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

Sven Behnke

Autonomous Intelligent Systems

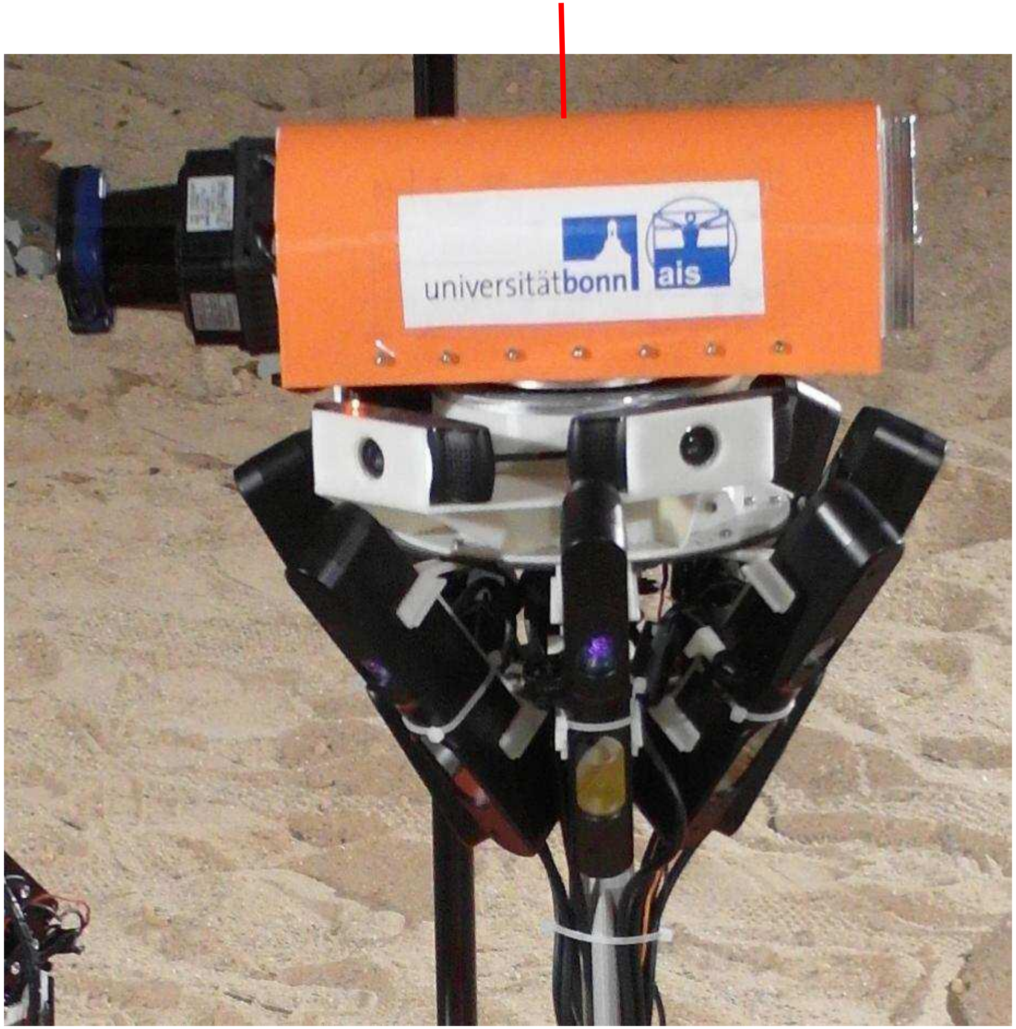
DLR SpaceBot Cup 2013

- 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]

Sensor Head

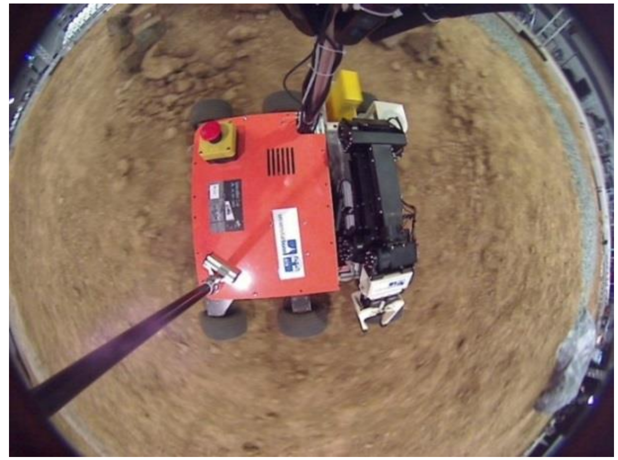
- 3D lidar with spherical FoV
- 8× RGB-D camera
- 3× Full HD camera
- Fisheye camera



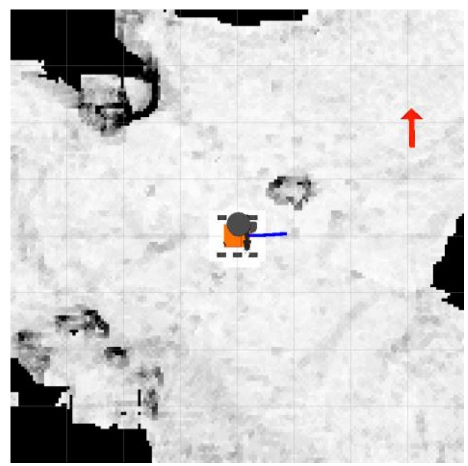
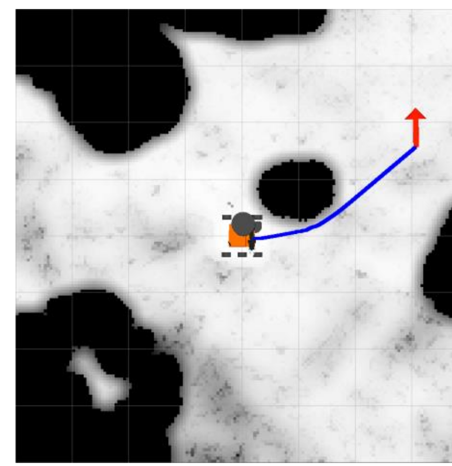
[Stückler et al. Journal of Field Robotics 2016]

