Sensors

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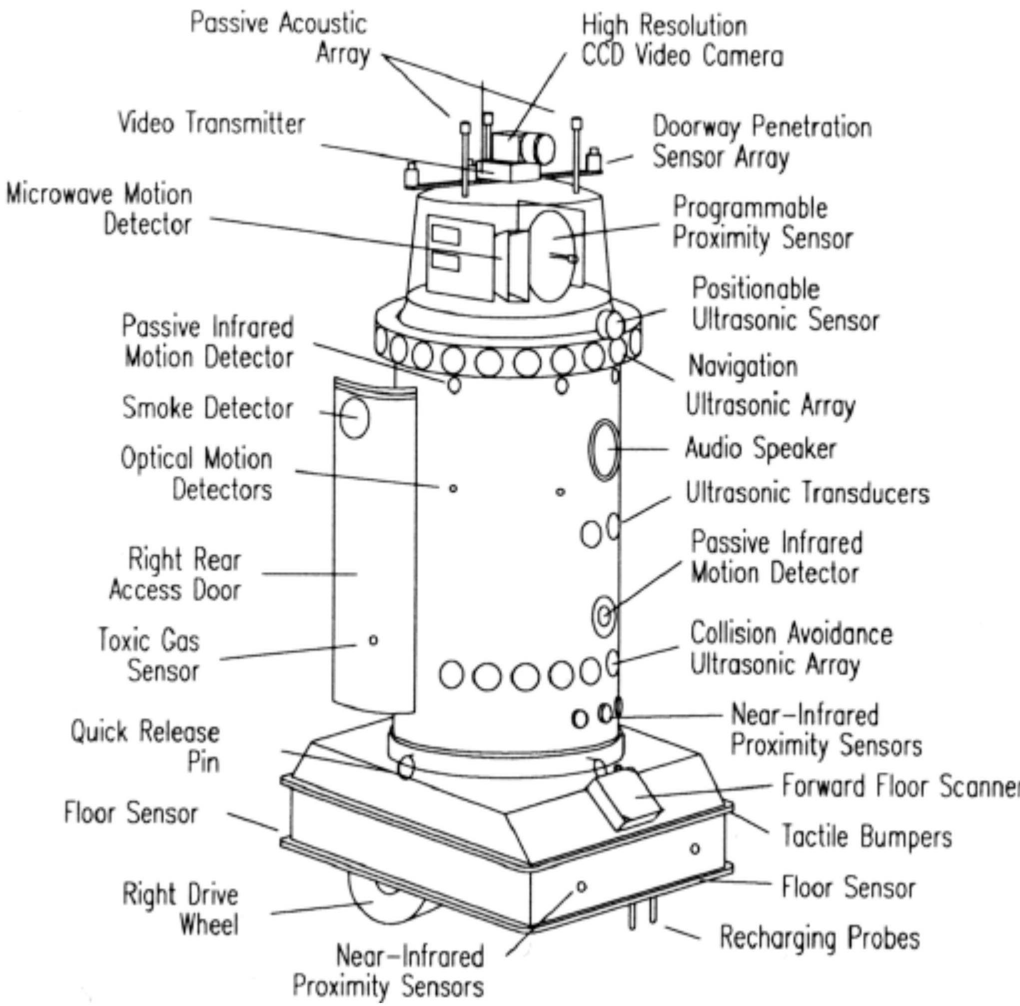


Structure

- What are
- Classification of sensors
- Performance
- Error
- Biological sensors
- Electronic Sensors
  - Motor encoders
  - Heading
  - Compas
  - Distance/ sonar
  - Gyroscop
  - Beacon/ GPS
  - Accelerometer
  - Rain
  - Color
  - IR
  - Video
  - others

Definition

- A sensor is a device, usually electrical, electronic, electro-mechanical, electromagnetic, photonic, or photovoltaic that converts one type of energy to another.

- Sensors essential for acquiring intelligence.
- For any given robot we typically use a range of different sensors.

Basic

Many different types of sensors with varying characteristics.

