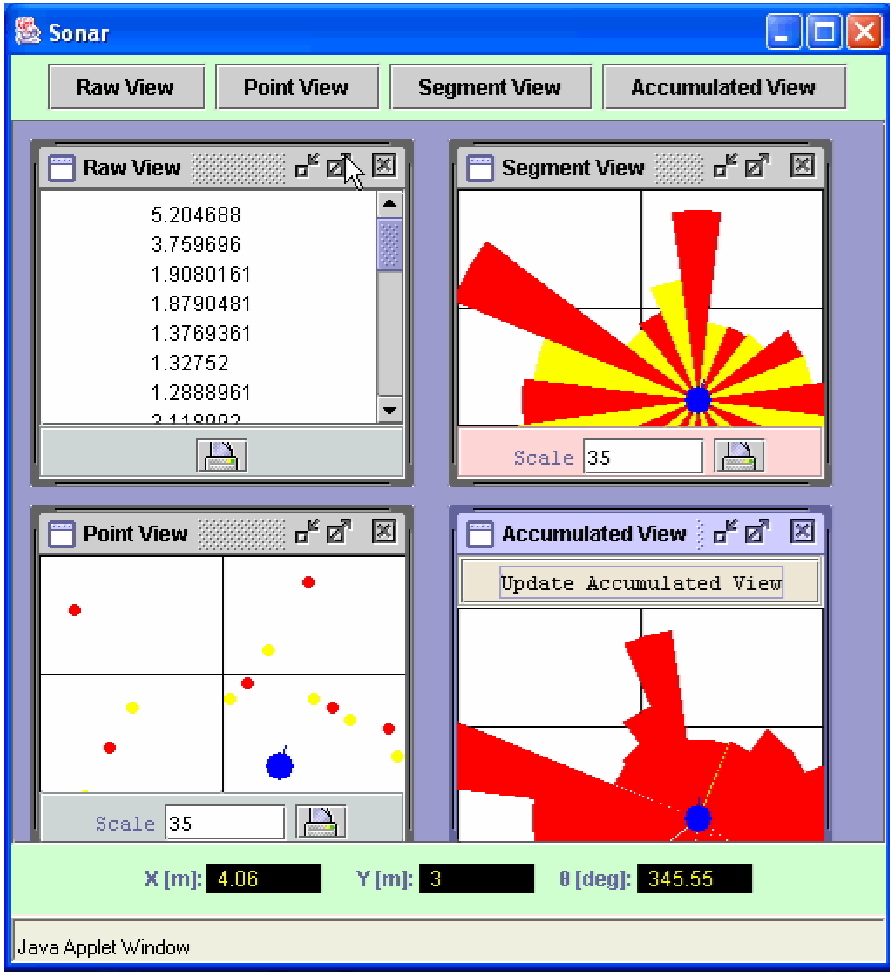




Outer-State (Exteroceptive) Sensors

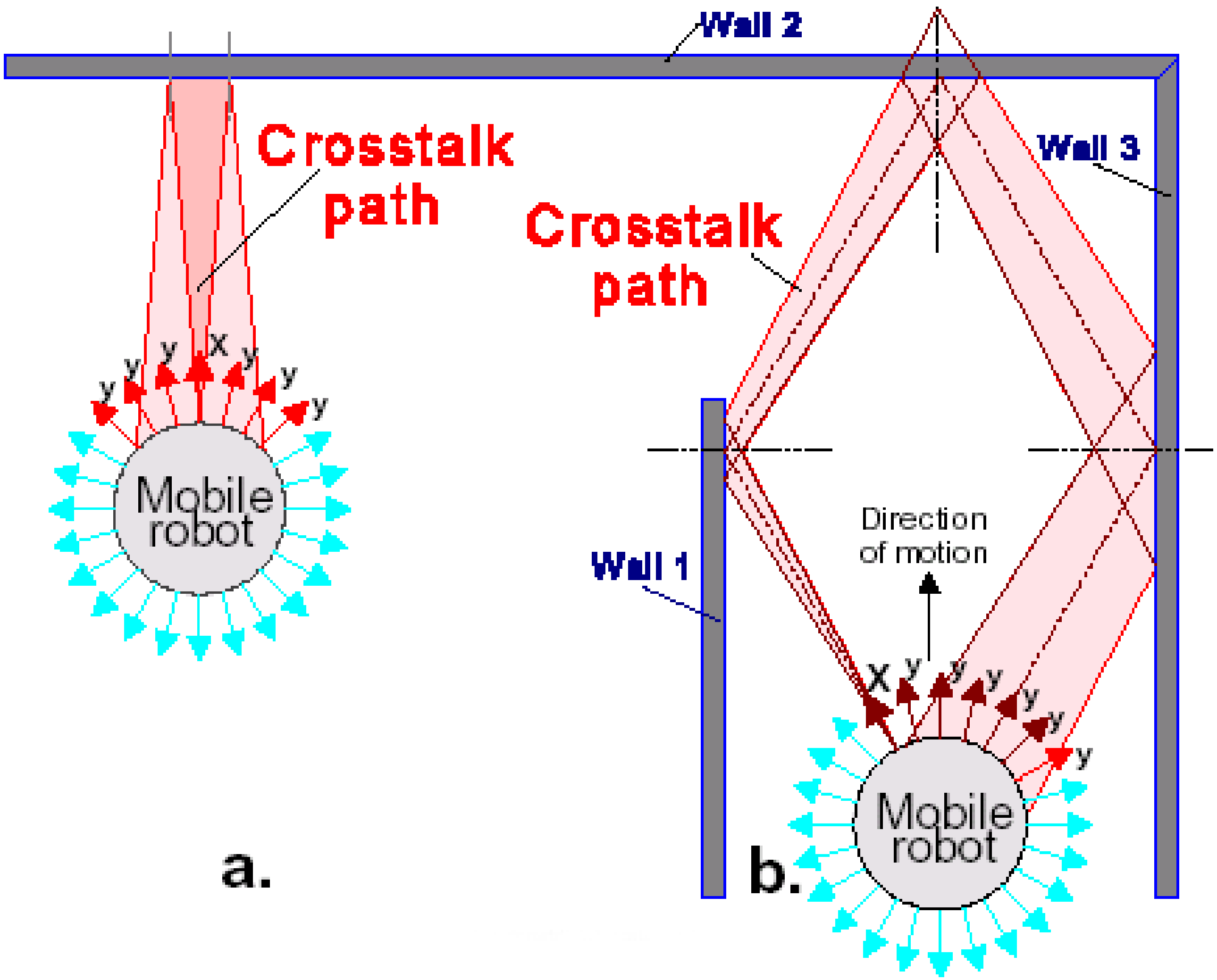
• **Range Sensors: Sonar**

Robot Navigation



Outer-State (Exteroceptive) Sensors

- **Range Sensors: Sonar**

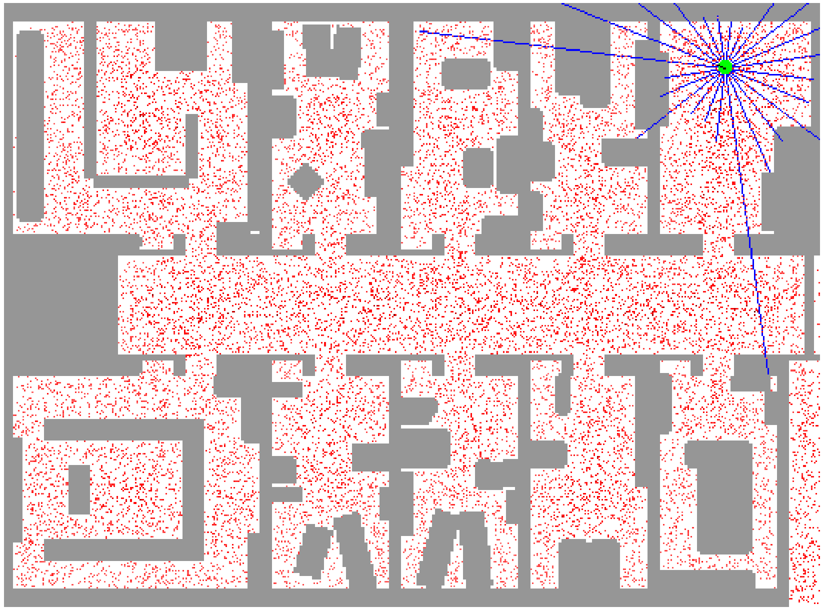


Outer-State (Exteroceptive) Sensors

- **Range Sensors: Sonar**

Sonars in robotics have three different, but related, purposes:

1. **Obstacle avoidance:** the first detected echo is assumed to measure the range to the closest object. Robots use this information to plan paths around obstacles and to prevent collisions.



[6]

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Sonar**

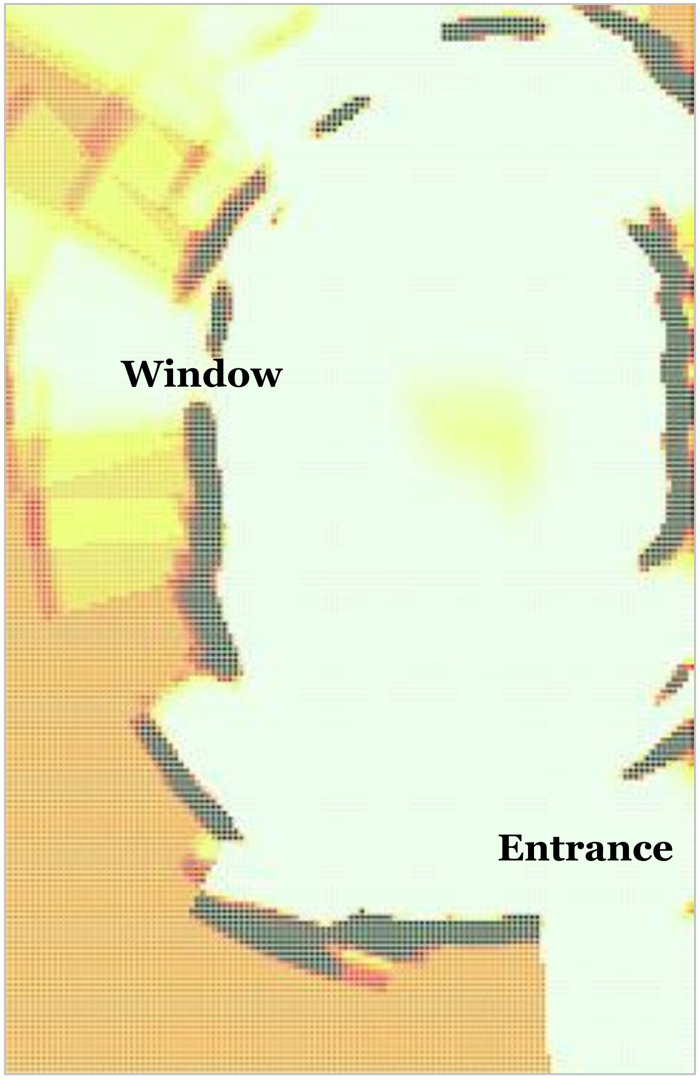
  2. **Sonar mapping:** a collection of echoes acquired by performing a rotational scan or from a sonar array is used to construct a map of the environment. Similar to a radar display, a range dot is placed at the detected range along the probing pulse direction.

[6]

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Sonar**

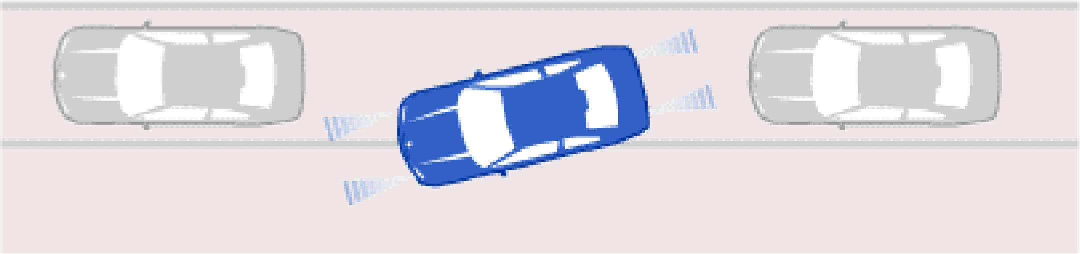
  3. **Object recognition:** a sequence of echoes or sonar maps is processed to classify echo-producing structures composed of one or more physical objects. When successful, this information is useful for robot registration or landmark navigation.



[6]

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Sonar**

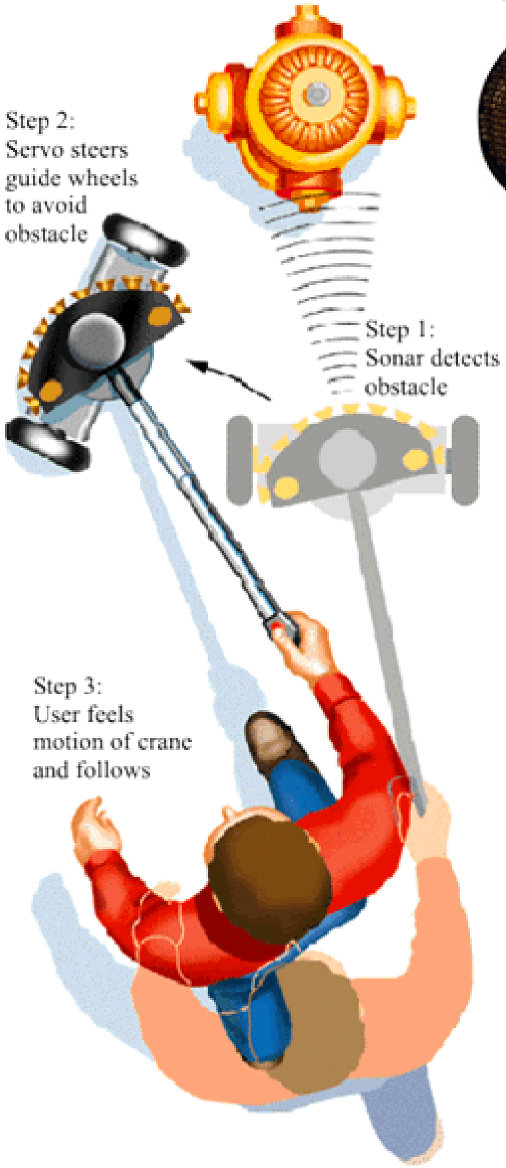


Toyota Yaris

BMW 745i

Self-Parking Cars

Aid for blind people – the small oval transducer is the transmitter and the other three components are receivers. The large oval receiver provides high resolution, enabling fixation by users' fine neck control.



