HYBRID DRIVING-STEPPING LOCOMOTION IN CHALLENGING ENVIRONMENTS

Tobias Klamt, Max Schwarz, David Droeschel, Sven Behnke

MOTIVATION

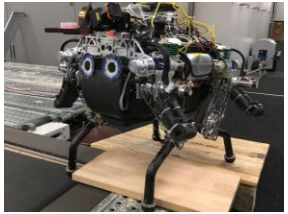
Wheeled / tracked locomotion

iRobot PackBot [Yamauchi et al.]

- \+ Fast
- \+ Energy efficient
- \+ High stability
- \- Only applicable to suitable terrain

\+

Legged locomotion



StarlETH [Wermelinger et al.]

- \+ Only requires isolated footholds
  ➡ Locomotion in challenging terrain
- \- Slow
- \- High energy consumption
- \- Less stable

=

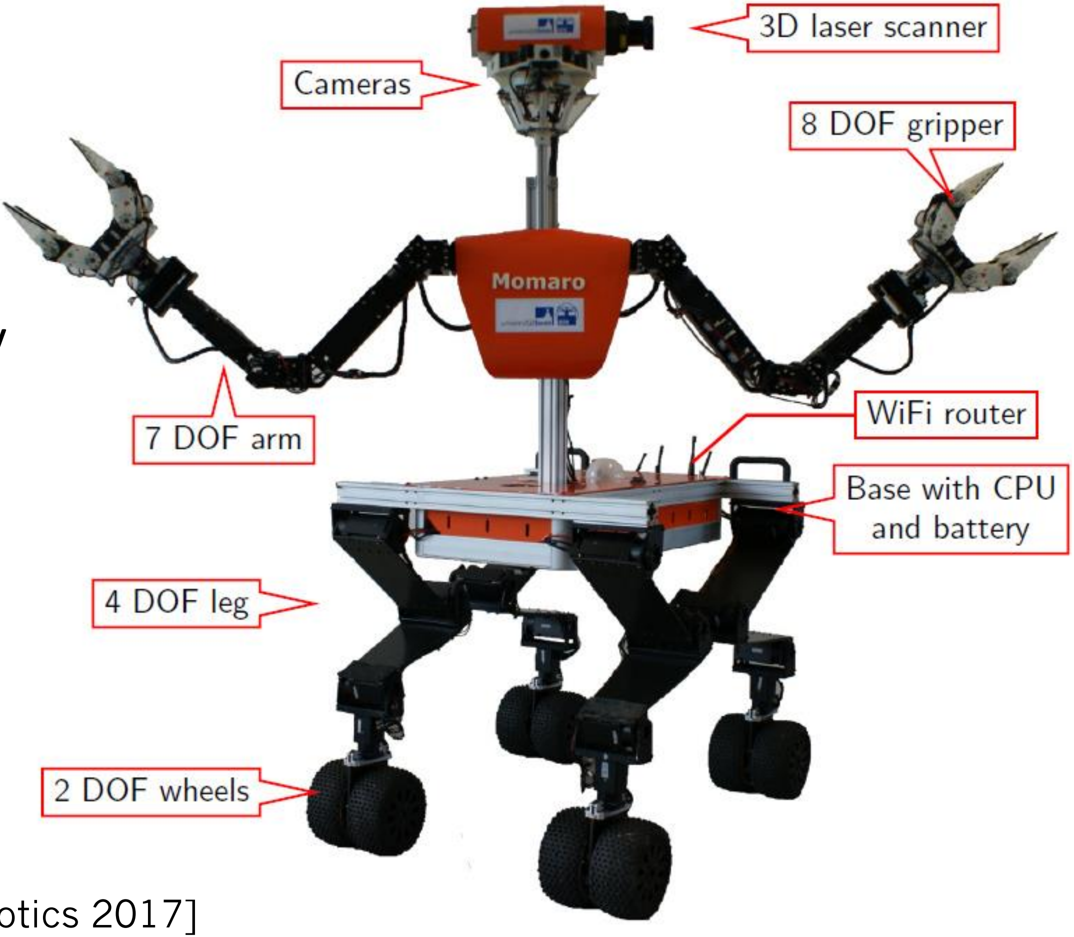
Hybrid driving-stepping locomotion

Momaro [Schwarz et al.]

- \+ Combines advantages of both locomotion types
- \+ Chooses best locomotion strategy for each situation
- \+ Enables unique locomotion features

MOBILE MANIPULATION ROBOT MOMARO

- Four compliant legs ending in pairs of steerable wheels
- Anthropomorphic upper body
- Sensor head
  - 3D laser scanner
  - IMU, cameras



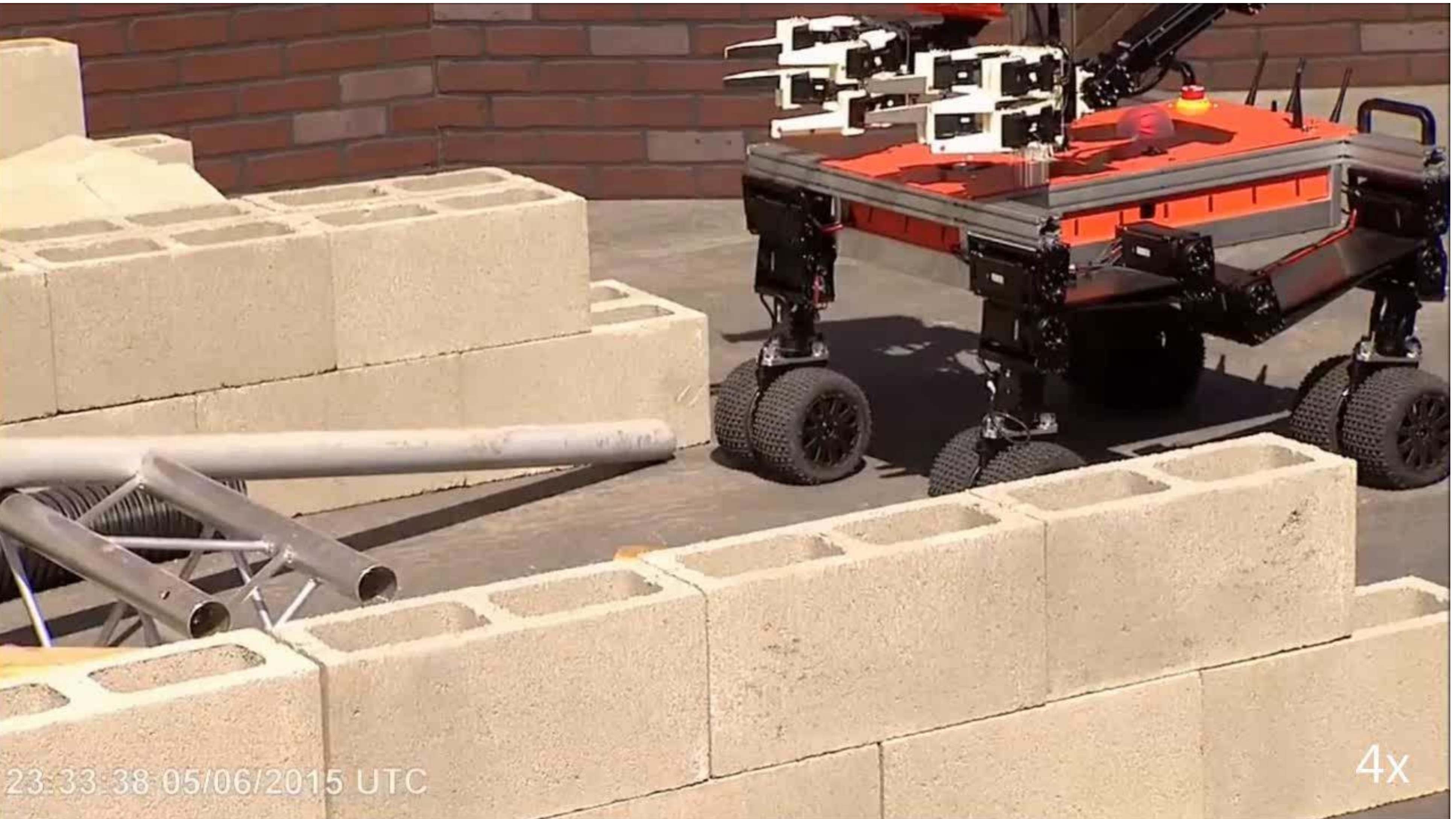
[Schwarz et al. Journal of Field Robotics 2017]


