CS-417 INTRODUCTION TO ROBOTICS AND INTELLIGENT SYSTEMS

Robot Hardware

Non-visual Sensors

Ioannis Rekleitis

Robot Sensors

- Sensors are devices that can sense and measure physical properties of the environment,
  - e.g. temperature, luminance, resistance to touch, weight, size, etc.
  - The key phenomenon is transduction
    - Transduction (engineering) is a process that converts one type of energy to another
- They deliver *low-level* information about the environment the robot is working in.
  - Return an incomplete description of the world.

Robot Sensors

- This information is **noisy** (imprecise).
- Cannot be modelled completely:
  - Reading = *f*(env) where *f* is the model of the sensor
  - Finding the inverse:
    - ill posed problem (solution not uniquely defined)
    - collapsing of dimensionality leads to ambiguity

Types of sensor

- General classification:
  - **active** *versus* **passive**
    - Active: emit energy in environment
      - More robust, less efficient
    - Passive: passively receive energy from env.
      - Less intrusive, but depends on env. e.g. light for camera
    - Example: stereo vision versus range finder.
  - **contact** *versus* **non-contact**

Sensors

- **Proprioceptive Sensors**
  (monitor state of robot)
  - IMU (accels & gyros)
  - Wheel encoders
  - Doppler radar …

- **Exteroceptive Sensors**
  (monitor environment)
  - Cameras (single, stereo, omni, FLIR …)
  - Laser scanner
  - MW radar
  - Sonar
  - Tactile…

Sensor Characteristics

- All sensors are characterized by various properties that describe their capabilities
  - **Sensitivity**:

    (change of output) ÷ (change of input)
  - **Linearity**: constancy of (output ÷ input)
    - Exception: logarithmic response cameras == wider dynamic range.
  - **Measurement/Dynamic range**:

    difference between min. and max.

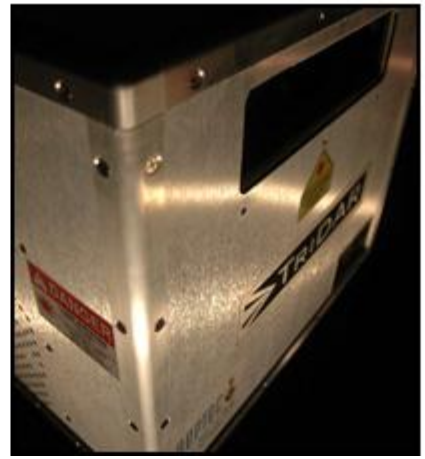
Sensor Characteristics

- **Response Time**: time required for a change in input to cause a change in the output
- **Accuracy**: difference between measured & actual
- **Repeatability**: difference between repeated measures
- **Resolution**: smallest observable increment
- **Bandwidth**: result of high resolution or cycle time

Types of sensor

Specific examples

- tactile
- close-range proximity
- angular position
- infrared
- Sonar
- laser (various types)
- radar
- compasses, gyroscopes
- Force
- GPS
- vision



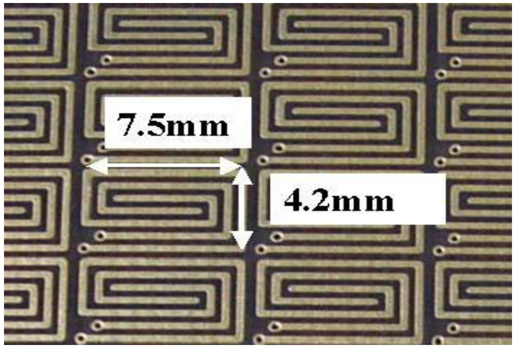
Tactile Sensors

- There are many different technologies
  - e.g. contact closure, magnetic, piezoelectric, etc.
- For mobile robots these can be classified as
  - tactile feelers (antennae) often some form of metal wire passing through a wire loop - can be active (powered to mechanically search for surfaces)
  - tactile bumpers

    solid bar / plate acts on some form of contact switch

    e.g. mirror deflecting light beam, pressure *bladder*, wire loops, etc.
  - Pressure-sensitive rubber with scanning array

"last line of defense"



Tactile Sensors (more)

- Vibrassae/whiskers of rats
  - Surface texture information.
  - Distance of deflection.
  - Blind people using a cane.

