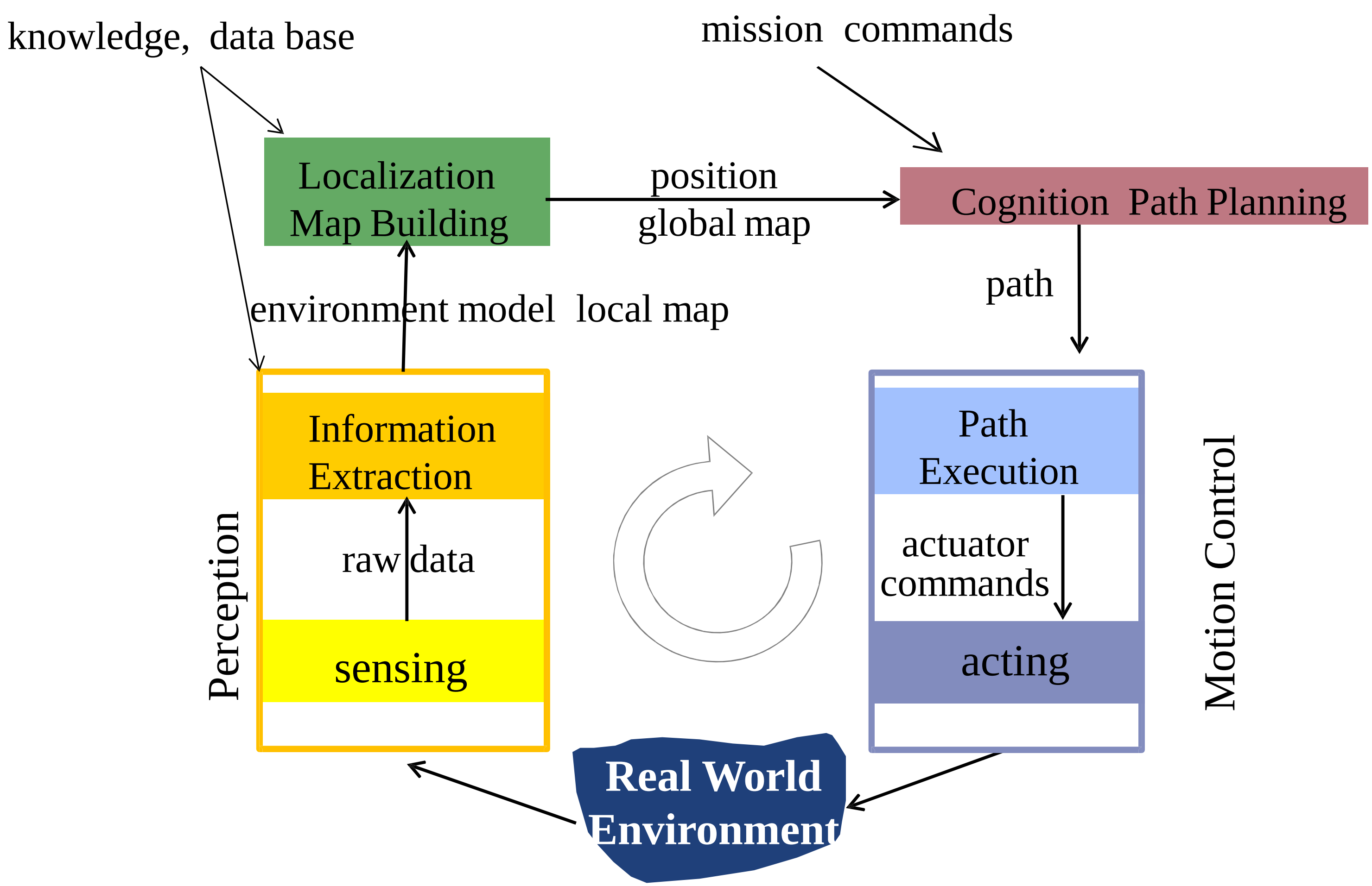
INTELLIGENT ROBOTS

CHAPTER 3: SENSORS

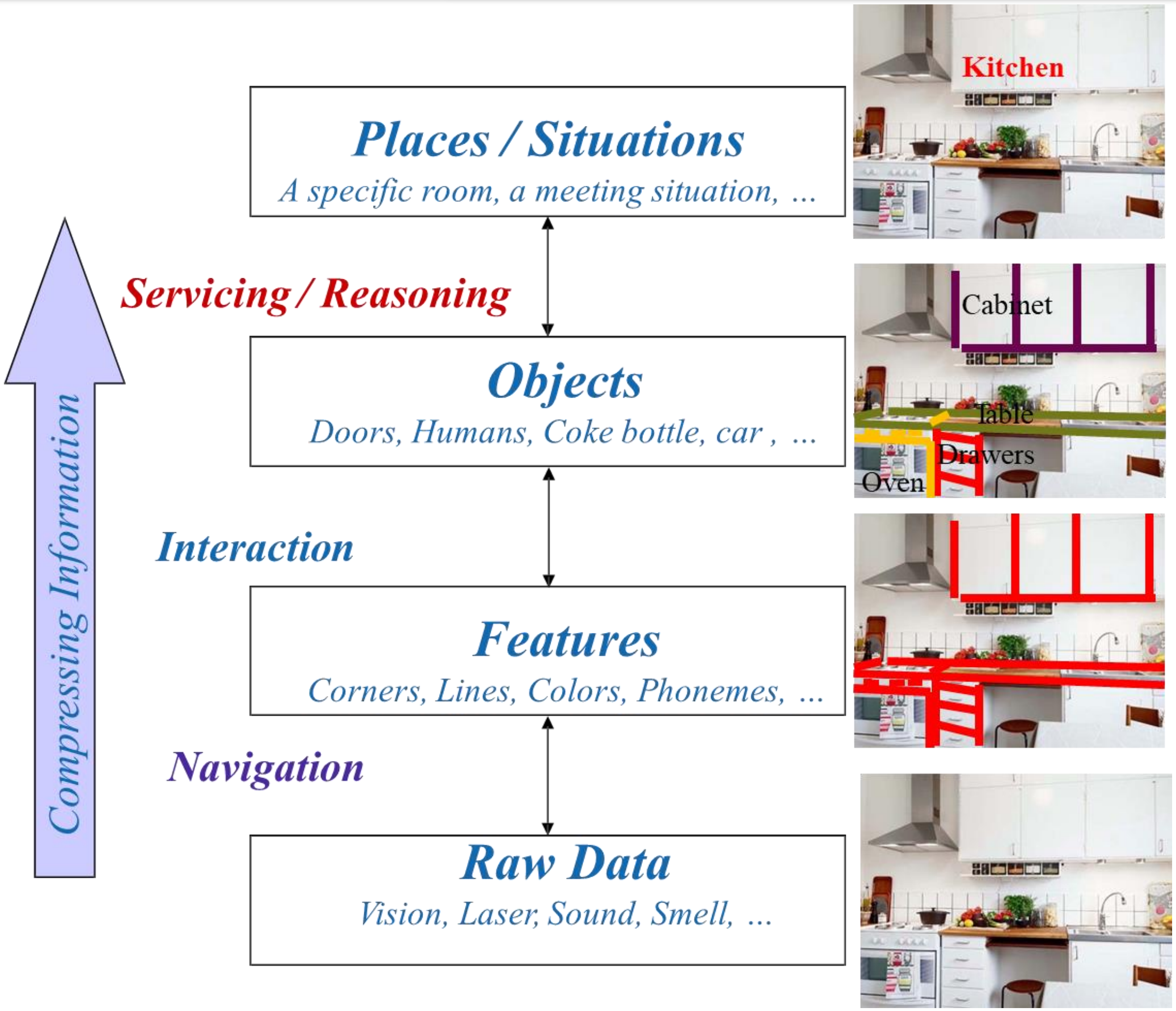
Outline

- Robot Perception
- Sensor Classification
- Sensor Specifications

Mobile Robot Control Scheme



Perception for Mobile Robots



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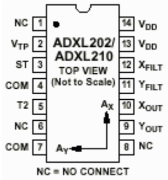
- Sensor Classification
- Sensor Specifications

Sensors for Mobile Robots

- Contact sensors: Bumpers
- Internal sensors
  - Motor encoder
  - Accelerometers (spring-mounted masses)
  - Gyroscopes (spinning mass, laser light)
  - Compasses, inclinometers (earth magnetic field, gravity)
- Proximity sensors
  - Ultrasonic Range Sensor (time of flight)
  - Laser range-finders (triangulation, tof, phase)
  - Structured light
  - Infrared (intensity)
- Visual sensors: Cameras
- Satellite-based sensors: GPS

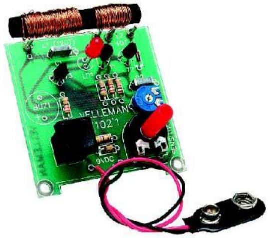


Accelerometer

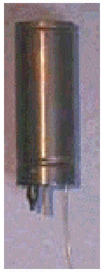

Gyro

Pendulum Resistive Tilt Sensors

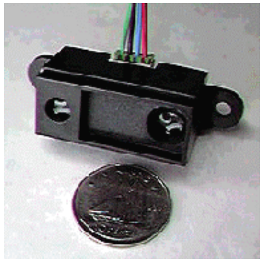

Piezo Bend Sensor


Metal Detector

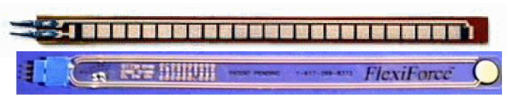
Gas Sensor


Gieger-Muller Radiation Sensor

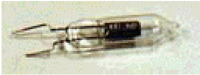

Pyroelectric Detector

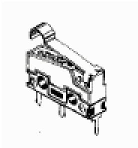

Digital Infrared Ranging

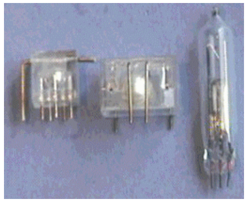