FAIRPLEX
FAIRPLEX
FAIRPLEX
POLARIS
23:15:03 05/06/2015 UTC
4x


CAUTION
POLARIS
23:16:59 05/06/2015 UTC
4x

FAIRPLEX
Momaro
POLARIS
RANGER
XP
23:20:32 05/06/2015 UTC
4x


23:28:21 05/06/2015 UTC
4x

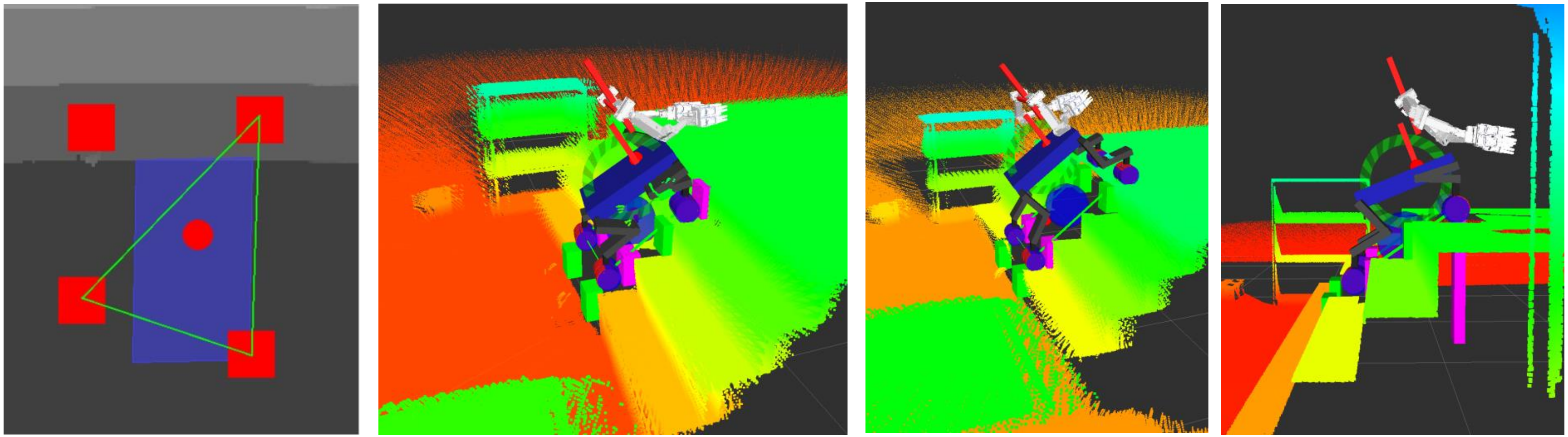

23:33:38 05/06/2015 UTC
4x

TEAM NIMBRO RESCUE

Best European Team (4th place overall), solved seven of eight tasks in 34 minutes

STAIR CLIMBING

- Determine leg that most urgently needs to step
- Weight shift: sagittal, lateral, driving changes support
- Step to first possible foot hold after height change



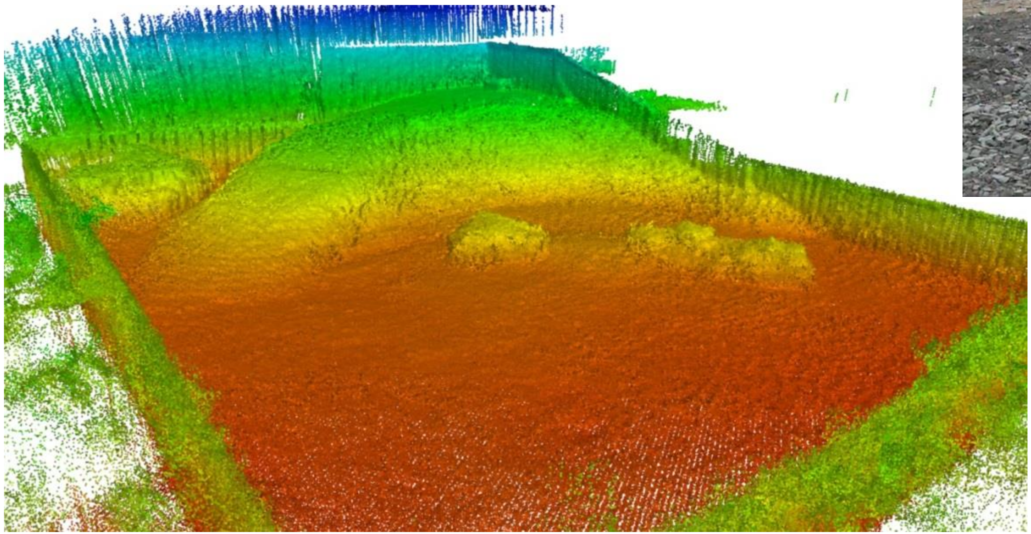
[Schwarz et al., ICRA 2016]