Proximity Sensors

- Tactile sensors allow obstacle *detection*
  - proximity sensors needed for true obstacle *avoidance*
- Several technologies can detect the presence of particular fields without mechanical contact
  - magnetic reed switches
    - two thin magnetic strips of opposite polarity not quite touching
    - an external magnetic field closes the strip & makes contact

Proximity Sensors

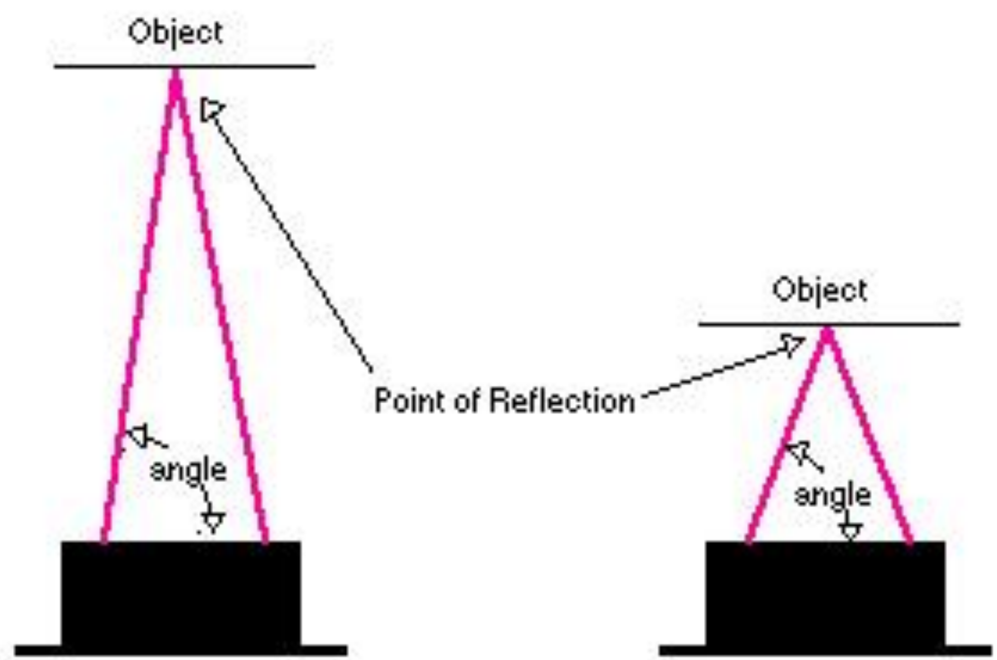
- Hall effect sensors
  - small voltage generated across a conductor carrying current $V_H \propto I \times B$
- inductive sensors, capacitive sensors
  - inductive sensors can detect presence of metallic objects
  - capacitive sensors can detect metallic or dielectric materials

Infrared Sensors

- Infrared sensors are probably the simplest type of non-contact sensor
  - widely used in mobile robotics to avoid obstacles
- They work by
  - emitting infrared light
    - to differentiate emitted IR from ambient IR (e.g. lights, sun, etc.), the signal is modulated with a low frequency (100 Hz)
  - detecting any reflections off nearby surfaces
- In certain environments, with careful calibration, IR sensors can be used for measuring the distance to the object
  - requires uniform surface colours and structures

Infrared Sensors (Sharp)

- Measures the return angle of the infrared beam.