- Basic distinctions:
  - *Active/passive*
  - *External / Internal*
- Tradeoff between
  - *Cost and*
  - *Processing*

Classification of Sensors

- Internal sensors
  - *measure values internally to the system (robot),*
  - *e.g. motor speed, wheel load, heading of the robot, battery status*

- External sensors
  - *information from the robots’ environment*
  - *distances to objects, intensity of the ambient light,*

- Passive sensors
  - *energy coming for the environment*
- Active sensors
  - *emit their proper energy and measure the reaction*
  - *better performance, but some influence on environment*

Types of sensors

Type	**Sensor**
Tactile (detection of physical contact)	Contact switches, bumpers, optical barriers.
Wheel, motor sensors (speed and position)	Optical encoders Magnetic encoders
Heading sensors	Compass, Gyroscope, Inclinometers
Ground-based beacons (fixed reference frame)	GPS
Active ranging	Ultrasonic, laser
Vision	Cameras
Motion sensors	Doppler

Properties of sensors

- the sensor should be sensitive to the measured property
- the sensor should be insensitive to any other property
- the sensor should not influence the measured property

Sensor Performance

- *Measurement in real world environment is error prone* !! !!! !!!!!!!!!!!!!!!!!!

- Basic sensor response ratings
  - ***Range***
    - *upper limit*
  - ***Dynamic range***
    - *ratio between lower and upper limits*
  - ***Resolution***
    - *minimum difference between two values*
  - ***Linearity***
    - *variation of output signal as function of the input signal*
  - ***Bandwidth or Frequency***
    - *the speed with which a sensor can provide a stream of readings*

Sensor Performance (2)

- Characteristics that are especially relevant for real world environments
  - Sensitivity
    - *ratio of output change to input change*
  - Error / Accuracy
    - *difference between the sensor's output and the true value*

error ***measured value***

true value

$$\left(accuracy = 1 - \frac{|m - v|}{v} \right)$$

Characterizing Errors

- Deterministic errors
  - *caused by factors that can (in theory) be modeled -> prediction*
  - *e.g. calibration of a laser sensor or of the distortion cause by the optic of a camera*

- Random error -> non-deterministic
  - *no prediction possible*
  - *however, they can be described probabilistically*

- reproducibility *of sensor results*

Multi-Modal Error Distributions

- Behavior of sensors modeled by probability distribution (random errors)
  - *usually very little knowledge about the causes of random errors*
- often probability distribution is assumed to be symmetric or even Gaussian
  - *however, it is important to realize how wrong this can be*
- *Examples:*
  - *Sonar (ultrasonic) sensor might overestimate the distance in real environment and is therefore not symmetric*

Sensors

- Biological
- Electronic

Biological sensors

- Specialized cells that are sensitive to:
  - light, motion, temperature, magnetic fields, gravity, humidity, vibration, pressure, electrical fields, sound, and other physical aspects of the external environment;
  - physical aspects of the internal environment, such as stretch, motion of the organism, and position of appendages;
  - an enormous array of environmental molecules, including toxins, nutrients, and pheromones;
  - many aspects of the internal metabolism, such as glucose level, oxygen level;
  - the differences between proteins of the organism itself and of the environment or alien creatures.

Biosensor

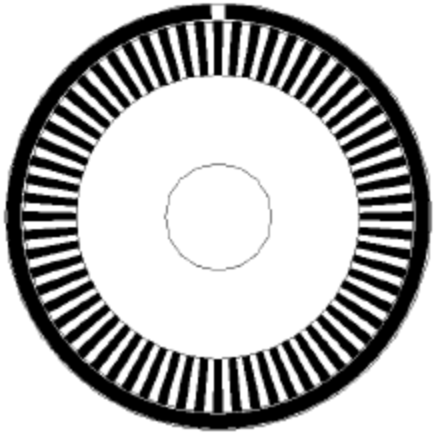
- Device for the detection of a substance
- Combines:
  - A biological component with
  - A physicochemical detector component.
- Commercial biosensor is the blood glucose biosensor (which uses an enzyme to break blood glucose down. In doing so it transfers an electron to an electrode and this is converted into a measure of blood glucose concentration).
- A canary in a cage, as used by miners to warn of gas could be considered a biosensor.
- Many of today's biosensor applications are similar, in that they use organisms which respond to toxic substances at a much lower level than us to warn us of their presence.
- Very good example: tsunami !

