Real-time SLAM, Traversability Analysis and Navigation Planning in Rough Terrain based on 3D Lidar

Sven Behnke
Autonomous Intelligent Systems
DLR SpaceBot Cup 2013

- Mobile manipulation in Mars-like environment
- Supervised autonomy
- Explorer robot with 6 wheels and 7 DoF manipulator

[Stückler et al. Journal of Field Robotics 2016]

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Sensor Head

- 3D lidar with spherical FoV
- 8× RGB-D camera
- 3× Full HD camera
- Fisheye camera

[Stückler et al. Journal of Field Robotics 2016]
Local Navigation

- Omnidirectional height from RGB-D cameras
- Navigation costs from local height differences
- A* path planning

[Schwarz, Behnke, Robotik 2014]
Allocentric Path Planning

- 3D map from registered 3D laser scans

- Cell costs derived from local terrain properties
  - Local height differences
  - Slope

- A* path planning

[Stückler et al. JFR 2016]
The robot starts to autonomously explore the arena

[Stückler et al. Journal of Field Robotics 2016]

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DARPA Robotics Challenge

- Motivated by Fukushima

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Mobile Manipulation Robot Momaro

- Four compliant legs ending in pairs of steerable wheels
- Anthropomorphic upper body
- Sensor head

[Schwarz et al. Journal of Field Robotics 2016]
Momaro Leg Design

- Robotis Dynamixel Pro Actuators
  - Hip, knee: 44 Nm
  - Ankle pitch: 25 Nm
  - Ankle yaw: 6 Nm
  - Wheel drive: $2 \times 6$ Nm
- Carbon composite springs in links
- Omnidirectional driving
- Base height and attitude changes
- Terrain adaptation
- Making steps

[Schwarz et al. Journal of Field Robotics 2016]
Egress

[Schwarz et al. Journal of Field Robotics 2016]

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Local Multiresolution Surfel Map

- Registration and aggregation of 3D laser scans
- Local multiresolution grid
- Surfel in grid cells

[Droeschel et al. ICRA 2014, IAS 2014]
Opening a Door

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[Schwarz et al. Journal of Field Robotics 2016]
Filtering Dynamic Objects

- Maintain occupancy in each cell

[Droeschel et al. under review]
Allocentric 3D Mapping

- Registration of egocentric maps by graph optimization

[Droeschel et al., ICRA 2014, IAS 2014]
Debris Task

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[Schwarz et al. Journal of Field Robotics 2016]
Stair Climbing

- Determine leg that most urgently needs to step
- Weight shift
  - Move the base relative to the wheels in sagittal direction
  - Drive the wheels on the ground relative to the base
  - Modify the leg lengths (and thus the base orientation)
- Step to first possible foot hold after height change

[Schwarz et al., ICRA 2016]
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Full-body Stair Climbing

[Schwarz et al., ICRA 2016]
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DLR SpaceBot Cup 2015

- 3D map

[Schwarz et al., Frontiers on Robotics and AI 2016]
[Schwarz et al., Frontiers on Robotics and AI 2016]
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Navigation Planning

- Costs from local height differences
- A* path planning

[Schwarz et al., Frontiers on Robotics and AI 2016]
Considering Robot Footprint

- Costs for individual wheel pairs from height differences
- Base costs
- Non-linear combination yields 3D (x, y, θ) cost map

[Klamt and Behnke, under review]

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3D Driving Planning \((x, y, \theta)\): A*

- 16 driving directions

- Orientation changes

\[ \Rightarrow \text{Obstacle between wheels} \]

[Klamt and Behnke, under review]
Making Steps

- If not drivable obstacle in front of a wheel
- Step landing must be drivable
- Support leg positions must be drivable

[Klamt and Behnke, under review]
Hybrid Driving-Stepping Plan

Path Planning Example

Scenario: Momaro has to step up a height difference and manoeuvre around a small wall.

[Klamt and Behnke, under review]
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Detailed Realization of Steps

Step Generation

[Klamt and Behnke, under review]
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Conclusions

- Compliant wheeled-legged base
  - Large adjustable support polygon
  - Omnidirectional driving
  - Terrain adaptation, weight shift, steps
- 3D lidar-based SLAM
- Geometric drivability analysis
- Demonstrated autonomous navigation in rough terrain
- Planned hybrid driving-stepping locomotion
- Future: Semantic surface segmentation

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Team NimbRo Rescue @ DRC

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http://www.nimbro.net/Rescue
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