Local Navigation

- Omnidirectional height from RGB-D cameras



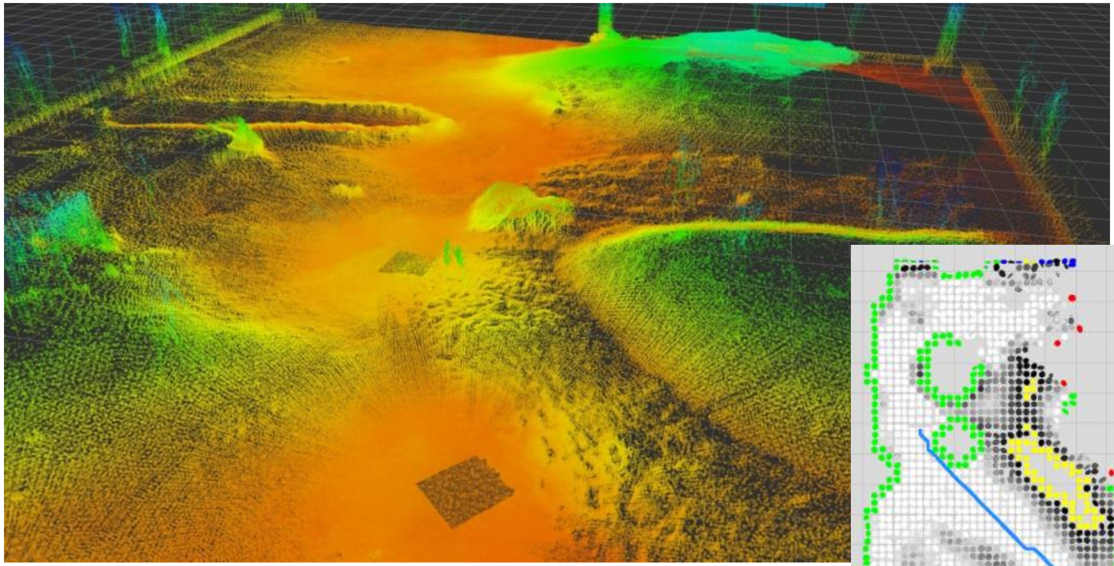

- Navigation costs from local height differences
- A* path planning

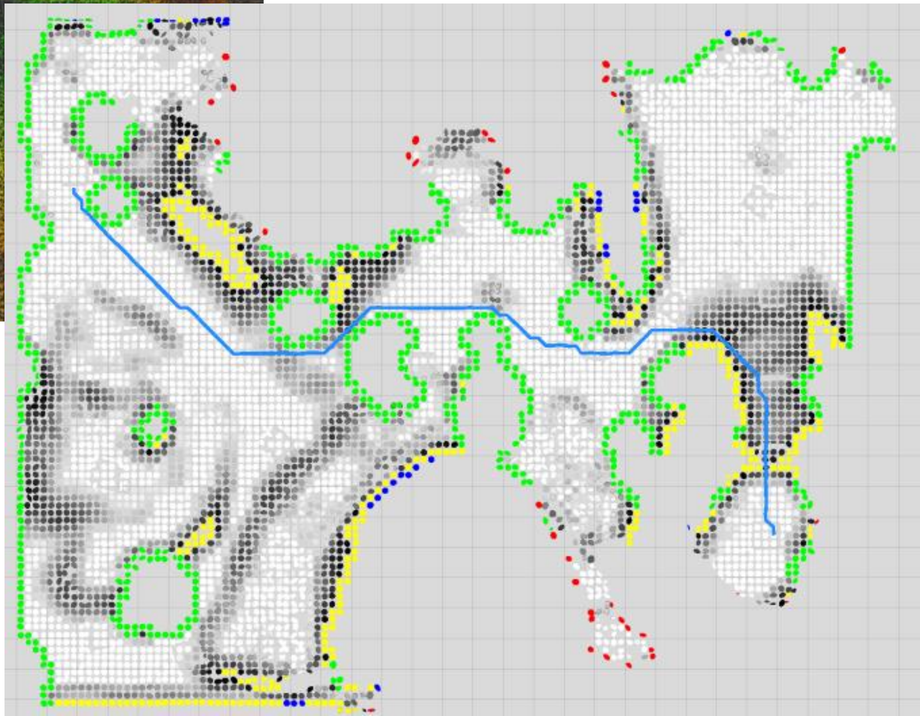
[Schwarz, Behnke, Robotik 2014]

Allocentric Path Planning

- 3D map from registered 3D laser scans



[Stückler et al. JFR 2016]



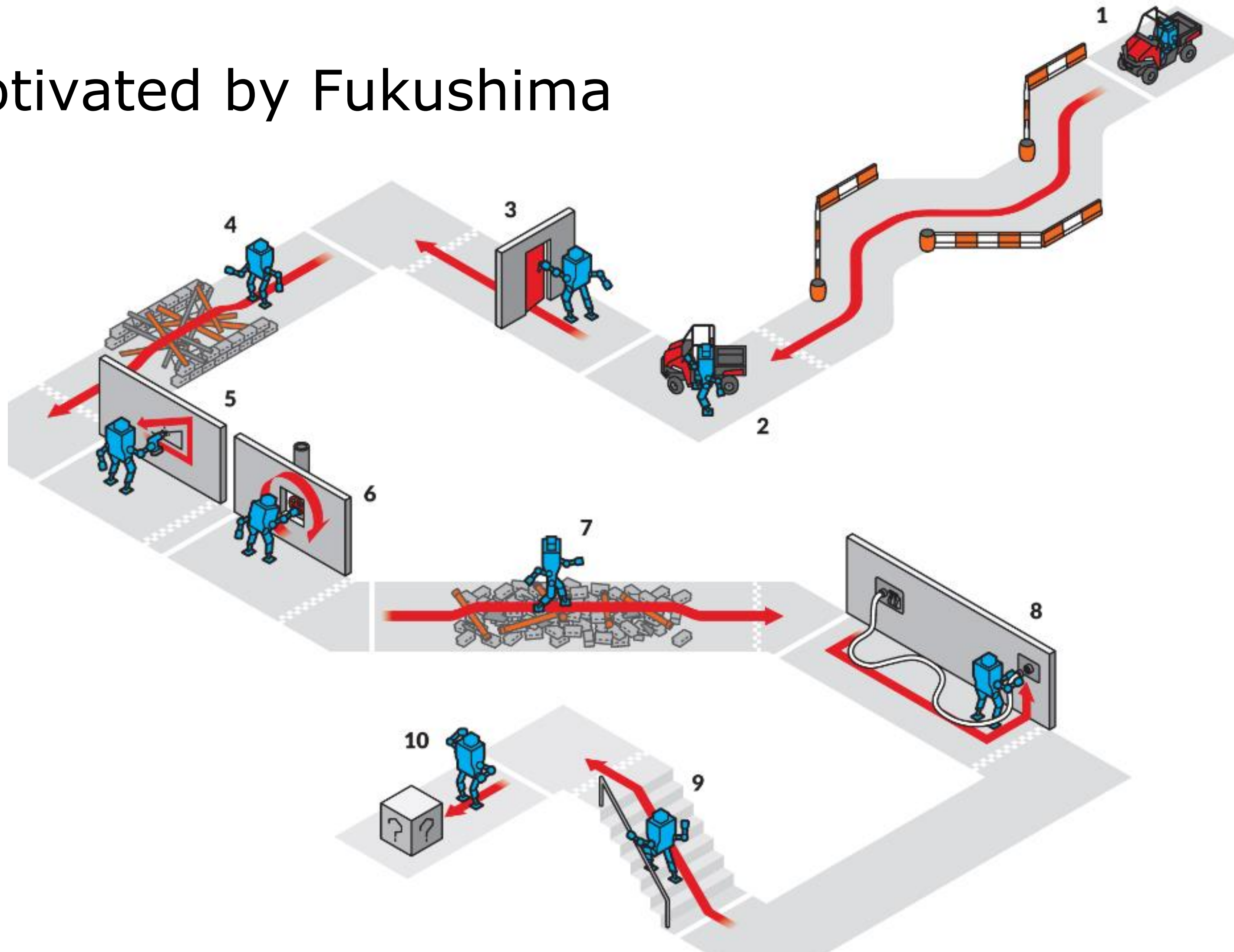
- Cell costs derived from local terrain properties
  - Local height differences
  - Slope
- A* path planning

DLR SpaceBot Cup 2013

[Stückler et al. Journal of Field Robotics 2016]