CDS Cell Resistive Light Sensor



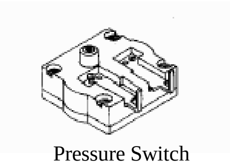
Resistive Bend Sensors

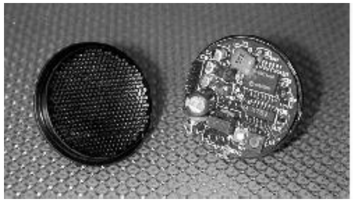

UV Detector

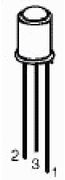

Limit Switch

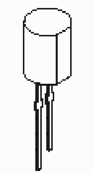

Mechanical Tilt Sensors

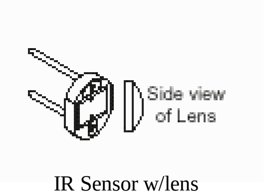

Touch Switch


Pressure Switch

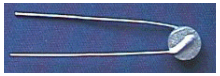

Miniature Polaroid Sensor

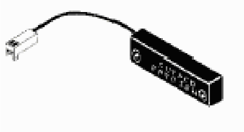


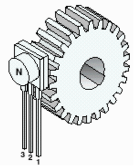

IR Pin Diode



IR Sensor w/lens


Thyristor

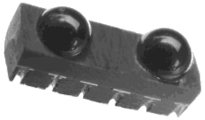

Magnetic Sensor


Hall Effect Magnetic Field Sensors

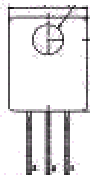

Polaroid Sensor Board

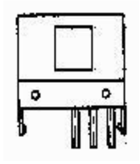

IR Reflection Sensor


IR Amplifier Sensor

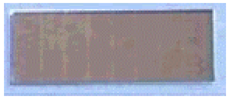

IRDA Transceiver

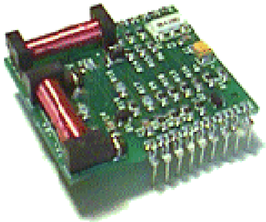

Magnetic Reed Switch

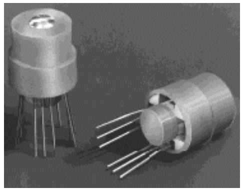

Lite-On IR Remote Receiver

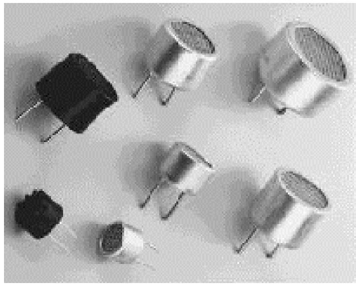

Radio Shack Remote Receiver


IR Modulator Receiver


Solar Cell


Compass


Compass


Piezo Ultrasonic Transducers

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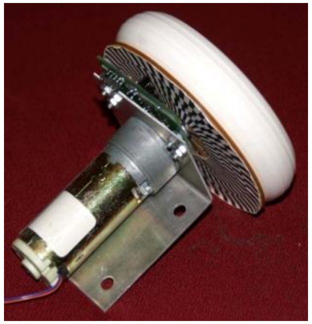
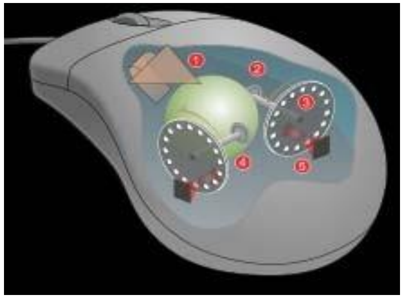
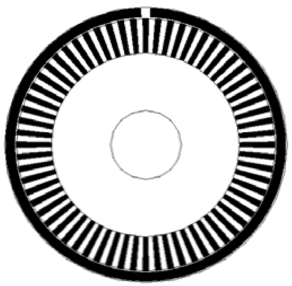
Encoders

