Mobile Robots | Summery
Autonomous Mobile Robots

Roland Siegwart, Margarita Chli, Juan Nieto, Nick Lawrance
Introduction | probabilistic map-based localization

- Localization
- Map Building
- Perception
  - Sensing
  - Information Extraction
    - raw data
  - environment model
    - local map
- "position"
  - global map
- Cognition
  - Path Planning
    - path
  - Path Execution
    - actuator commands
- Acting
- Motion Control
- Real World Environment

see-think-act

knowledge, data base

mission commands
Legged Robots and Kinematics

- Types and application of legged systems
  - Number of legs
  - Analogy to nature
- Static and dynamic stability
- Locomotion control

- Basics of rigid body kinematics
  - Translation, rotations, and homogeneous transformation
  - Translational and angular velocities
  - Rigid body kinematics formulation
  - Vector differentiation in moving coordinate systems
Wheeled Locomotion

- Wheeled types and arrangements

- Kinematics
  - Constraints imposed by wheels
  - Forward or inverse differential kinematics

- Analysis of the differential kinematics equations
  - the degree of maneuverability = degree of mobility + degree of steerability
Computer Vision | Projective Geometry

- Perspective projection
  - Intrinsic and extrinsic parameters

- Stereo vision
  - Correspondence search
  - Rectification
  - Disparity map

- Structure from motion
  - Epipolar geometry
  - Epipolar constraint
  - Essential matrix
  - 8-point algorithm

Perspective Projection Matrix

\[ \lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K[R|T] \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \]

Disparity

\[ Z_p = \frac{bf}{u_l - u_r} \]

\[ R, T = \]
Image Saliency | image filtering & place recognition

Image Filtering:

**Correlation vs. Convolution**
- Use in template matching, smoothing & taking the derivative of an image

- **Image filtering for Edge Detection**
- **Point Features:** Harris, SIFT, FAST, BRIEF, BRISK & their characteristics e.g. scale/rotation invariance, computational time

Building and using the visual vocabulary for Place Recognition

Examples of Visual Words
**The Error Propagation Law**

- How uncertainties propagate through a function.

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- **Line Fitting algorithms** for image/laser point clouds
  - Split-and-merge, RANSAC, Hough Transform,..
  - How they work & their relative characteristics and applications

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*Courtesy of ETH - ASL*
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)
SLAM | approaches & current challenges

- What is SLAM and how does it work?
- The graphical representation SLAM & the approaches to solve it:
  - Full graph optimization
  - Filtering
  - Keyframe-based

Popular techniques & how they work:
- EKF SLAM via MonoSLAM [Davison et al. 2007]

SLAM today & Challenges
Motion Planning | the planning problem
Motion Planning | hierarchical decomposition & approaches

1. Local collision avoidance
   - Dynamic Window Approach
   - (Reciprocal) Velocity Obstacles
   - Local potential fields

2. Global planning
   - Harmonic potential fields
   - Graph search (BF, Dijkstra, A*)
   - Randomized tree search (RRT)
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

- **Aids**
  - 4 A4-pages personal summary; Calculator
Exam | Wednesday 15.08.2017, 14:00-16:00

- Content of the exam:
  - MOOC (video segment, exercises, quizzes)
  - Book “Autonomous Mobile Robots” and add on slides

- Mode: The exam will be a combination of
  - Multiple Choice (comprehensive) 20-30%
  - Comprehension questions
  - Calculations, similar to exercises, but simpler and solvable without computer

- Two preparation sessions:
  - First: around 2 weeks before the exam
  - Second: 2-3 day before the exam

- More information about the preparation session and an example exam will be sent to you before the end of June.
Exam (example exercise exam)

**Autonomous Mobile Robots - Exercise Exam**

*Roland Siegwart, Margarita Chli, Martin Ruffli*

*Date of Exam: Exercise summer 2016*

<table>
<thead>
<tr>
<th>Question</th>
<th>Points</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Multiple Choice</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>B. Mobile Robot Kinematics</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>C. Forward Kinematics</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>D. Kinematic Constraints</td>
<td>8+2</td>
<td></td>
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<tr>
<td>E. Stereo Vision</td>
<td>7+1+2+5</td>
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<tr>
<td>F. Markov Localization</td>
<td>4+4</td>
<td></td>
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<tr>
<td>G. Kalman Filter Based Localization</td>
<td>7</td>
<td></td>
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<tr>
<td>H. SLAM</td>
<td>6+3+2+4</td>
<td></td>
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<tr>
<td>I. Graph Search: Dijkstra’s Algorithm</td>
<td>6+5+2</td>
<td></td>
</tr>
<tr>
<td>J. Collision Avoidance: Velocity Obstacle Approach</td>
<td>2+2+3</td>
<td></td>
</tr>
</tbody>
</table>
## Exam (example exercise exam)

### A. Multiple Choice Questions

Decide whether the following statements are true or false. Cross the checkbox on the corresponding answer. 
You will be credited 1 point for a correct answer, while 1 point will be subtracted from the total, if your answer is wrong.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1</td>
<td>In a holonomic system, the measure of the traveled distance of each wheel is sufficient to calculate the final position of the robot.</td>
<td>TRUE</td>
</tr>
<tr>
<td>2</td>
<td>For a robot with 2 degrees of maneuverability, position of instantaneous center of rotation is constrained to a line.</td>
<td>TRUE</td>
</tr>
<tr>
<td>3</td>
<td>Open-loop control can be used to move the robot in the unknown environment.</td>
<td>TRUE</td>
</tr>
<tr>
<td>4</td>
<td>Non-holonomic robot is able to move instantaneously in any direction in the space of its degrees of freedom.</td>
<td>TRUE</td>
</tr>
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</table>
Exam (example exercise exam)

B. Mobile Robot Kinematics

Please specify degrees of maneuverability, mobility and steerability for the following three-wheel configurations and explain why.

Differential  Tricycle  Omnidirectional