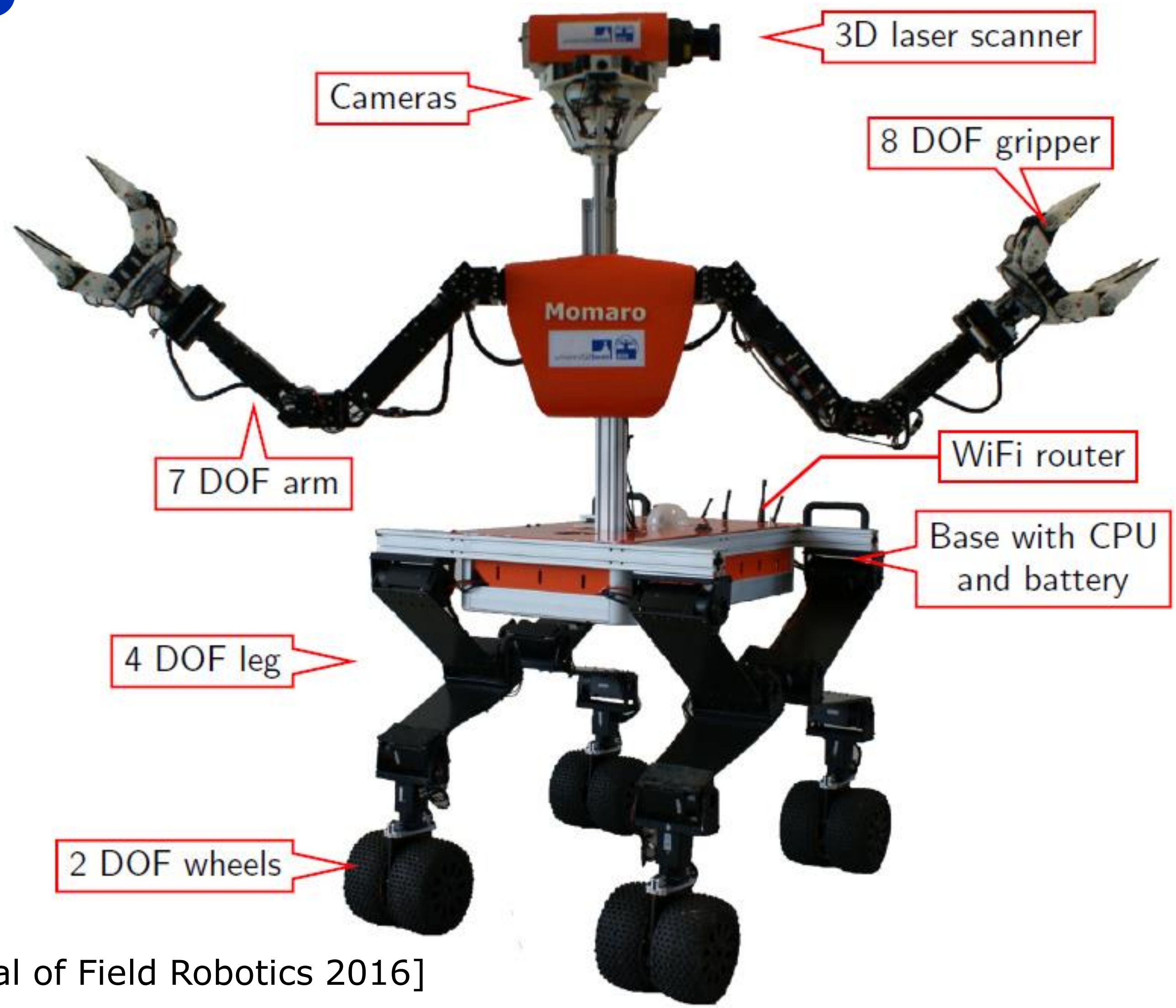
DARPA Robotics Challenge

- Motivated by Fukushima



Mobile Manipulation Robot Momaro

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



[Schwarz et al. Journal of Field Robotics 2016]

Driving a Vehicle

[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× 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

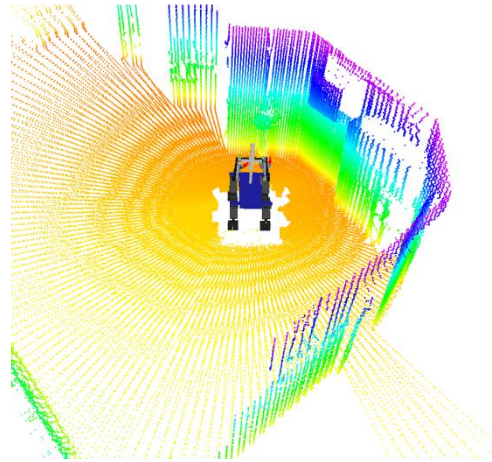
[Schwarz et al. Journal of Field Robotics 2016]

Local Multiresolution Surfel Map

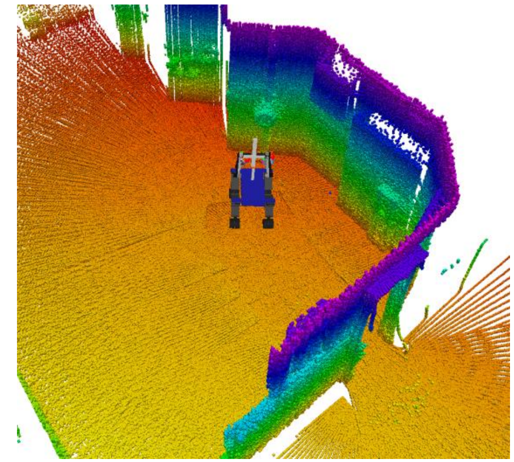
- Registration and aggregation of 3D laser scans
- Local multireso-lution grid
- Surfel in grid cells

[Droeschel et al. ICRA 2014, IAS 2014]