Guide-Cane

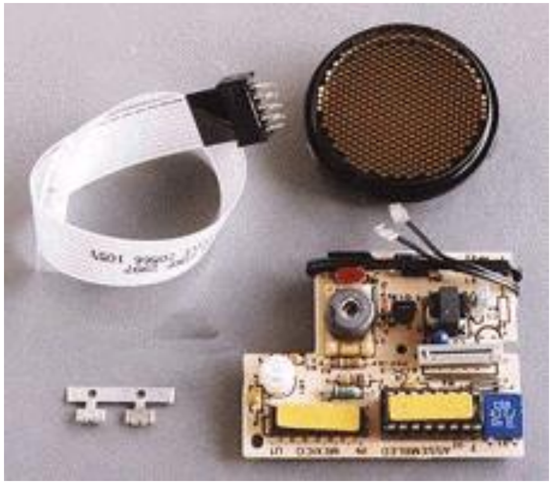
Outer-State (Exteroceptive) Sensors

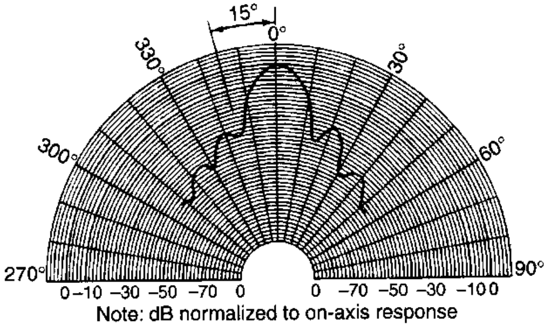
- **Range Sensors: Sonar**

Sensor	Range	Characteristics	URL
SRF04	3 cm - 3m	Small and inexpensive (£13)	http://www.robot-electronics.co.uk
SRF08	3cm - 6m	£25.5	http://www.robot-electronics.co.uk
Cebek	3cm – 1m	Inexpensive (16 euros) Can be purchased as separate units (control C-0508 and transducer C-7210)	http://www.cebek.com
Polaroid	15cm – 10m	Poor: blanking time, cross-talk, reflections 100mA-2A Big Expensive (£ 57)	http://www.acroname.com/robotics/info/articles/sonar/sonar.html

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Sonar**



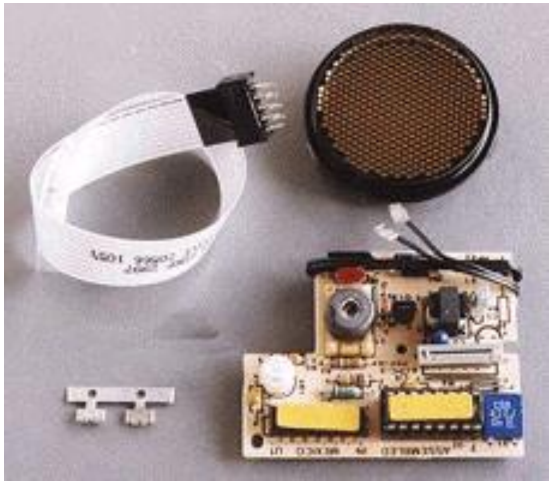


Polaroid Sensor

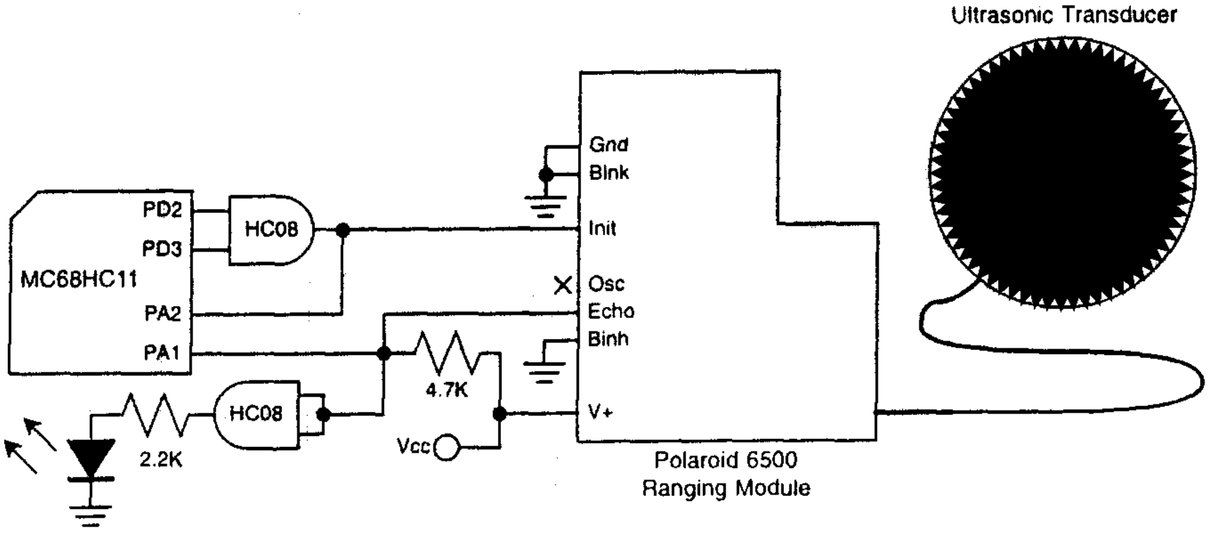
Parameter	Original	SN28827	6500 units
Maximum Range	10.5	10.5	10.5 m
Minimum Range	25	20	20 cm
Number of Pulses	56	16	16
Blanking Time	1.6	2.38	3.38 ms
Resolution	1	2	1%
Gain Steps	16	12	12
Multiple Echo	no	yes	yes
Programmable Frequency	no	no	yes
Power	4.7-6.8 200	4.7-6.8 100	4.7-6.8 V 100 mA

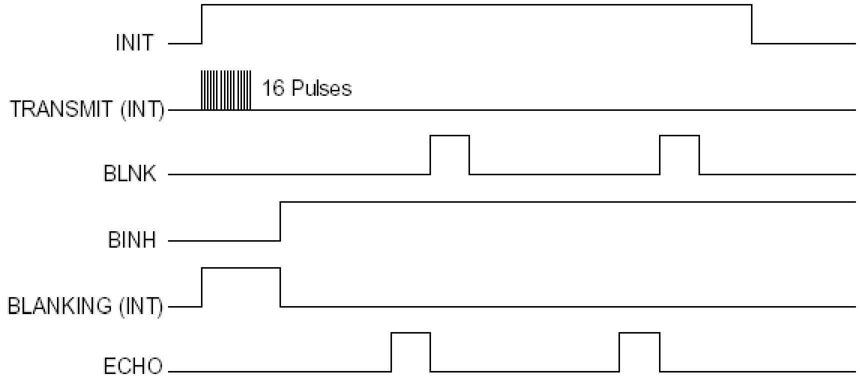
Outer-State (Exteroceptive) Sensors

- **Range Sensors: Sonar**



Polaroid Sensor





Outer-State (Exteroceptive) Sensors

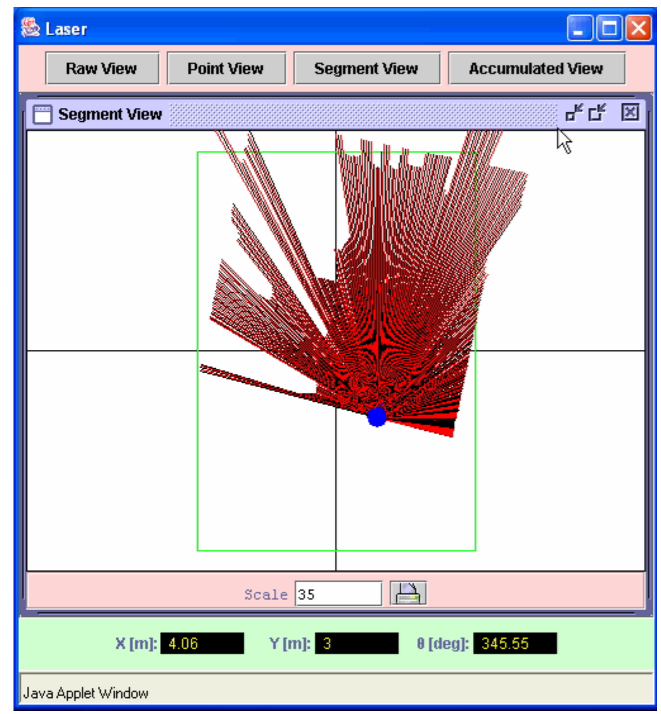
- **Range Sensors: Laser**
  - ◇ Depends on using the laser beam to determine the distance of an object. It operates on the **time of flight** principle by sending a laser pulse in a narrow beam towards the object and measuring the time taken by the pulse to be reflected off the target and returns to the sender.

180° Laser Scanner

360° Laser Scanner

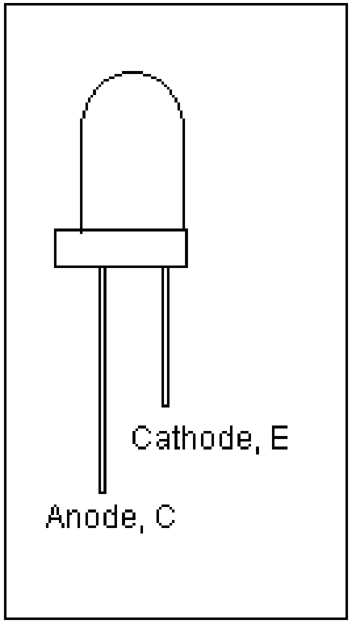
270° Laser Scanner

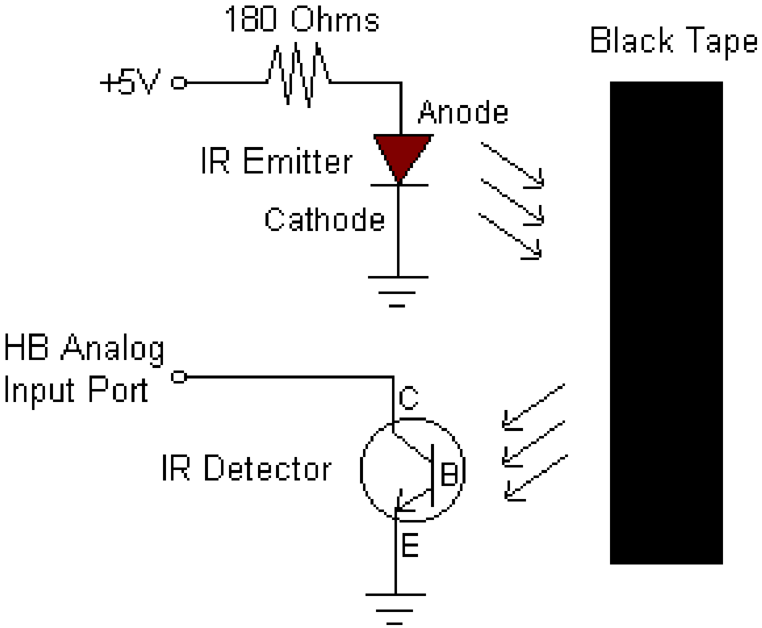
Robot using Laser sensors to scan environment



Outer-State (Exteroceptive) Sensors

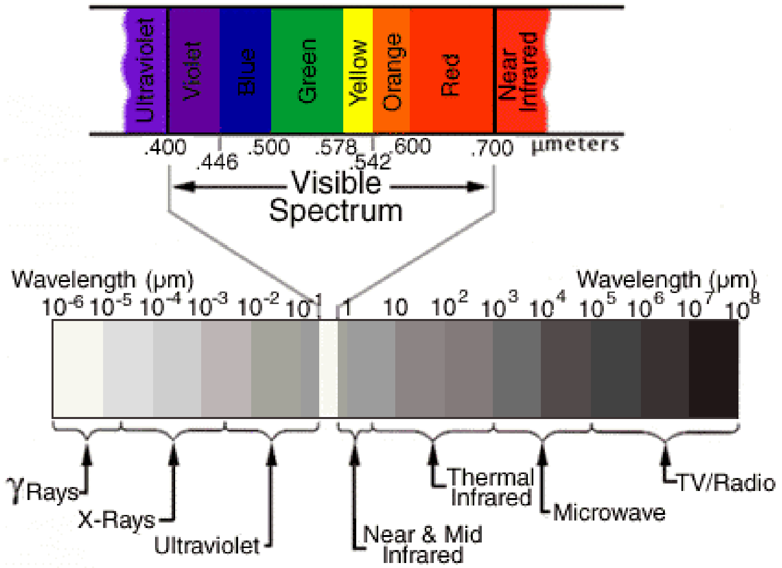
- **Range Sensors: Infrared**
  - ◇ The sensor transmits an IR beam, the beam hits an object and portion of the light reflected back through the receiver optics and strikes at a point on the **Photo Sensing Device (PSD)**.
  - ◇ **PSD** is capable of generating a voltage characteristic to the point on which the reflected beam struck.





Outer-State (Exteroceptive) Sensors

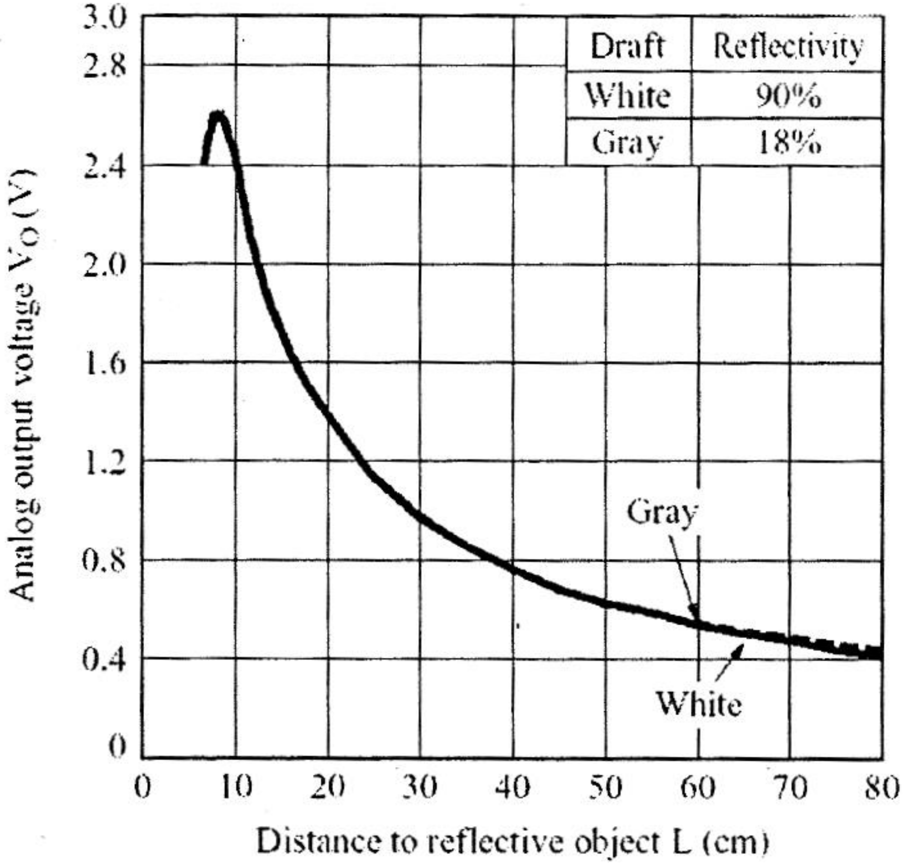
- **Range Sensors: Infrared**



Radiation	Wavelength (Angstroms)	Wavelength (centimeters)	Frequency (Hz)	Energy (eV)
Radio	$> 10^9$	> 10	$< 3 \times 10^9$	$< 10^{-5}$
Microwave	$10^9 - 10^6$	10 - 0.01	$3 \times 10^9 - 3 \times 10^{12}$	10^{-5} - 0.01
Infrared	10^6 - 7000	$0.01 - 7 \times 10^{-5}$	$3 \times 10^{12} - 4.3 \times 10^{14}$	0.01 - 2
Visible	7000 - 4000	$7 \times 10^{-5} - 4 \times 10^{-5}$	$4.3 \times 10^{14} - 7.5 \times 10^{14}$	2 - 3
Ultraviolet	4000 - 10	$4 \times 10^{-5} - 10^{-7}$	$7.5 \times 10^{14} - 3 \times 10^{17}$	$3 - 10^3$
X-Rays	10 - 0.1	$10^{-7} - 10^{-9}$	$3 \times 10^{17} - 3 \times 10^{19}$	$10^3 - 10^5$
Gamma Rays	< 0.1	$< 10^{-9}$	$> 3 \times 10^{19}$	$> 10^5$