Bumper

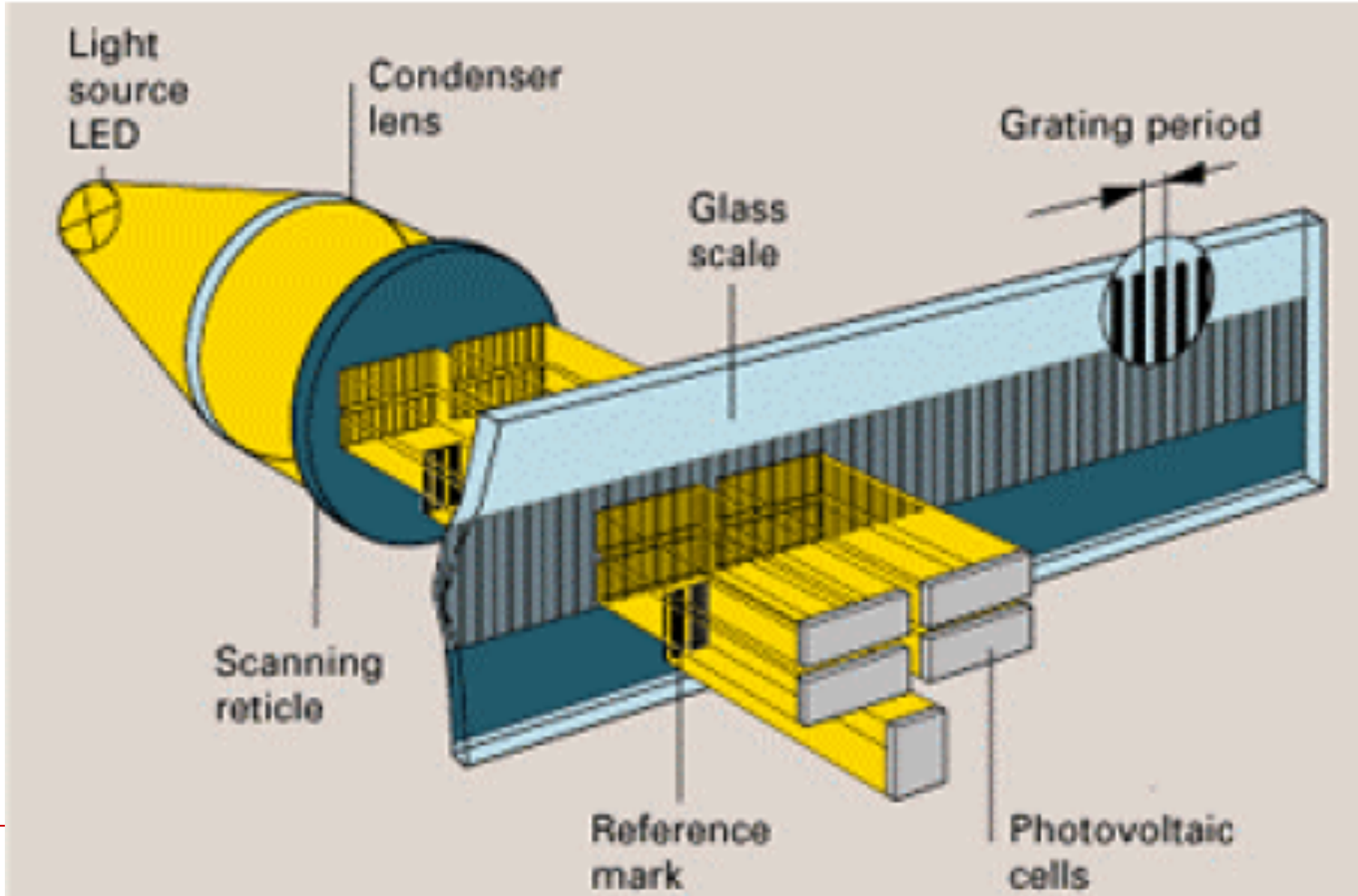
- Switch
- Used for collision detection.
- No power is required for operation.

Wheel / Motor Encoders (1)

- The encoder is a sensor attached to a rotating object (such as a wheel or motor) to measure rotation.
- Usefulness: determine displacement, velocity, acceleration, or the angle of a rotating sensor.
- Can be magnetic, optical,
  mechanical.



Optical encoder



Problems with encoders

- If wheel rotate does it means that robot is moving?
- Encoders have a finite accuracy. Errors acumulate over large distances.

Heading Sensors

- Internal (gyroscope, inclinometer) or external (compass).
- Used to determine the robots orientation and inclination.
- Allow, together with an appropriate velocity information, to integrate the movement to an position estimate.