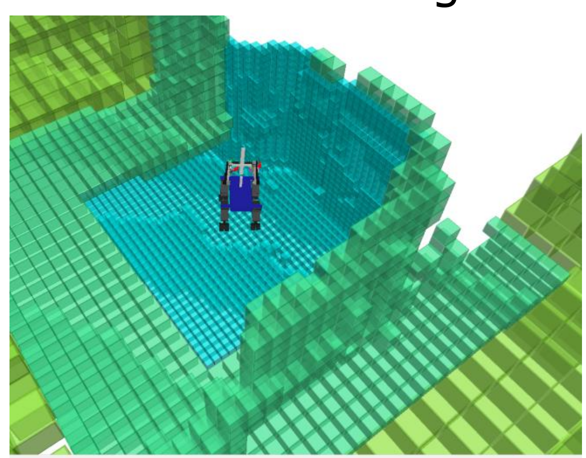
3D scan



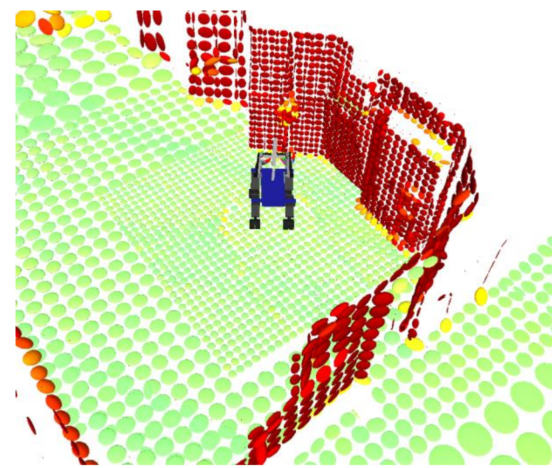
Aggregated scans



Multiresolution grid



Surfels

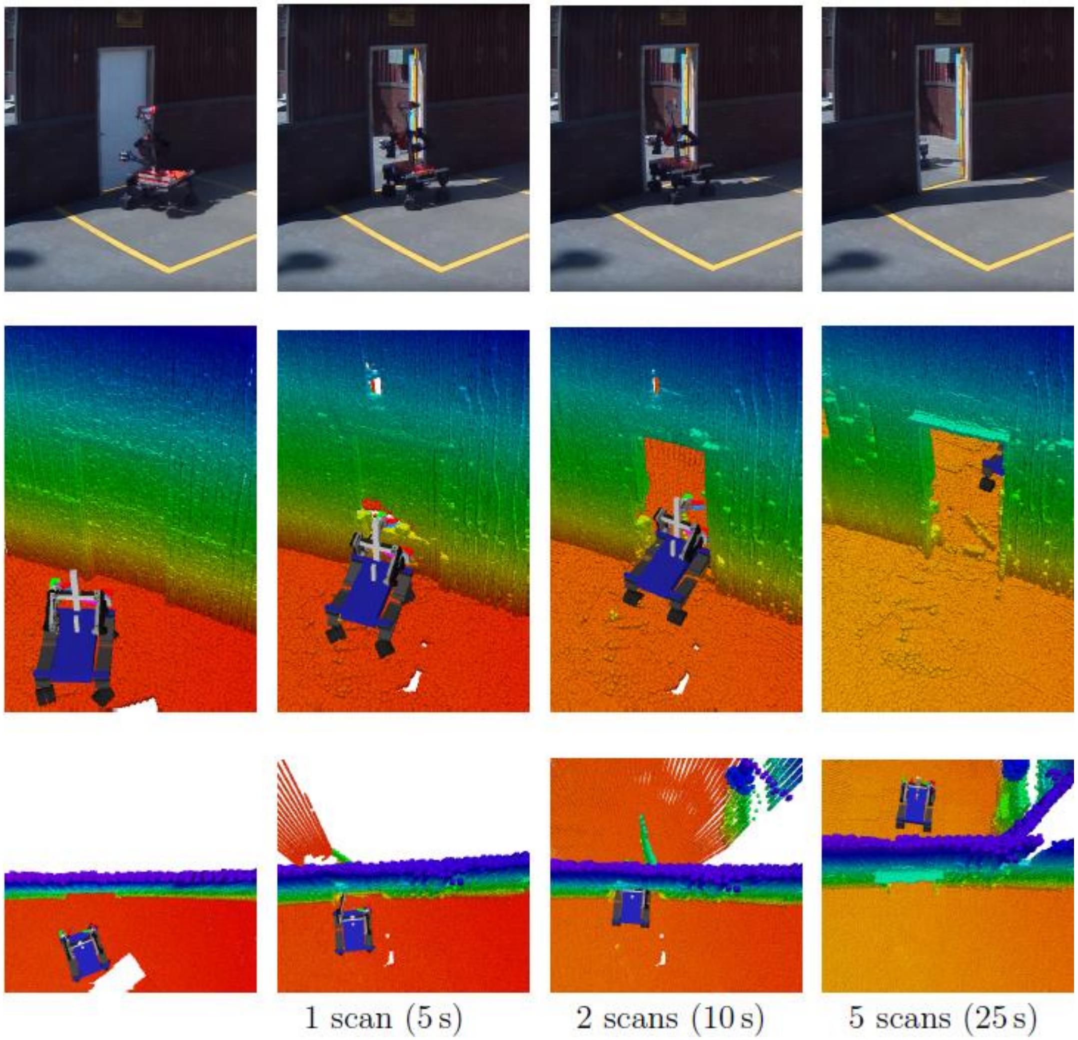


Opening a Door

[Schwarz et al. Journal of Field Robotics 2016]

Filtering Dynamic Objects

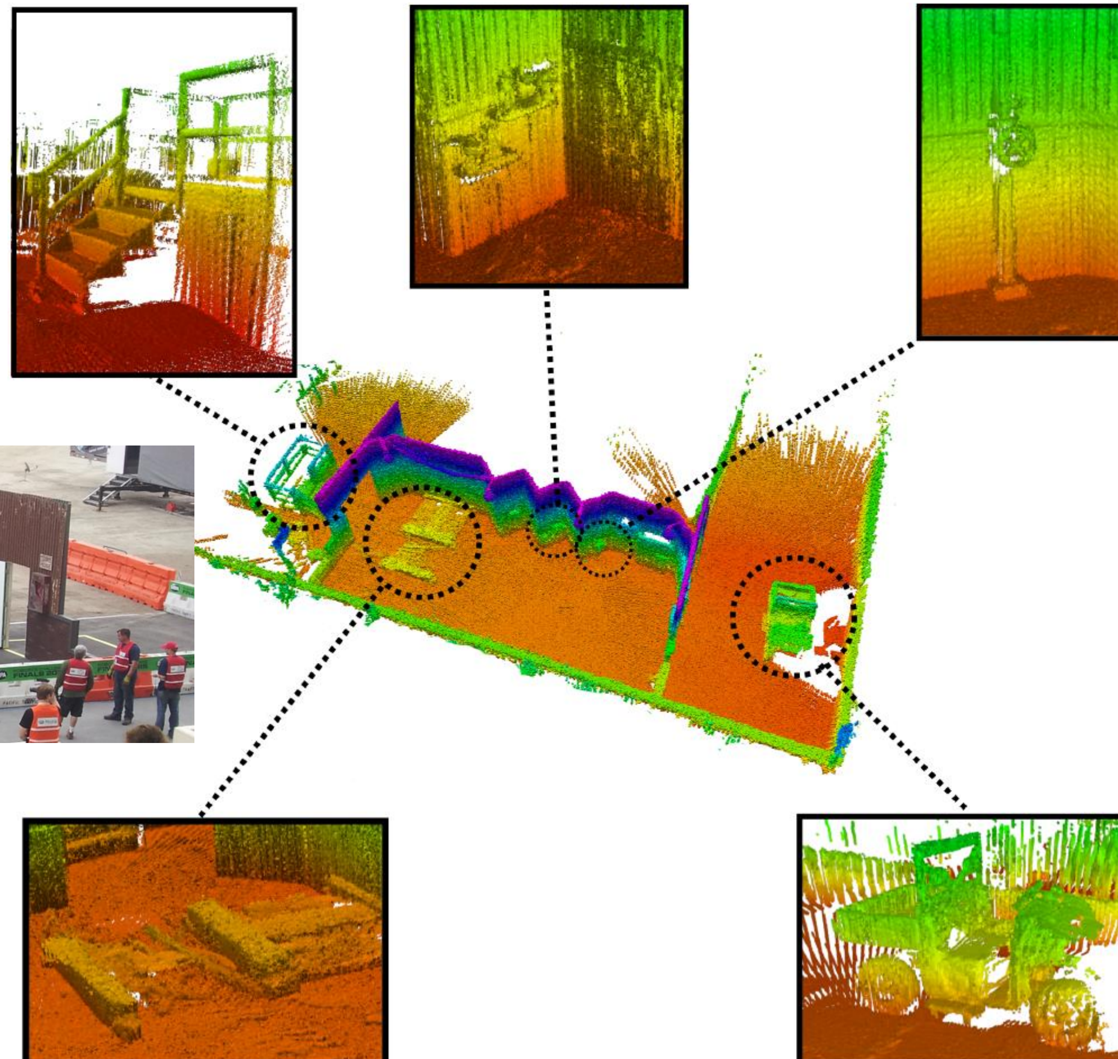
- Maintain occupancy in each cell



[Droeschel et al. under review]