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Infrared**



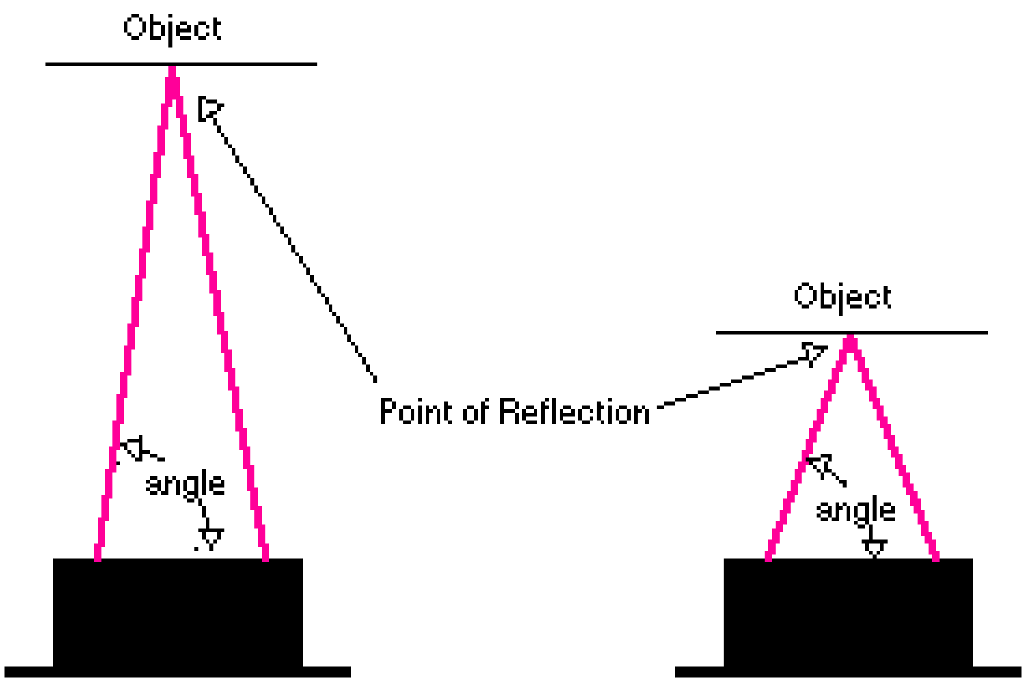
- Sensing Range: 4 – 150 cm
- 1.5^o Measurement Angle
- Affected by lightning
- Inexpensive (≈ £0.6)
- Can be used to detect color

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Infrared**

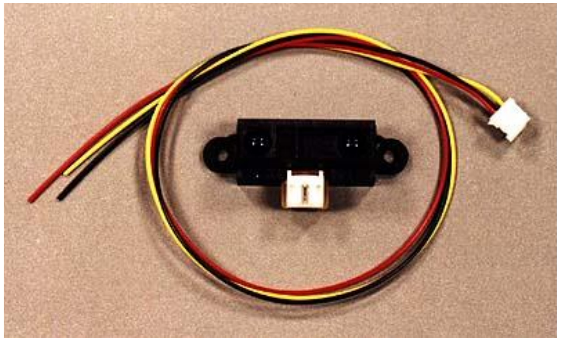
The theory of operation is based on the idea of triangulation.

Triangulation is the process of finding coordinates and distance to a point by calculating the length of one side of a triangle, given measurements of angles and sides of the triangle formed by that point and two other known reference points, using the law of sines



Outer-State (Exteroceptive) Sensors

- **Range Sensors: Infrared**

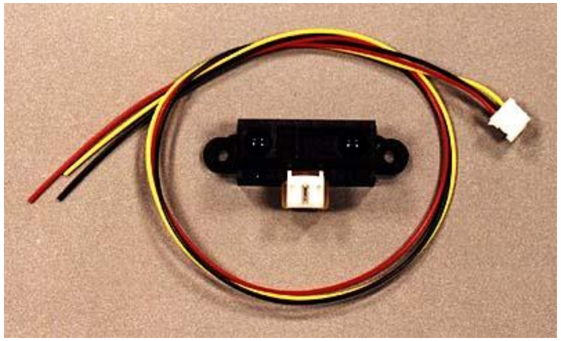


Sharp GP2Dxx

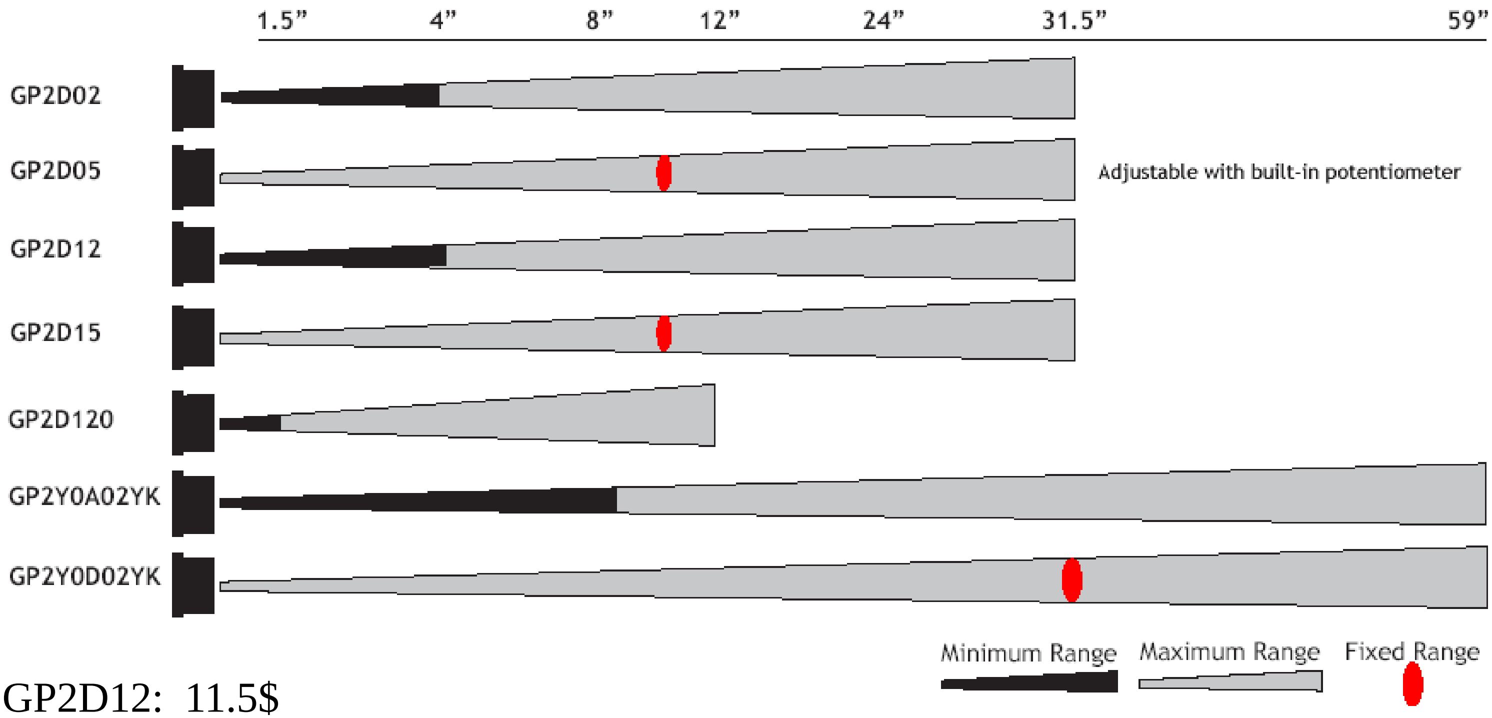
Detector	Output Type	Range	Enable Method	On Current	Off Current
GP2D02	Serial	10cm – 80cm	Each reading triggered by an external clock	~25 mA	~2 uA
GP2D05	Digital	10cm – 80cm adjustable threshold with small integrated potentiometer	Each reading triggered by an external clock	~25 mA	~2 uA
GP2D12	Analog	10cm – 80cm	Continuous readings ~38ms per reading	~25 mA	*
GP2D15	Digital	factory preset to 24cm	Continuous readings ~38ms per reading	~25 mA	*

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Infrared**



Sharp GP2Dxx

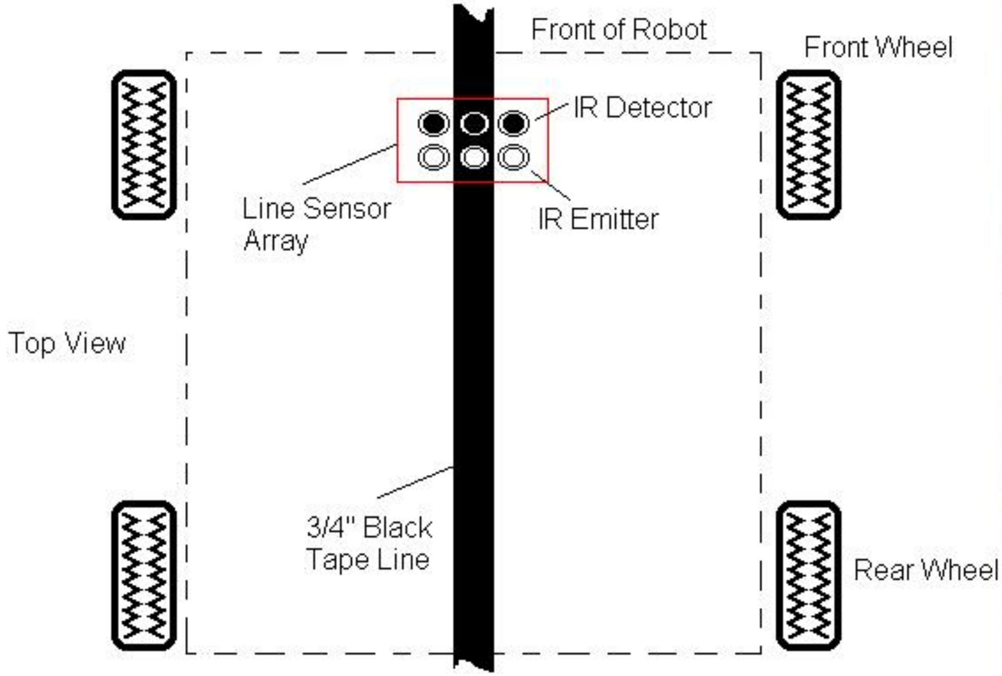


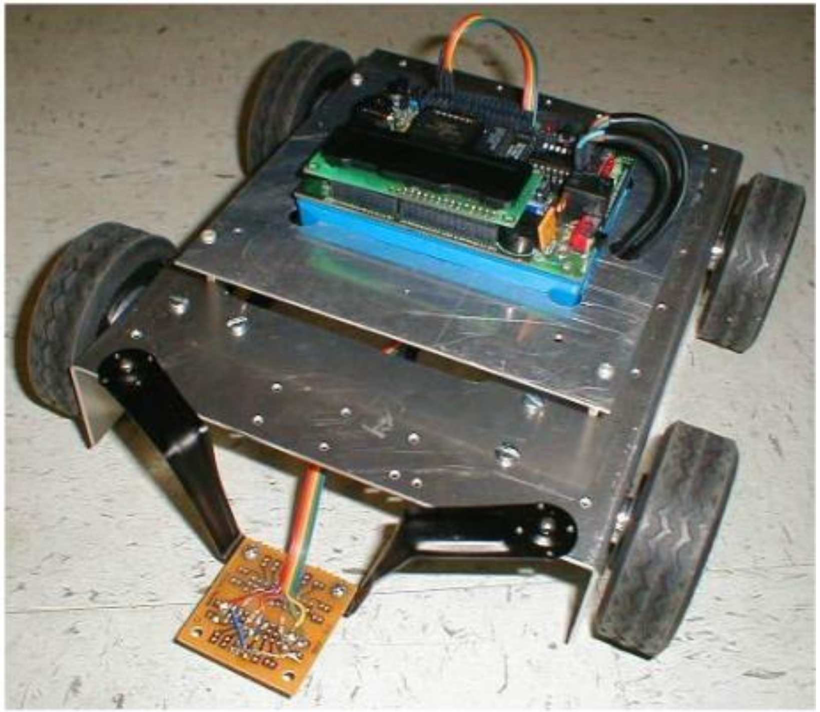
GP2D12: 11.5$

GP2Y0D02YK: 15$

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Infrared**

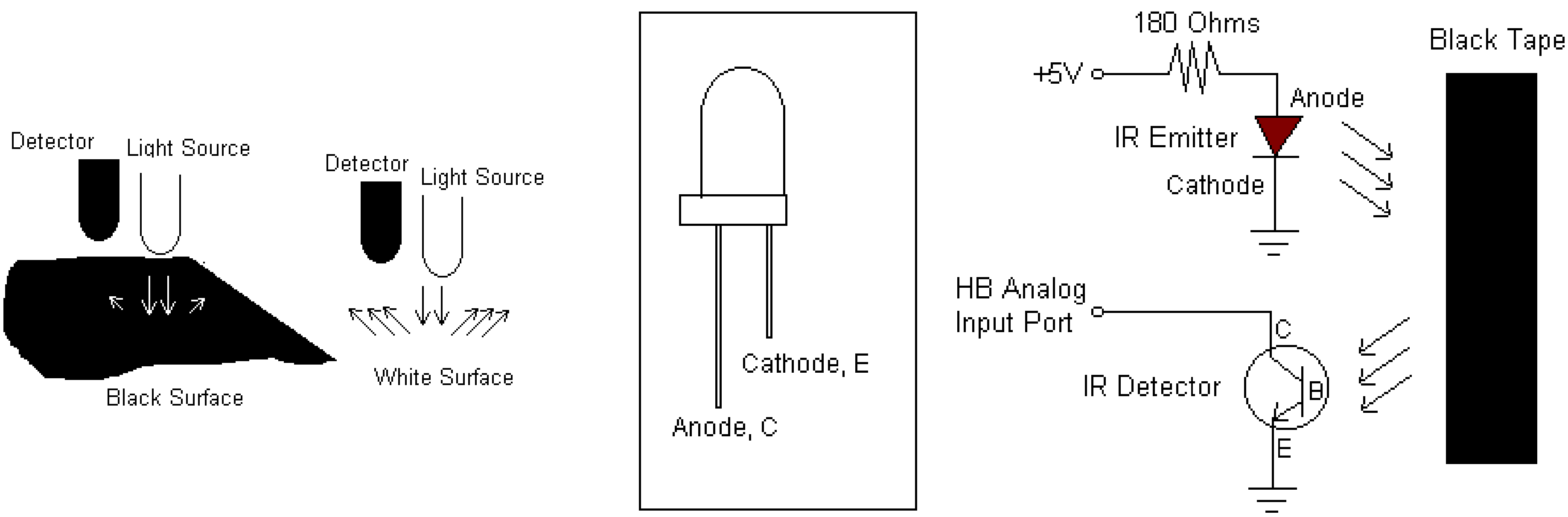




Tracker or Line Following Sensors

Outer-State (Exteroceptive) Sensors

- **Range Sensors: Infrared**



Tracker or Liner Following Sensors

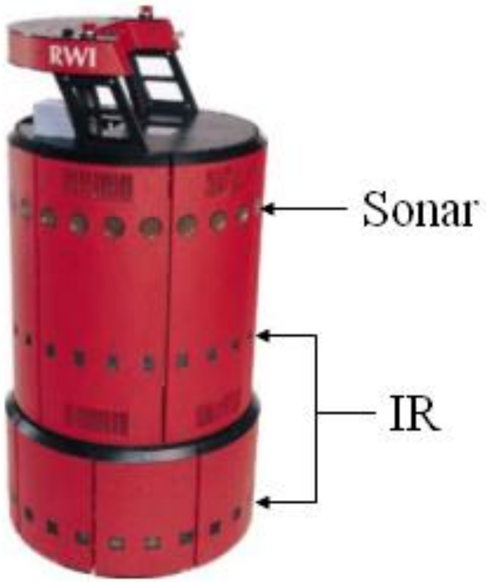
Outer-State (Exteroceptive) Sensors

- **Range Sensors: Infrared**
  - ◇ The parking assistant system is fully autonomous and intelligent. A central controller keeps track of external environmental information from infrared sensors as well as internal states.