Compass

- Since over 2000 B.C.
  - *when Chinese suspended a piece of naturally magnetite and used it for guiding purposes.*
- Magnetic field on earth
  - *absolute measure for orientation.*
- Major drawback
  - *weakness of the earth field*
  - *easily disturbed by magnetic objects or other sources*

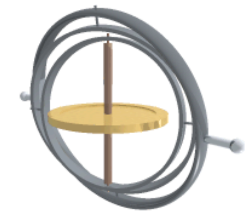
Digital compass

- Contains (M*icro-Electrical Mechanical Systems*) MEMS - tiny nano-structures that bend due to electromagnetic fields.
- When this MEMS experiences any form of EM field, the tiny structures bend by an amount which can be electrically detected.
- Resolution of around +/- 5 degrees and better

Gyroscope

- Heading sensor, that keep the orientation to a fixed frame
  - *absolute measure for the heading of a mobile system.*
- Two categories,
- the mechanical and
- the optical

Mechanical Gyroscopes



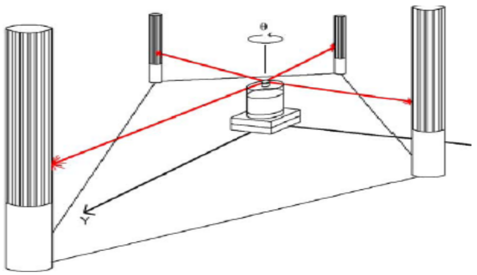
- Concept: inertial properties of a fast spinning rotor
  - *gyroscopic precession*
- Angular momentum associated with a spinning wheel keeps the axis of the gyroscope inertially stable.
- Reactive torque *t* (tracking stability) is proportional to the spinning speed *w*, the precession speed W and the wheels inertia *I*.
- No torque can be transmitted from the outer pivot to the wheel axis
  - *spinning axis will therefore be space-stable*
- If the spinning axis is aligned with the north-south meridian, the earth's rotation has no effect on the gyro's horizontal axis

http://www.youtube.com/watch?v=cquvA_IpEsA

Optical Gyroscopes

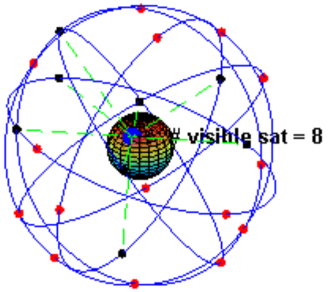
- A **fiber optic gyroscope** (FOG) is a gyroscope that uses the interference of light to detect mechanical rotation
- One beam travels clockwise in a cylinder around a fiber, the other counterclockwise.
- The beam traveling in direction of rotation:
  - *slightly shorter path -> shows a higher frequency (Due to the **Sagnac** effect, the beam traveling against the rotation experiences a slightly shorter path than the other beam.)*