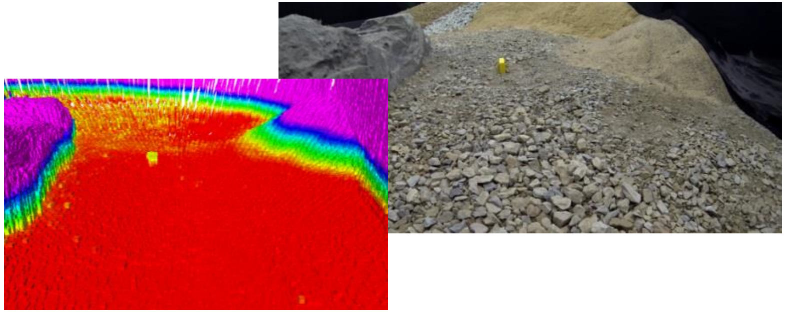
STAIR CRAWLING

DLR SPACEBOT CUP 2015

- Mobile manipulation in rough terrain

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

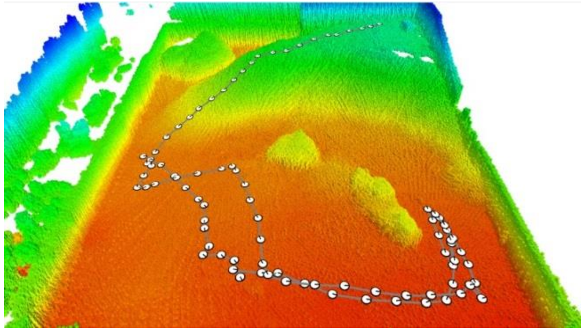




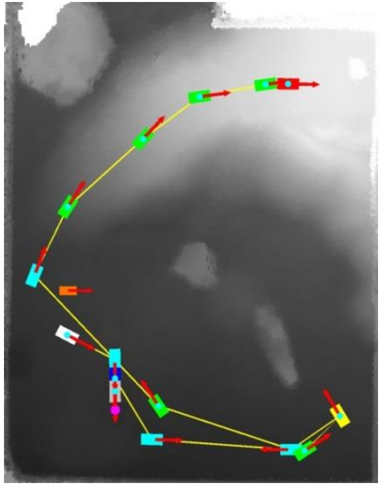

8X

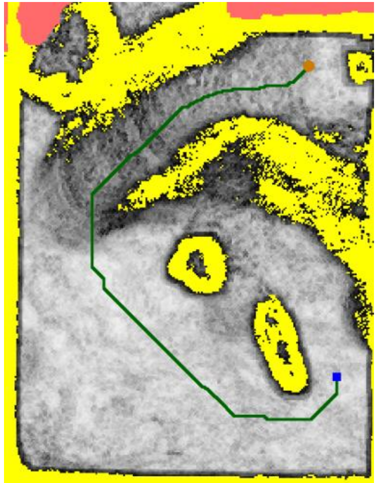
AUTONOMOUS MISSION EXECUTION

- 3D mapping & localization



- Mission and navigation planning

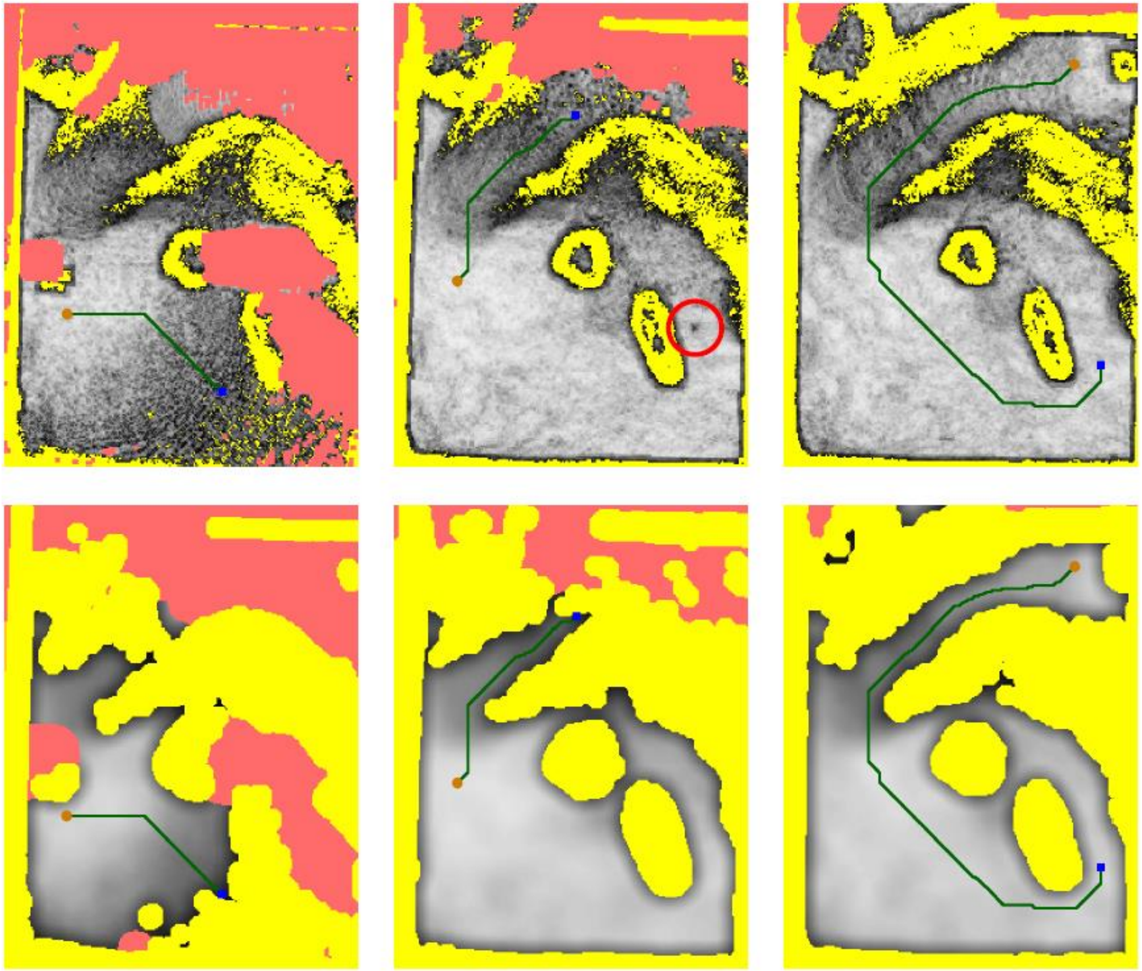




[Schwarz et al. Frontiers 2016]

