EE-381 Robotics-1
UG ELECTIVE

Lecture 12

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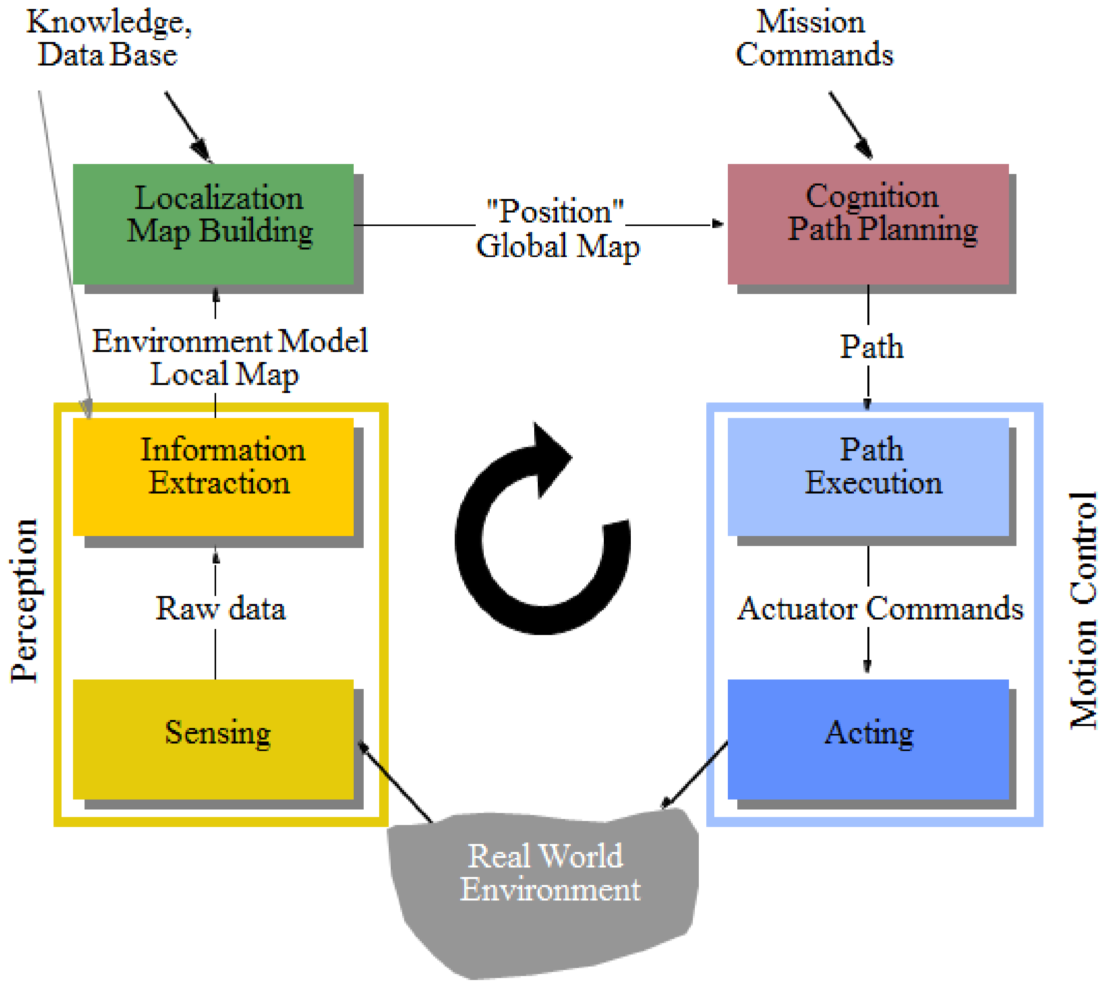
Introduction

- The three key questions in Mobile Robotics
  - Where I am?
  - Where am I going?
  - How do I get there?