Beacons



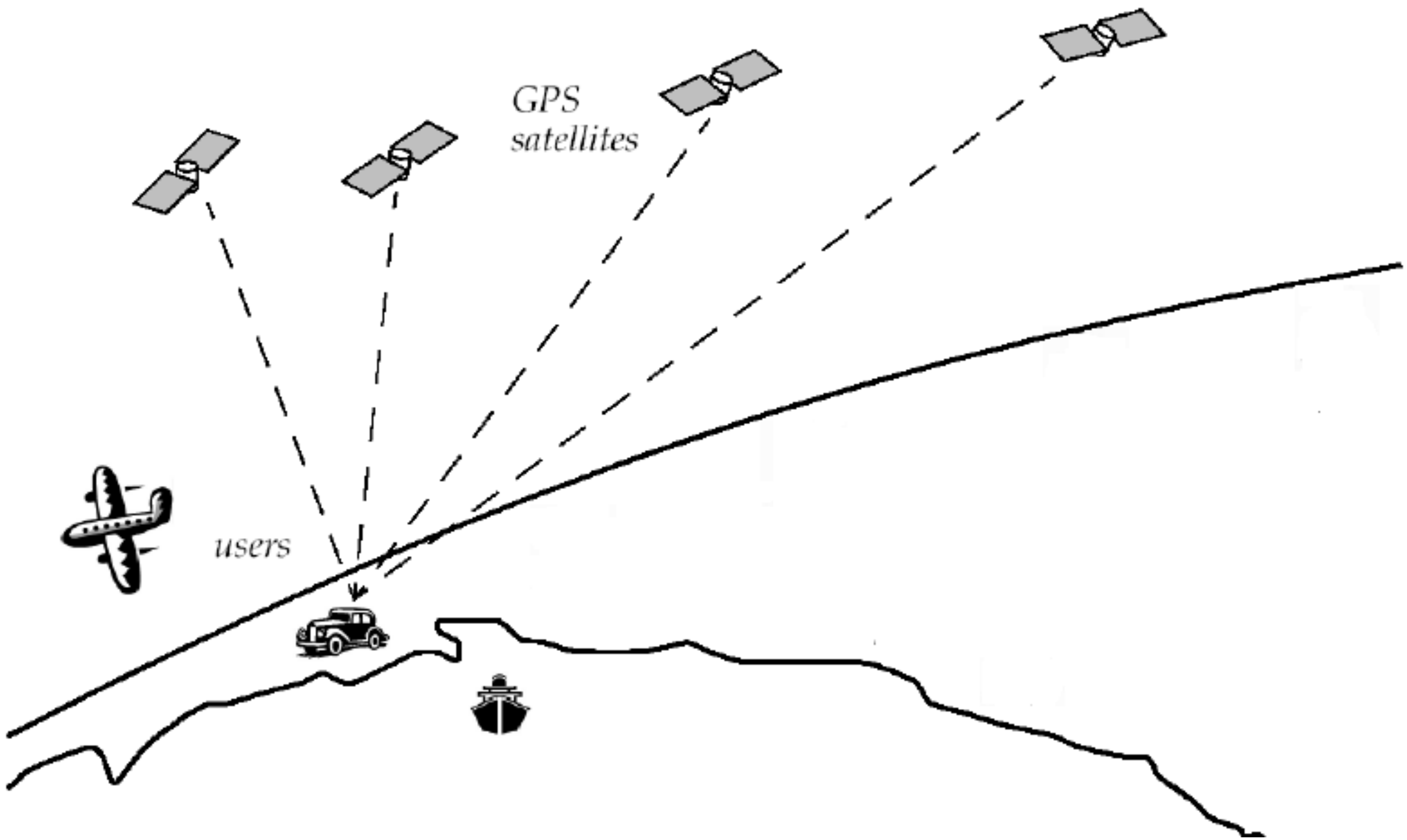
- Elegant way to solve the localization problem in mobile robotics
- Beacons are signaling guiding devices with a precisely known position
- Beacon base navigation is used since the humans started to travel
  - *Natural beacons (landmarks) like stars, mountains or the sun*
  - *Artificial beacons like lighthouses*
- The recently introduced Global Positioning System (GPS) revolutionized modern navigation technology
  - *Already one of the key sensors for outdoor mobile robotics*
  - *For indoor robots GPS is not applicable,*
- Major drawback with the use of beacons in indoor:
  - *Beacons require changes in the environment -> costly.*
  - *Limit flexibility and adaptability to changing environments.*

Global Positioning System (GPS) - NAVSTAR-GPS



- *Developed for military use*
- *32 satellites orbiting the earth at a height of 20.190 km.*
- *First satellite: 1989. Last one: 1994*
- *Full operational capability was declared by NAVSTAR in April 1995.*
- *Reagan ordered to became accessible for commercial applications - after Korean Air Lines Flight 007 was shot down in 1983 after straying into the USSR's prohibited airspace.*
- *Location of any GPS receiver is determined through a time of flight measurement*

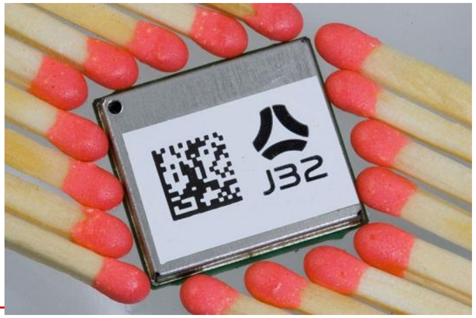
Global Positioning System



Technical challenges

- *Time synchronization between the individual satellites and the GPS receiver*
- *Real time update of the exact location of the satellites*
- *Precise measurement of the time of flight*
- *Interferences with other signals*