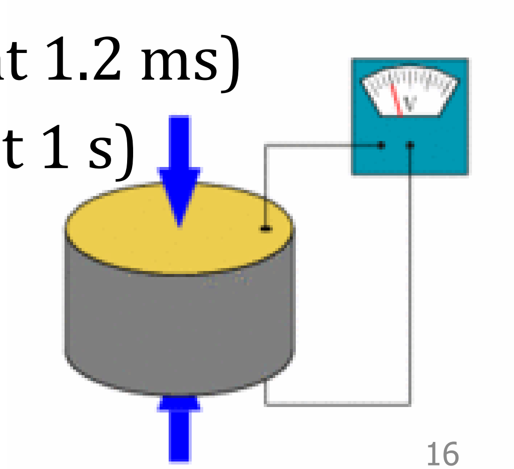


Infrared Problems

- If the IR signal is detected, it is safe to assume that an object is present
- However, the absence of reflected IR does not mean that no object is present!
  - "Absence of evidence is not evidence of absence."
    C. Sagan
  - certain dark colours (black) are almost invisible to IR
  - IR sensors are not absolutely safe for object detection
- In realistic situations (different colours & types of objects) there is no accurate distance information
  - it is best to avoid objects as soon as possible
- IR are short range
  - typical maximum range is 50 to 100 cm

Sonar Sensors

- The fundamental principle of robot sonar sensors is the same as that used by bats
  - emit a chirp (e.g. 1.2 milliseconds)
    - a short powerful pulse of a range of frequencies of sound
  - its reflection off nearby surfaces is detected
- As the speed of sound in air is known ($\approx 330\ m \cdot s^{-1}$) the distance to the object can be computed from the elapsed time between chirp and echo
  - minimum distance = $165\ t_{chirp}$ (e.g. 21 cm at 1.2 ms)
  - maximum distance = $165\ t_{wait}$ (e.g. 165 m at 1 s)
- Usually referred to as *ultrasonic* sensors



Sonar Problems

- There are a number of problems and uncertainties associated with readings from sonar sensors
  - it is difficult to be sure in which direction an object is because the 3D sonar beam spreads out as it travels
  - *specular reflections* give rise to erroneous readings
    - the sonar beam hits a smooth surface at a shallow angle and so reflects away from the sensor
    - only when an object further away reflects the beam back does the sensor obtain a reading - *but distance is incorrect*
  - arrays of sonar sensors can experience *crosstalk*
    - one sensor detects the reflected beam of another sensor
  - the speed of sound varies with air temp. and pressure
    - a 16° C temp. change can cause a 30cm error at 10m!
- **More Next Class**

Laser Range Finders

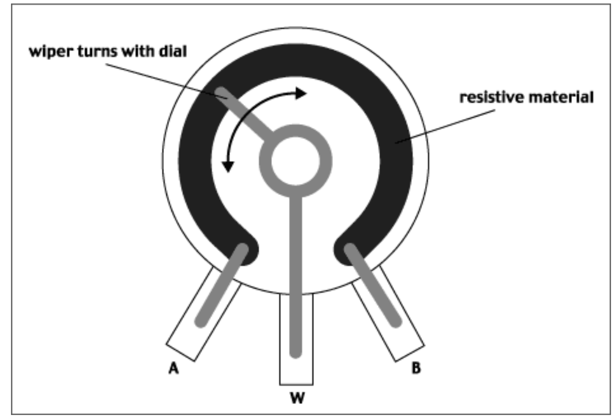
- Laser range finders commonly used to measure the *distance*, *velocity* and *acceleration* of objects
  - also known as *laser radar* or *lidar*
- The operating principle is the same as sonar
  - a short pulse of (laser) light is emitted
  - the time elapsed between emission and detection is used to determine distance (using the speed of light)
- Due to the shorter wavelengths of lasers, the chance of specular reflections is much less
  - accuracies of millimetres (16 - 50mm) over 100m
  - 1D beam is usually swept to give a 2D planar beam
- May not detect transparent surfaces (e.g. glass!) or dark objects