Outer-State (Exteroceptive) Sensors

- **Range Sensors**

Aspect	IR	Sonar
Range	4 – 140 cm	41 cm – 10.5 m
Accuracy	Higher in the range of 24 cm	Higher in the range bigger than 40 cm
Color sensitivity	Sensitive	Non-sensitive
Climate conditions	Non-sensitive	Sensitive
Power consumption	Low (30-50 mA)	High (100-200mA)
Cost	Low	Higher



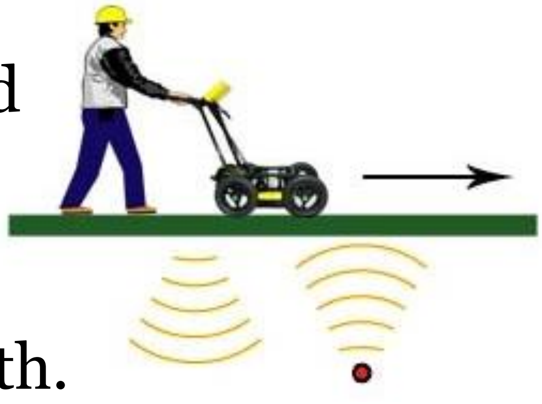
Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**

Video

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**
  - ◇ Ground Penetrating Radar (commonly called GPR) is a high resolution electromagnetic technique that is designed primarily to investigate the shallow subsurface of the earth.



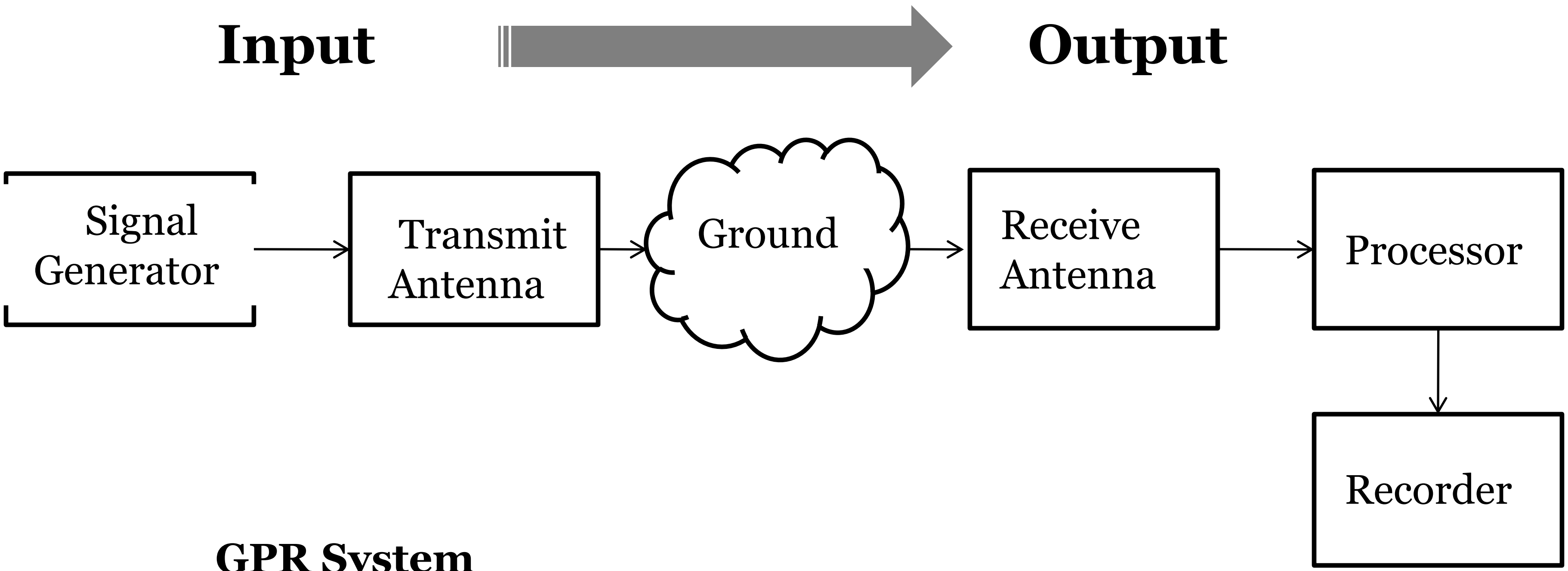
  - ◇ GPR can provide precise information concerning the nature of buried objects.
  - ◇ GPR uses the principle of scattering of electromagnetic waves to locate buried objects.
  - ◇ The controller measures the time taken for a pulse to travel to and from the target which indicates its depth and location.

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**



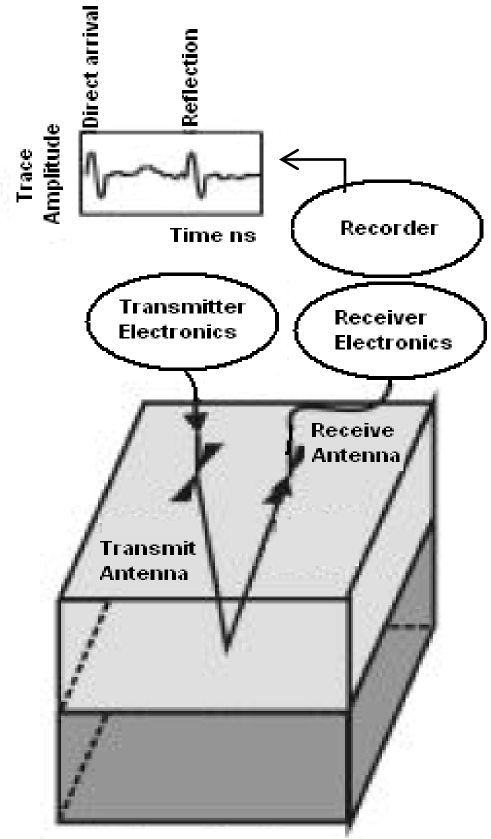
GPR System

Reading Material

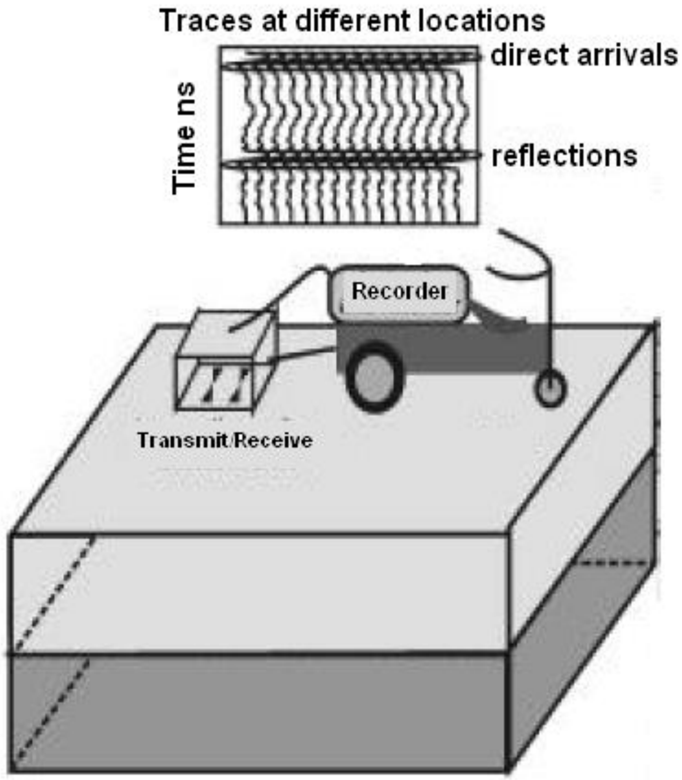
[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**



GPR Trace Fixed mode equipment



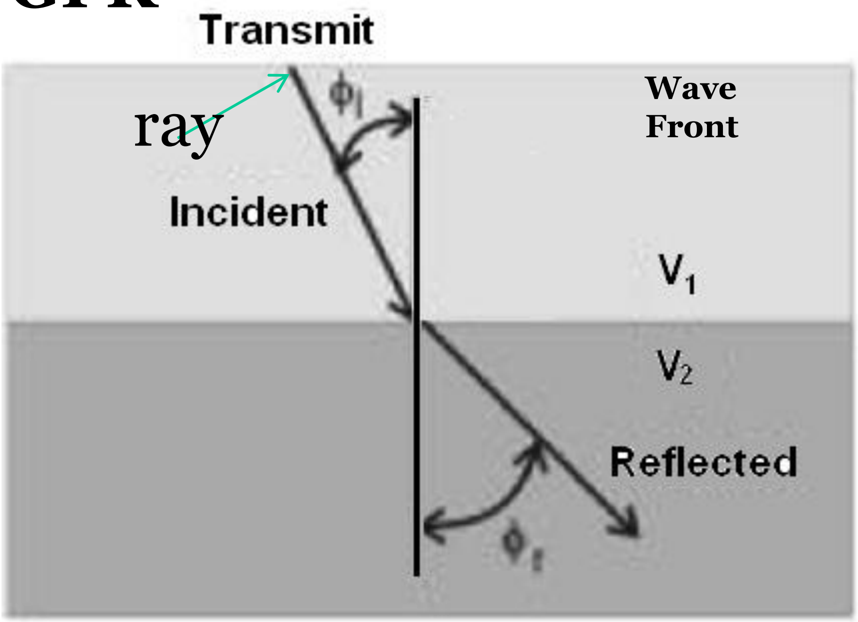
GPR Trace Moving Mode Equipment

GPR equipment consists of antennas, electronics and a recording device, The transmitter and receiver electronics are always separate

Reading Material

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**
  - ◇ The electromagnetic wave is radiated from a transmitting antenna, travels through the
  - ◇ material at a velocity which is determined primarily by the permittivity of the material.
  - ◇ The wave spreads out and travels downward until it hits an object that has different electrical properties from the surrounding medium, is scattered from the object, and is detected by a receiving antenna. The surface surrounding the advancing wave is called a *wavefront*.



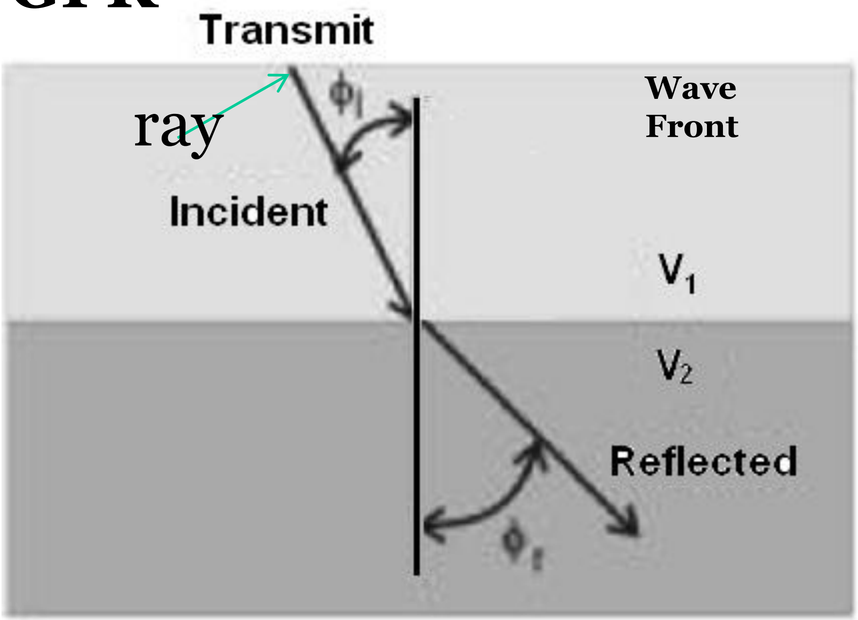
$$R = \frac{v}{2}\Delta t$$

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**
  - A straight line drawn from the transmitter to the edge of the wavefront is called a *ray*.
  - Rays are used to show the direction of travel of the wavefront in any direction away from the transmitting antenna.
  - If the wave hits a buried object, then part of the waves energy is “reflected” back to the surface, while part of its energy continues to travel downward.
  - The wave that is reflected back to the surface is captured by a receive antenna, and
  - recorded on a digital storage device.

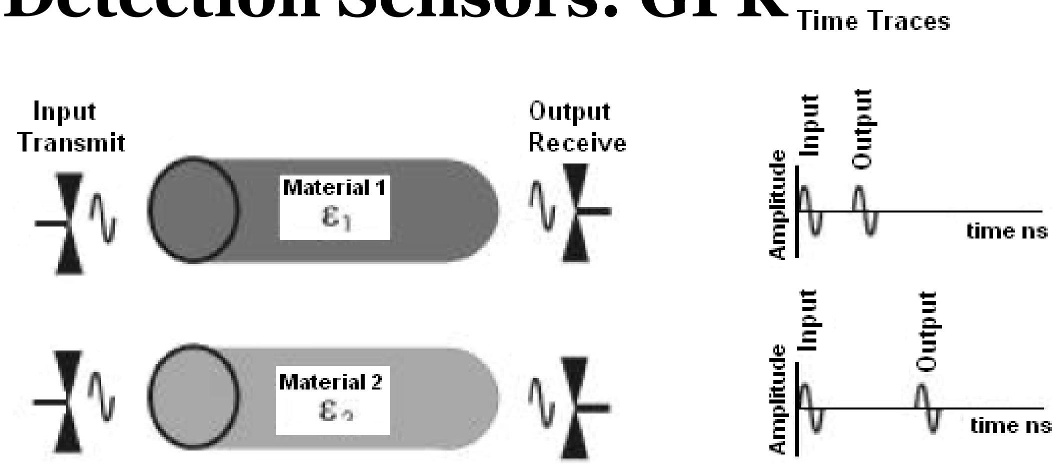


$$R = \frac{v}{2}\Delta t$$

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**



Samples with different permitivites and input/output pulse

input and output signals plotted as a function of time

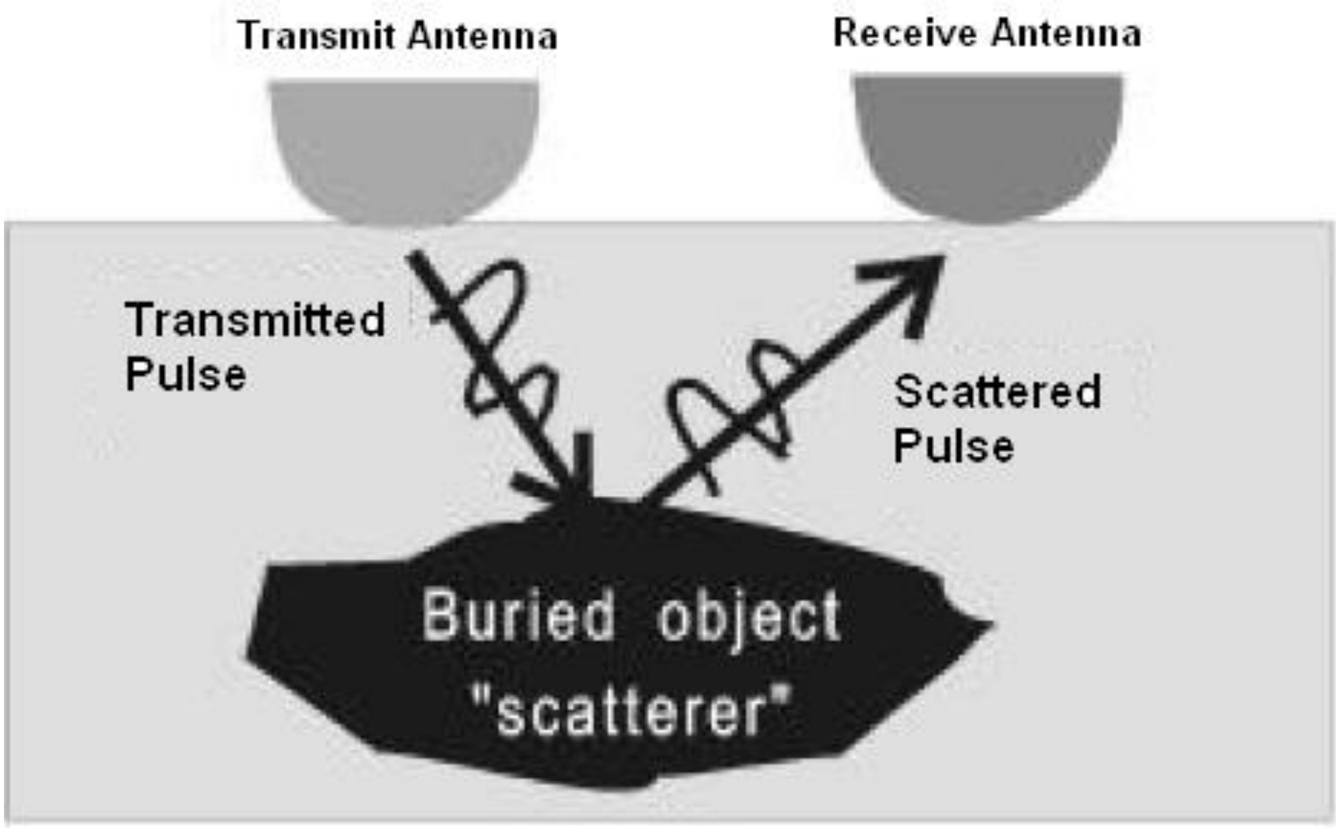
- ◇ if a at precisely the instant that the pulse is transmitted, then two pulses will be recorded by the receive antenna.
- ◇ The first pulse will be the wave that travels directly through the air (since the velocity of air is greater than any other material), and the second pulse that is recorded will be the pulse that travels through the material and is scattered back to the surface, traveling at a velocity that is determined by the permittivity (e) of the material.