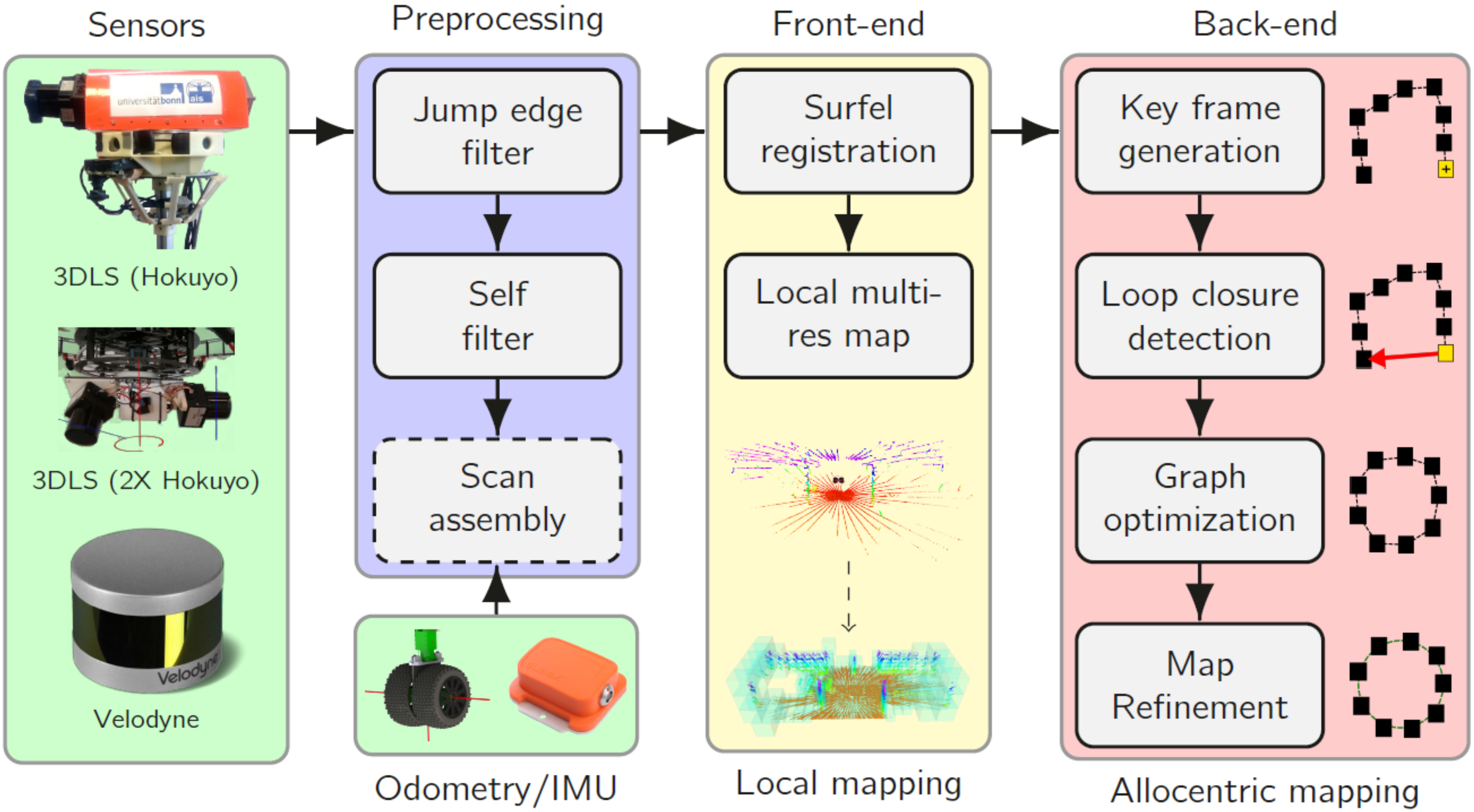
NAVIGATION WHILE BUIDING A 3D MAP

- Exploration of the arena during mission
- Frequent replanning
  - Costs from local height differences
  - A* path planning



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

LIDAR-BASED 3D SLAM



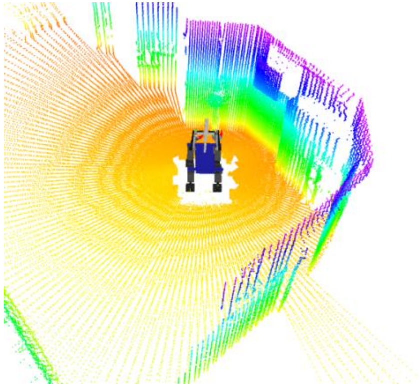
[Droeschel and Behnke, ICRA 2018]

LOCAL MULTIRESOLUTION SURFEL MAP

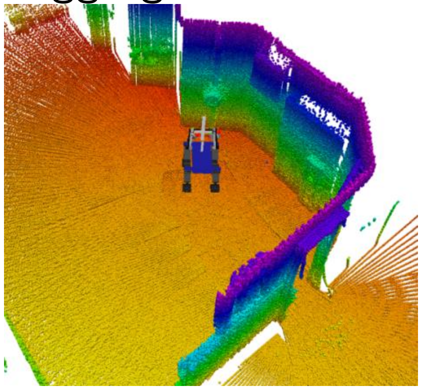
- Registration and aggregation of 3D laser scans
- Local multi-resolution grid
- Surfel in grid cells

[Droeschel et al., Robotics and Autonomous Systems 2017]

