Mobile Robots | Introduction and Lecture Overview

Autonomous Mobile Robots

https://edge.edx.org/courses/course-v1:ETHx+AMRx_Internal_FS2016+2016_Spring/

Roland Siegwart, Margarita Chli, Martin Rufli
Autonomous mobile robot | your teachers

- Roland Siegwart, ETH Zurich
- Margarita Chli, ETH Zurich
- Martin Rufli, IBM Research

Video segments

- Marco Hutter, ETH Zurich
- Davide Scaramuzza, Univ. of Zürich
- Paul Furgale, Apple
Autonomous mobile robot | about the course
https://edge.edx.org/courses/course-v1:ETHx+AMRx_Internal_FS2016+2016_Spring/

- Running as an ETH-internal MOOC (Massive Open Online Course)
  - Over 30 short video lectures that we call “segments”.
  - The “segments” are complemented with:
    - short questions for each segment to verify your understanding and progress
    - various exercises (problem sets)
    - videos showing the current state-of-the-art in the field
  - Please register on edge.edx.org and sign up for the lecture AMRx of ETHx

- Textbook
  “Introduction to Autonomous Mobile Robots“
  Roland Siegwart, Illah Nourbakhsh, Davide Scaramuzza
  The MIT Press
  On sale in LEE J206 for CHF 40

- Other materials
We expect you to view and study the following elements beforehand:
- video segment
- relevant AMR book chapters
- problem sets and quizzes

Lecture on Tuesday 10:15 – 12:00 in CAB G 11
- Organized as flipped classroom – we need your active participation!!
- Video Segments will not be repeated
- Focus on putting the learnt content into context
  - Questions from students (in forum until Friday before the related lecture)
  - go over difficult problems
  - go a bit more in detail where needed (e.g. proofs of theorems, etc.)

Exercises on Tuesday 14:15 – 16:00 in CAB G 11 (around every second week)
- Special exercises only supported for ETH students
## Lecture Program

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<th>Topic</th>
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<td>01.03.2016</td>
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<td>Introduction to V-Rep simulator</td>
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<td>Perception III: Image Saliency (to 4.5)</td>
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<td>14</td>
<td>31.05.2016</td>
<td>Summary</td>
<td>R. Siegwart</td>
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Exam

- **Type**
  - Written session examination

- **Language of examination**
  - English

- **Course attendance confirmation required**
  - No

- **Repetition**
  - The performance assessment is only offered in the session after the course unit. Repetition only possible after re-enrolling.

- **Mode of examination**
  - written 120 minutes

- **Written aids**
  - 4 A4-pages personal summary
The three key questions in Mobile Robotics
- Where am I?
- 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 mobile robot | the see-think-act cycle

Autonomous Systems Lab

Real World Environment

Knowledge, data base

Localization
Map Building

Environment model
Local map

Information Extraction

Raw data

Sensing

Perception

"Position" global map

Cognition
Path Planning

Path

Motion Control

Mission commands

Path Execution

Actuator commands

Acting

See-think-act

Autonomous Mobile Robots
Roland Siegwart, Margarita Chli, Martin Ruffli
Motion Control | kinematics and motion control

- Wheel types and its constraints
  - Rolling constraint
  - no-sliding constraint (lateral)

- Motion control

\[
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\theta}
\end{bmatrix} = f(\dot{\phi}_1 \ldots \dot{\phi}_n, \theta, \text{geometry})
\]

\[
\begin{bmatrix}
\dot{\phi}_1 \\
\vdots \\
\dot{\phi}_n
\end{bmatrix} = f(\dot{x}, \dot{y}, \dot{\theta})
\]
Autonomous mobile robot | the see-think-act cycle

knowledge, data base

Localization
Map Building

environment model
local map

Information Extraction

raw data

Sensing

"position" global map

Cognition
Path Planning

mission commands

Path Execution

actuator commands

Acting

Motion Control

Real World Environment

see-think-act

Perception

Real World Environment
Perception | sensing

- Laser scanner
  - time of flight

- Camers

- Lens
- Focal Plane
- Focal Point
- Focal Length: $f$

Object

GPS
IMU
Laser scanners
Omnidirectional camera
Standard camera
Security switch
Wheel encoders
Perception | information extraction

- Keypoint Features
  - features that are reasonably invariant to rotation, scaling, viewpoint, illumination
  - FAST, SURF, SIFT, BRISK, ...

- Keypoint matching
  - BRISK example

- Filtering / Edge Detection

Image from [Rosten et al., PAMI 2010]
Autonomous mobile robot | the see-think-act cycle

- **Localization**
- **Map Building**
- **Sensing**
- **Information Extraction**
- **Path Planning**
- **Path Execution**
- **Acting**

**Perception**
- Raw data
- Environment model
- Local map

**Real World Environment**

**Cognition**
- "position" global map
- Mission commands
- Path

**Motion Control**
- Path execution
- Actuator commands
Localization | where am I?

- **SEE**: The robot queries its sensors → finds itself next to a pillar
- **ACT**: Robot moves one meter forward
  - motion estimated by wheel encoders
  - accumulation of uncertainty
- **SEE**: The robot queries its sensors again → finds itself next to a pillar
- **Belief update (information fusion)**
Autonomous mobile robot | the see-think-act cycle

- **Sensing**: raw data -> **Localization** -> **Map Building**: environment model, local map -> **Information Extraction**: knowledge, data base -> **Path Planning**: "position" global map

- **Acting**: path -> **Path Execution**: actuator commands -> **Motion Control**: commands

- **Real World Environment**: SEE, THINK, ACT cycle
Cognition | Where am I going? How do I get there?
Cognition | Where am I going? How do I get there?