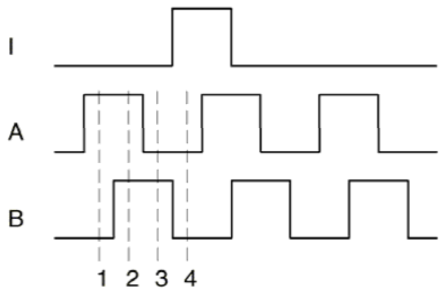
- electro-mechanical device that converts linear or angular position of a shaft to an analog or digital signal, making it an linear/anglular transducer



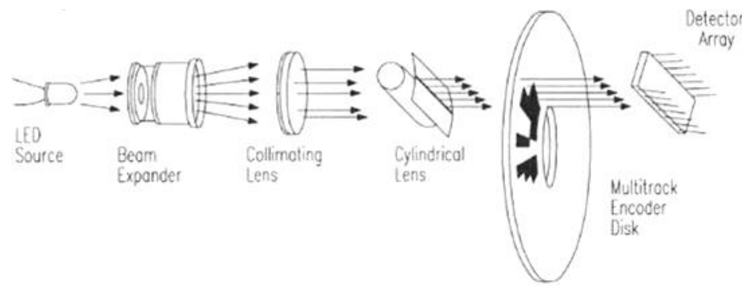


Wheel / Motor Encoders





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



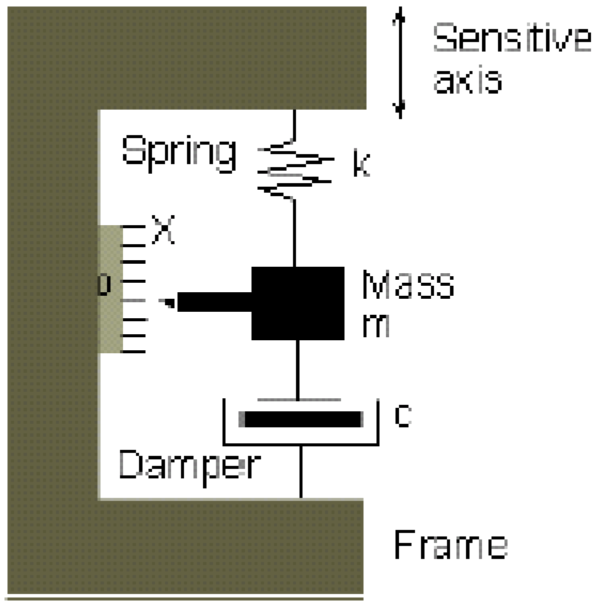
- **Applications:**
  - measure position or speed of the wheels or steering
  - integrate wheel movements to get an estimate of the position -> odometry
  - optical encoders are proprioceptive sensors

- **Mechanisms:**
  - regular: counts the number of transitions but cannot tell the direction of motion
  - quadrature: uses two sensors in quadrature-phase shift. The ordering of which wave produces a rising edge first tells the direction of motion. Additionally, resolution is 4 times higher

Mechanical Accelerometer

Main elements:

1. Mass 2. Suspension mechanism 3. Sensing element



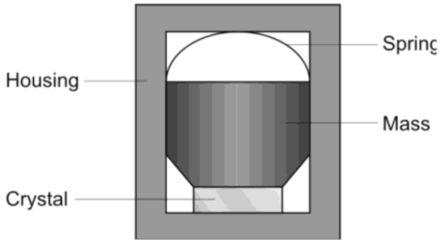
$$F = m\frac{d^2x}{d^2t} + c\frac{dx}{dt} + kx$$

- measure all external forces acting upon them, including gravity
- acts like a spring–mass–damper system

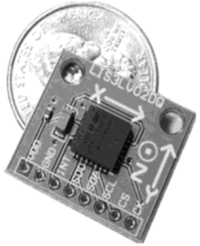
High quality accelerometers include a servo loop to improve the linearity of the sensor.

Other Accelerometers

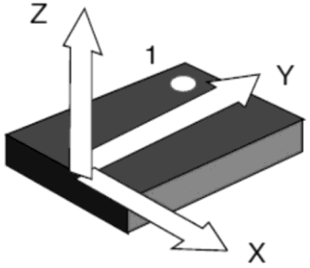
- **Micro Electro-Mechanical Systems (MEMS) accelerometers**: consisting of a spring-like structure with a proof mass; damping results from the residual gas sealed in the device.



- **Capacitive accelerometers**: the capacitance between a fixed structure and the proof mass is measured



- **Piezoelectric accelerometers**: based on the property exhibited by certain crystals to generate a voltage when a mechanical stress is applied to them



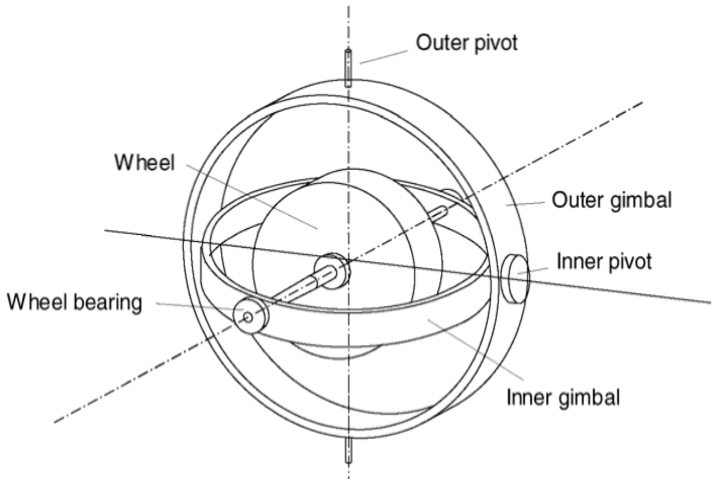
Gyroscope

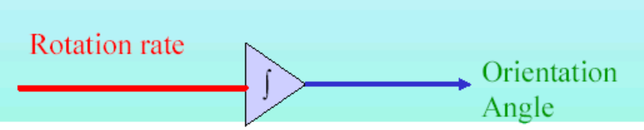
- **Definition:**
  - provide an absolute measure for the heading of a mobile system
  - preserve the orientation in relation to a fixed reference frame.