Global Positioning System



- Time synchronization:
  - *atomic clocks on each satellite*
  - *monitoring them from different ground stations.*
- Ultra-precision time synchronization is extremely important
  - *electromagnetic radiation propagates at light speed,* roughly 0.3 m per nanosecond.
  - *position accuracy proportional to precision of time measurement.*
- Real time update of the exact location of the satellites:
  - *monitoring the satellites from a number of widely distributed ground stations*
  - *master station analyses all the measurements and transmits the actual position to each of the satellites*
- Exact measurement of the time of flight
  - *the receiver correlates a pseudocode with the same code coming from the satellite*
  - *The delay time for best correlation represents the time of flight.*
  - *quartz clock on the GPS receivers are not very precise*
  - *the range measurement with four satellite*
  - *allows to identify the three values (x, y, z) for the position and the clock correction* ΔT
  - *Error 10 ns – 3m*
- Recent commercial GPS receiver devices allows position accuracies down to a couple meters

Concurent GPS

- GLONASS – Russia – 2011
- Galileo – EU – 2020
- COMPASS – China – 2000 (china only)
- Indian Regional Navigational Satellite System – India -2012

Range Sensors

- Large range distance measurement -> called range sensors
- Range information:
  - *key element for localization and environment modeling*
- Ultrasonic sensors as well as laser range sensors make use of propagation speed of sound or electromagnetic waves respectively.
- The distance traveled by a sound or electromagnetic wave is given by
  - $d = c * t$
- Where
  - d = *distance traveled (usually round-trip)*
  - c = *speed of wave propagation*
  - t = *time of flight.*

Range Sensors - quality

- The quality of time of flight range sensors mainly depends on:
  - *Uncertainties about the exact time of arrival of the reflected signal*
  - *Inaccuracies in the time of flight measure (laser range sensors)*
  - *Opening angle of transmitted beam (ultrasonic range sensors)*
  - *Interaction with the target (surface, reflections)*
  - *Variation of propagation speed*
  - *Speed of mobile robot and target (if not at stand still)*

Ultrasonic Sensor

- transmit a packet of (ultrasonic) pressure waves
- distance *d* of the echoing object can be calculated based on the propagation speed of sound *c* and the time of flight *t*.
- The speed of sound *c* (340 *m/s*) in air depends on several factors

Ultrasonic Sensor (2)

- typically a frequency: 40 - 180 kHz
- generation of sound wave: piezo transducer
  - *transmitter and receiver separated or not separated*
- sound beam propagates in a cone like manner
  - *opening angles around 20 to 40 degrees*

- *Power*
  - *100 mA (standby)*
  - *2 Amps when pings*
- *Range*
  - *> 3 cm (electronics are not so fast as the sound returns)*

Ultrasonic Sensor - problems

- soft surfaces that absorb most of the sound energy (differences between a mirror and a carpet)
- surfaces that are far from being perpendicular to the direction of the sound -> specular reflection
- Problems using multiple sonars in the same room

Laser Range Sensor

- Transmitter illuminates a target wi collimated beam
- Received detects the time needed for round-trip
- A mechanical mechanism with a mirror sweeps
  - *2 or 3D measurement*
- Pulsed laser
  - *measurement of elapsed time directly*
  - *resolving picoseconds*

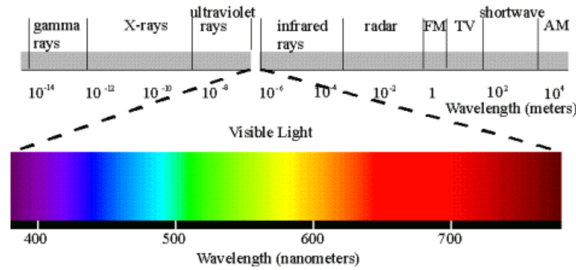
Vision

- Our most powerful sense
- Many devices/algorithms have been developed
- …

PHOTORESISTOR

- Photoresistors -also called phototransistors or photocells.
- Simple resistors that altar resistance depending on the amount of light place over them.
- More light means less resistance.
- Usefulness
  - color sensors,
  - act as an optical switch (non-mechanical button)