- Global path planning
  - Graph search

- Local path planning
  - Local collision avoidance
Autonomous mobile robot | the see-think-act cycle

- **Localization** and **Map Building**
  - Environment model
  - Local map

- **Information Extraction**
  - Raw data

- **Sensing**

- **Cognition**
  - Path Planning
  - Path

- **Acting**
  - Actuator commands

- **Motion Control**

- **Real World Environment**

**See-think-act** cycle:
- See: Sensing
- Think: Information Extraction
- Act: Cognition and Motion Control
Autonomous mobile robot | we invite you to join the course

EUROPA: The European Robotic Pedestrian Assistant
Autonomous Mobile Robots | Some recent examples
Examples – not part of MOOC Video Segment
From Perception to Understanding

- **Places / Situations**: A specific room, a meeting situation, ...
- **Features**: Lines, Contours, Colors, Phonemes, ...
- **Objects**: Doors, Humans, Coke bottle, car, ...
- **Navigation**: Raw Data
  - Vision, Laser, Sound, Smell, ...
- **Interaction**: Servicing / Reasoning
- **Fusing & Compressing Information**: Relationships of Objects
  - Functional / Contextual
  - imposed
  - learned
  - spatial / temporal / semantic
- **Models / Semantics**: imposed
  - learned
- **Models**: imposed
  - learned
Laser-based outdoor navigation

Repeat Phase - May 2013 during a rainy day

White points: Learned map

Colored points by elevation: Current scan

Green line: Learned path
V-Charge | Autonomous driving using close-to-market sensors

Autonomous Driving

Google’s modified Toyota Prius uses an array of sensors to navigate public roads without a human driver. Other components, not shown, include a GPS receiver and an inertial motion sensor.

LIDAR
A rotating sensor on the roof scans more than 200 feet in all directions to generate a precise three-dimensional map of the car’s surroundings.

POSITION ESTIMATOR
A sensor mounted on the left rear wheel measures small movements made by the car and helps to accurately locate its position on the map.

VIDEO CAMERA
A camera mounted near the rear-view mirror detects traffic lights and helps the car’s onboard computers recognize moving obstacles like pedestrians and bicyclists.

RADAR
Four standard automotive radar sensors, three in front and one in the rear, help determine the positions of distant objects.
V-Charge | Autonomous driving using close-to-market sensors
Typical Situation
V-Charge Review 2 | Driving Demo
V-Charge | the ultimate vision

- Mixed-traffic scenarios
Project goals
- Robotic help for Urban Search and Rescue
- UGV and UAV combined for scene exploration
- Yearly evaluation of system by firemen

Environment modeling
- Online 3D mapping from laser sensor
- Based on enhanced ICP released open-source
- Topological segmentation for human-robot interaction
Vision only UAV navigation

- Swarm of small helicopters
  - Vision only navigation (one camera, GPS denied)
  - Fully autonomous with on-board computing
  - Feature based visual SLAM
UAV | collision avoidance and path planning

- Real time 3D mapping (on-board)
- optimal path planning considering localization uncertainties
Solar powered fixed wing airplanes: Long duration / continuous flights

**senseSoar**
- Wingspan: 3 m
- Wing area: 0.725 m²
- Peak Solar power: 140 W
- Power Consumption: 50 W
- Masses:
  - Overall: 3.72 kg
  - Batteries: 1.89 kg
- Nominal Speed: 10 m/s
- Sensors
  - Air speed
  - IMU, GPS
  - Camera and **IR camera**

**Atlantik Solar**
- Wingspan: 5.64 m
- Solar area: 1.5 m²
- Peak Solar power: 280 W
- Power Consumption: 40 W
- Masses:
  - Overall: 6.2 kg
  - Batteries: 1.89 kg
- Nominal Speed: 10 m/s
- Sensors
  - Air speed
  - IMU, GPS
  - Camera
Efficient Walking and Running | what nature evolved (Extreme Jumpy Dog)

- http://www.youtube.com/watch?v=Jql6TSyudFE
Efficient Walking and Running | serial elastic actuation
StarlETH | agile, efficiency and robust

- precise torque control during stance
- fast task space position control during swing
- virtual model controller for ground contact
- autonomous gait discovery by stochastic optimization
Humanoid Robot: ASIMO

- Honda’s ASIMO - Advanced Step in Innovative MObility
- Designed to help people in their everyday lives
- One of the most advanced humanoid robots
  - Compact, lightweight
  - Sophisticated walk technology
  - Human-friendly design

Video: Honda 2012
Beyond Mobility | PR2 robot from Willow Garage

Fold towels

Clean-up

Courtesy of Willow Garage