- **Classification:**
  - Mechanical Gyroscopes
    - Standard gyro (angle) and rate gyro (speed)
  - Optical Gyroscopes
    - Rate gyro (speed)

Standard Gyro

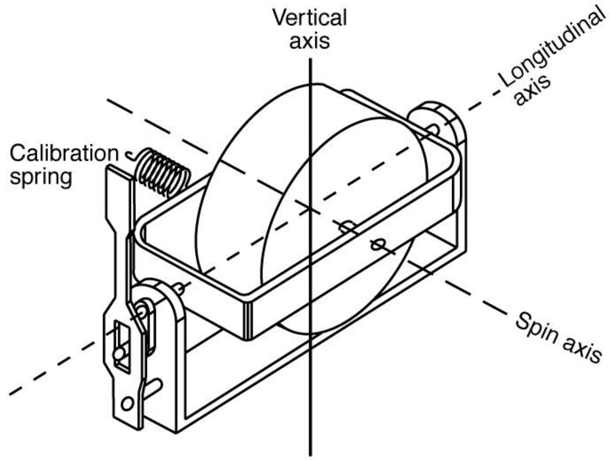
- **Concept:**
  - Inertial properties of a fast spinning rotor
  - Angular momentum associated with a spinning wheel keeps the axis of the gyroscope inertially stable.
- **Mechanism:**
  - No torque transmitted from the outer pivot to the wheel axis
  - spinning axis will be space-stable
  - friction in the axes bearings will introduce torque and drift
- **Quality:**
  - 0.1° in 6 hours (a high quality mech. gyro costs up to 100,000 $)





$$\theta\ (t) = \int \dot{\theta}\ (t)\ dt$$

Rate Gyros

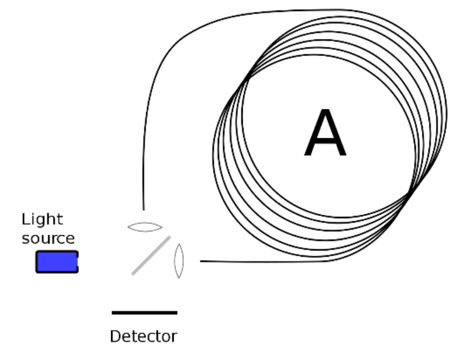


rate gyro

- Same basic arrangement shown as regular mechanical gyros
- But: gimbals are restrained by torsional springs
  - enables to measure angular speeds instead of the orientation.

Optical Gyro

- **Concept**: (Sagnac effect)
  - angular speed (heading) sensors using two monochromic light (or laser) beams from the same source.
  - One is traveling in a fiber clockwise, the other counterclockwise around a cylinder



- **Mechanism:**
  - Laser beam traveling in direction opposite to the rotation experiences slightly shorter path
  - phase shift of the two beams is proportional to the angular velocity W of the cylinder
  - In order to measure the phase shift, coil consists of as much as 5km optical fiber

Single axis optical gyro

- **Product:**
  - solid-state optical gyroscopes

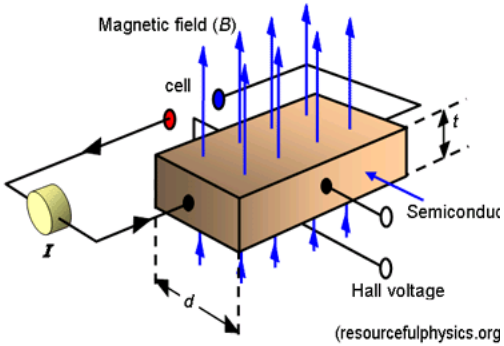
3-axis optical gyro

Compass

- **Concept:**
  - Magnetic field on earth
  - absolute measure for orientation (even birds use it for migrations (2001))
  - Used since before 2000 B.C.

- **Classification:**
  - mechanical magnetic compass
  - direct measure of the magnetic field (Hall-effect, magneto-resistive sensors)
  - Gyrocompass (non-magnetic, finds true north by using fast-spinning wheel and friction forces in order to exploit the rotation of the Earth) -> used on ships

- **Major drawbacks:**
  - weakness of the earth field (30 µTesla)
  - easily disturbed by magnetic objects or other sources
  - bandwidth limitations (0.5 Hz) and susceptible to vibrations



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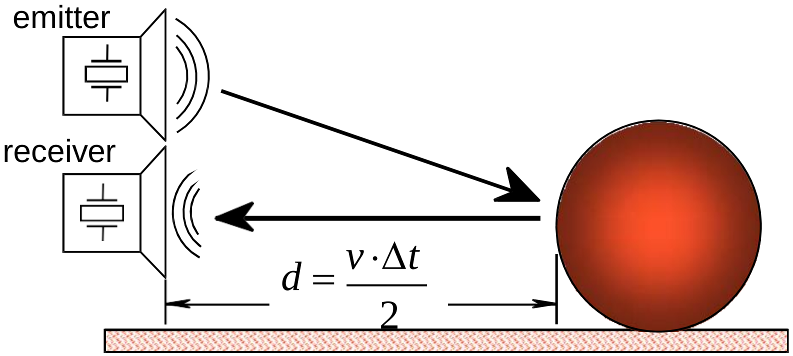
Ultrasonic Range Sensor



1. Operational Principle

An ultrasonic pulse is generated by a piezo-electric emitter, reflected by an object in its path, and sensed by a piezo-electric receiver. Based on the speed of sound and the time between emission and reception, the distance between the sensor and the object is easily calculated.

2. Main Characteristics

- Precision influenced by angle to object (as illustrated on the next slide)
- Useful in ranges from several cm to several meters
- **Typically relatively inexpensive**