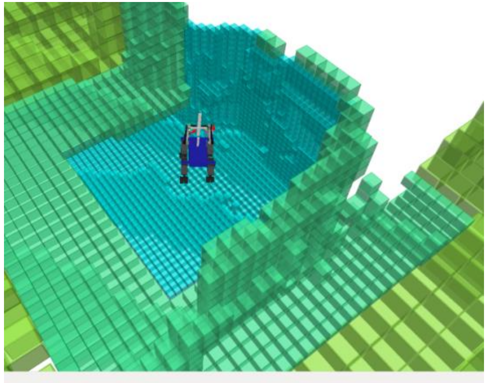
3D scan



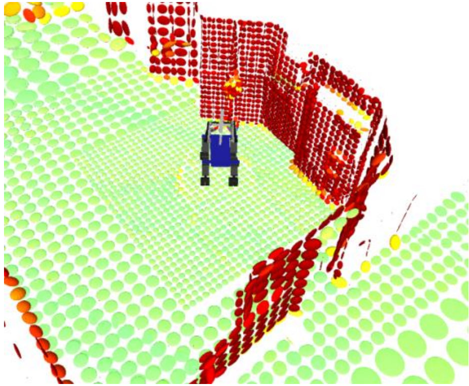
Aggregated scans



Multiresolution grid

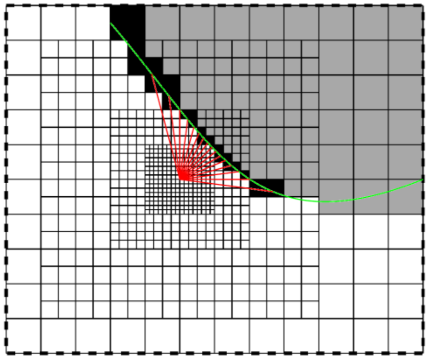


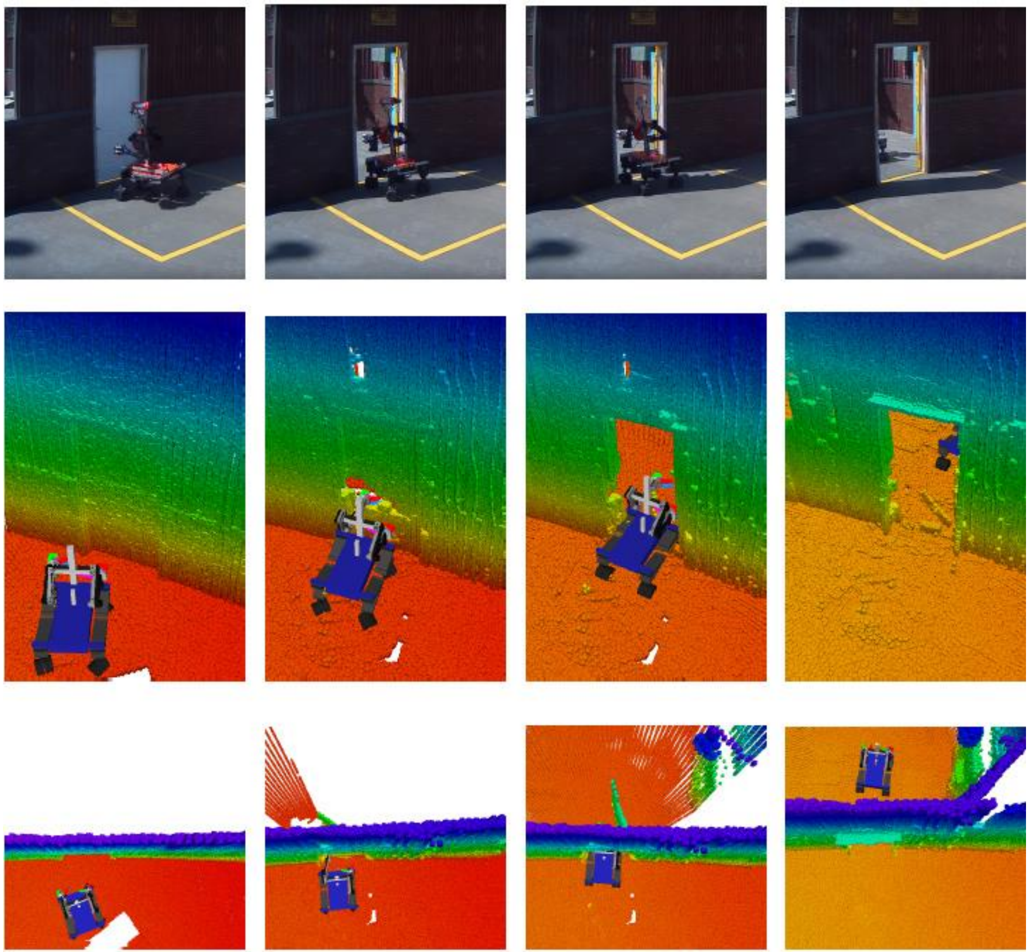
Surfels



FILTERING DYNAMIC OBJECTS

- Maintain occupancy in each cell
- Incorporate measurements by ray casting
- Log-odds

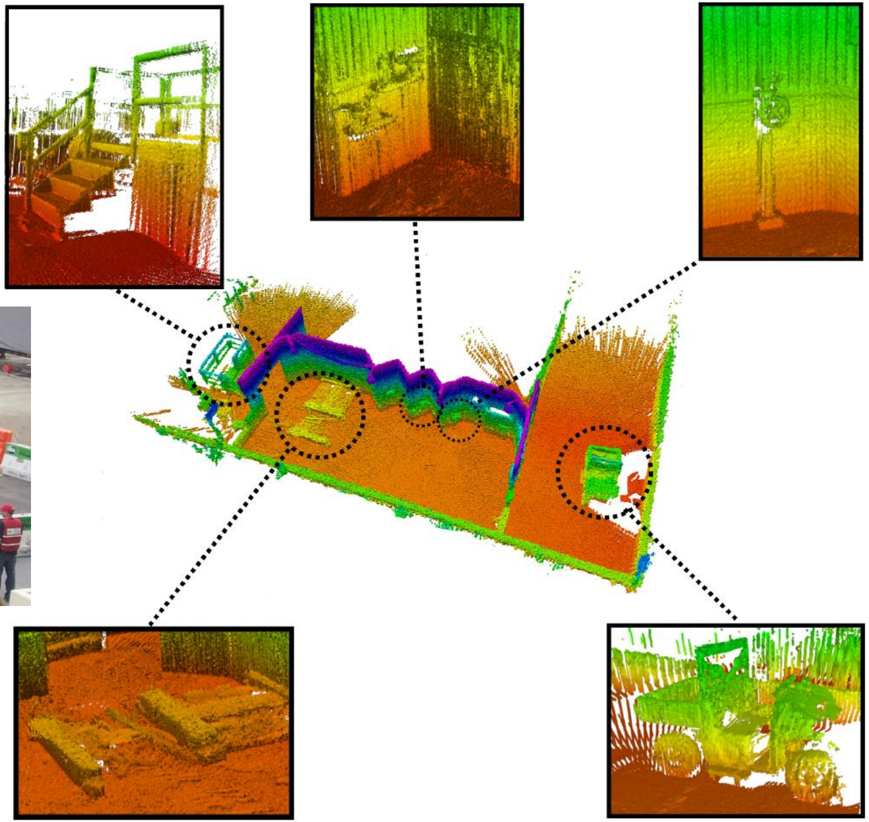




1 scan (5 s) | 2 scans (10 s) | 5 scans (25 s)