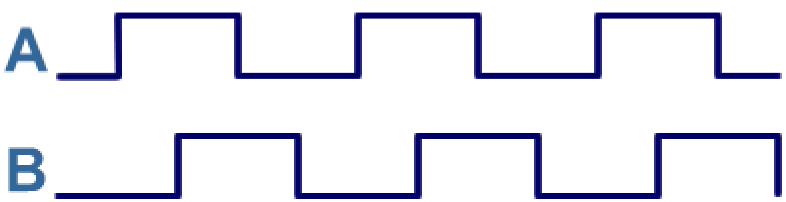
RADAR

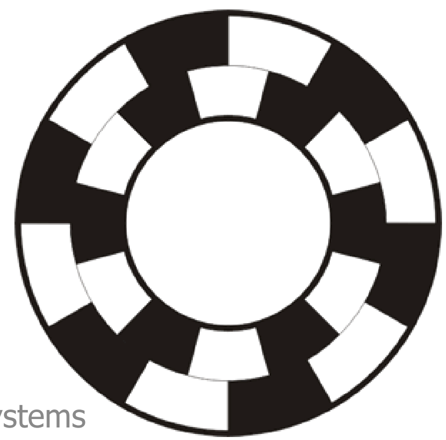
- Radar usually uses electromagnetic energy in the 1 - 12.5 GHz frequency range
  - this corresponds to wavelengths of 30 cm - 2 cm
    - microwave energy
  - unaffected by fog, rain, dust, haze and smoke
- It may use a pulsed time-of-flight methodology of sonar and lidar, but may also use other methods
  - continuous-wave phase detection
  - continuous-wave frequency modulation
- Continuous-wave systems make use of Doppler effect to measure relative velocity of the target

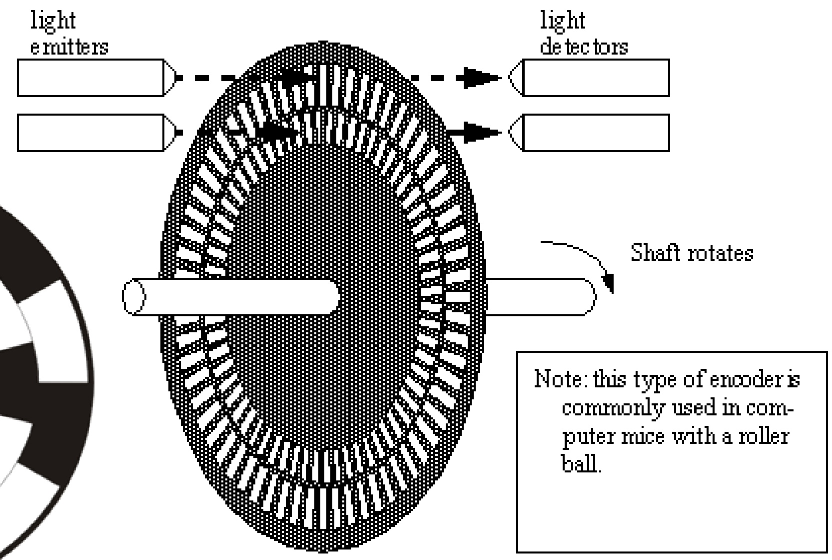
Angular Position: Rotary Encoder

- Potentiometer
  - Used in the Servo on the boebots
- Optical Disks (Relative)
  - Counting the slots
  - Direction by having pars of emitters/receivers out of phase: Quadrature decoding
  - Can spin very fast: 500 kHz



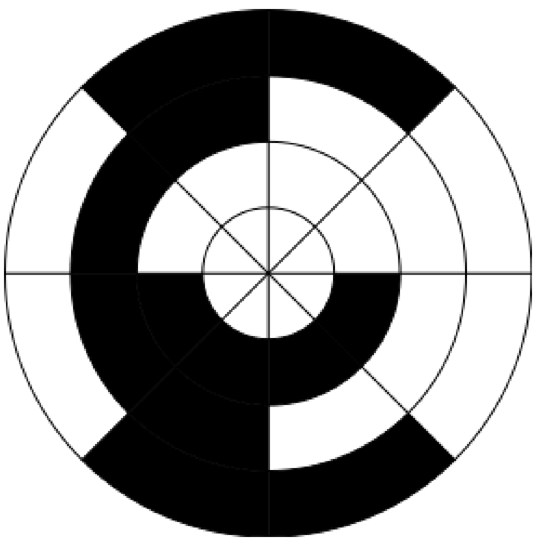






Angular Position: Rotary Encoder

- Optical Disks (Absolute)
  - Grey encoding for absolute:
    - 0:0000, 1:1000, 2:1100, 3:0100, 4:0110,
    - 5:1110, 6:1010, 7:0010, 8:0011
    - 9:1011, 10:1111, 11:0111, 12:0101, 13:1101, 14:1001, 15:0001