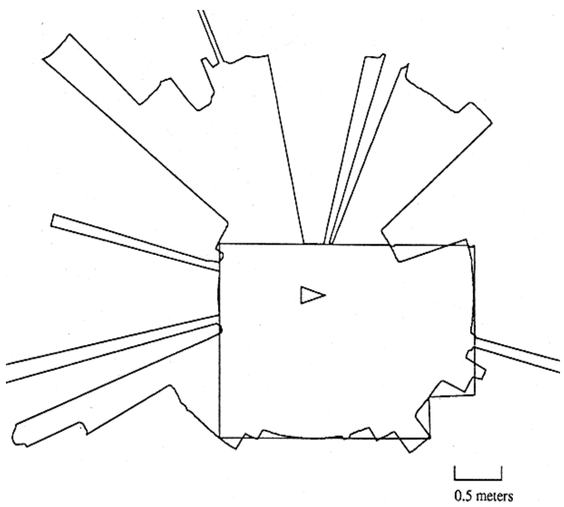
3. Applications

- Distance measurement (also for transparent surfaces)
- Collision detection

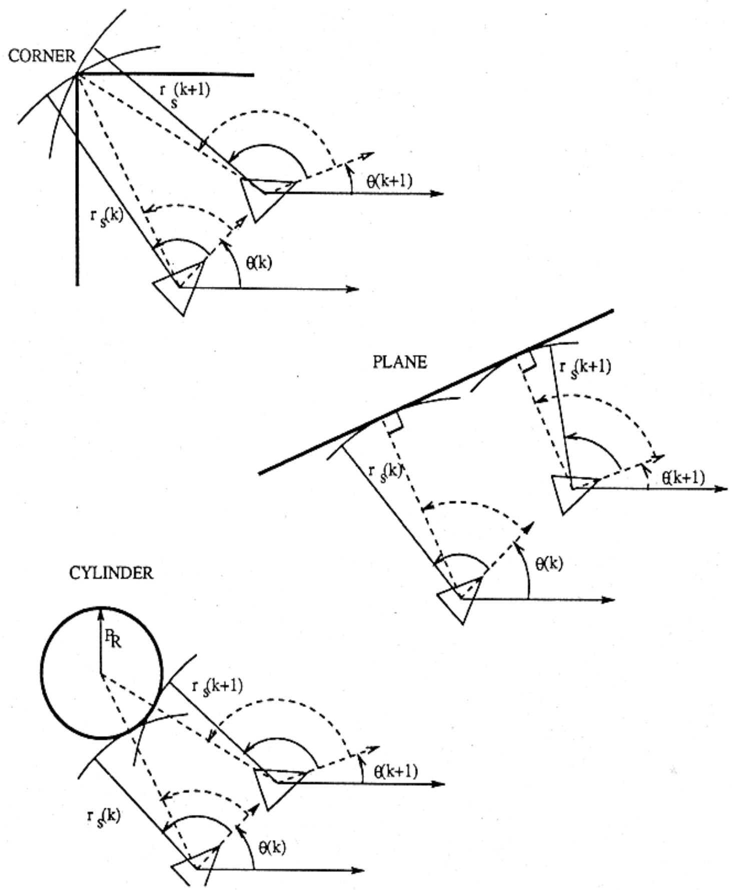
Ultrasonic Range Sensor

Other problems for ultrasonic sensors

- soft surfaces that absorb most of the sound energy
- surfaces that are far from being perpendicular to the direction of the sound specular reflections



a) 360° scan



b) results from different geometric primitives

Laser Range-Finder

Laser range finder are also known as Lidar (Light Detection And Ranging)

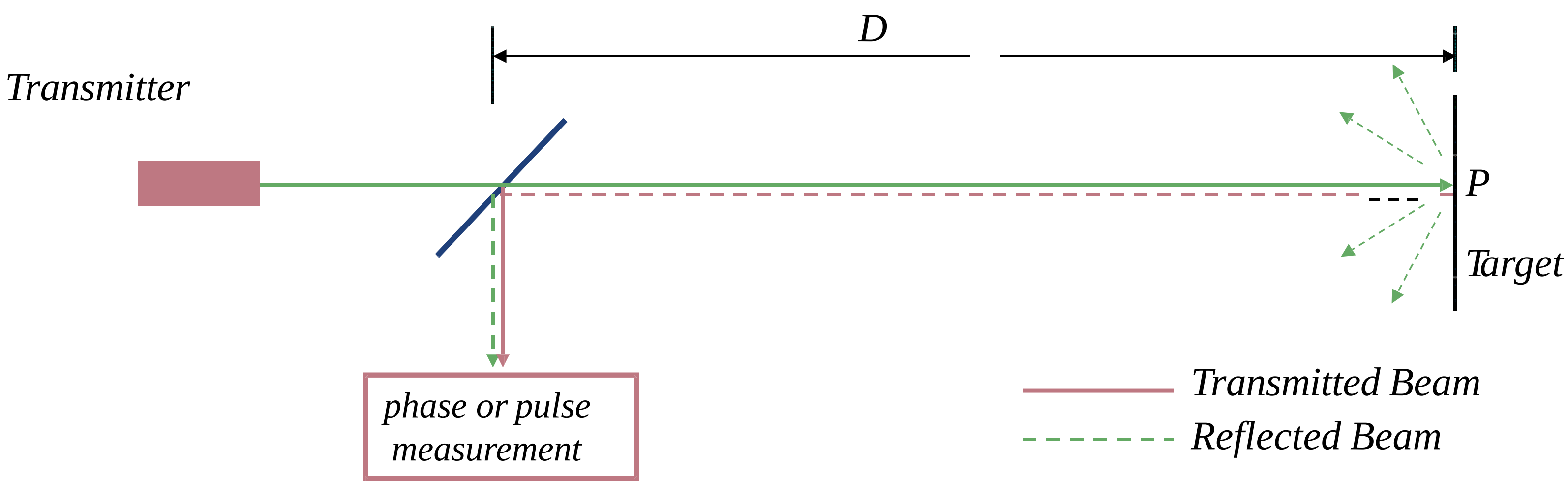
SICK

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

Hokuyo

Laser Range-Finder

- **Phase-Shift Measurement**



$$D' = 2D = \frac{\theta}{2\pi}\lambda \qquad \lambda = \frac{c}{f}$$

where:

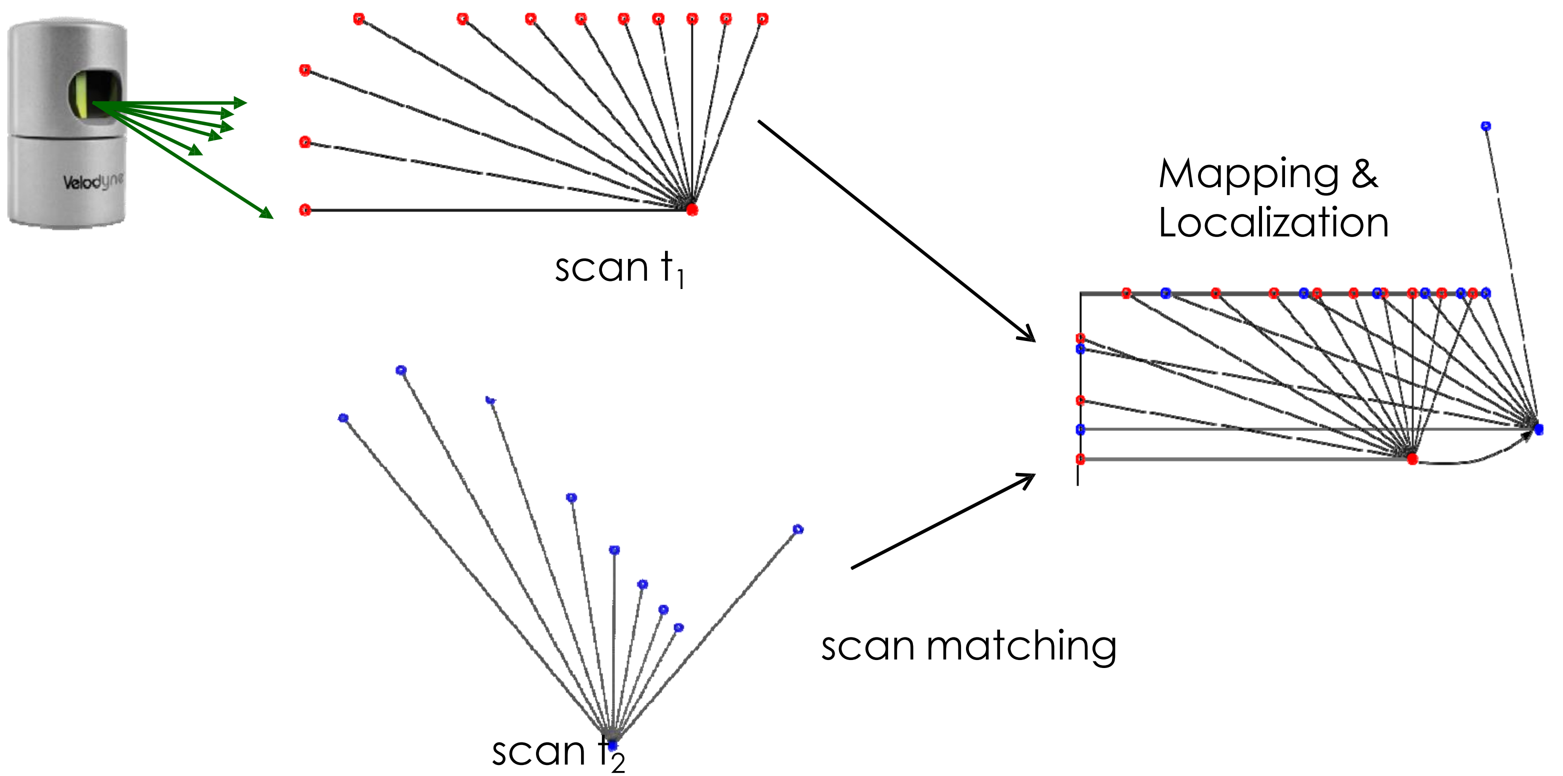
c: is the speed of light; f the modulating frequency; D' the distance covered by the emitted light

