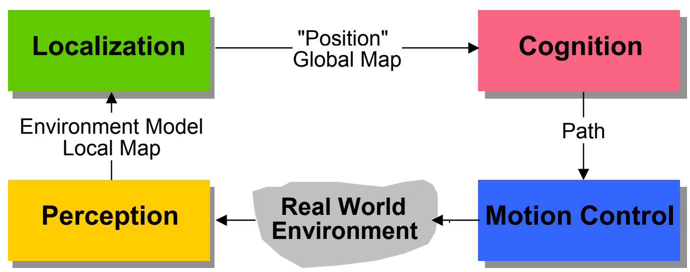
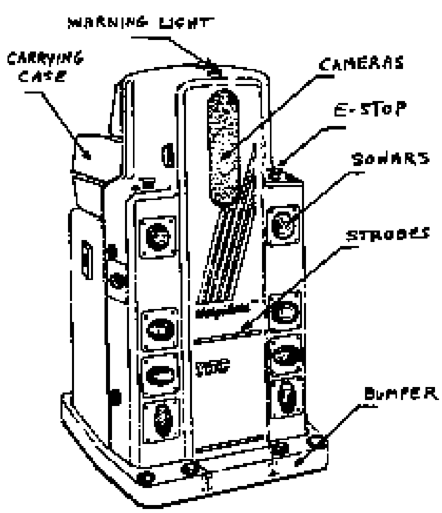
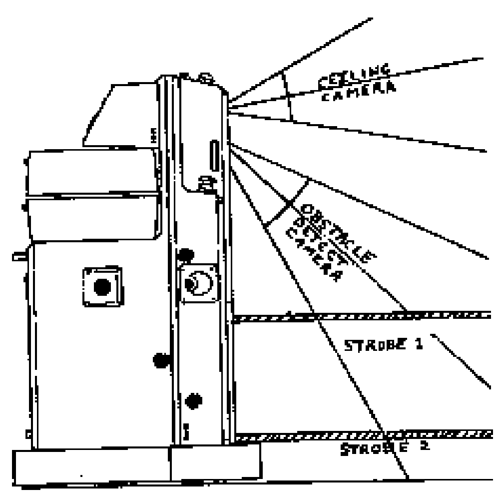
Perception

- Sensors
- Uncertainty
- Features

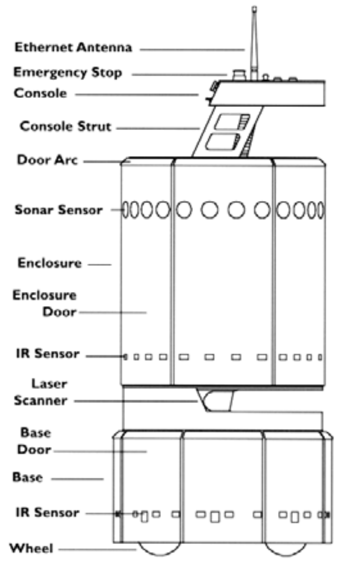


Example HelpMate, Transition Research Corp.