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**

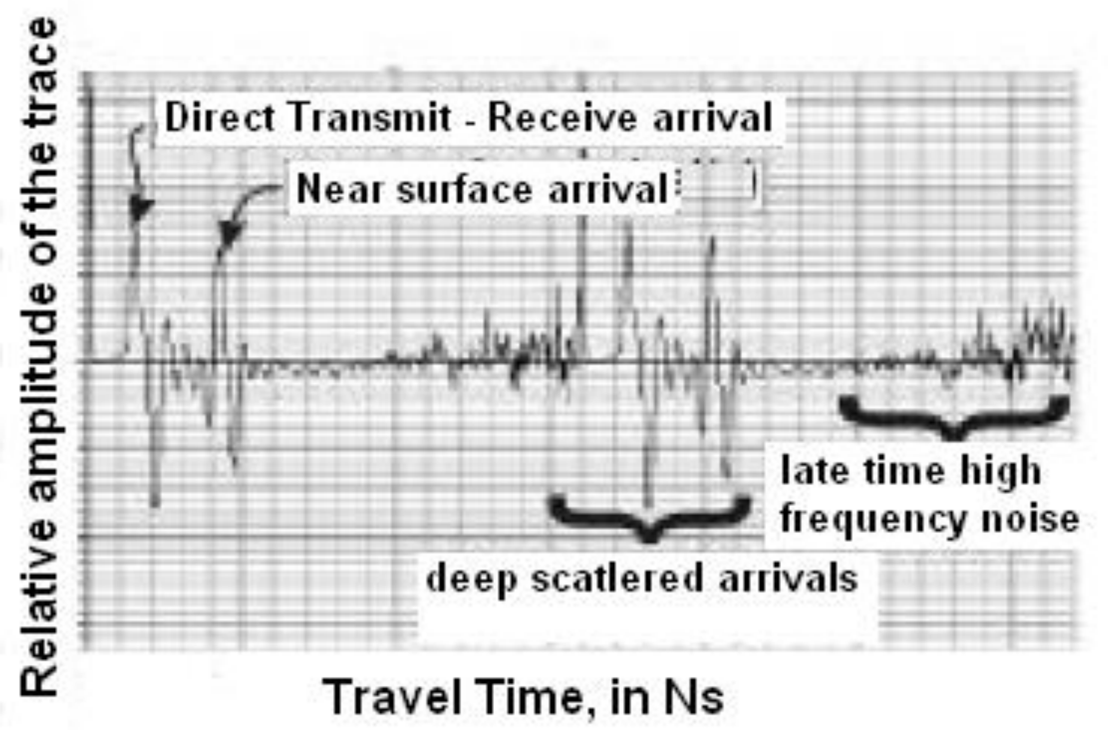


Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**



The received energy is recorded as a trace at a point on the surface

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: GPR**

GPR Advantages

1. GPR provides a three dimensional pseudo-image that can easily be converted to depths that are accurate down to a few centimeters.

2. GPR responds to both metallic and non-metallic objects. GPR is an excellent tool for mapping nearly any in-homogenity in the subsurface that is characterized by a small difference in density, or porosity.

Reading Material

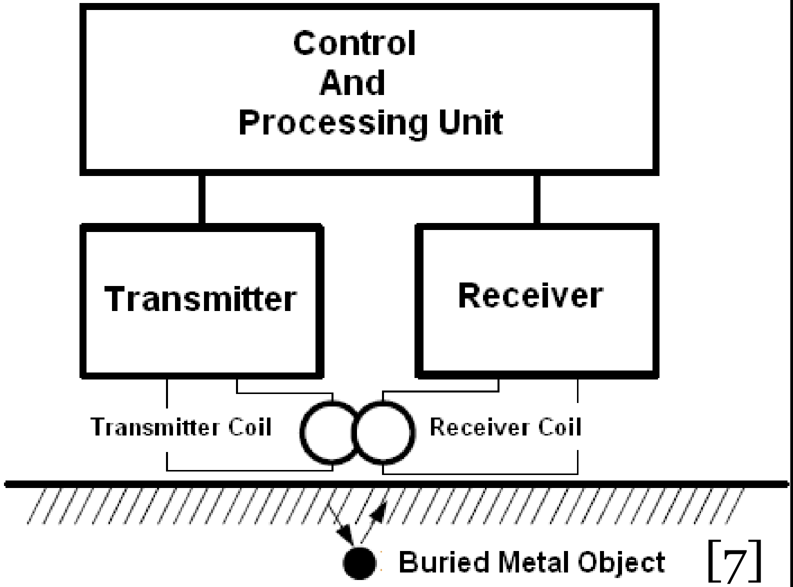
[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: EMI**

Electromagnetic Induction sensor (Metal Detector) has wide application areas for buried metallic object searching, such as detection of buried pipes and mine.

If the target is composed of ferromagnetic material, it can easily be detected by EMI (Electro Magentic Induction) sensor, if it is in the detection range



[7]

Reading Material

Outer-State (Exteroceptive) Sensors

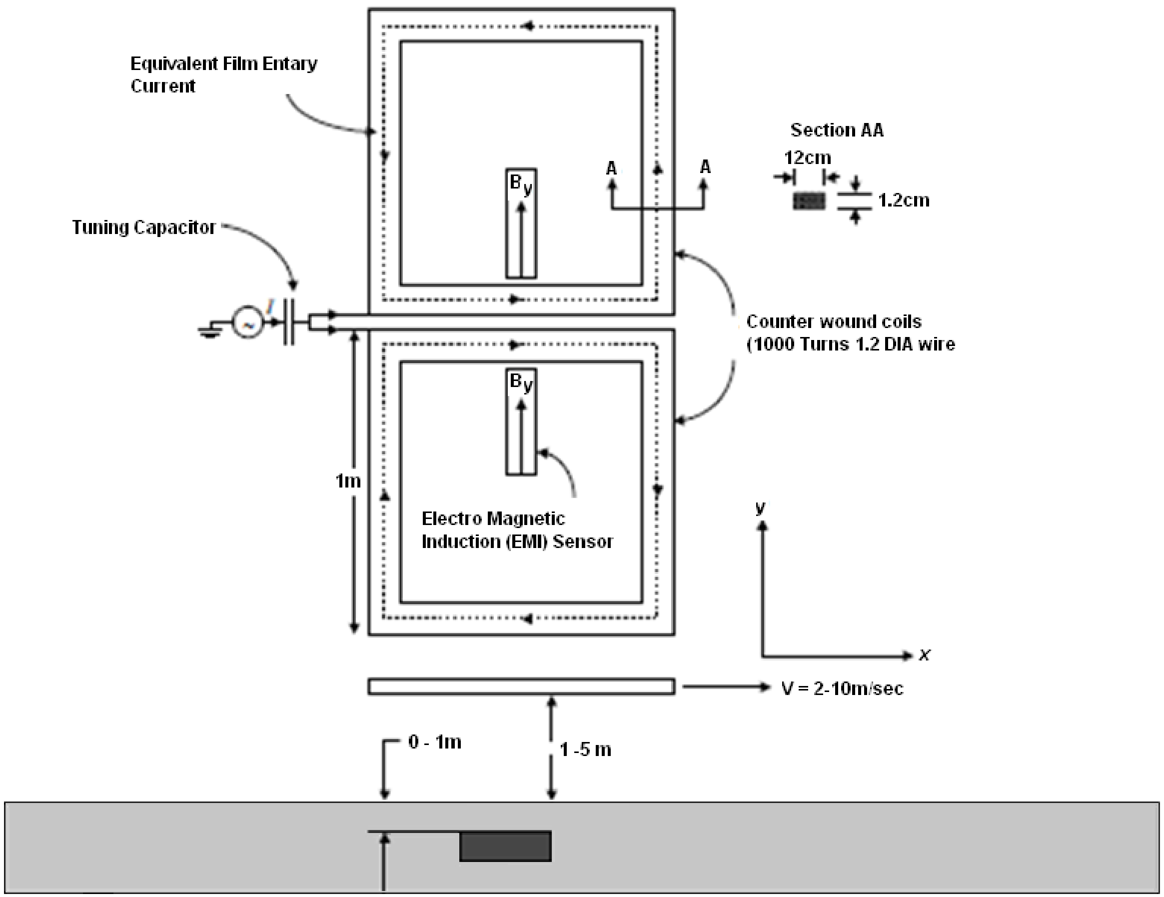
- **Landmine Detection Sensors: EMI**
  - ◊ The method is based on Electromagnetic Induction (EMI) technique.
  - ◊ two different coils are used, transmitter coil creates primary magnetic field and receiver coil takes inducted magnetic field.
  - ◊ If there is a ferro-magnetic object in the region, receiver coil field is inducted by small eddy currents originated by metallic objects, additionally.
  - ◊ These additional currents are converted to voltage, utilizing appropriate circuits to produce warning signals.

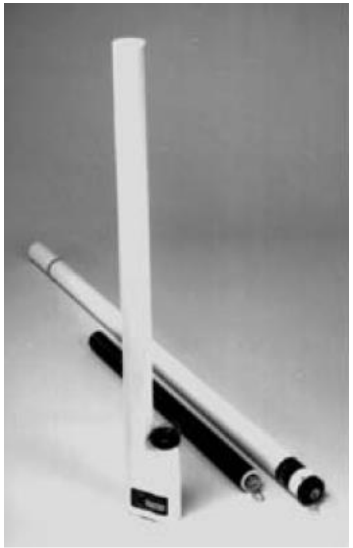
Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: Conductivity Sensor**