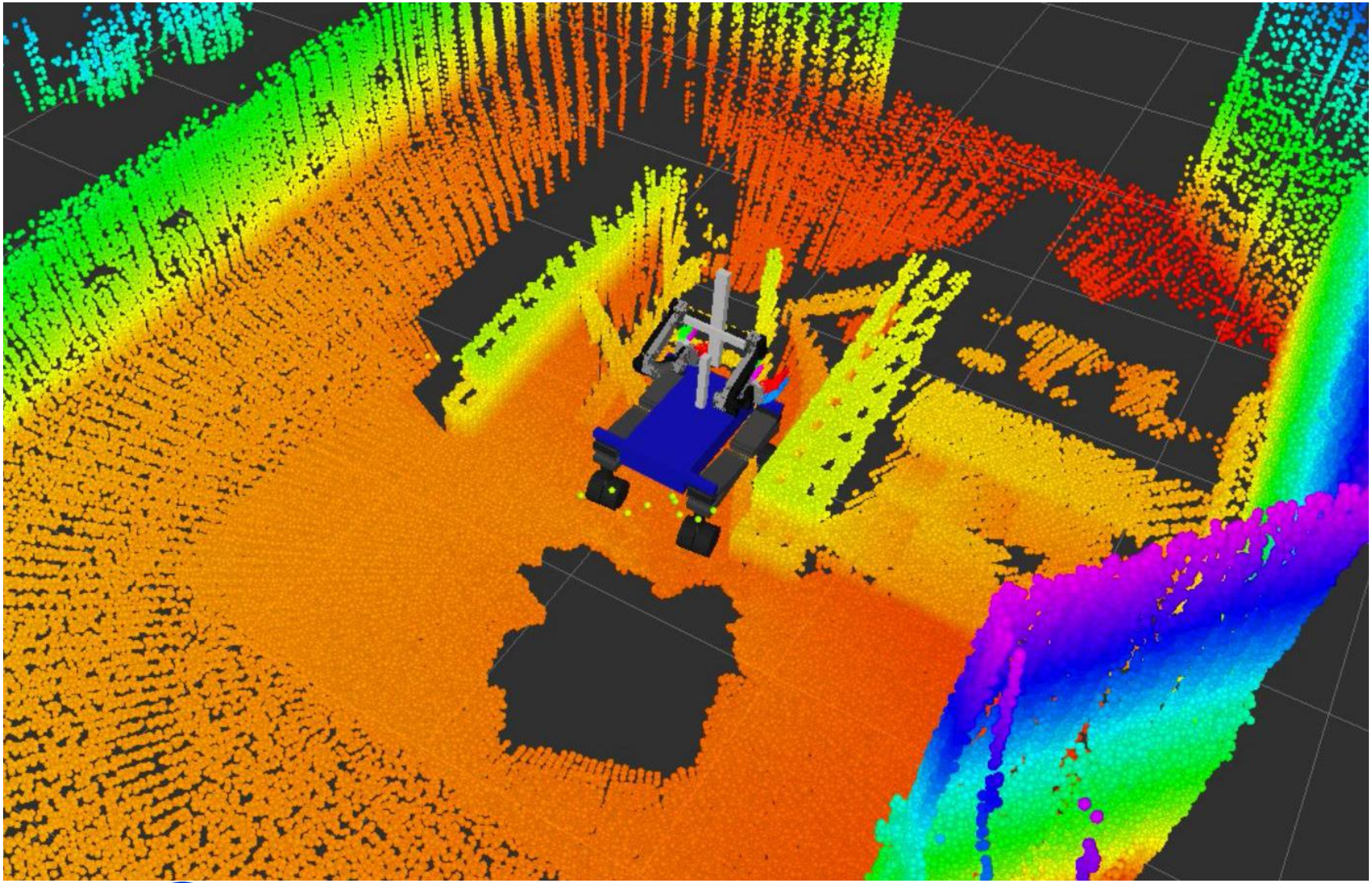
Allocentric 3D Mapping

- Registration of egocentric maps by graph optimization

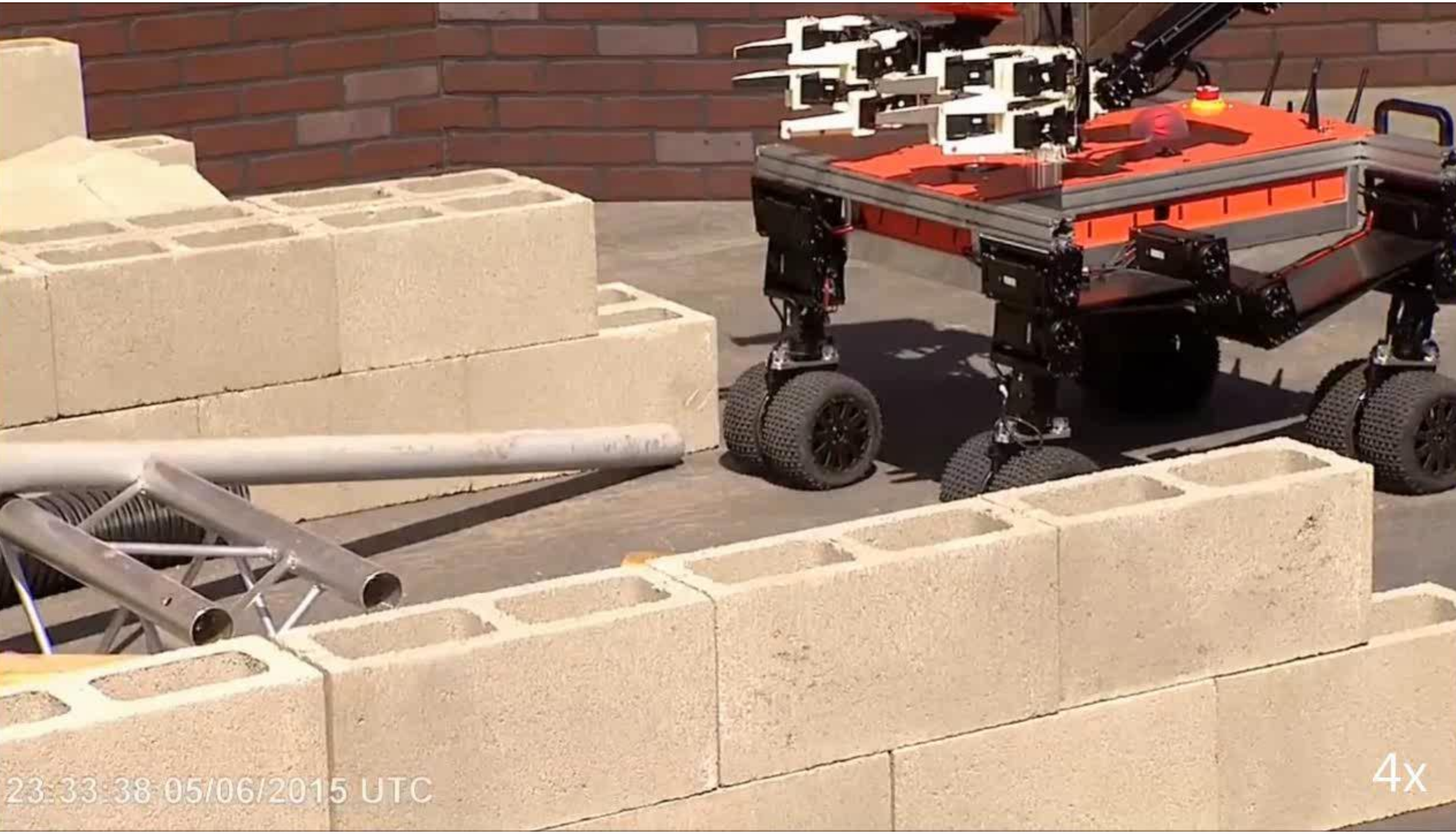


[Droeschel et al., ICRA 2014, IAS 2014]

Debris Task



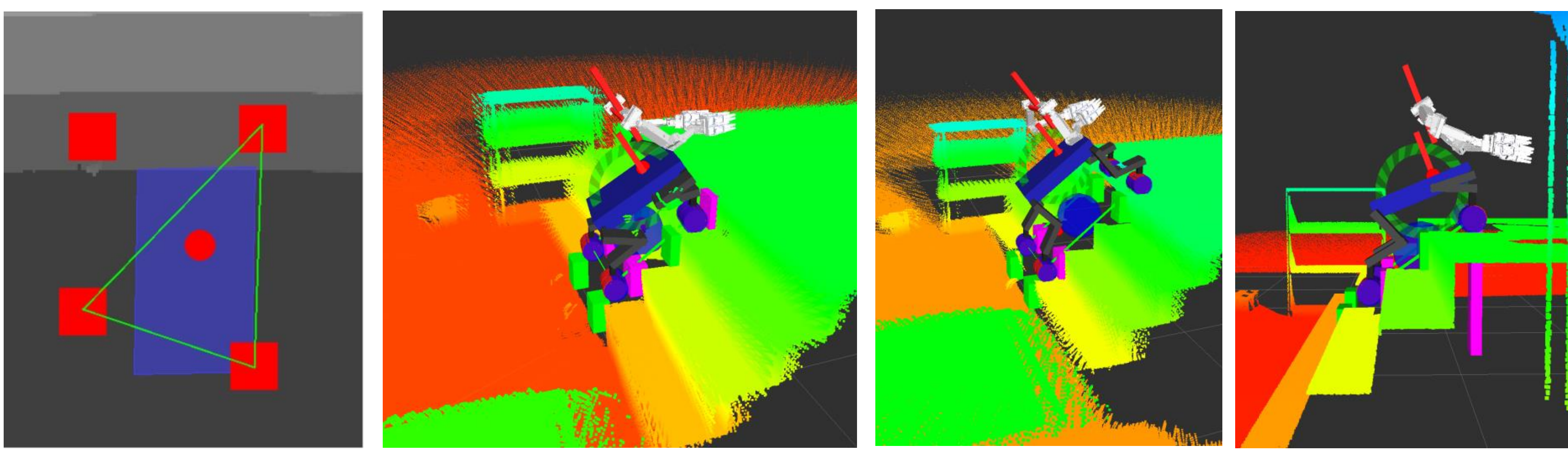
Drive Through Debris



[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]