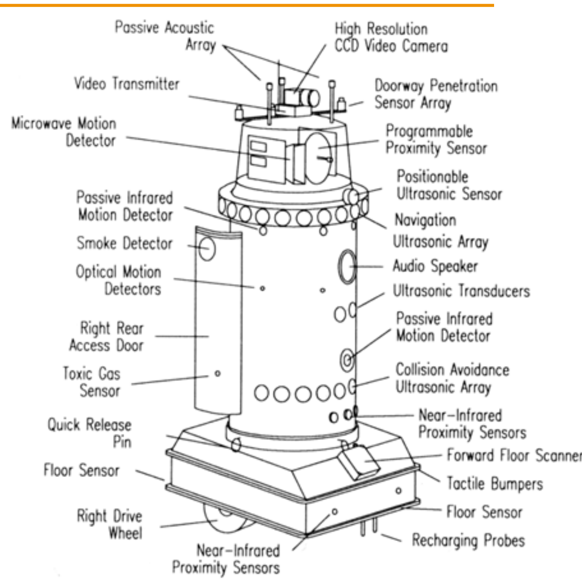


Example B21, Real World Interface



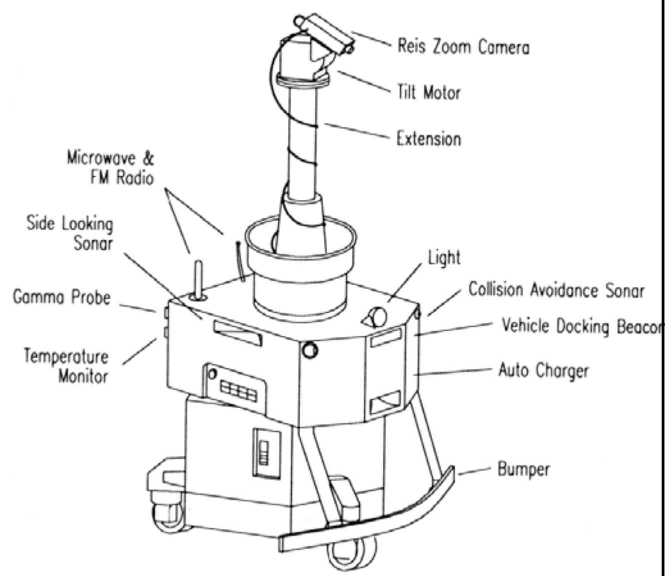
Autonomous Mobile Robots, Chapter 4
4.1

Example Robart II, H.R. Everett



© R. Siegwart, I. Nourbakhsh

Savannah, River Site Nuclear Surveillance Robot



BibaBot, BlueBotics SA, Switzerland

IMU
Inertial Measurement Unit

Emergency Stop Button

Wheel Encoders

Omnidirectional Camera

Pan-Tilt Camera

Sonar Sensors

Laser Range Scanner

Bumper

Classification of Sensors

- Proprioceptive sensors
  - *measure values internally to the system (robot),*
  - *e.g. motor speed, wheel load, heading of the robot, battery status*
- Exteroceptive sensors
  - *information from the robots environment*
  - *distances to objects, intensity of the ambient light, unique features.*
- Passive sensors
  - *energy coming for the environment*
- Active sensors
  - *emit their own energy and measure the reaction*
  - *better performance, but some influence on envrionment*

General Classification (1)

General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Tactile sensors (detection of physical contact or closeness; security switches)	Contact switches, bumpers	EC	P
	Optical barriers	EC	A
	Noncontact proximity sensors	EC	A
Wheel/motor sensors (wheel/motor speed and position)	Brush encoders	PC	P
	Potentiometers	PC	P
	Synchros, resolvers	PC	A
	Optical encoders	PC	A
	Magnetic encoders	PC	A
	Inductive encoders	PC	A
	Capacitive encoders	PC	A
Heading sensors (orientation of the robot in relation to a fixed reference frame)	Compass	EC	P
	Gyroscopes	PC	P
	Inclinometers	EC	A/P

A, active; P, passive; P/A, passive/active; PC, proprioceptive; EC, exteroceptive.

General Classification (2)

General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Ground-based beacons (localization in a fixed reference frame)	GPS Active optical or RF beacons Active ultrasonic beacons Reflective beacons	EC EC EC EC	A A A A
Active ranging (reflectivity, time-of-flight, and geometric triangulation)	Reflectivity sensors Ultrasonic sensor Laser rangefinder Optical triangulation (1D) Structured light (2D)	EC EC EC EC EC	A A A A A
Motion/speed sensors (speed relative to fixed or moving objects)	Doppler radar Doppler sound	EC EC	A A
Vision-based sensors (visual ranging, whole-image analysis, segmentation, object recognition)	CCD/CMOS camera(s) Visual ranging packages Object tracking packages	EC	P

Characterizing Sensor Performance (1)

Measurement in real world environment is error prone

- Basic sensor response ratings
  - *Dynamic range*
    - *ratio between lower and upper limits, usually in decibels (dB, power)*
    - *e.g. power measurement from 1 Milliwatt to 20 Watts*

$$10 \cdot \log\left[\frac{20}{0.001}\right] = 43dB$$

    - *e.g. voltage measurement from 1 Millivolt to 20 Volt*

$$20 \cdot \log\left[\frac{20}{0.001}\right] = 86dB$$

    - 20 instead of 10 because square of voltage is equal to power!!
  - *Range*
    - *upper limit*

Characterizing Sensor Performance (2)

- Basic sensor response ratings (cont.)
  - *Resolution*
    - *minimum difference between two values*
    - *usually: lower limit of dynamic range = resolution*
    - *for digital sensors it is usually the A/D resolution.*
      e.g. 5V / 255 (8 bit)
  - *Linearity*
    - *variation of output signal as function of the input signal*
    - *linearity is less important when signal is post-processed by a computer*
  - *Bandwidth or Frequency*
    - *the speed with which a sensor can provide a stream of readings*
    - *usually there is an upper limit depending on the sensor and the sampling rate*
    - *Lower limit is also possible, e.g. acceleration sensor*

In Situ Sensor Performance (1)