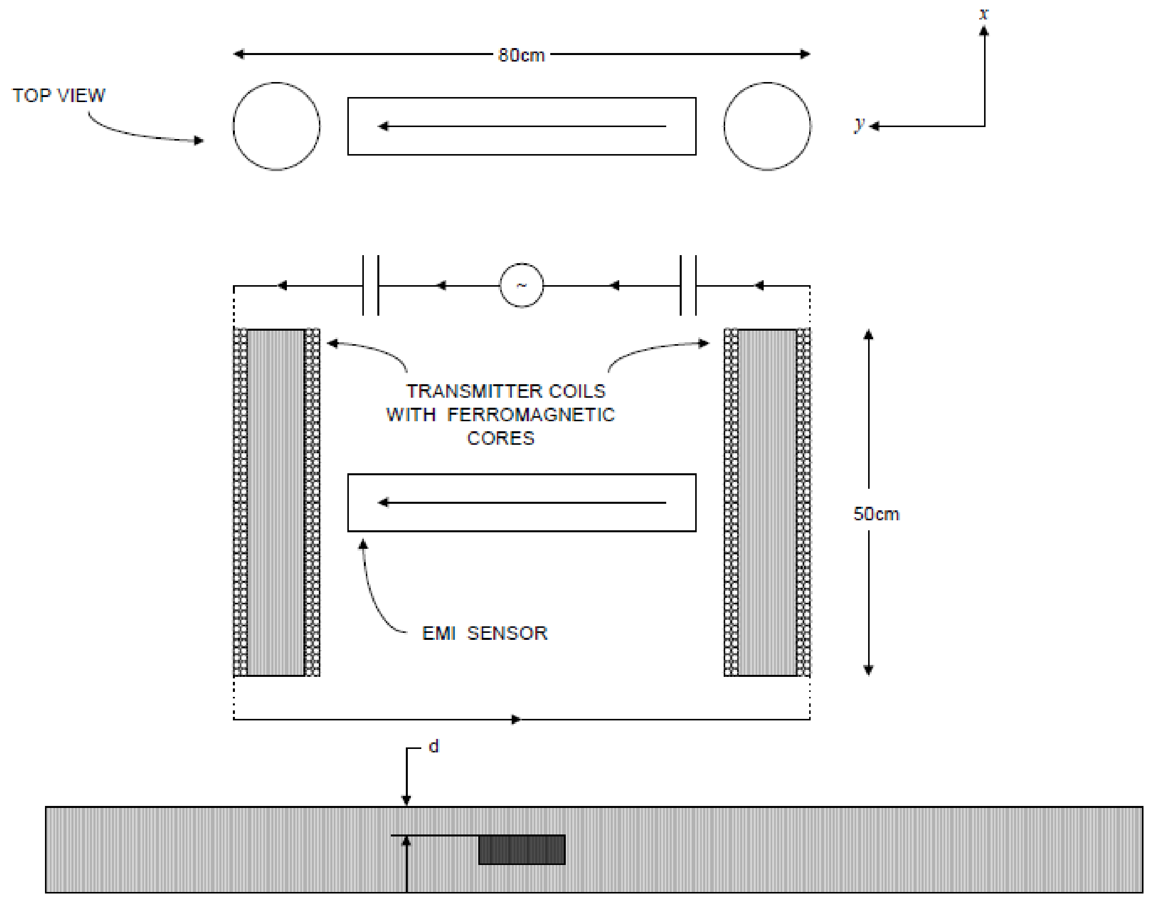


Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: Conductivity Sensor**

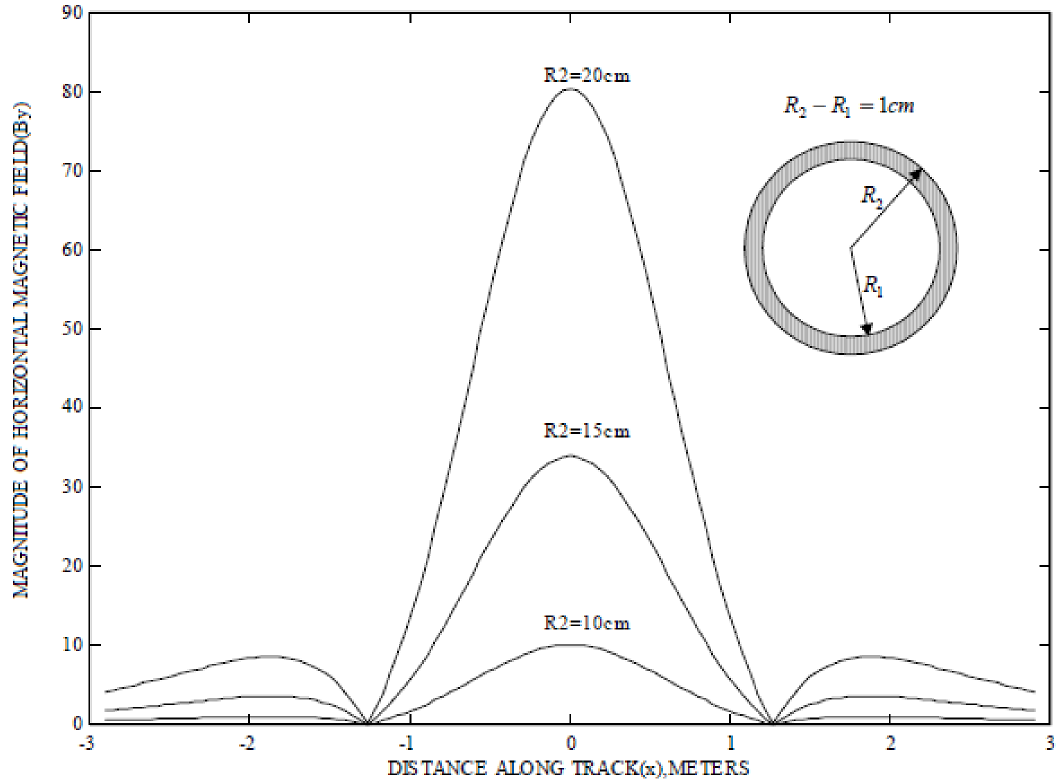


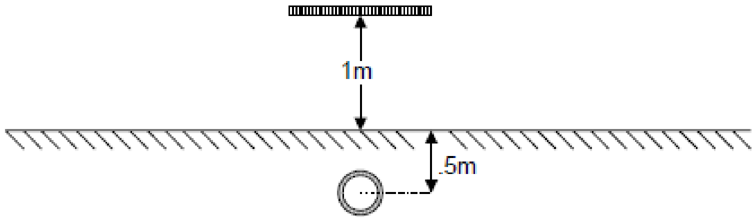
Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: Conductivity Sensor**





Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: Conductivity Sensor**

Features

◇ Detection of plastic covered mines in dry soil

◇ Localization within 1 sq.m

◇ retain the capability to detect metallic and non-metallic mines

◇ Deep penetration capability (several meters)

◇ Classification -metallic and non-metallic

◇ Shallow mines can be detected from a height of several meters

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: Conductivity Sensor**

Transmitter

◇ two horizontal multi-turn coils resonant at the transmitter frequency

◇ nominal transmitter power 200 w.

◇ operating voltage 220 at (30 - 50 KHz).

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: Conductivity Sensor**

Receiver

◇ detects temporal changes in amplitude and phase of the induced magnetic field as the electric field of the moving transmitter sweeps across the spatial subsurface conductivity in homogeneities

◇ a cots EMI sensor detects the fluctuations of the horizontal magnetic field or its gradient.

◇ a synchronous detector provides i & q channel outputs followed by filters and a threshold device.

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: IR**
  - ◇ IR radiation can be more readily detected for the heat. Heated materials provide good sources of infrared radiation.
  - ◇ IR radiation is referred to as thermal radiation. Since visualization is easier than other sensors.
  - ◇ IR has been widely used for mine detection. Another advantage of IR is that it does not need as much serious preprocessing as GPR. However, the performance of IR relies highly on the environment at the moment of measurement.
  - ◇ IR can work in either way, actively or passively. It can work by accepting only the natural radiation from the object, or it can provide an extra heat source and receive the artificial radiation created by that heat source .

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

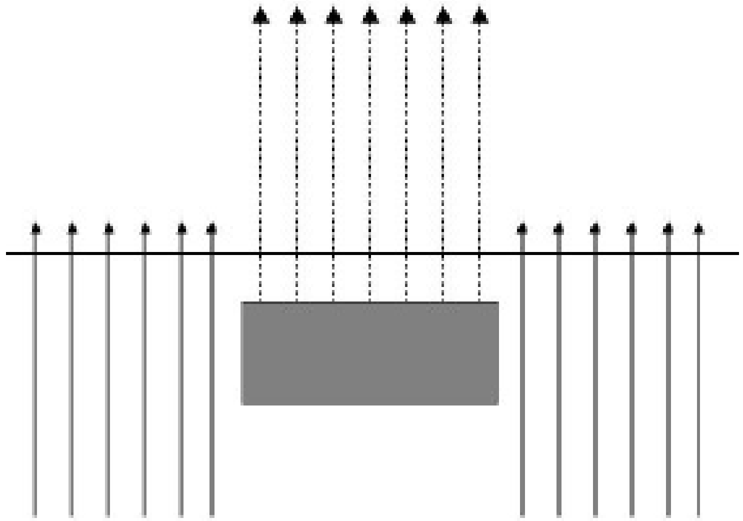
- **Landmine Detection Sensors: IR**
  - ◊ The general concept of using infrared thermography for mine detection is based on the fact that mines may have different thermal properties from the surrounding material.

Reading Material

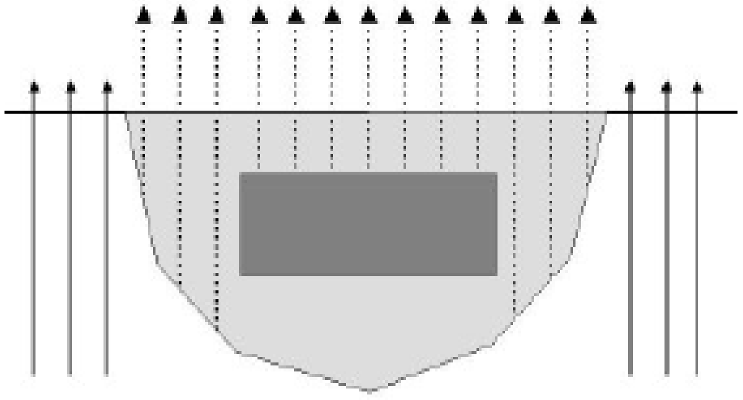
[7]

Outer-State (Exteroceptive) Sensors

- **Landmine Detection Sensors: IR**



Volume effect



Surface effect

Reading Material

[7]

Outer-State (Exteroceptive) Sensors

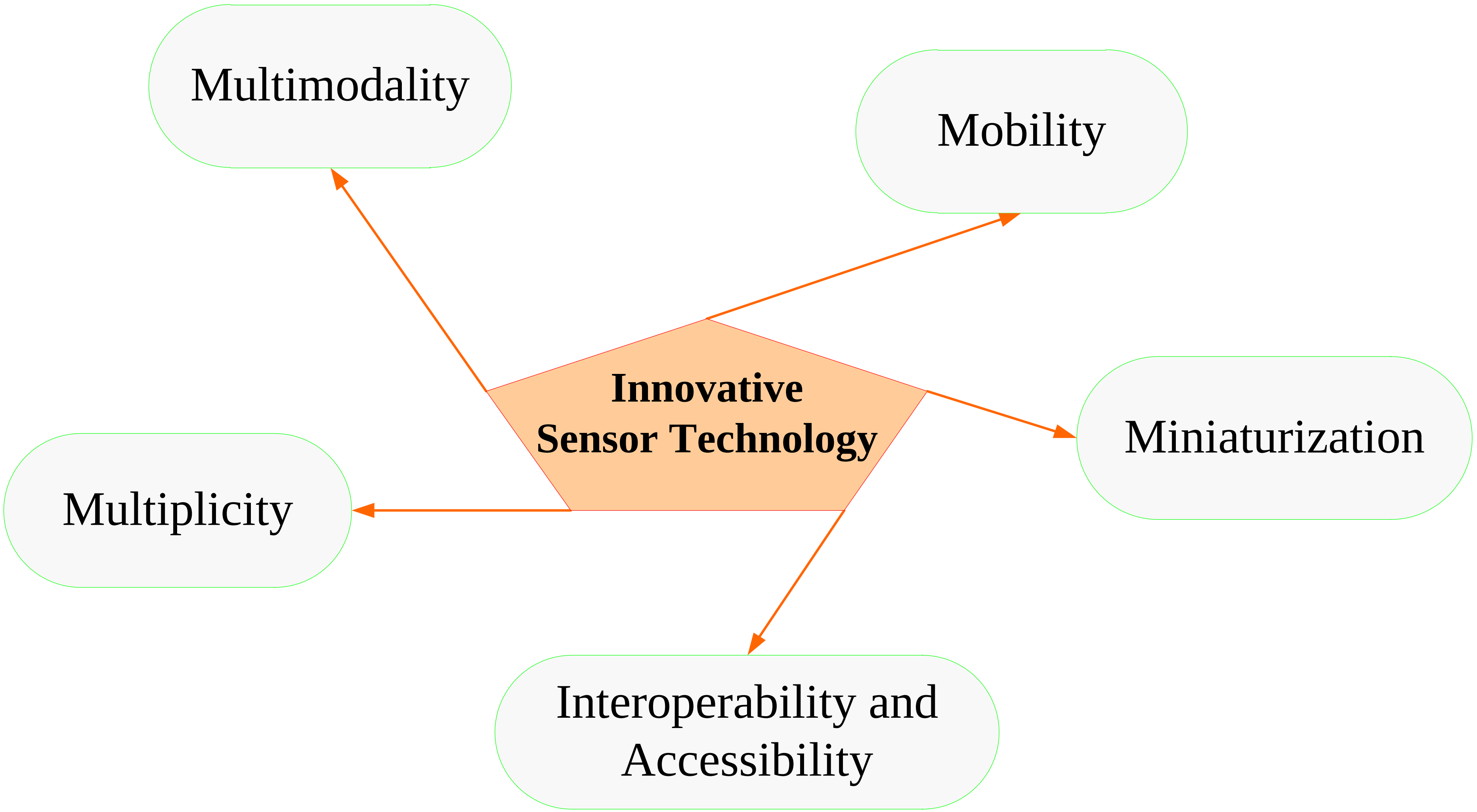
- **Vision Systems**

For Reading: Visual Servoing

Outline

- Introduction to Sensors
- Inner-State (Interoceptive) Sensors
- Surface Sensors
- Outer-State (Exteroceptive) Sensors
- **Innovative Sensor Technologies**
- Summary

Innovative Sensor Technologies



For more info: Alaa Khamis, "Innovative Sensor Technologies, State Estimation and Multisensor Data Fusion", last accessed: October 12, 2016.

Innovative Sensor Technologies

- **Multiplicity**

  The use of multiple sensors designed aiming to perform some collective sensing aims to overcome the limitations of single sensors. These systems are gaining great interest because of the following reasons:

  ◇ Resolving task complexity

  ◇ Increasing the performance

  ◇ Increasing reliability of measurements

  ◇ Reducing data imperfection aspects

  ◇ Simplicity in design

Innovative Sensor Technologies

- **Multiplicity: Resolving task complexity**

The complexity may be due to the **distributed nature** of the tasks.

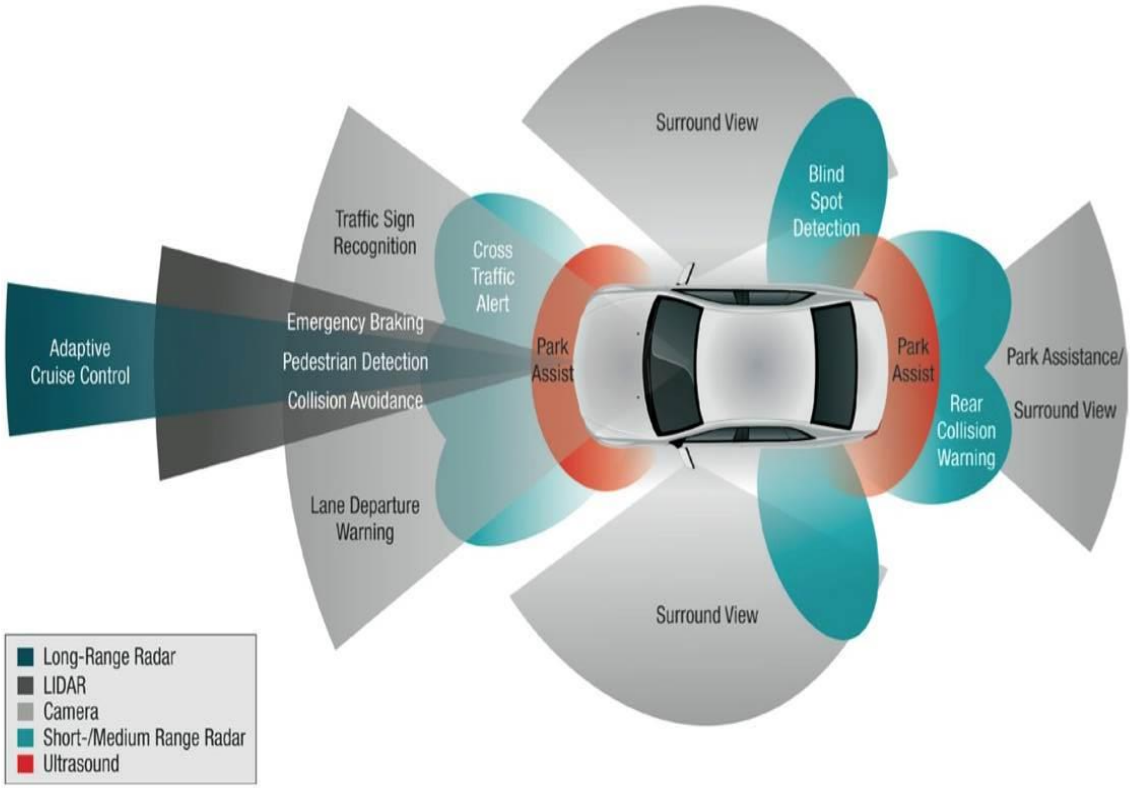
Intelligent transportation systems
Intelligent transportation systems are physically distributed over a wide area. Monitoring such complex systems is behind the capability of a single sensor

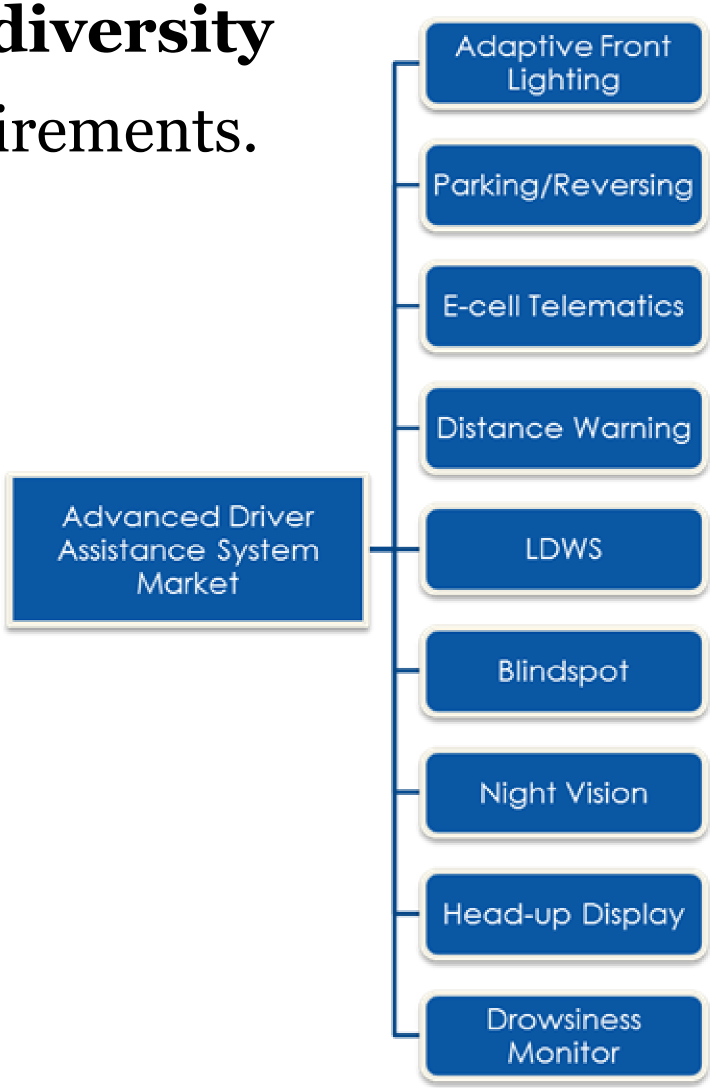
Military/Urban Surveillance Systems
Heterogeneous team of an air and two ground vehicles that can perform cooperative reconnaissance and surveillance

Innovative Sensor Technologies

- **Multiplicity: Resolving task complexity**

  The complexity may also be due to the **diversity of the tasks** in terms of different requirements.