Full-body Stair Climbing

[Schwarz et al., ICRA 2016]

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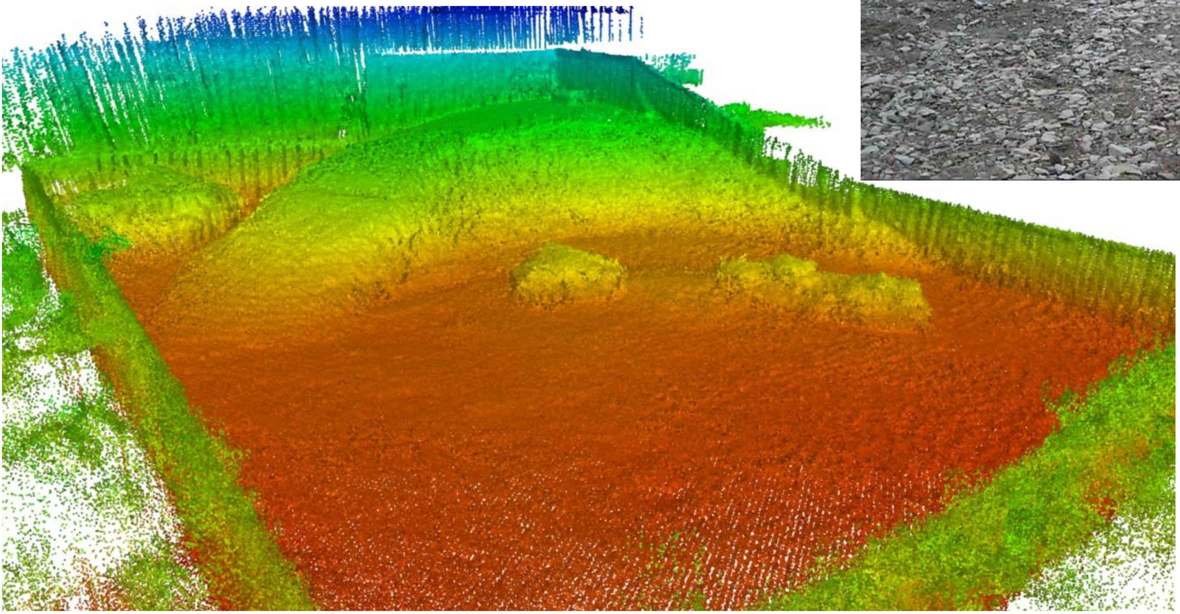
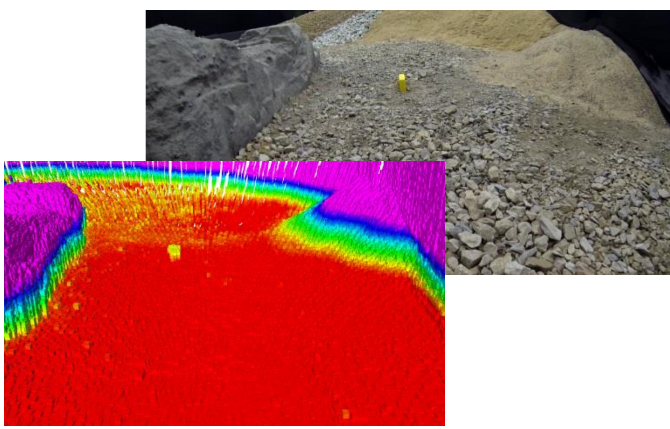
DLR SpaceBot Cup 2015

- 3D map

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





DLR SpaceBot Camp 2015

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

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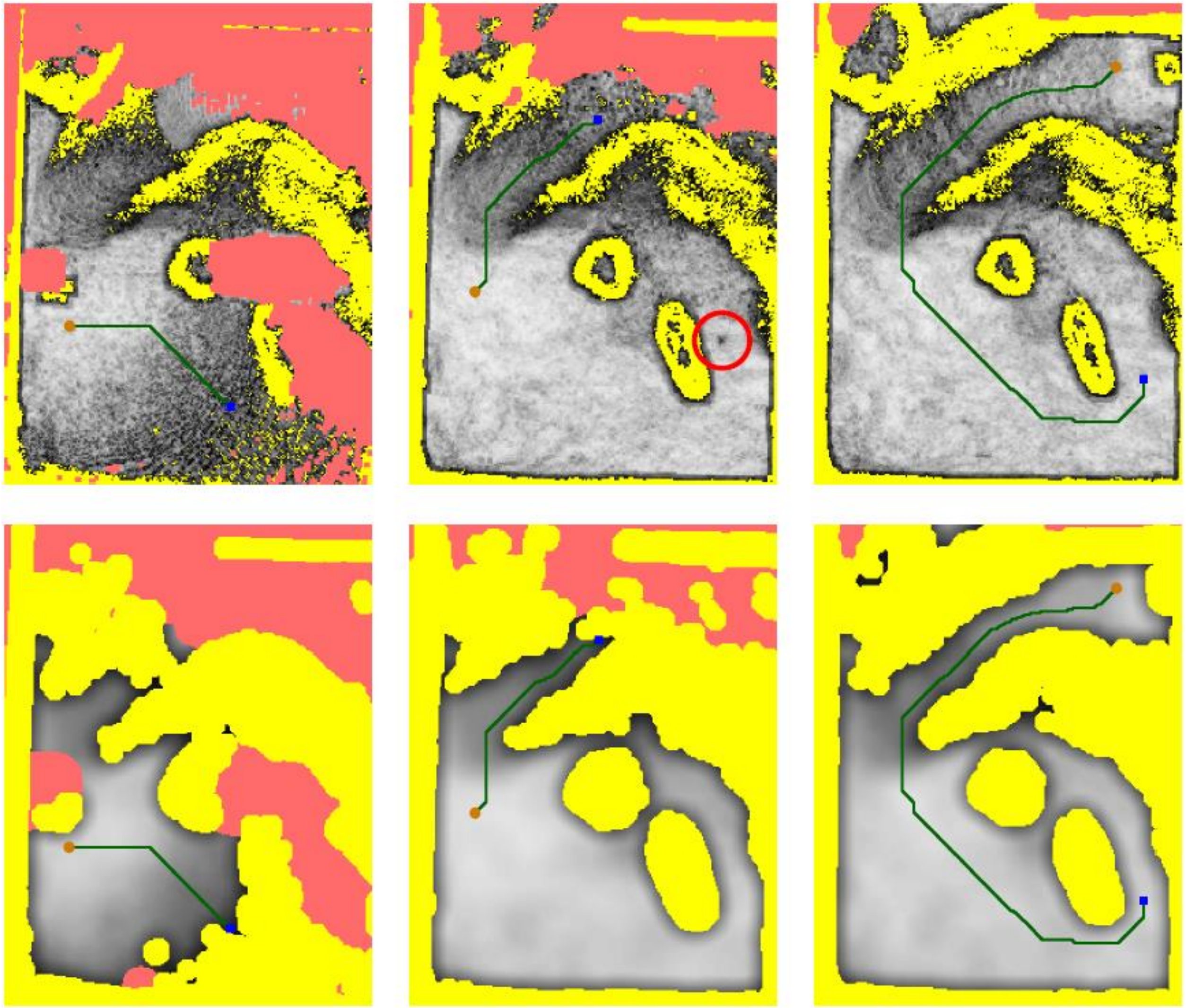
Navigation Planning