for f = 5 MHz (as in the A.T&T. sensor), λ = 60 meters

Laser Range-Finder

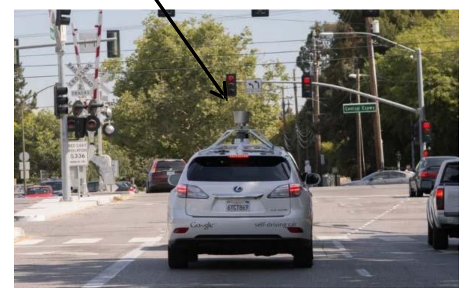
- **Operating Principles**:
  - Pulsed laser (today the standard)
    - measurement of elapsed time directly
    - resolving picoseconds
  - Phase shift measurement to produce range estimation
    - technically easier than the above method

Laser-based 3D Mapping



3D Laser Sensors

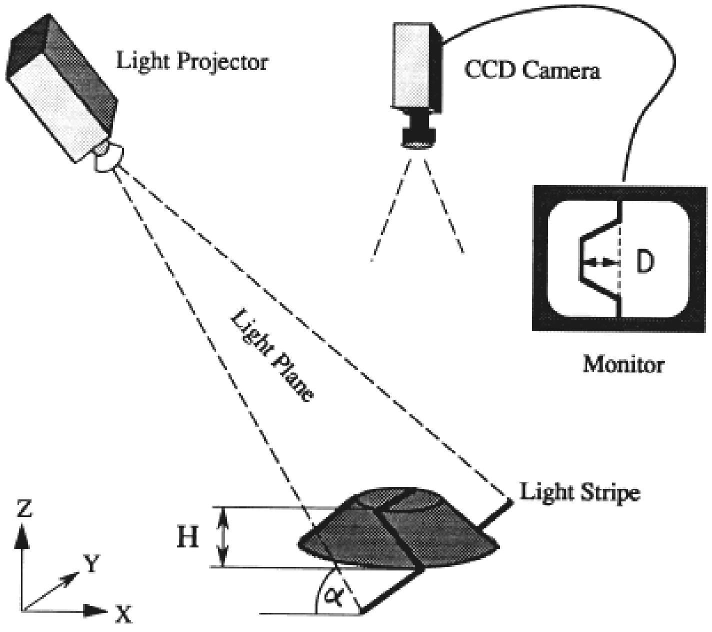
Expensive, complex and cumbersome



- **Self-Driving** (status summer 2015)
  - > 20 vehicles in use
  - > 2,7 mio km, 1.5 mio km in autonomous mode
  - > 11 accidents
  - No people insured
  - Non of them caused by car control algorithm

Structured Light

- Eliminate the correspondence problem by projecting structured light on the scene.
- Slits of light or emit collimated light (possibly laser) by means of a rotating mirror.



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Camera

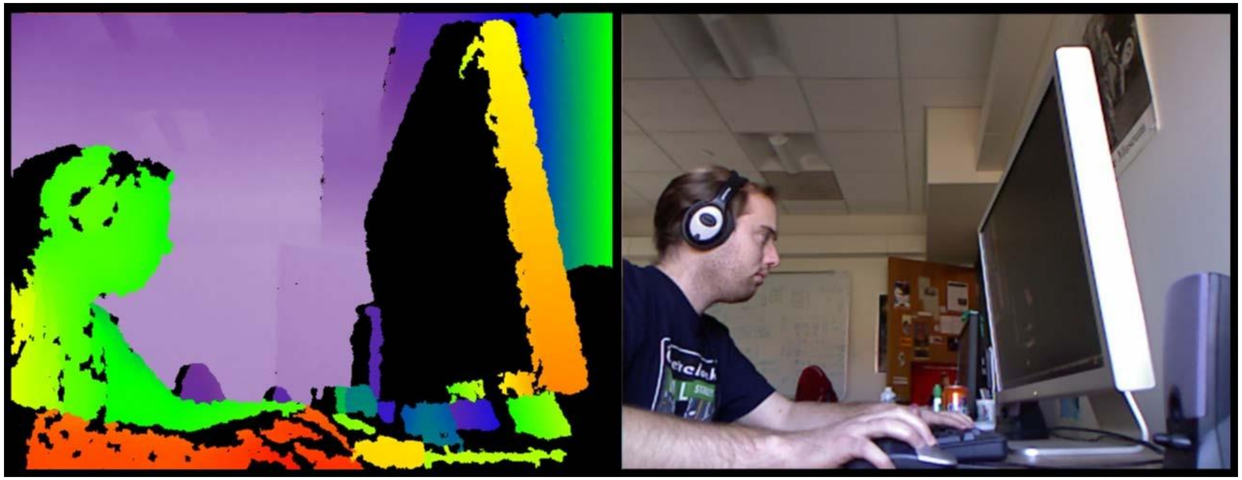
Microsoft Kinect I

- Developed by Israeli company PrimeSense in 2010
- Major components
  - IR Projector
  - IR Camera
  - VGA Camera
  - Microphone Array
  - Motorized Tilt
  - Field of view: 57.5 deg (horizontal) – 43.5 (vertical)
  - Camera resolution: 640x480 pixels

Camera

Video Out

- 30 fps
- 57 degree
- 8 bit VGA RGB 640x480



Camera

Time of Flight / Projected Light Patterns

e.g. Kinect 2.0 & Intel RealSense

- Typical characteristic
  - Resolution 1920x1080 pixels
  - Field of view: 70 deg (H), 60 deg (V)
  - Claimed accuracy: 1 mm
  - Claimed max range: 6 meters