Characteristics that are especially relevant for real world environments

- Sensitivity
  - *ratio of output change to input change*
  - *however, in real world environment, the sensor has very often high sensitivity to other environmental changes, e.g. illumination*
- Cross-sensitivity
  - *sensitivity to environmental parameters that are orthogonal to the target parameters*
- Error / Accuracy
  - *difference between the sensor's output and the true value*

error

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

m = measured value
v = true value

In Situ Sensor Performance (2)

Characteristics that are especially relevant for real world environments

- Systematic error -> 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*
  - *e.g. Hue instability of camera, black level noise of camera ..*
- Precision
  - reproducibility *of sensor results*

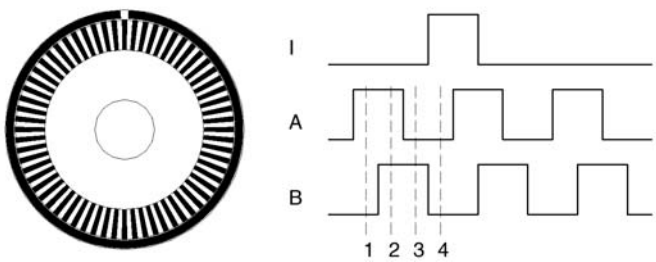
$$precision = \frac{range}{\sigma}$$

Characterizing Error: The Challenges in Mobile Robotics

- Mobile Robot has to perceive, analyze and interpret the state of the surrounding
- Measurements in real world environment are dynamically changing and error prone.
- Examples:
  - *changing illuminations*
  - *specular reflections*
  - *light or sound absorbing surfaces*
  - *cross-sensitivity of robot sensor to robot pose and robot-environment dynamics*
    - *rarely possible to model -> appear as random errors*
    - *systematic errors and random errors might be well defined in controlled environment.* This is not the case for mobile robots !!

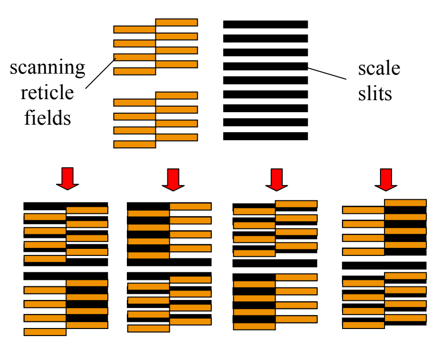
Wheel / Motor Encoders (1)

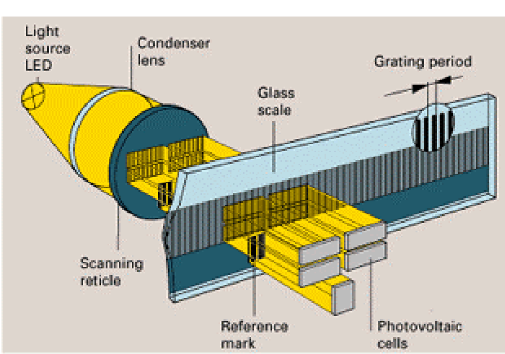
- measure position or speed of the wheels or steering
- wheel movements can be integrated to get an estimate of the robots position -> odometry
- optical encoders are proprioceptive sensors
  - *thus the position estimation in relation to a fixed reference frame is only valuable for short movements.*
- typical resolutions: 2000 increments per revolution.
  - *for high resolution: interpolation*



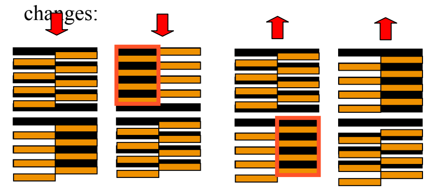
State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Wheel / Motor Encoders (2)





Notice what happen when the direction changes:



Heading Sensors

- 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)*

Compass

- Since over 2000 B.C.
  - *when Chinese suspended a piece of naturally magnetite from a silk thread and used it to guide a chariot over land.*
- Magnetic field on earth
  - *absolute measure for orientation.*
- Large variety of solutions to measure the earth magnetic field
  - *mechanical magnetic compass*
  - *direct measure of the magnetic field (Hall-effect, magnetoresistive sensors)*
- Major drawback
  - *weakness of the earth field*
  - *easily disturbed by magnetic objects or other sources*
  - *not feasible for indoor environments*