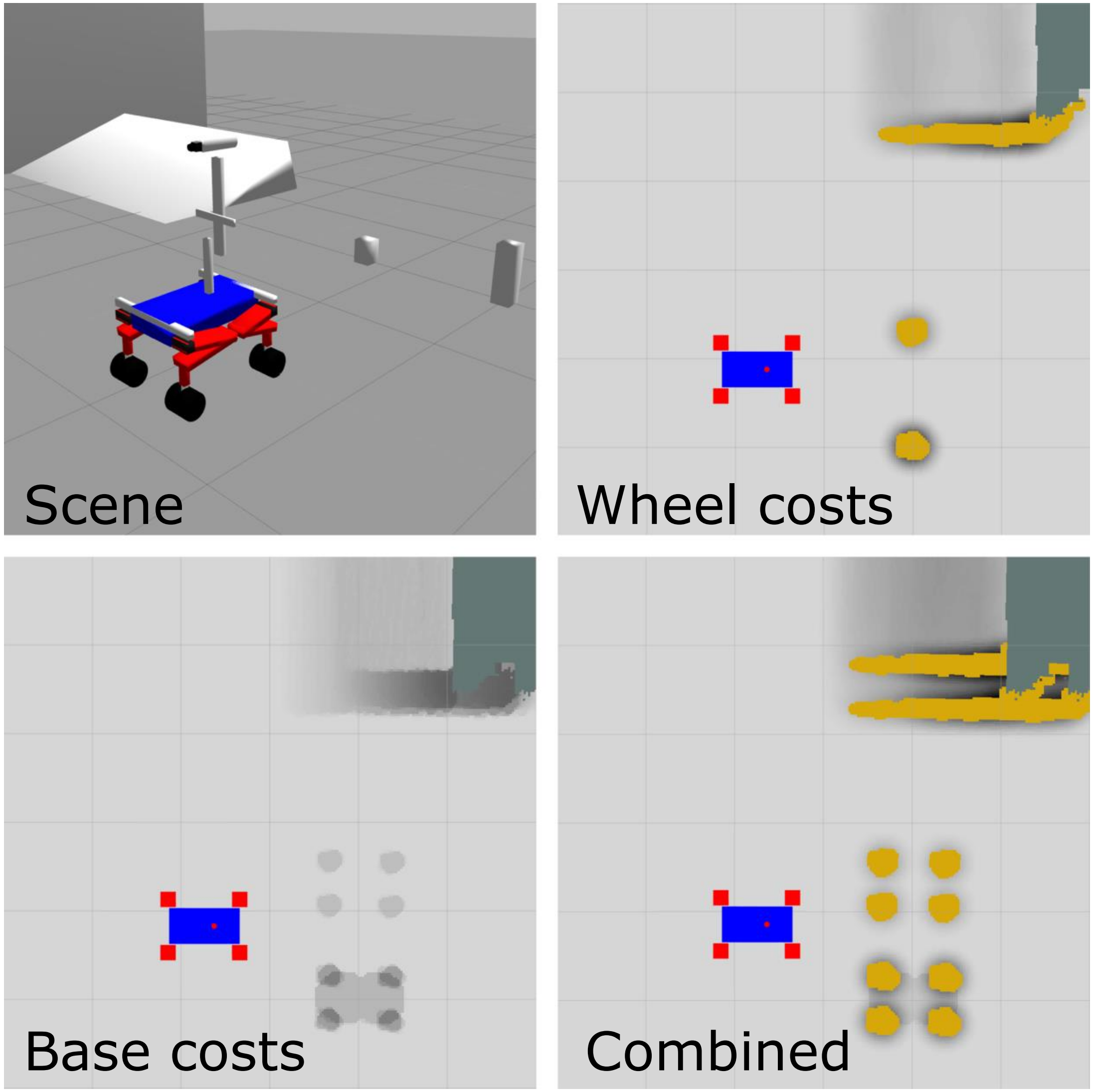
- Costs from local height differences
- A* path planning



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

Considering Robot Footprint

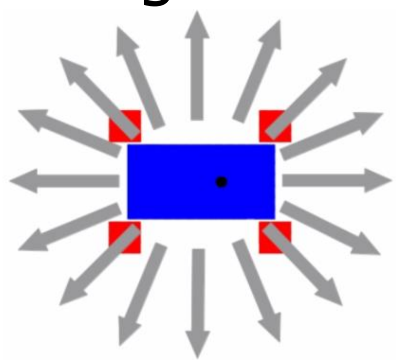
- Costs for individual wheel pairs from height differences
- Base costs
- Non-linear combination yields 3D (x, y, θ) cost map



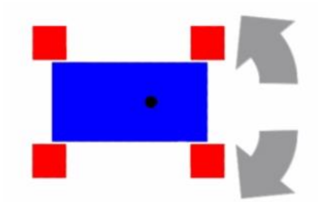
[Klamt and Behnke, under review]