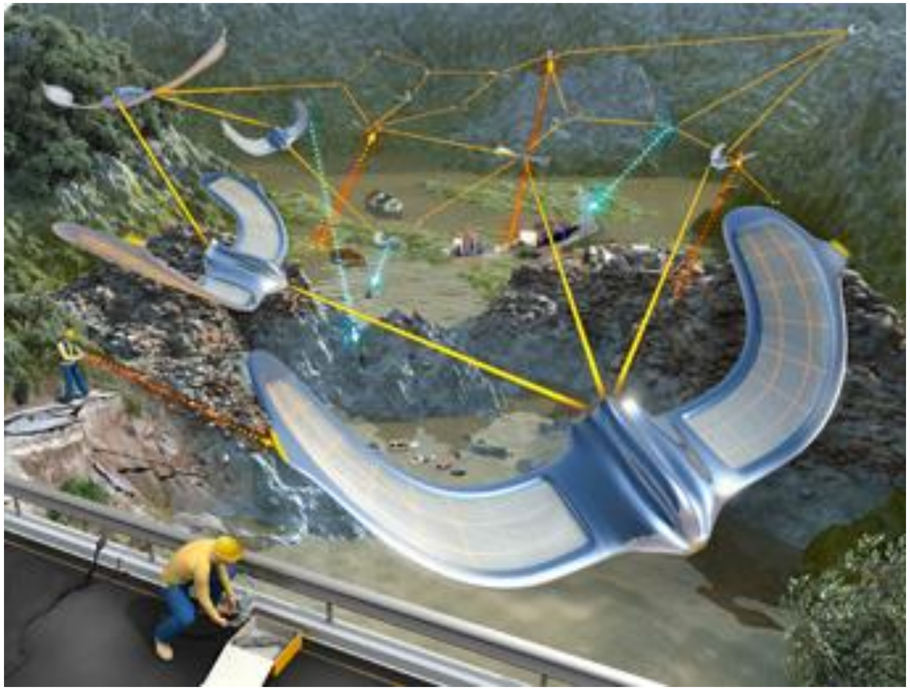




Innovative Sensor Technologies

- **Multiplicity: Increasing the performance**

  Task completion time can be dramatically decreased if many sensors cooperate to perform the tasks in **parallel**. Moreover, the use of multiple sensors allows **extended spatial and/or temporal coverage**.



Minimize:

- Task completion time (Performing task faster using parallelism)

Maximize:

- Area Coverage
- Object Coverage
- Radio Coverage

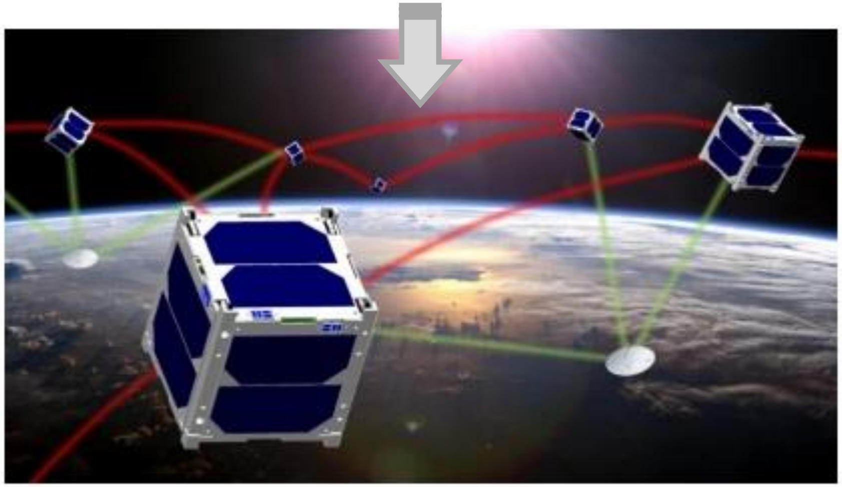
Innovative Sensor Technologies

- **Multiplicity: Increasing reliability of measurements**

Increasing the **reliability through redundancy** because having only a single sensor may work as a bottleneck for the whole system especially in critical times.

But when having multiple sensor doing a task and one fails, others could still do the job.

Giant Solar-powered Satellite



Network of CubeSat

More info: Klaus Schilling, IEEE Distinguished Lecture. Available at: http://ras-egypt.org/activities.html

Innovative Sensor Technologies

- **Multiplicity: Reducing data imperfection aspects**

  Data provided by sensors is always affected by different imperfection aspects such as uncertainty and imprecision including vagueness, ambiguity and incompleteness. Other imperfection aspects include inconsistency, out-of-sequence and correlation. **Combining data from different sensors** helps in reducing these imperfection aspects.

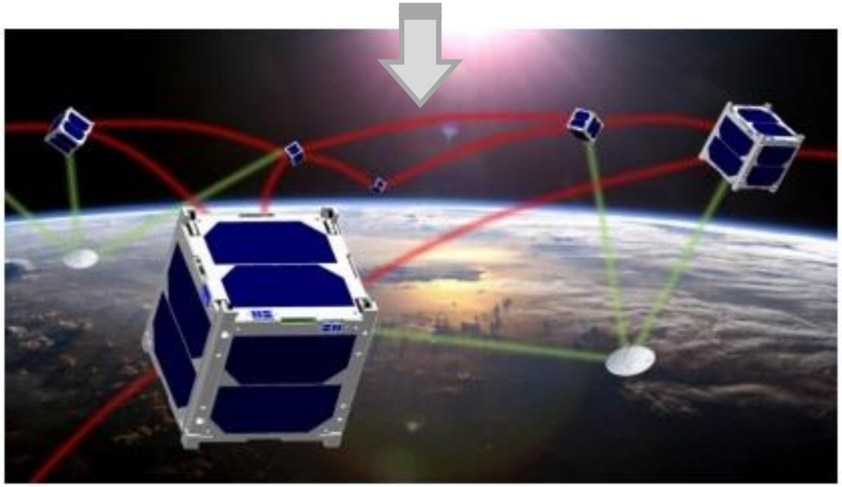
Innovative Sensor Technologies

- **Multiplicity: Simplicity in design**

Having small, simple sensors will be easier and cheaper to implement than having only single highly sophisticated sensor

Example: Picosatellite or “picosat” is an artificial satellite with a wet mass between 0.1 and 1 kg and costs ~25K$ to build and another 25K$ for launch.

Giant Solar-powered Satellite

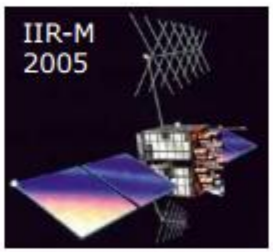


Network of CubeSat

More info: Klaus Schilling, IEEE Distinguished Lecture.
Available at: http://ras-egypt.org/activities.html

Innovative Sensor Technologies

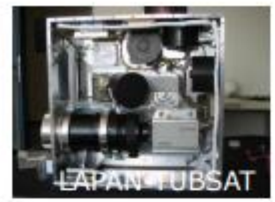
- **Multiplicity: Simplicity in design**
  - ◇ Advantages of small satellites: less expensive, more flexible, but limited Capabilities



Typical Satellite (>500 kg)

Mini-Satellite (100 – 500 kg)

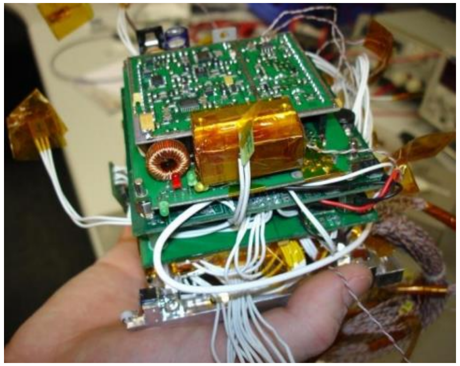
Mikro-Satellite (50 – 100 kg)



Nano-Satellite (1-50 kg)

Pico-Satellite (~1 kg)

  - ◇ Students can learn how to build a CanSat with sensors in order to characterize the atmosphere.

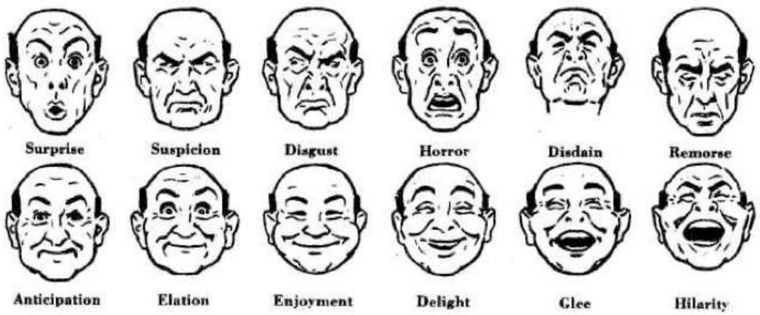


More info: Klaus Schilling, IEEE Distinguished Lecture. Available at: http://ras-egypt.org/activities.html

Innovative Sensor Technologies

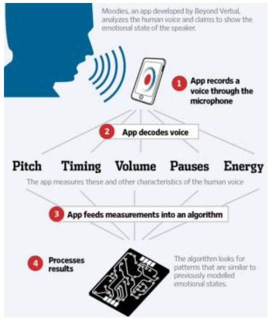
- **Multimodality**

The multimodal systems exploit the complementary features of different modalities to lead to superior performance.



Facial expression recognition

+



Voice emotion recognition

Better and more accurate emotion state recognition

Innovative Sensor Technologies

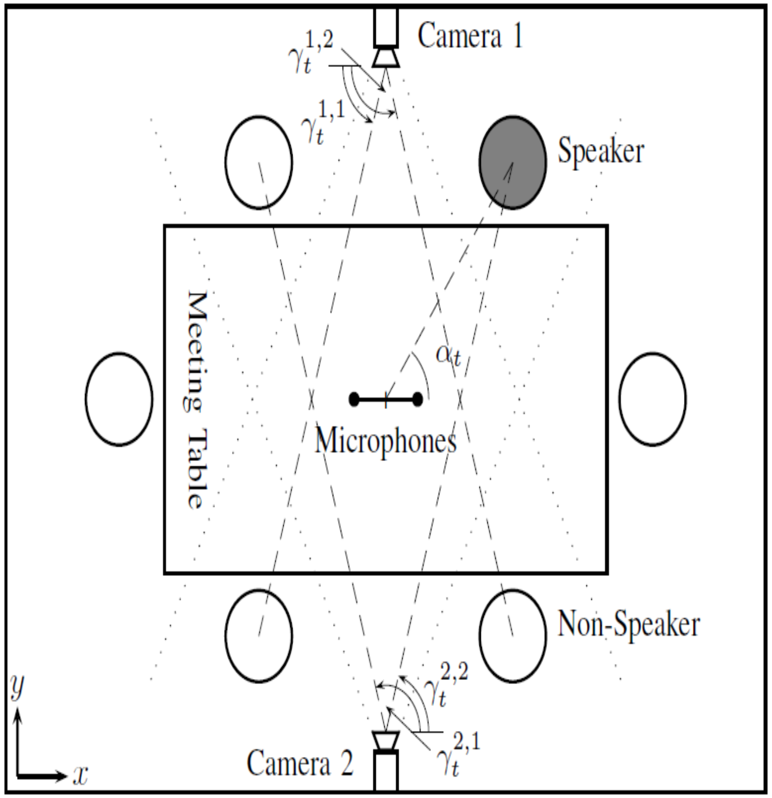
- **Multimodality**

Example-1: speaker detection

◇ Detect and track participants using machine vision techniques.

◇ Recognize the active participant using acoustic source localization.

◇ Fuse this information using a particle filter tracker.

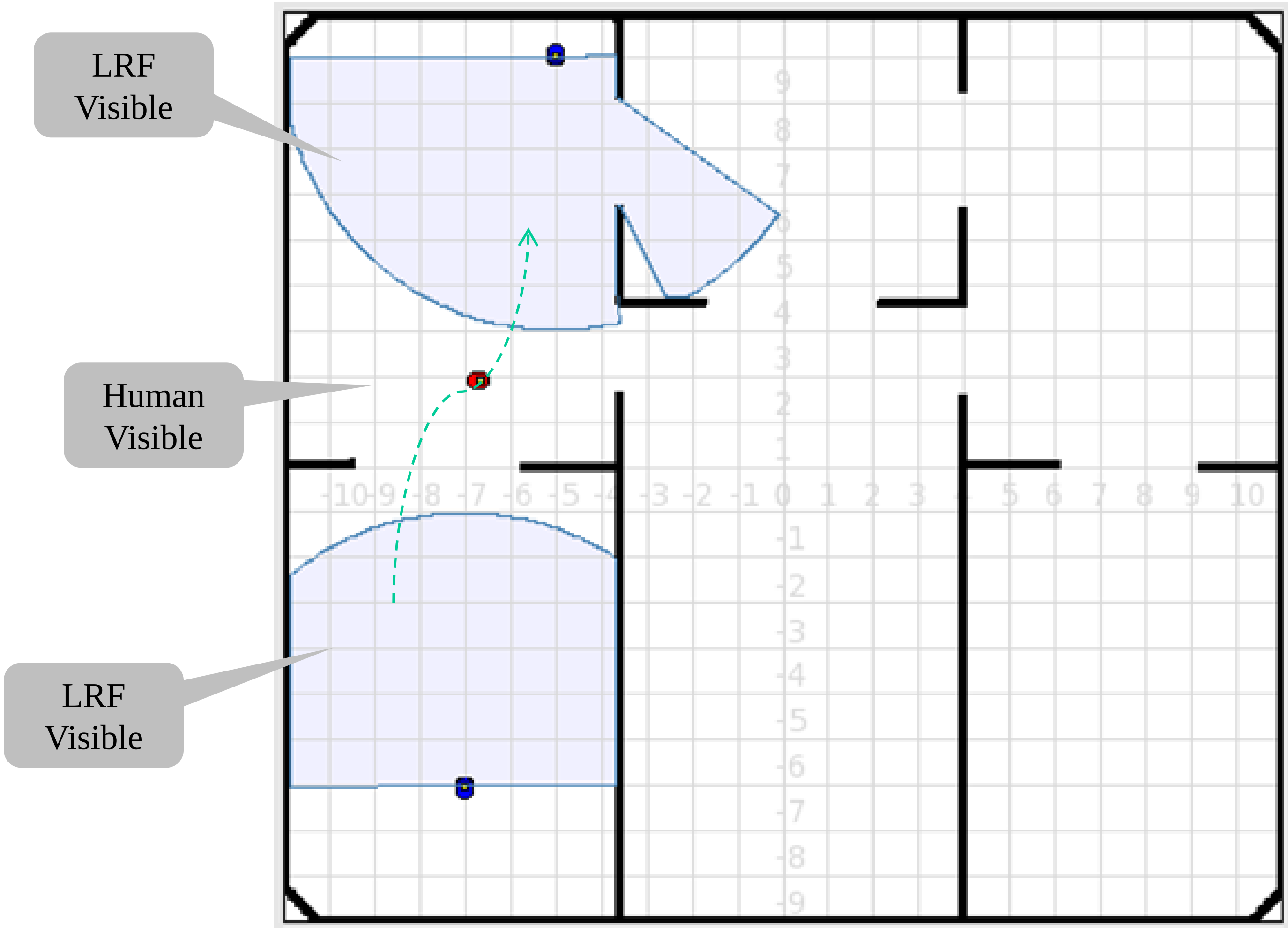


[8]

Innovative Sensor Technologies

- **Multimodality (cont'd)**

Example-2: Human-assisted Tracking



[9]

Innovative Sensor Technologies

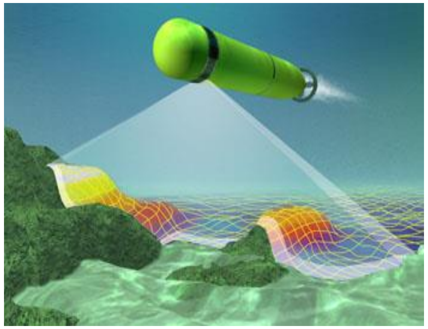
- **Mobility**

  Sensors mounted on autonomous or teleoperated ground /aerial/submarine vehicles overcome the limitations of stationary sensors as they can **sample the environment at different locations**, exchange the information with other sensing/acting agents, and collaboratively achieve the required tasks.

