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Class: Robotika
Lecture: Sensors and Introduction to Computer Vision
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Sensor for Mobile Robots
Aim:
- Learn about key performance characteristics for robotic sensors
- Learn about a full spectrum of sensor, proprioceptive/exteroceptive, passive/active

Classification of Sensors
Proprioceptive: Measure values internal to the robot
- Motor speed, robot arm joint angles, and battery voltage

Exteroceptive: Acquire information from the robot's environment
- Distance measurements and light intensity

Passive: Measure ambient environmental energy entering the sensor
- Challenge: Performance heavily depends on the environments
- Temperature probes and cameras

Active: Emit energy into the environment and measure the reaction
- Challenge: Might affect the environment
- Ultrasonic sensors and laser rangefinders

Sensor Performance: Design Specs
- Dynamic range: ratio between the maximum and minimum input values (for normal sensor operation)
  Resolution: Minimum difference between two values that can be detected by a sensor
- Linearity: whether the sensor's output response depends linearly on the input
  Bandwidth or frequency: speed at which a sensor provides readings (in Hertz)

Sensor Performances: in situ specs
- Sensitivity: ratio of output change to input change
- Cross-sensitivity: Sensitivity to quantities that are unrelated to the target quantity
- Error: difference between the sensor output and the true value
- Accuracy: degree of conformity between the sensor's measurements and the true value
- Precision: reproducibility of the sensor results

Sensor Errors

- Systematic errors: caused by factors that can in theory be modeled; they are deterministic

- E.g.: calibration errors

- Random errors: cannot be predicted with sophisticated models; they are stochastic

- E.g.: spurious range-finding errors

- Error analysis: performed via a probabilistic analysis

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- Common assumption: symmetric, unimodal (and often Gaussian) distributions; convenient, but often a coarse simplification
- Error propagation characterized by the error propagation law

An Ecosystem of Sensors

- Encoders: an electro-mechanical device that converts motion into a sequence of digital pulses, which can be converted to relative or absolute position measurements
  Can be used for robot localization
  Fundamentals principle of optical encoders: use a light shining onto a photodiode through slits in a metal or glass disc
- proprioceptive sensor
- Heading sensors: Used to determine robot's orientation, it can be:
  Proprioceptive, e.g., gyroscope (heading sensor that preserves its orientation in relation to a fixed reference frame)
  Exteroceptive, e.g., compass (shows direction relative to the geographic cardinal directions)
  Fusing measurements with velocity information, one can obtain a position estimate (via integration) -> dead reckoning
  Fundamentals principle of mechanical gyroscopes: angular momentum associated with spinning wheel keeps the axis of rotation inertially stable
- Accelerometers and IMU
  Accelerometer: device that measure all external forcing acting upon it
  Mechanical accelerometer: essentially, a spring mass damper system
  Definition: device that uses gyroscopes and accelerometers to estimate the relative position, orientation, velocity, and acceleration of a moving vehicle with respect to an inertial frame
  Drift is a fundamental problem: to cancel drift, periodic references to external measurements are required
- Beacons
  Definition: Signaling devices with precisely known positions
  Early examples: stars, lighthouse
  Modern examples: GPS, motion capture system
- Active ranging
  Provide direct measurements of distance to objects in vicinity
  Key elements for both localization and environment reconstruction
  Main types:
  1. Time of flight active ranging sensors (ultrasonic and laser rangefinder)
  Fundamental principle: time-of-flight ranging makes use of the propagation of the speed of sound or of an electromagnetic wave

  Travel distance is given by
  $d = ct$
  where d is the distance traveled, c is the speed of the wave propagation, and t is the time of flight
  Propagation speeds:

Sound: 0.3 m/ms
Light: 0.3 m/ns
Performance depends on several factors, e.g., uncertainties in determining the exact time of arrival and interaction with the target
2. Geometric active ranging sensors
Fundamental principle: use geometric properties in the measurements to establish distance
readings
The sensor projects a known light pattern (e.g., point, line, or texture); the reflection is captured by a receiver and, together with known
geometric values, range is estimated via
triangulation
Examples:
Optical triangulation (1D sensor) Structured light (2D and 3D sensor

- Cameras