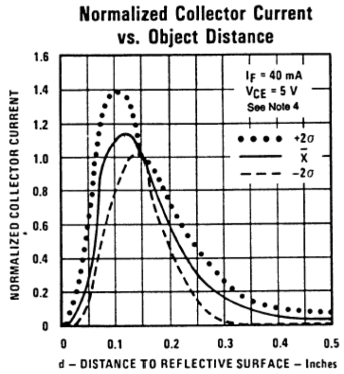
Color sensor

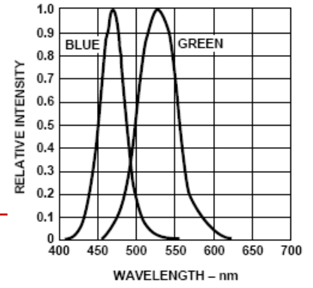


- Objects don’t have color !
  - Their surface reflect certain wavelenghts while absorbing others.
  - Your brain gives you the red, blue, green impression!
- Sensing a color (red)
  - Need a sensor which can make distinction between red and all other colors.
- Making distinction between colors (red and green)
  - Use a photoresistor
  - Shed a red light on both objects
  - Red one will reflect red light and green object will absorb the red light
  - Red object will appear brighter to the sensor

Problems with color sensors

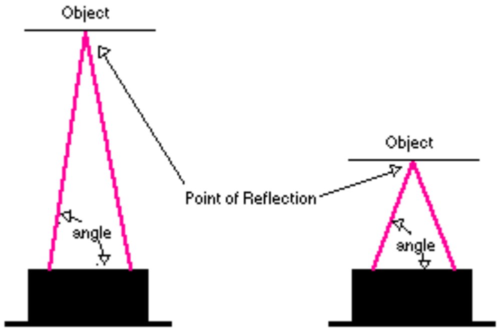
- Photoresistors have different levels of sensitivity to different colors. Optimal peak is at around 520nm.
- Sensitive to distance away from the target.
- Different colors share some wavelengths.





Infrared emitters / detectors

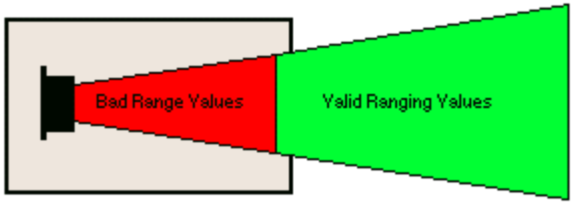
- Same as color sensor, but the emission is done in IR.
- The emmiter and detector have very narrow emission and detection angles, so it is important how are placed.
- Many objects are opaque to visible light (that means light doesn't pass through it, like wood, black plastic, metal), but are transparent to IR light. Black plastic is a good example.
- Aluminum foil covered with electr works as a great shielding materi