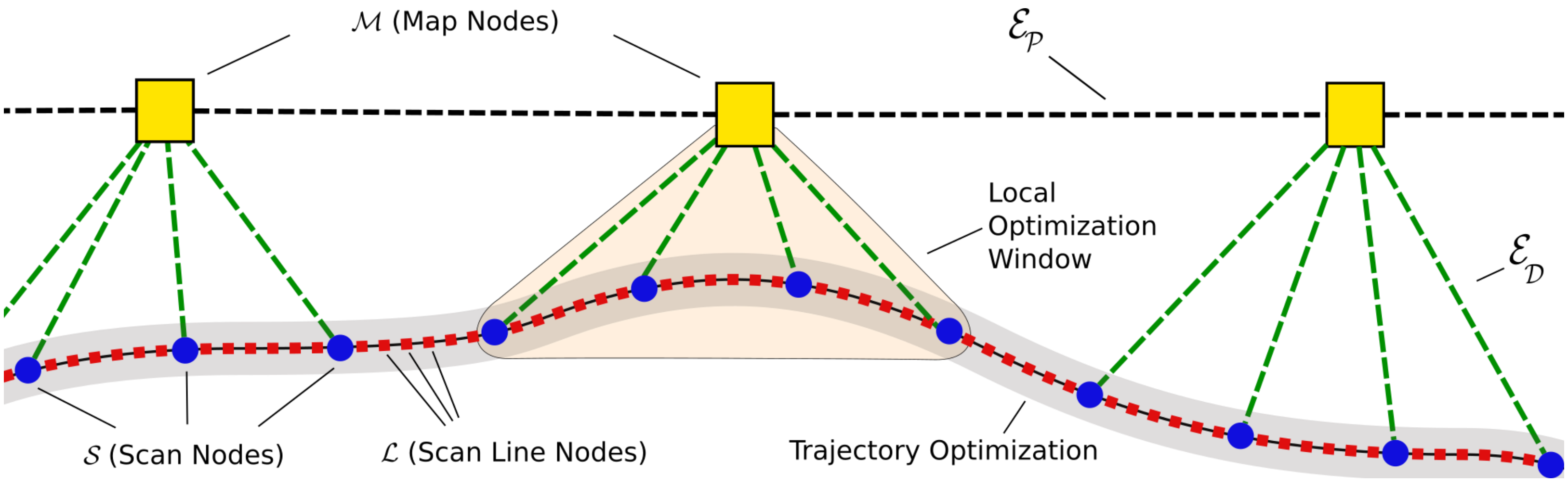
ALLOCENTRIC 3D MAPPING

- Registration of egocentric maps by graph optimization



[Droeschel et al., Robotics and Autonomous Systems 2017]

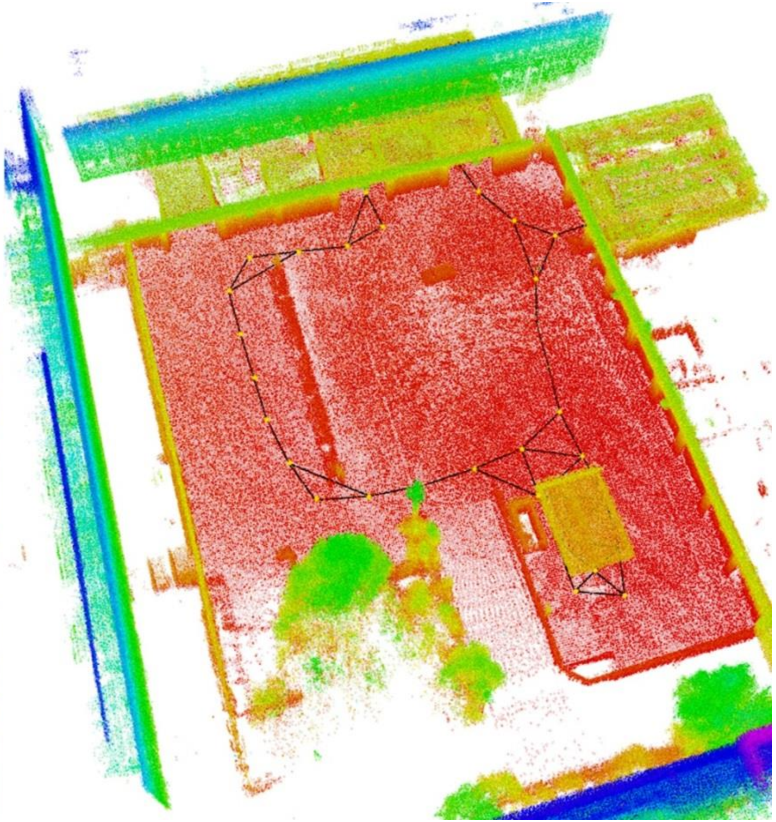
HIERARCHICAL POSE GRAPH



- Local multiresolution maps as nodes in allocentric pose graph
- Scan poses in local multiresolution map (local optimization window)
- Continuous-time trajectory between scan poses

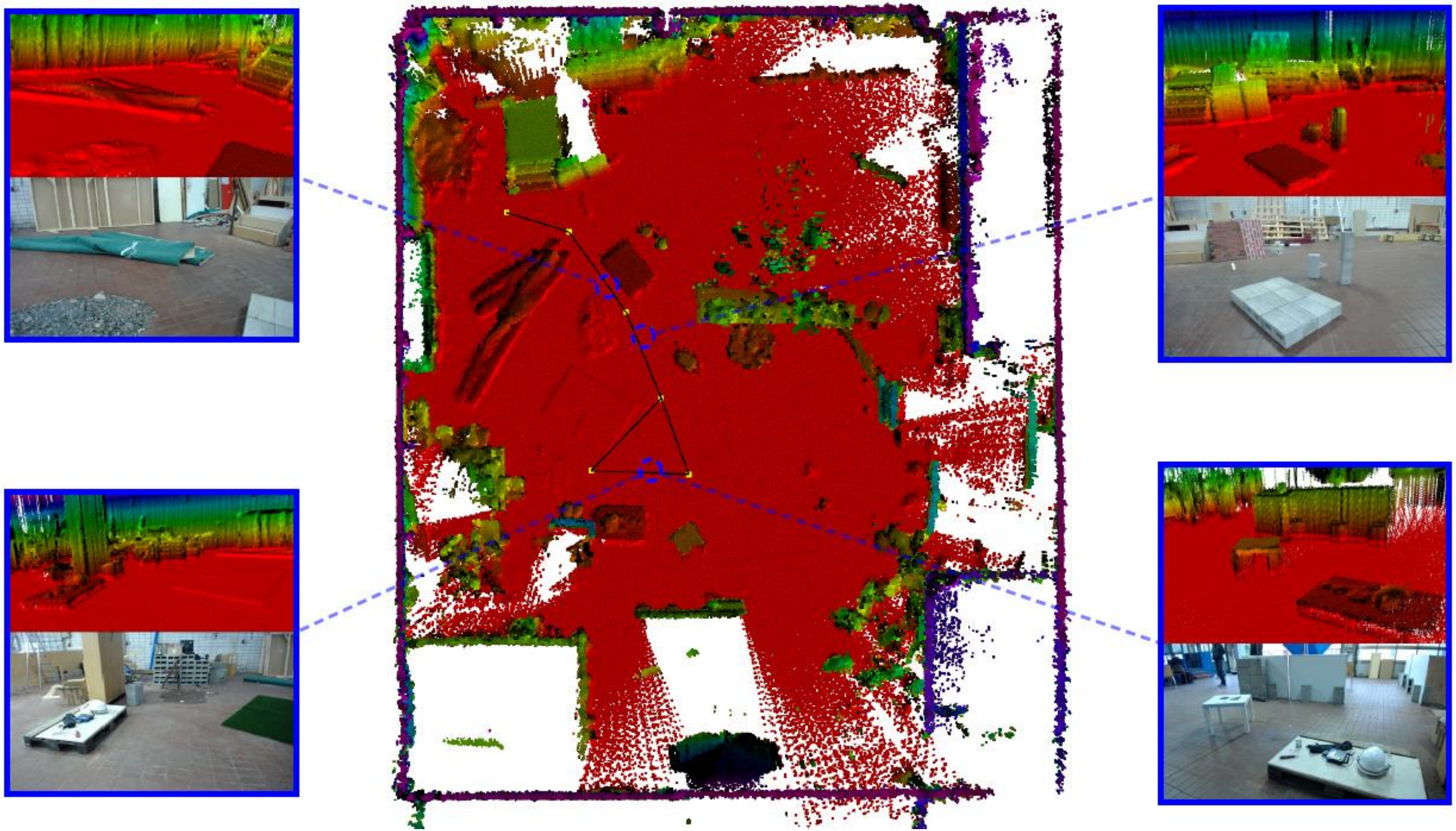
[Droeschel and Behnke, ICRA 2018]

