Perception, Part 1
Sensors and Ranging

Computer Science 6912

Department of Computer Science
Memorial University of Newfoundland

June 7, 2017
1. Sensor Characteristics

2. Optical Encoders

3. Heading Sensors

4. Active Ranging
Robart II, H.R. Everett

Sensors: inertial measurement unit, wheel encoders, omnidirectional camera, pan-tilt camera, sonars, laser rangefinder, bumpers
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Sensors are classified along two main dimensions:

- **Proprioceptive / Exteroceptive**
  - Proprioceptive: Sensors which measure quantities internal to the robot (e.g. wheel angle, motor speed, internal temperature,...)
  - Exteroceptive: Sensors which measure properties of the environment (e.g. light intensity, sound level, distance of wall,...)

- **Passive / Active**
  - Passive: Sensors which measure the existing forces and energies in the environment (e.g. cameras, microphones, contact switches)
  - Active: Sensors which emit energy and measure the environment's response to that energy (e.g. radar, ultrasonic sensors, laser rangefinders,...)

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<table>
<thead>
<tr>
<th>General classification (typical use)</th>
<th>Sensor System</th>
<th>PC or EC</th>
<th>A or P</th>
</tr>
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<tbody>
<tr>
<td>Tactile sensors (detection of physical contact or closeness; security switches)</td>
<td>Contact switches, bumpers</td>
<td>EC</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Optical barriers</td>
<td>EC</td>
<td>A</td>
</tr>
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<td>Noncontact proximity sensors</td>
<td>EC</td>
<td>A</td>
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<tr>
<td>Wheel/motor sensors (wheel/motor speed and position)</td>
<td>Brush encoders</td>
<td>PC</td>
<td>P</td>
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<tr>
<td></td>
<td>Potentiometers</td>
<td>PC</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Synchros, resolvers</td>
<td>PC</td>
<td>A</td>
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<tr>
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<td>Magnetic encoders</td>
<td>PC</td>
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<tr>
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<td>Inductive encoders</td>
<td>PC</td>
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<tr>
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<td>Capacitive encoders</td>
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<td>Heading sensors (orientation of the robot in relation to a fixed reference frame)</td>
<td>Compass</td>
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<td>P</td>
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<td>Gyroscopes</td>
<td>PC</td>
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A, active; P, passive; P/A passive/active; PC proprioceptive; EC exteroceptive
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<tr>
<th>Ground-based beacons (localization in a fixed reference frame)</th>
<th>GPS</th>
<th>Active optical or RF beacons</th>
<th>Active ultrasonic beacons</th>
<th>Reflective beacons</th>
<th>EC</th>
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<td>Active ranging (reflectivity, time-of-flight, and geometric triangulation)</td>
<td>Reflectivity sensors</td>
<td>Ultrasonic sensor</td>
<td>Laser rangefinder</td>
<td>Optical triangulation (1D)</td>
<td>Structured light (2D)</td>
<td>EC</td>
</tr>
<tr>
<td>Motion/speed sensors (speed relative to fixed or moving objects)</td>
<td>Doppler radar</td>
<td>Doppler sound</td>
<td></td>
<td></td>
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<td>A</td>
</tr>
<tr>
<td>Vision-based sensors (visual ranging, whole-image analysis, segmentation, object recognition)</td>
<td>CCD/CMOS camera(s)</td>
<td>Visual ranging packages</td>
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Sensor Characteristics

- **Range**: The minimum and maximum input values
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- **Dynamic range**: Ratio of maximum to minimum input values

Example: the ratio in sound pressure from the loudest rock concert to the lowest audible tone is about 10,000,000,000.

Usually measured in decibels: $10 \cdot \log_{10} \left( \frac{\text{max. input value}}{\text{min. input value}} \right)$

Human hearing: 100 dB

Decibels describe the ratio between two quantities of power; if measuring something which has to be squared to be proportional to power (e.g. voltage), the 10 is replaced with 20.
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- **Gray–Code**
- **Dual–Code**

![Gray–Code](image1.png)

![Dual–Code](image2.png)
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- For each ring there is a photo-emitter / detector pair
- Direction of rotation given by the phase difference between the emitter signals (i.e. by which one is ‘leading’)
The two rings allow four different states to be detected; this doubles the resolution over a one-ring incremental encoder. Typically around 2000 CPR (cycles per revolution).