- To answer these questions the robot has to
  - Have a model of the environment (given or autonomously built)
  - Perceive and analyze the environment
  - Find its position/situation within the environment
  - Plan and execute the movement

Autonomous Robotics (Mobile)

See, think and act cycle



Perception- sensors

Outlines

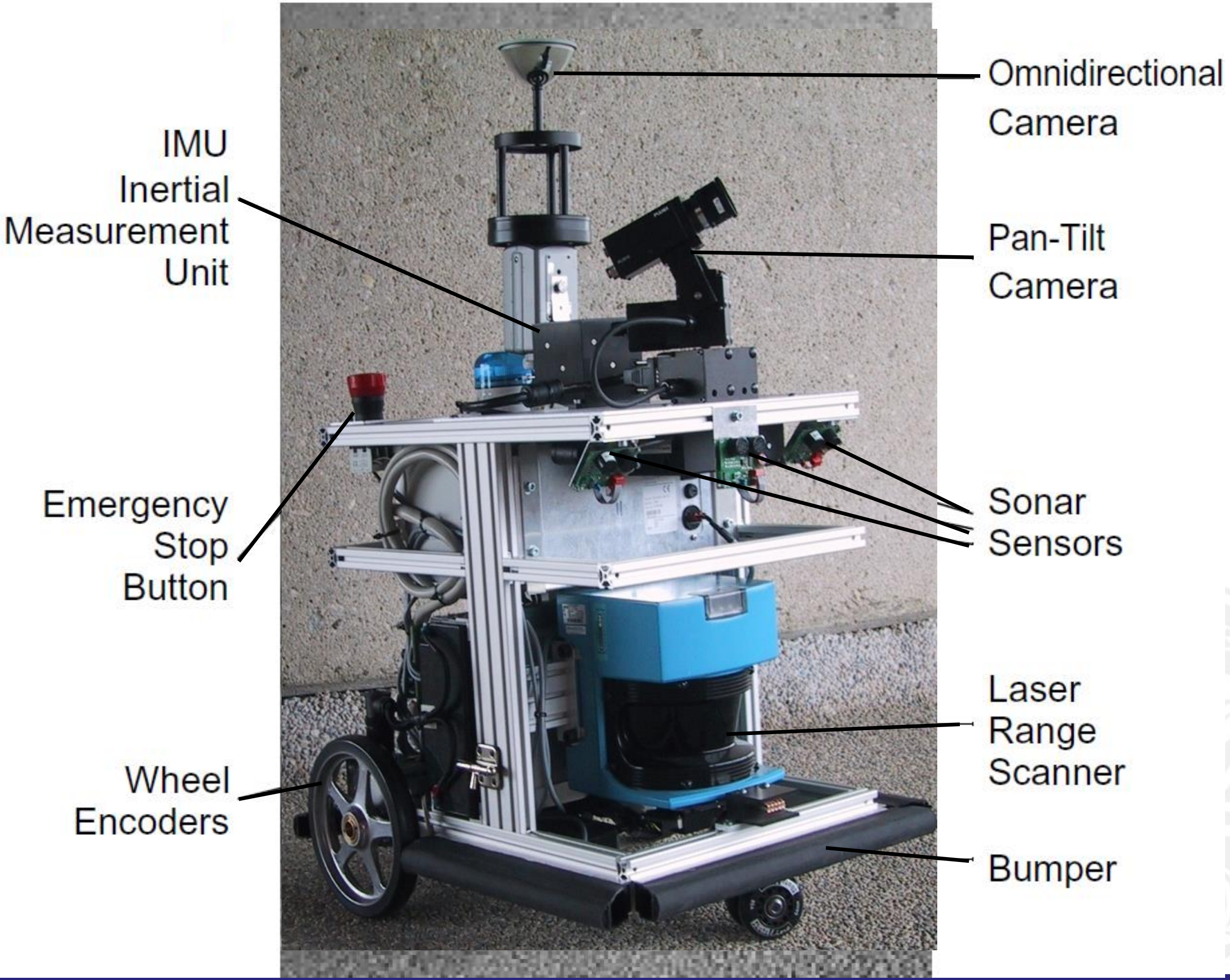
- Optical encoders
- Heading sensors
    - Compass
    - Gyroscopes
- Accelerometer
- IMU
- GPS
- Range sensors
    - Sonar
    - Laser
    - Structured light
- Camera

Sensors

- Why should a robotics engineer know about sensors?
  - Is the **key technology** for perceiving the environment
  - **Understanding the physical principle** enables appropriate use

- Understanding the physical principle behind sensors enables us:
  - To **properly select** the sensors for a given application
  - To **properly model** the sensor system, e.g. resolution, bandwidth, **uncertainties**

BIBA Robot, BlueBotics SA



Classification of Sensors

What:

- **Proprioceptive sensors**
  - measure values internal 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.