3D MAP OF INDOOR+OUTDOOR SCENE



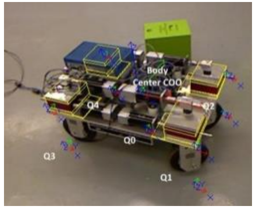
[Droeschel et al., Robotics and Autonomous Systems 2017]

3D MAP



HYBRID DRIVING-STEPPING LOCOMOTION

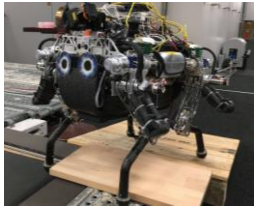
- Driving locomotion planning



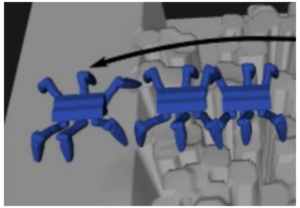
Omnidirectional
[Ziaei et al., 2014]

Actively reconfigurable
[Brunner et al., 2012]

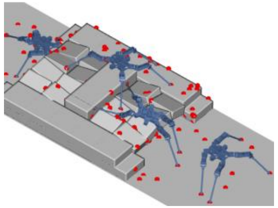
- Legged locomotion planning for challenging terrain



[Wermelinger et al., 2016]



[Perrin et al., 2016]



[Short et al., 2017]

- Hybrid driving-stepping robots

HUBO

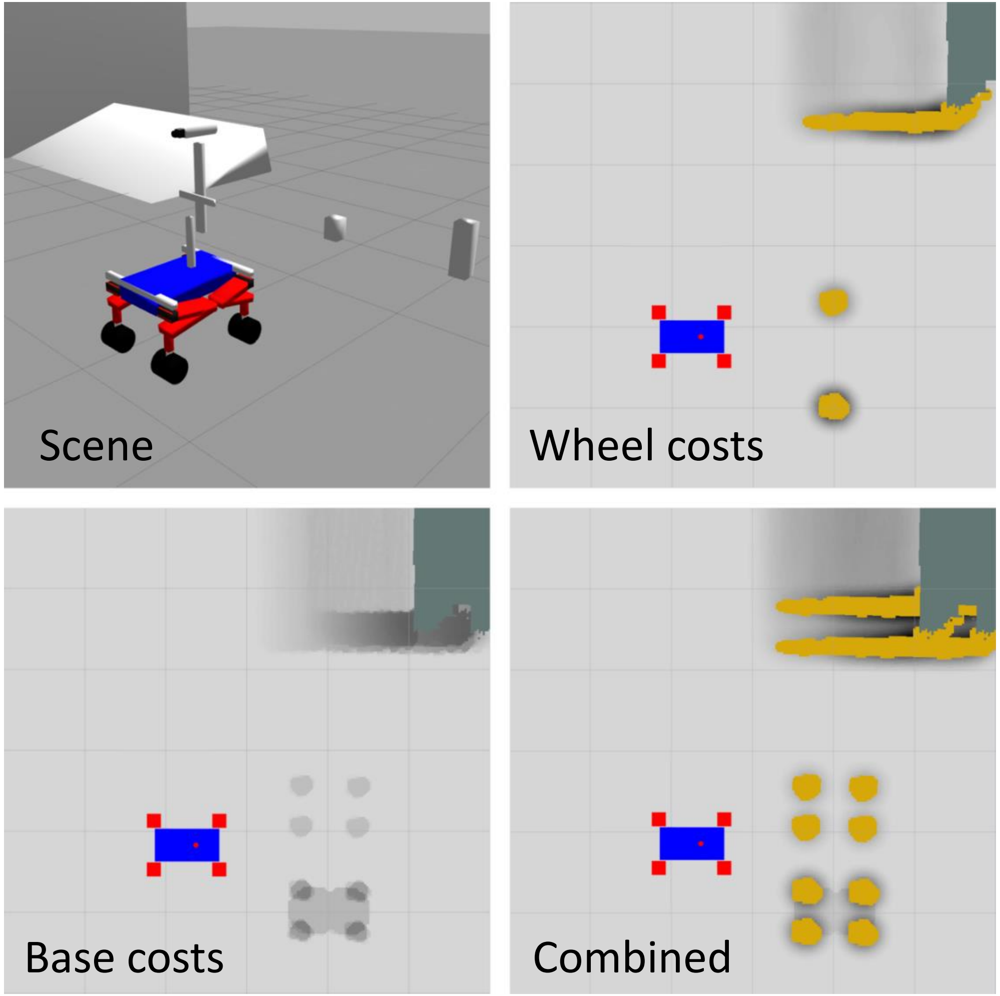
Handle

Chimp

CONSIDERING ROBOT FOOTPRINT

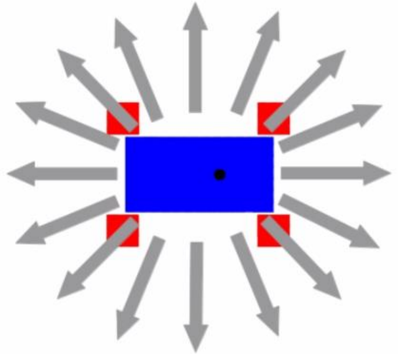
- Costs for individual wheel pairs from height differences
- Base costs
- Non-linear combination yields 3D (x, y, θ) cost map

[Klamt and Behnke, IROS 2017]