3D Driving Planning (x, y, θ): A*

- 16 driving directions

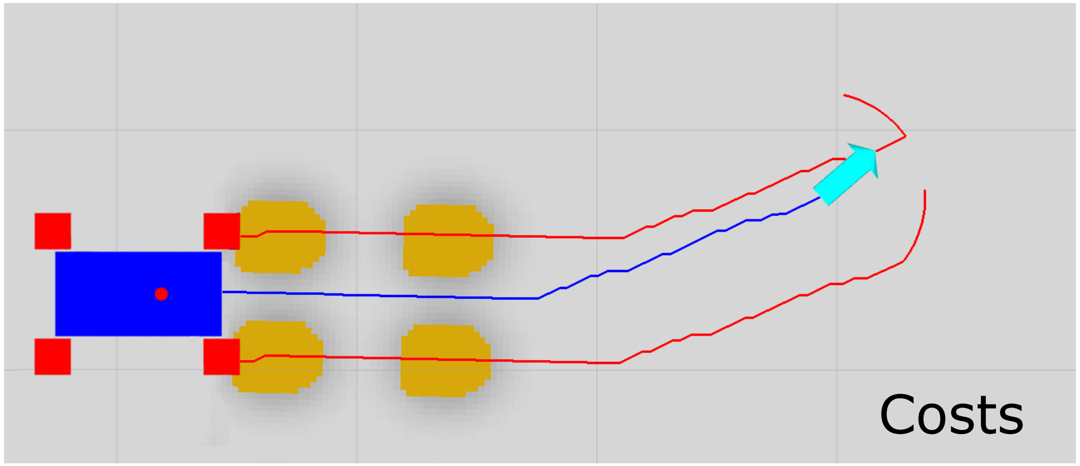


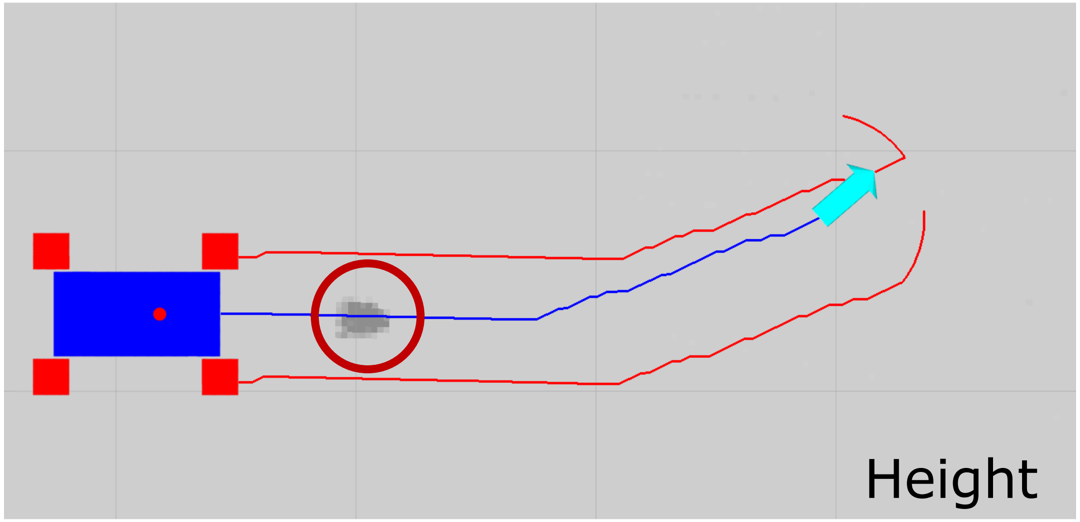
- Orientation changes



=> Obstacle between wheels

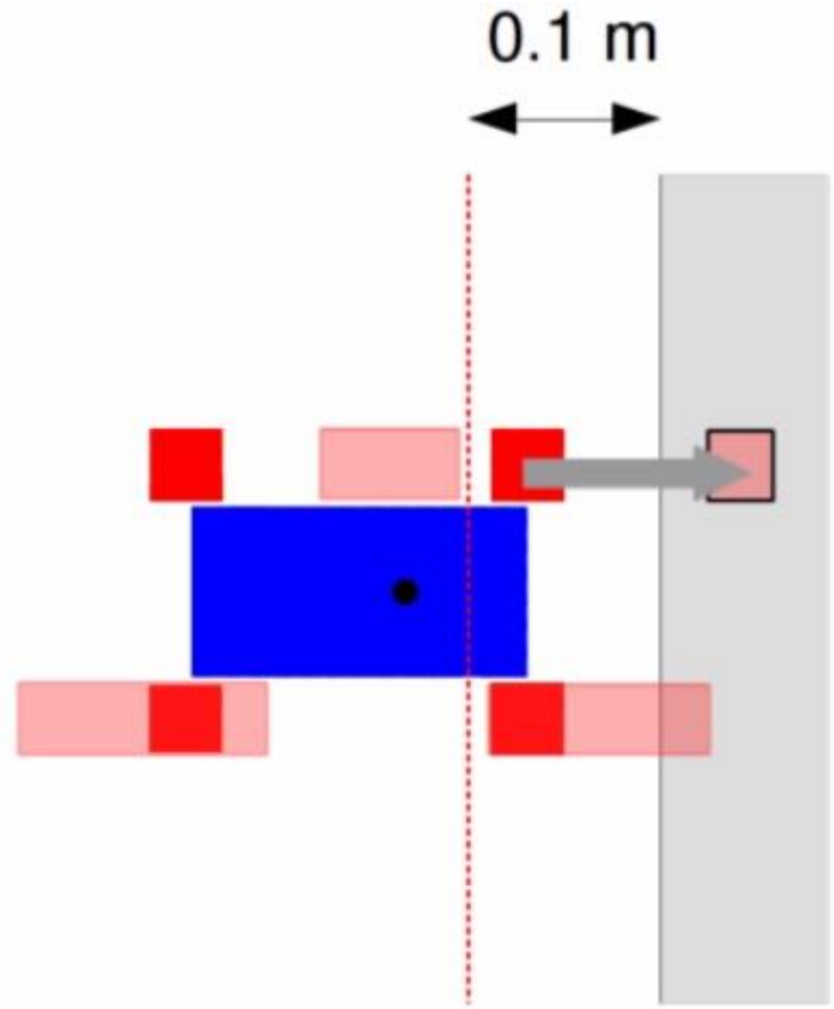
[Klamt and Behnke, under review]





Making Steps

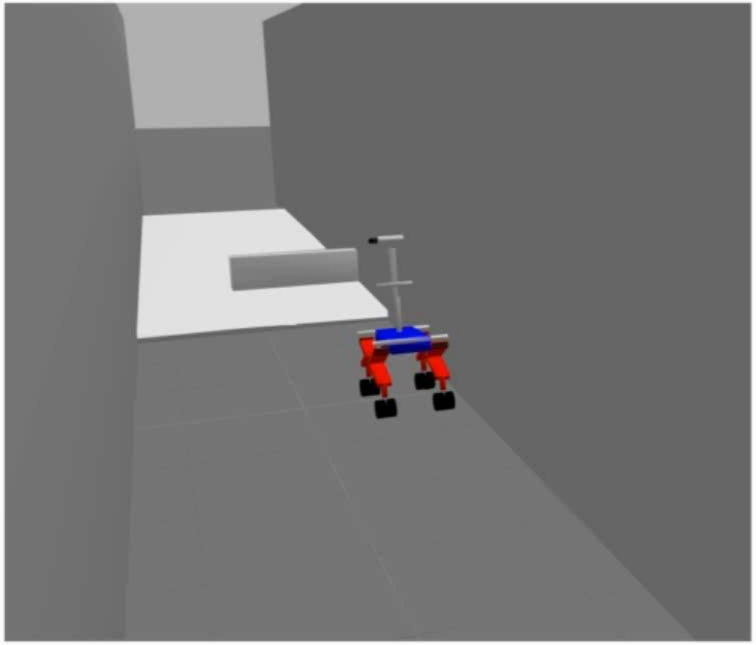
- If not drivable obstacle in front of a wheel
- Step landing must be drivable
- Support leg positions must be drivable



[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]

Detailed Realization of Steps

[Klamt and Behnke, under review]
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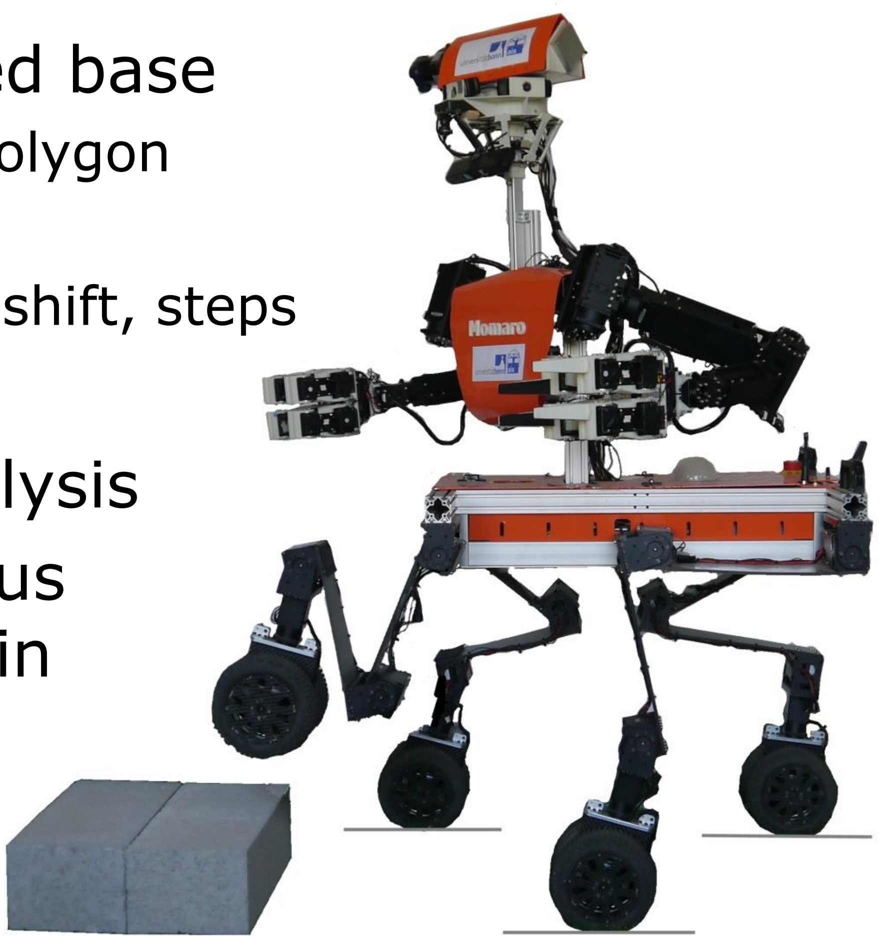
Conclusions

- 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



Team NimbRo Rescue @ DRC

http://www.nimbro.net/Rescue

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