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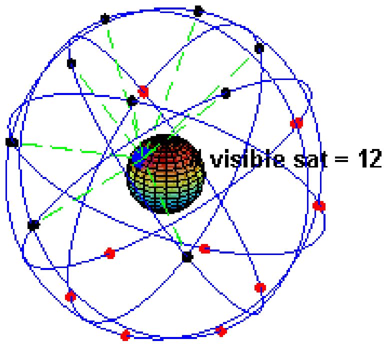
Global Positioning System (GPS)

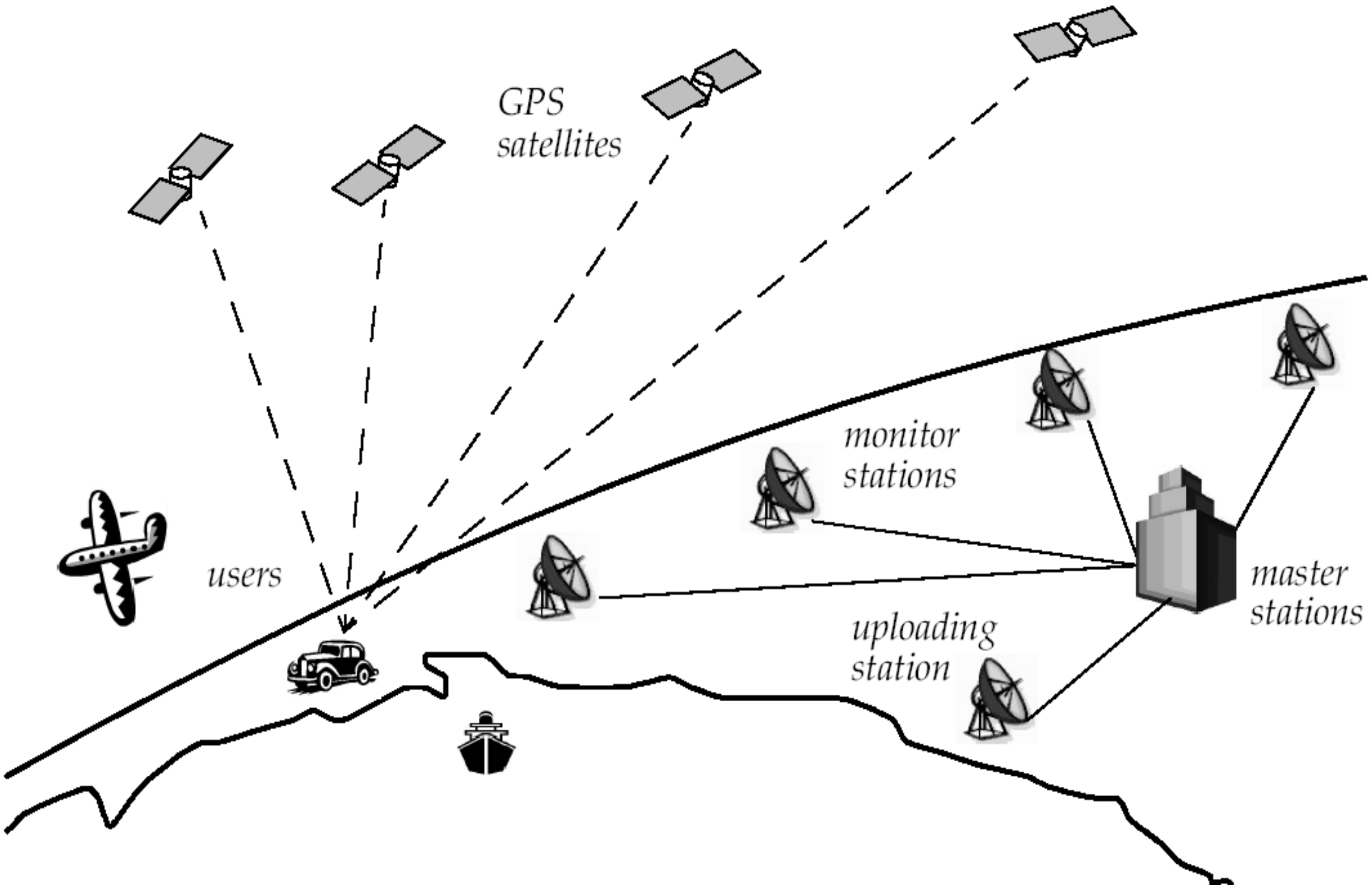
- **History**：
  - Commercial applications in 1995， initially 24 satellites orbiting the earth every 12 hours at a height of 20.190 km.
  - 4 satellites were located in each of 6 orbits with 60 degrees orientation between each other.



- **Principle**：
  - Location of any GPS receiver is determined through a time of flight measurement (satellites send orbital location plus time; the receiver computes its location through trilateration and time correction)

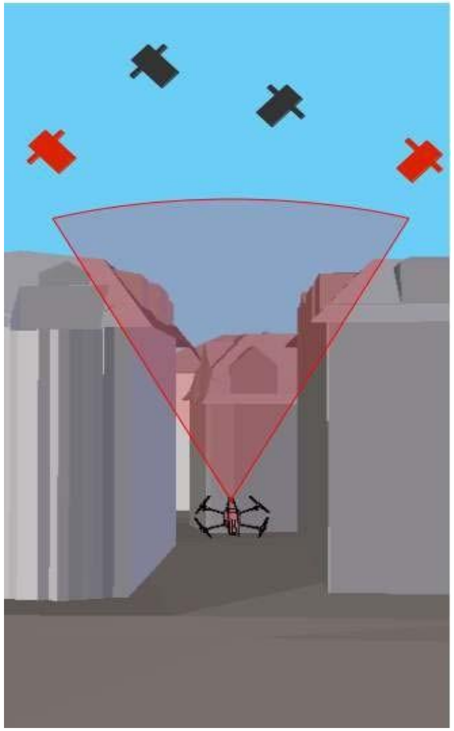
- **Challenges**:
  - Time synchronization between the satellites and the GPS receiver
  - Real time update of the exact location of the satellites
  - Precise measurement of the time of flight
  - Interferences with other signals

Global Positioning System (GPS)

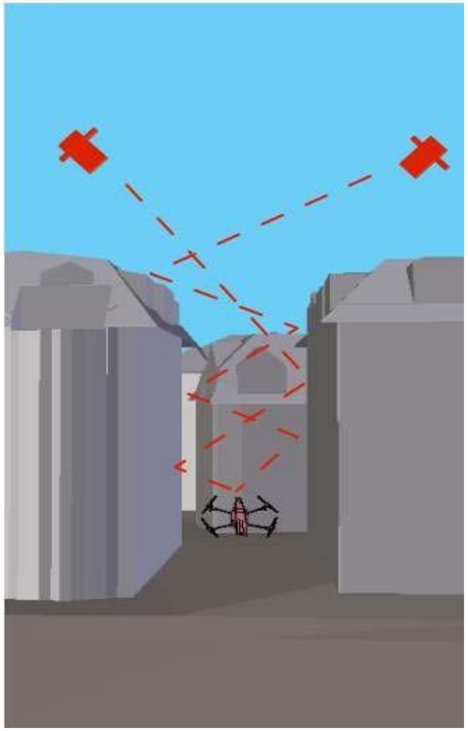


Global Positioning System (GPS)