Unmanned Ground Vehicles (UGV)

Unmanned Aerial Vehicles (UAV) & Micro Aerial Vehicles (MAV)

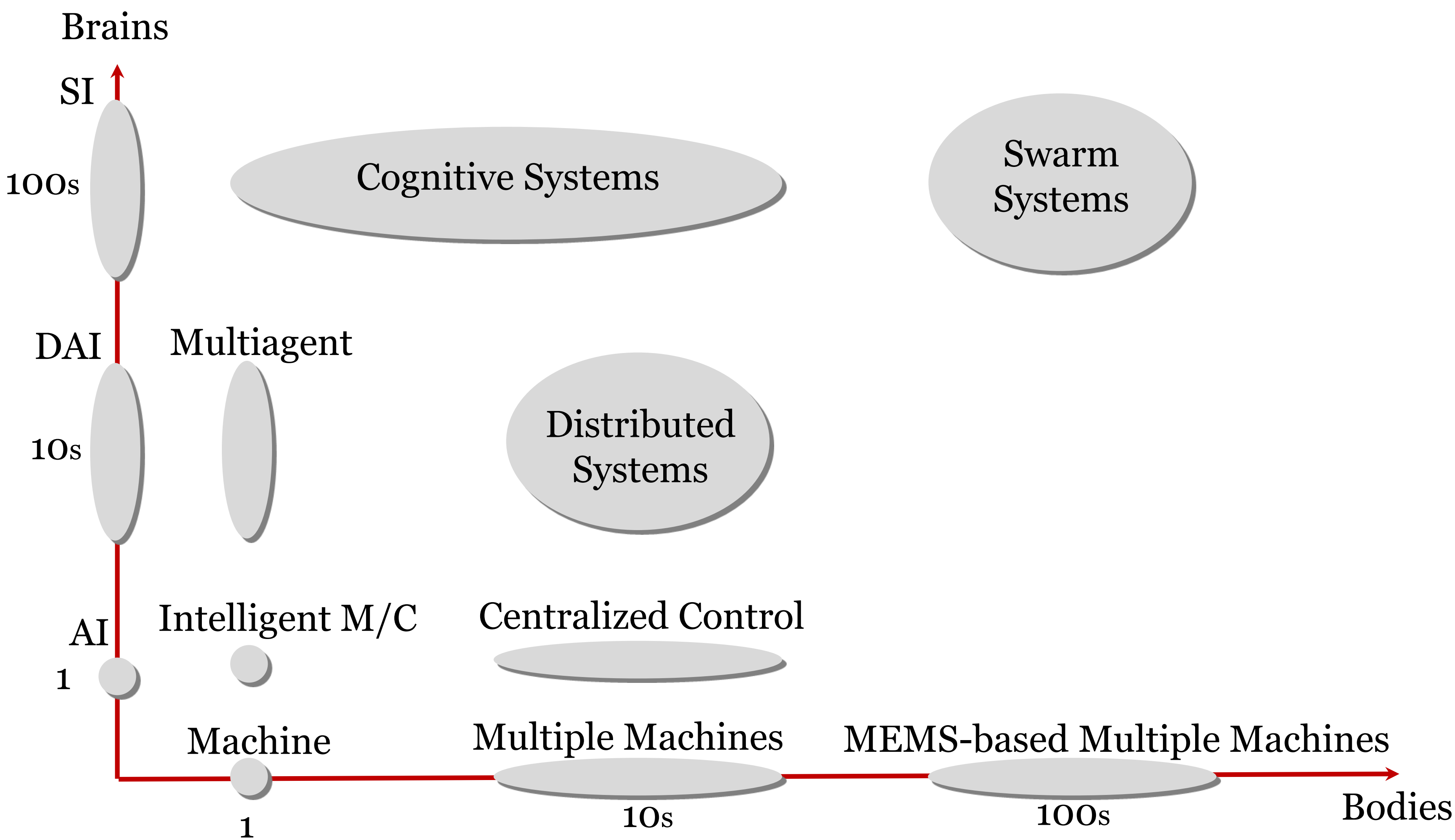
Unmanned Surface Vehicles (USV)



Unmanned Underwater Vehicles (UUV)

Innovative Sensor Technologies

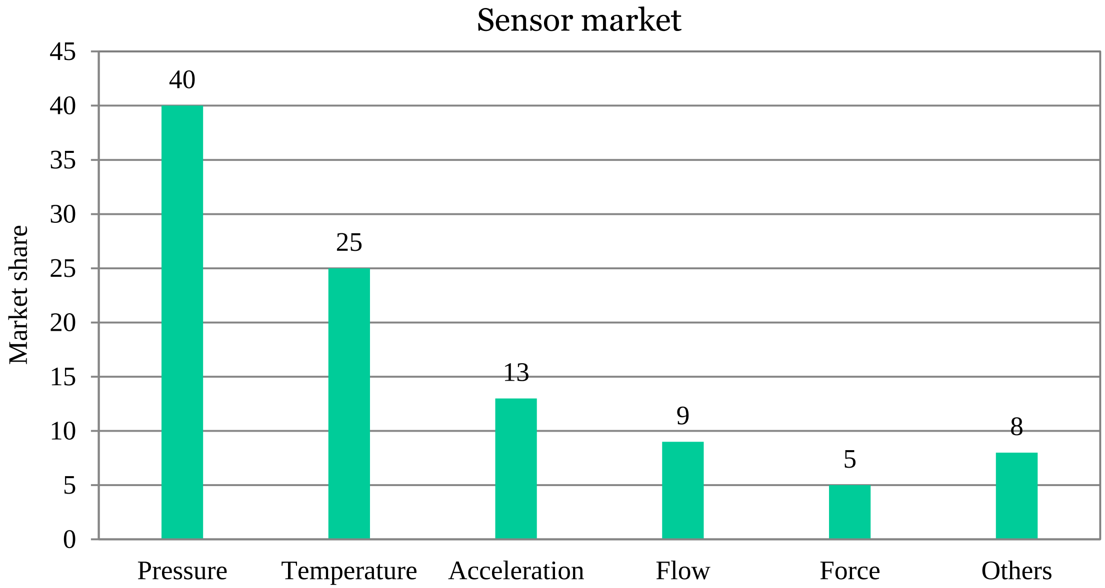
- **Miniaturization: Brain/Body Evolution**



Innovative Sensor Technologies

- **Miniaturization**

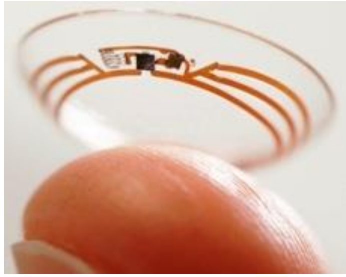
  Advances in sensor technology, low-power electronics, and low-power radio frequency (RF) design have enabled the development of small, relatively inexpensive and low-power sensors, called **microsensors** that can be connected via a wireless network [10].



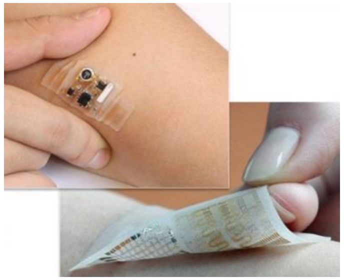
[11]

Innovative Sensor Technologies

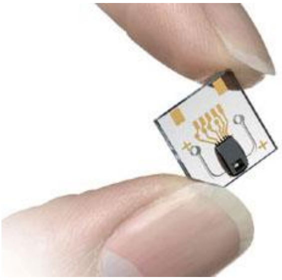
- **Miniaturization: Why microsensors?**
  - ◇ lower manufacturing cost (mass-production, less materials)
  - ◇ wider exploitation of IC technology (integration)
  - ◇ wider applicability to sensor arrays
  - ◇ lower weight (greater portability)



Google contact lens with embedded circuitry to monitor **blood glucose** levels



Smart patch: a wearable health monitor sensors. Besides the thermal sensor and accelerometer, the device carries a signal amplifier, batteries and radio

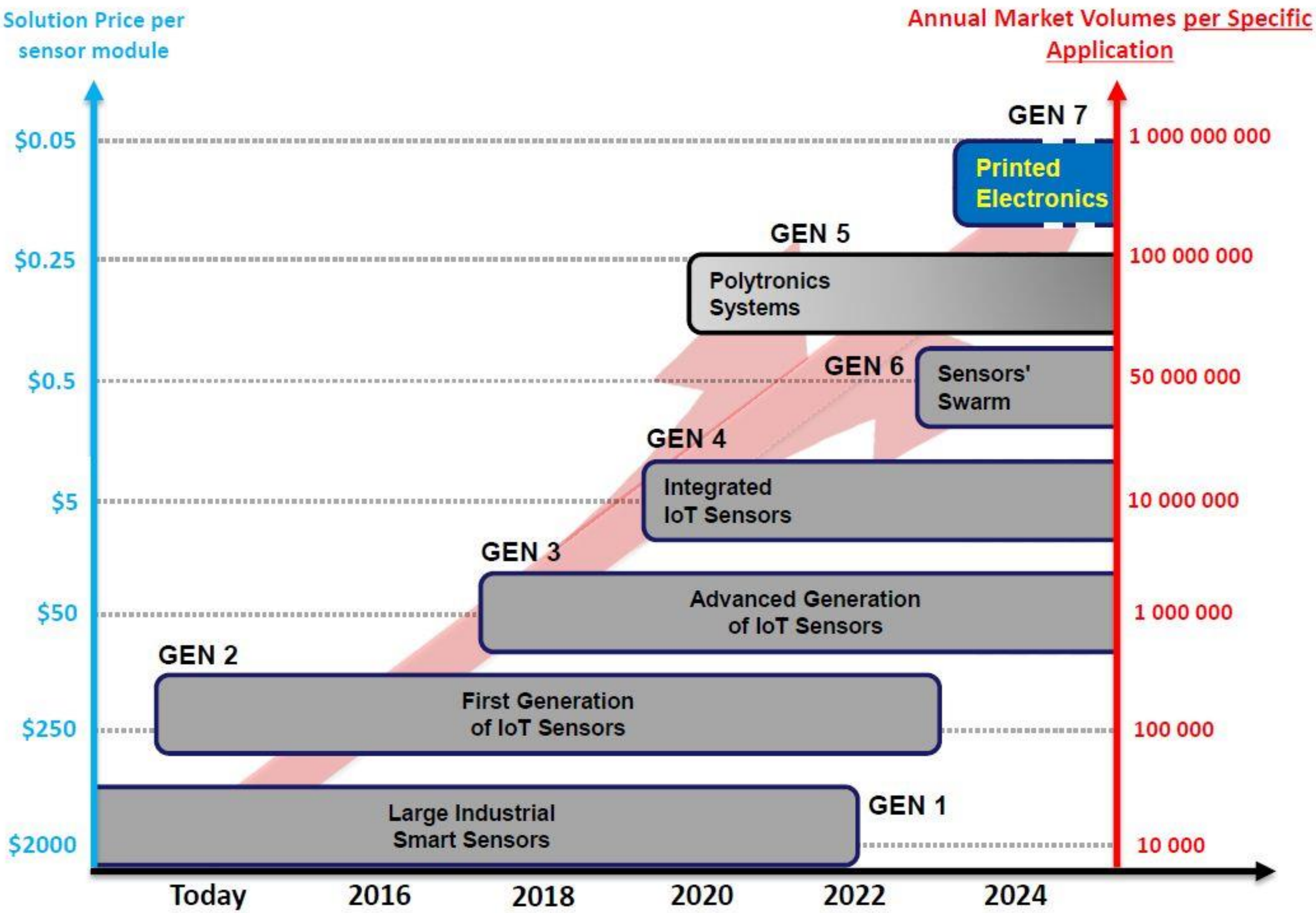


Sensirion's highly sensitive **thermal flow sensor** microchips to measure non-invasively through the wall of a flow channel inside a microfluidic substrate

Printed sensors: Unique sensing labels – based on printed electronics- bring new functionality and crystal clear reads to temperature controlled supply chains.

Innovative Sensor Technologies

• **Miniaturization**



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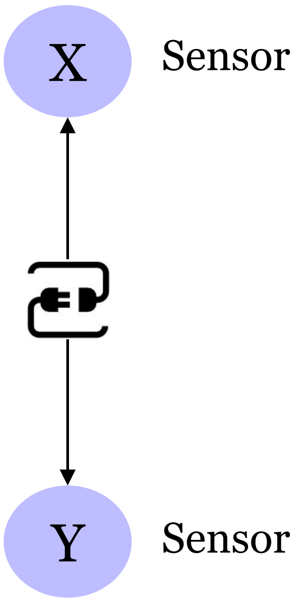
Innovative Sensor Technologies

- **Interoperability and Accessibility**
  - ◇ **Interoperability** is the ability of two or more sensors or fusion nodes to communicate and cooperate among themselves despite differences in language, context, format or content. This ability allows these sensors/fusion nodes to exchange data/information and to use the data/information that has been exchanged.



X and Y are able to interact effectively at run-time to achieve shared goals

  - ◇ **Accessibility** can be viewed as the ability to access the data gather by the sensors and ability to access its functionality in order to control it.

Outline

- Introduction to Sensors
- Inner-State (Interoceptive) Sensors
- Surface Sensors
- Outer-State (Exteroceptive) Sensors
- Innovative Sensor Technologies
- **Summary**

Summary

- Situation awareness is the perception of environmental elements with respect to time and/or space, the comprehension of their meaning, and the projection of their status after some variable has changed, such as time, or some other variable, such as a predetermined event .
- Machine perception includes a vast array of transducers that can inform robots about their surroundings. Bats and dolphins use sonar, cats use whiskers and birds use magnetic fields in navigation.
- Sensors for unmanned vehicles can be classified into Inner-State (Interoceptive), Sensors Surface Sensors and Outer-State (Exteroceptive) Sensors.
- Multiplicity, multimodality, mobility, miniaturization, interoperability and accessibility are novel dimensions of sensor technologies.

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