How:

- **Passive sensors**
  - Measure energy coming from the environment (microphones, cameras, temperature probes etc)
- **Active sensors**
  - emit their proper energy and measure the reaction (ultrasonic sensors and rangefinders etc)
  - better performance, but some influence on environment

General Classification

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

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

Measurement in real world environment is error prone

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

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

    - e.g. voltage measurement from 1 mV to 20 V

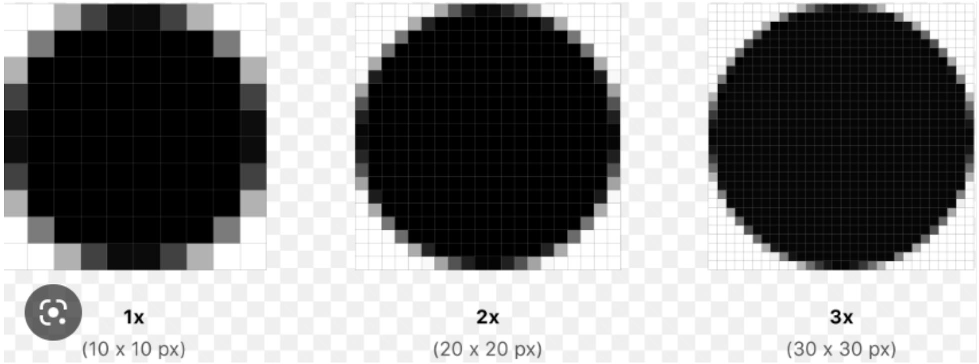
$$20 \cdot \log\left[\frac{20}{0.001}\right] = 86dB$$

$$P = U \cdot I = \frac{1}{R}U^2$$

    - 20 instead of 10 because square of voltage is equal to power!!

Characterizing Sensor Performance

- Basic sensor response ratings (cont.)
  - Range
    - upper limit
  - 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)



Characterizing Sensor Performance

- Basic sensor response ratings (cont.)
  - Linearity
    - variation of output signal as function of the input signal

$$x \to f(x) \qquad \alpha \cdot x + \beta \cdot y \to f(\alpha \cdot x + \beta \cdot y) = \alpha \cdot f(x) + \beta \cdot f(y)$$
$$y \to f(y)$$

  - Bandwidth or Frequency
    - the speed with which a sensor can provide a stream of readings (formally the number of measurements per second)
    - usually there is an upper limit depending on the sensor and the sampling rate
    - lower limit is also possible, e.g. acceleration sensor
    - one has also to consider phase (delay) of the signal

In Situ Sensor Performance

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 (and cross-talk)
  - sensitivity to other environmental parameters (e.g. temperature, magnetic field)
  - influence of other active sensors

error

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

m = measured value
v = true value

- Error / Accuracy
  - difference between the sensor's output and the true value

In Situ Sensor Performance

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 caused 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

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

σ is the standard deviation

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 sensor, robot-environment dynamics
    - rarely possible to model -> *error blurring*: appear as "random" errors but are neither systematic nor random.
    - systematic errors and random errors might be well defined in **controlled** environment. *This is not the case for mobile robots !!*

Multi-Modal Error Distributions: The Challenges in …

- Sensors modeled by probability distribution (random errors)
  - usually very little knowledge about the causes of random errors
  - often assumed to be symmetric or even Gaussian
  - however, it is important to realize how wrong this can be!

  - Examples:
    - Sonar (ultrasonic) sensor might overestimate the distance in real environment and is therefore not symmetric
      - Thus the sonar sensor might be best modeled by two modes:
        - mode for the case that the signal returns directly
        - mode for the case that the signals returns after multi-path reflections.
    - Stereo vision system might correlate to images incorrectly, thus causing results that make no sense at all

Section 4.2 (Representing Uncertainty) is just basics of probability theory. Read it yourself.

Sensors: outline

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- GPS
- Range sensors
  - Sonar
  - Laser
  - Structured light
- Vision (next lectures)