Satellite coverage



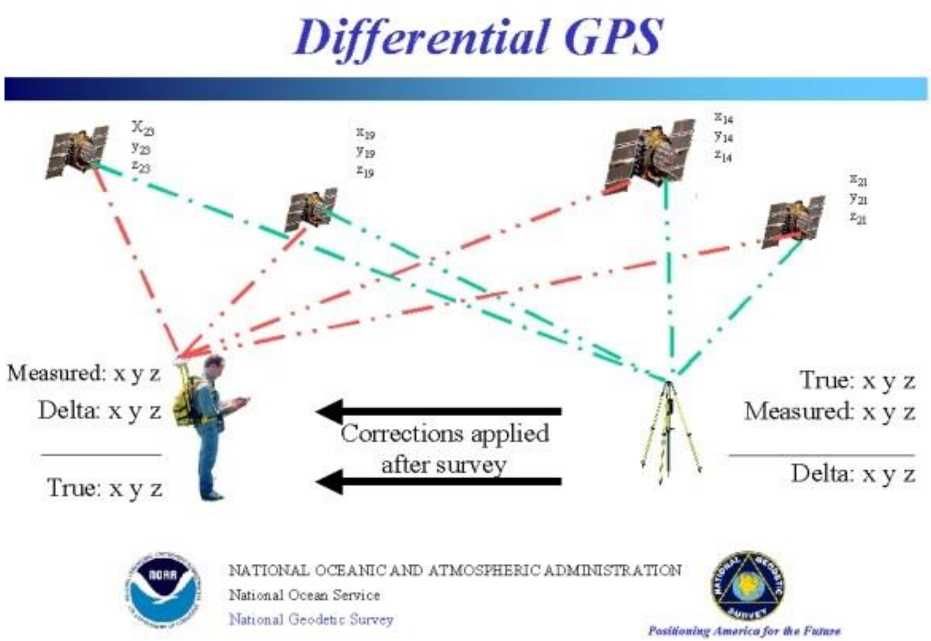
Multipath problem



GPS Device for Car

Differential Global Positioning System

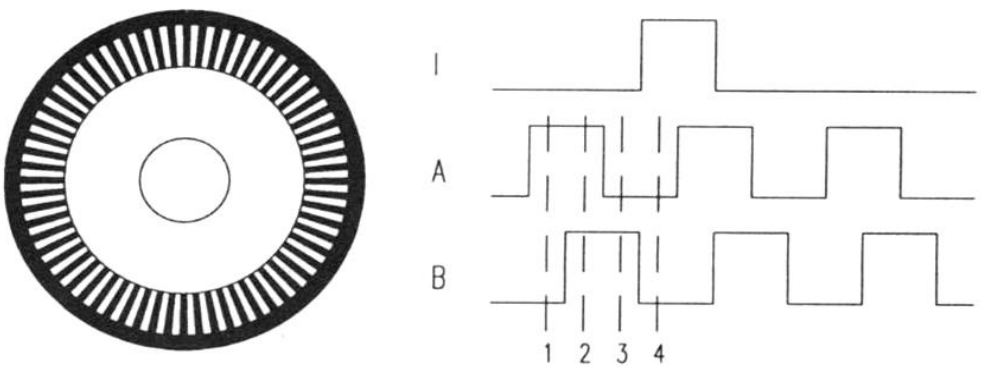
- DGPS requires that a GPS receiver, known as the **base station**, be set up on a **precisely known location.** The base station receiver calculates its position based on satellite signals and compares this location to the known location. The difference is applied to the GPS data recorded by the roving GPS receiver
- **position accuracies in sub-meter to cm range**



Homework 2

Problem 1: If there are 100 lines in the grating, what is the smallest detectable change in motor-shaft angle?

Problem 2: Explain how to determine the rotation directions if the following encoders are used. List two concerns while choosing an encoder.

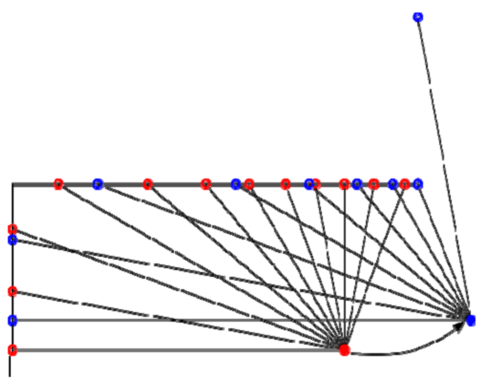


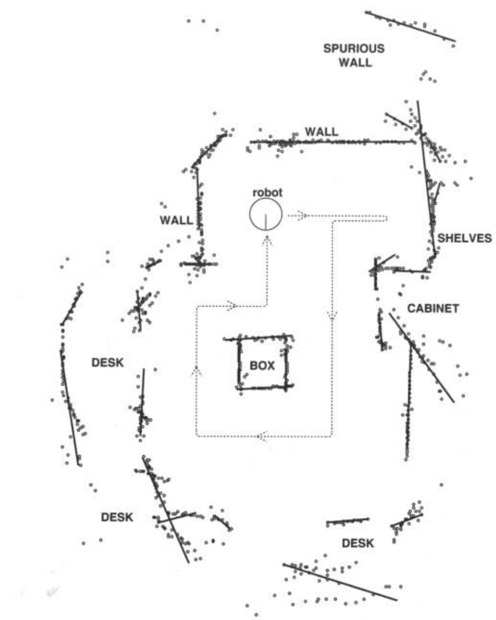
State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Homework 2

Problem 3: Simulate the process of mapping of a room by using a moving range sensor which knows its location accurately (randomly walking, or moving along a circle).

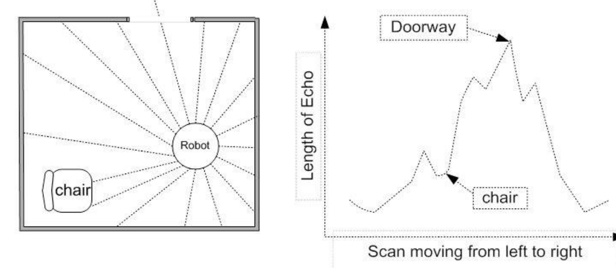
Laser Sensors





Ultrasonic Sensors

- Applications:
  - Distance Measurement
  - Mapping: Rotating proximity scans (maps the proximity of objects surrounding the robot)



Scanning at an angle of 15° apart can achieve best results

Problem 4: Simulate the process of localization with GPS signals. When sender-receiver clocks are either synchronized or not synchronized, how many satellites are needed to achieve 3D accurate positions, respectively?