Gyroscope

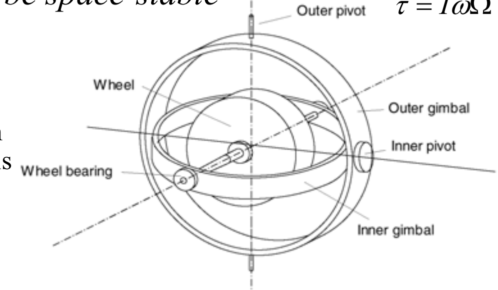
- Heading sensors, that keep the orientation to a fixed frame
  - *absolute measure for the heading of a mobile system.*
- Two categories, the mechanical and the optical gyroscopes
  - *Mechanical Gyroscopes*
    - *Standard gyro*
    - *Rated gyro*
  - *Optical Gyroscopes*
    - *Rated gyro*

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 wheel's inertia I.
- No torque can be transmitted from the outer pivot to the wheel axis
  - *spinning axis will therefore be space-stable*
- Quality: 0.1° in 6 hours

- If the spinning axis is aligned with the north-south meridian, the earth's rotation has no effect on the gyro's horizontal axis
- If it points east-west, the horizontal axis reads the earth rotation

$$\tau = I\omega\Omega$$



Rate gyros

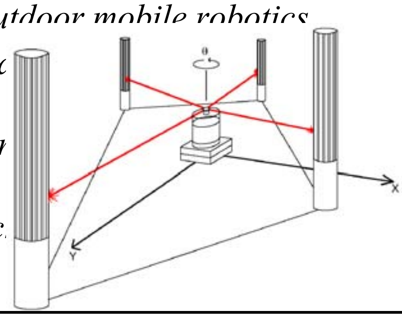
- Rate gyros use the same basic arrangement shown as regular mechanical gyros
- However, the gimbles are restrained by torsional springs
  - *force on the spring is proportional to the rate of turning.*
  - *makes it possible to measure angular speeds instead of the orientation.*
- Others, more simple gyroscopes, use Coriolis forces to measure changes in heading.
  - *measure the effect of gravitational resistance to turning.*

Optical Gyroscopes

- First commercial use started only in the early 1980 when they where first installed in airplanes.
- Optical gyroscopes
  - *angular speed (heading) sensors using two monochromic light (or laser) beams from the same source.*
- 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*
  - *difference in frequency Δf of the two beams is proportional to the angular velocity Ω of the cylinder/fiber.*
- New solid-state optical gyroscopes based on the same principle are build using microfabrication technology.

Ground-Based Active and Passive 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 applica*
- Major drawback with the use of beacons in indoor:
  - *Beacons require changes in the envi -> costly.*
  - *Limit flexibility and adaptability to c environments.*

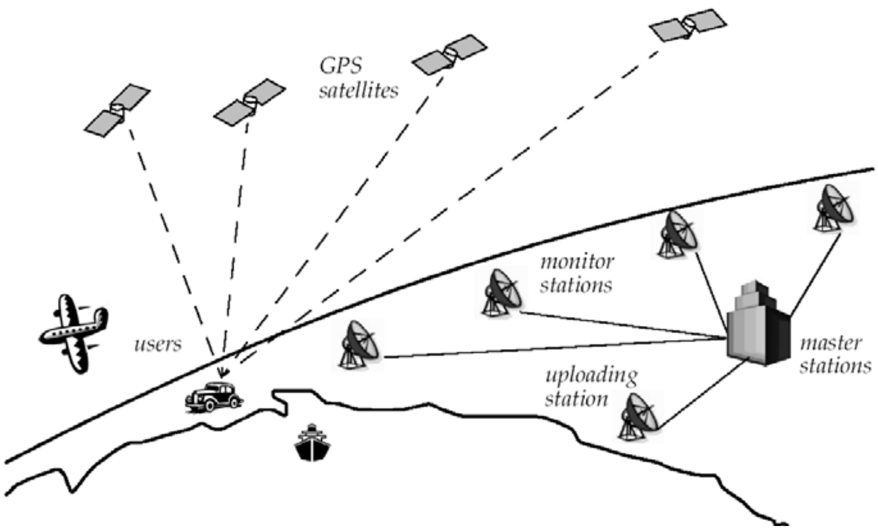


Global Positioning System (GPS) (1)

- *Developed for military use*
- *Recently it became accessible for commercial applications*
- *24 satellites (including three spares) orbiting the earth every 12 hours at a height of 20.190 km.*
- *Four satellites are located in each of six planes inclined 55 degrees with respect to the plane of the earth's equators*
- *Location of any GPS receiver is determined through a time of flight measurement*

- 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 (GPS) (2)



Global Positioning System (GPS) (3)

- 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*

Global Positioning System (GPS) (4)

- 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*
- Recent commercial GPS receiver devices allows position accuracies down to a couple meters.
- Still not enough for some applications.

Time to take a break