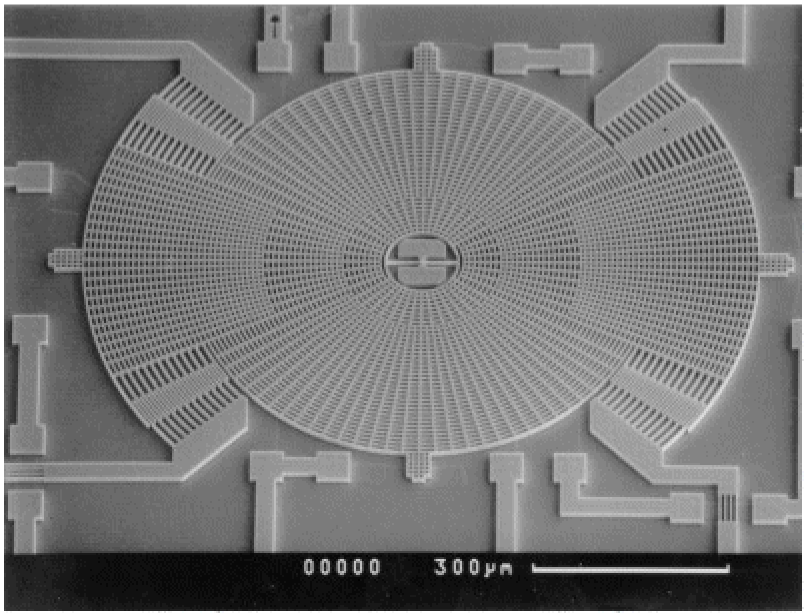
Compass Sensors

- Compass sensors measure the horizontal component of the earth’s magnetic field
  - some birds use the vertical component too
- The earth’s magnetic field is very **weak** and **non-uniform,** and **changes over time**
  - indoors there are likely to be many other field sources
    - steel girders, reinforced concrete, power lines, motors, etc.
  - an accurate absolute reference is unlikely, but the field is approx. constant, so can be used for local reference