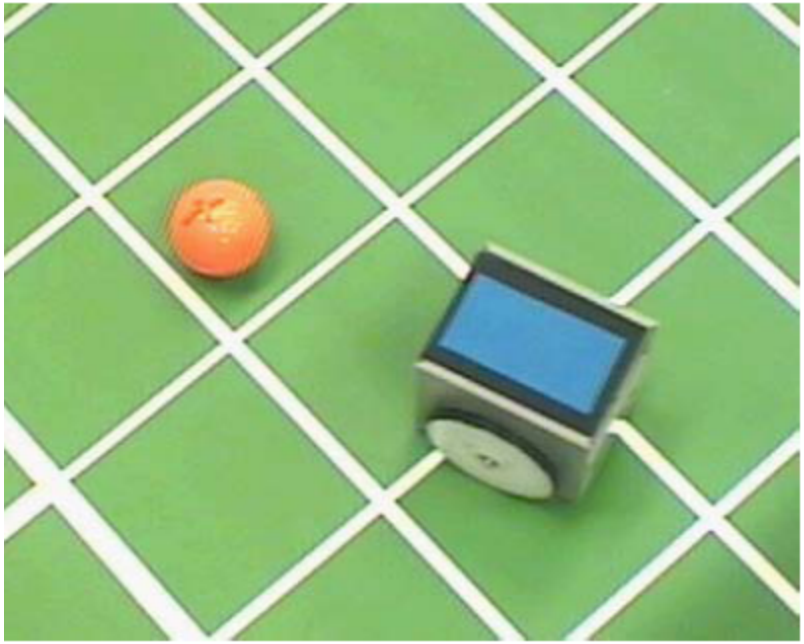
Problems with IR

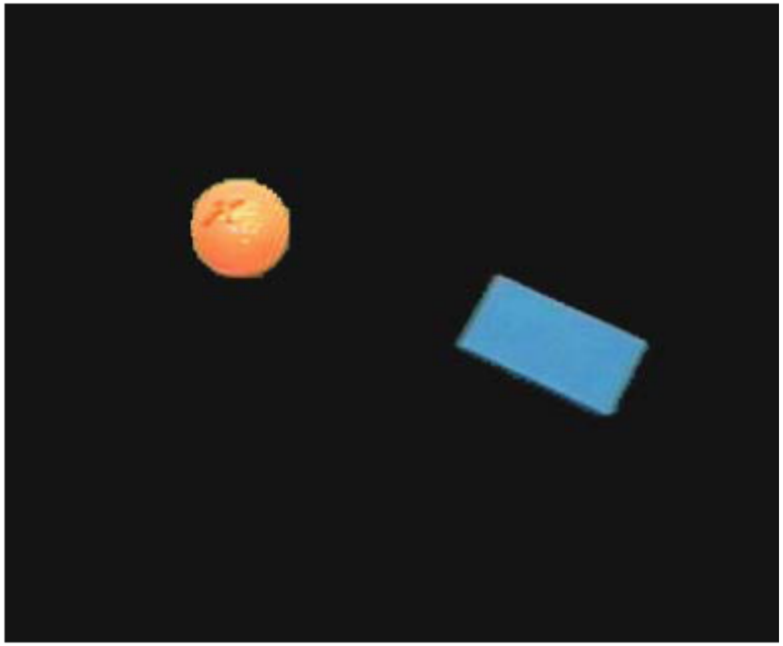
- Non-linear output.

- When an object is very close the sensor cannot get an accurate reading, and it tells your robot that a really close object is really far.



Color tracking





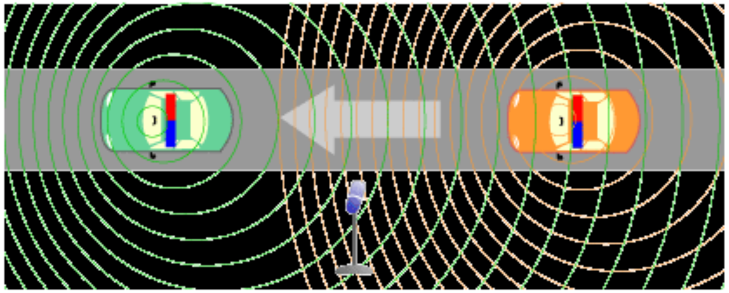
Accelerometer

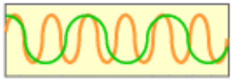
- Inside an accelerator there are MEMS devices that bend due to momentum and gravity.
- On any form of acceleration these tiny structures bend by an equivelent amount which can be electrically detected.
- Applications:
  - Laptop movement,
  - Web camera stabilization
  - Gaming controls
  - Airbag control

Rain Sensor

- Irrigation Sensors
  - causes the system to shut down in the event of rainfall
- Automotive Sensors
  - close the convertible top and raise the open windows.
  - In 1958, the Cadillac Motor Car Division of General Motors experimented with a water-sensitive switch.
  - an infrared light is beamed at a 45-degree angle into the windshield from the inside near the lower edge — if the glass is wet, less light makes it back to the sensor, and the wipers turn on.

Doppler





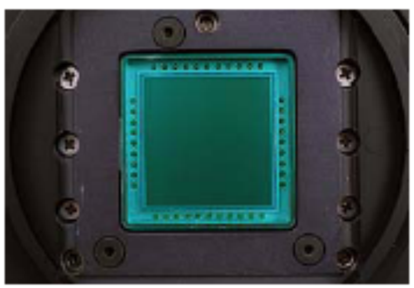
- The received frequenc,
  - is increased (compared to the emitted frequency) during the approach,
  - it is identical at the instant of passing by, and
  - it is decreased during the recession.

Vision-based Sensors: Hardware

- Capture light and convert it into electrical signals:
  - CCD (*Charge-Coupled Device*)
  - CMOS (*Complementary Metal Oxide Semiconductor technology*)

CCD (Charge-Coupled Device)

- Analog device.
- When light strikes the chip it is held as a small electrical charge in each photo sensor.
- The charges are converted to voltage one pixel at a time as they are read from the chip.
- Additional circuitry in the camera converts the voltage into digital information.


2048 x 2048 CCD array


Orangemicro iBOT Firewire


Sony DFW-X700


Cannon IXUS 300

Complementary metal–oxide–semiconductor (CMOS)

- Active pixel sensor (each pixel containing a photodetector and an active amplifier) made using the CMOS semiconductor process.
- Extra circuitry next to each photo sensor converts the light energy to a voltage.
- Additional circuitry on the chip converts the voltage to digital data.