Industrial optical encoders present no bandwidth limitation to mobile robot applications.

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<tr>
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<th>Ch B</th>
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</tr>
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Heading Sensors

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- Each satellite transmits...

Time (measured by atomic clock)
Its position and the positions of all other GPS satellites

A GPS receiver is passive and exteroceptive; it measures the time of flight and uses this to estimate the pseudorange to the satellites. This is not a true range because of the offset of the receiver's inexpensive quartz clock from satellite time.

Four satellites must be in view so that the variables \(x\), \(y\), \(z\), and \(\Delta t\) can be estimated. The requirement of four line-of-sight satellites means that GPS information is unavailable in confined spaces—generally not useful indoors.
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transmitted sound

wave packet

analog echo signal

threshold

digital echo signal

integrated time

output signal

integrator

time of flight (sensor output)
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- **Accuracy:** Diminishes with increasing angle between viewpoint and surface

- **Bandwidth:**
  - Single sensor: To allow time to detect object at 12 m, requires 70 ms → 14.3 Hz
  - 20 sensors: Apply each in sequence to avoid interference, requires 20 * 70 ms → 0.7 Hz
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  - Coherent reflection only for extreme angles and/or highly polished surfaces.
Unlike ultrasonic sensors, measuring time of flight directly is difficult.

- Speed of sound $\approx 0.3 \, \text{m/ns}$; Speed of light $\approx 0.3 \, \text{m/ns}$
- A single "pulse" would take 20 ns to return after hitting a wall 3 m away.
- Measuring events that take place within 10's of nanoseconds requires expensive electronics.
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\[ D \]
 Transmitting at frequency $f$

The time it takes for a full period to be transmitted is $T = \frac{1}{f}$, and the wavelength is therefore $\lambda = \frac{c}{f}$ where $c$ is the speed of light.

Assume $f = 5 \text{ MHz}$, $\lambda = 60 \text{ m}$.

A beam which travels 30 m, reflects and returns with 0 phase difference. For the general case, the phase difference $\theta \in [0, 2\pi)$.

The ratio $\theta/2\pi$ reflects gives this phase as a proportion of a wavelength.

Hence, the overall distance of travel (both ways) is $\lambda \theta / 2\pi$.

The final distance is half the overall distance $D = \lambda \theta / 4\pi$.

Theoretically, the same distance measurement would be obtained for any other positive distance $nD$ where $n$ is an integer; in practice, the signal attenuates, so we will not likely get a sufficiently strong return for distances larger than $D$. 
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Perception, Part 1: Sensors and Ranging  
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Figure 4.11
(a) Schematic drawing of laser range sensor with rotating mirror; (b) Scanning range sensor from EPS Technologies Inc.; (c) Industrial 180 degree laser range sensor from Sick Inc., Germany
The laser can be swept in a plane using a rotating mirror to obtain a one-dimensional image of the environment.

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(a) Schematic drawing of laser range sensor with rotating mirror; (b) Scanning range sensor from EPS Technologies Inc.; (c) Industrial 180 degree laser range sensor from Sick Inc., Germany

3D information can be obtained by pitching the apparatus upwards and downwards.
**General principle:** We are more confident in measuring large signals than small signals which can get ‘lost in the noise’
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![Graph showing Line length ≡ uncertainty](image)

- e.g. Characteristics: Hokuyo URG-04LX-UG01
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![Line length ≡ uncertainty](image)

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![Graph showing line length and uncertainty](image)

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Line length ≡ uncertainty

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![Graph showing line length equivalence to uncertainty](image)

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![Graph with line length equivalent to uncertainty]

**Line length ≡ uncertainty**

- e.g. **Characteristics: Hokuyo URG-04LX-UG01**
  - Angular resolution: 0.36°
  - Accuracy: ± 3 cm
  - Angular range: 240°
  - Depth range: 2 cm - 5.6 m
  - Bandwidth: 10 Hz
Laser rangefinders are an extremely important sensor in modern autonomous robotics.
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“Stanley”, Stanford University’s entry in the 2005 DARPA Grand Challenge