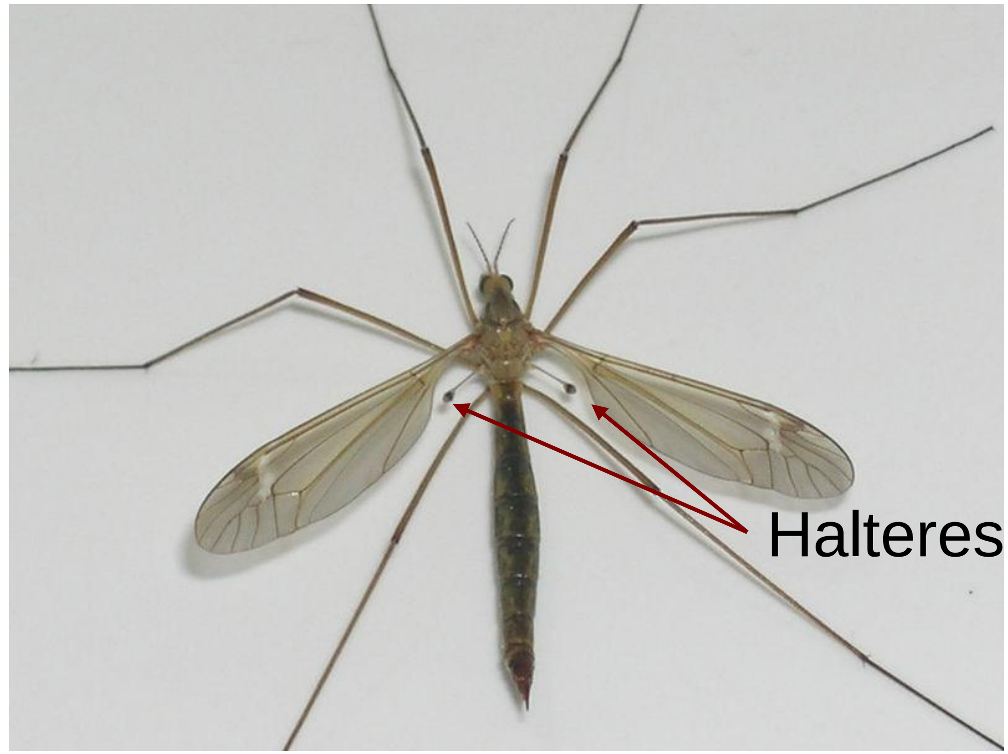
Gyroscopes

- A gyroscope is a spinning wheel with most of its mass concentrated in the outer periphery
  - e.g. a bicycle wheel
- Due to the law of *conservation of momentum*
  - the spinning wheel will stay in its original orientation
  - a force is required to rotate the gyroscope
- A gyro. can thus be used to maintain orientation or to measure the rate and direction of rotation
- In fact there are different types of mechanical gyro.
  - and even optical gyro's with no moving parts!
    - these can be used in e.g. space probes to maintain orientation

Vibrating Structure Gyroscopes



MEMS

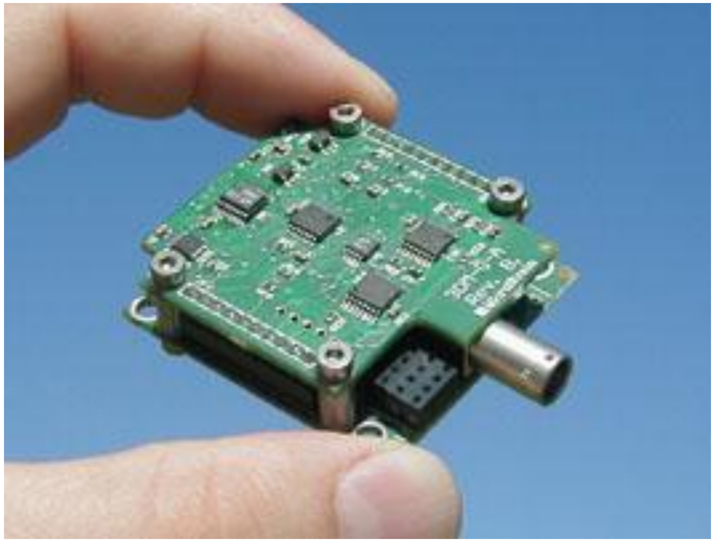


Ring gyro's

- Use standing waves set up
  - between mirrors (laser ring gyro)
  - within a fiber optic cable (fibre optic ring gyro)
- Measure rotation by observing beats in standing wave as the mirrors "rotate through it".

IMU's

- Gyro, accelerometer combination.
- Typical designs (e.g. 3DM-GX1™) use tri-axial gyros to track dynamic orientation and tri-axial DC accelerometers along with the tri-axial magnetometers to track static orientation.
- The embedded microprocessors contains programmable filter algorithms, which blend these static and dynamic responses in real-time.



GPS

- GPS uses a constellation of between 24 and 32 Medium Earth Orbit satellites.
- Satellite broadcast their position + time.
- Use travel time of 4 satellites and trilateration.
- Suffers from “canyon” effect in cities.

WiFi

- Using the SSID and database.

Odor sensing

Smell is ubiquitous in nature
... both as a active and a passive sensor.
Why is it so important?

Advantages: evanescent, controllable, multi-valued, useful.

References:

[1] T. Hayes, A. Martinoli, and R. M. Goodman. "Swarm Robotic Odor Localization: Off-Line Optimization and Validation with Real Robots". Special issue on Biological Robotics, Robotica, Vol. 21, Issue 4, pp. 427-441, 2003. © Cambridge University Press

[2] T. Yamanaka, R. Matsumoto, and T. Nakamoto, "Fundamental study of odor recorder for multi-component odor using recipe exploration method based on singular value decomposition", IEEE Sensors Journal, Vol. 3, Issue 4, 2003, pp. 468-474.