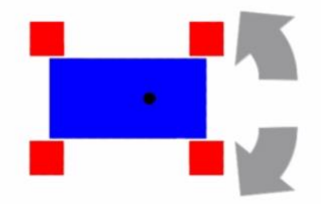


3D DRIVING PLANNING (X, Y, Θ): A*

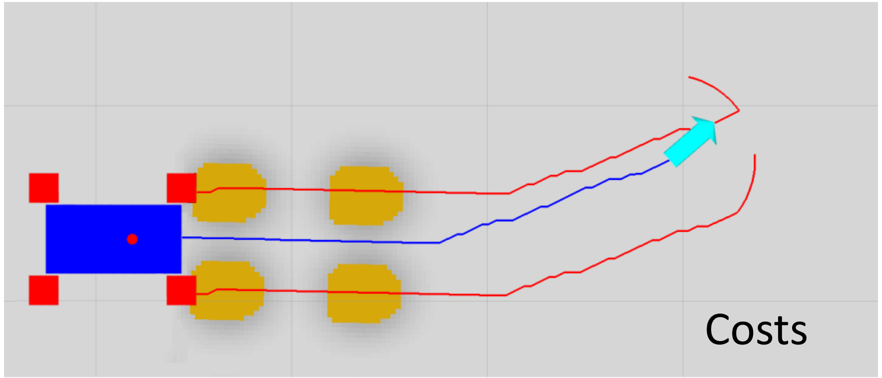
- 16 driving directions

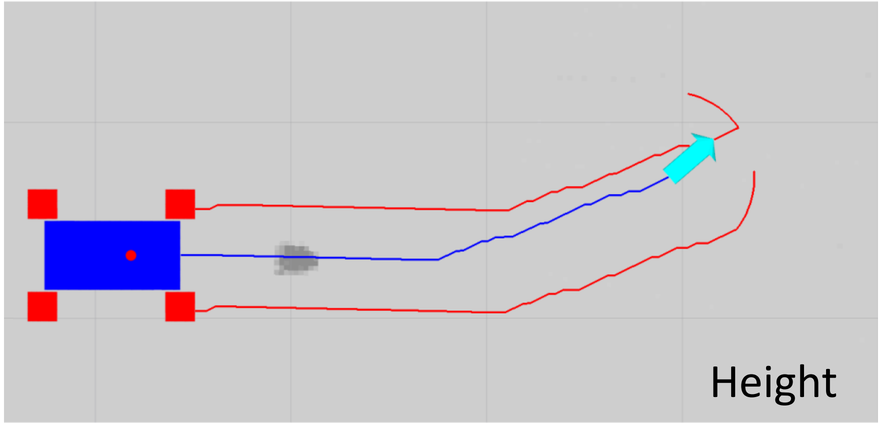


- Orientation changes



=> Obstacle between wheels

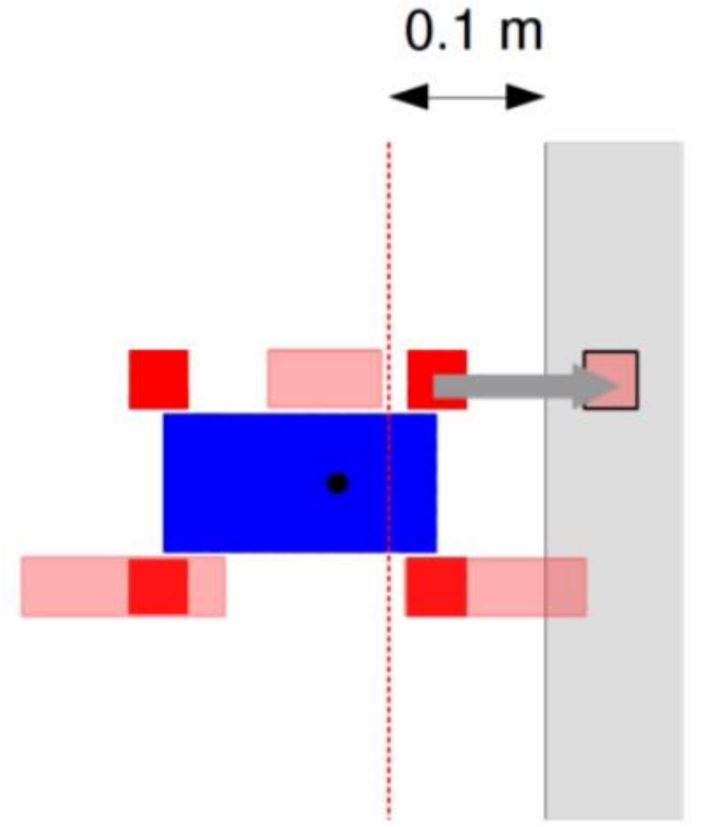




[Klamt and Behnke, IROS 2017]

MAKING STEPS

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

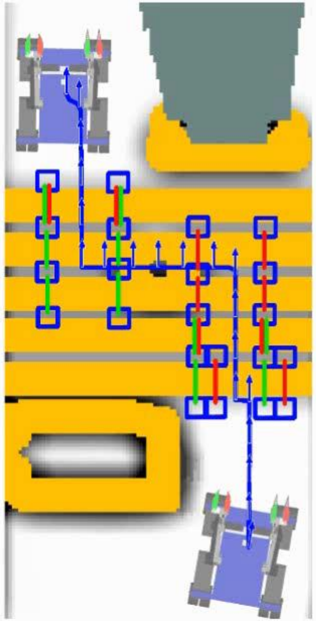


[Klamt and Behnke: IROS 2017]

Expanding Abstract Steps to Detailed Motion Sequences

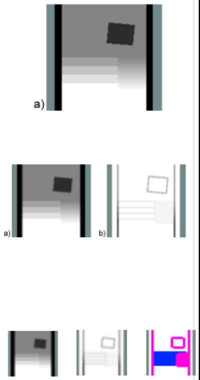
[Klamt and Behnke: IROS 2017]

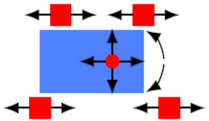
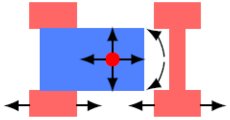
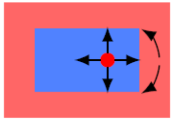
Planning for Challenging Scenarios



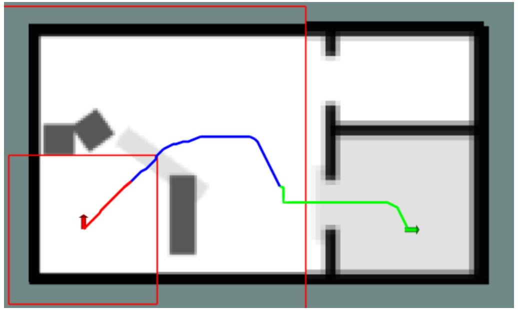
[Klamt and Behnke: IROS 2017]

PLANNING ON MULTIPLE LEVELS OF ABSTRACTION



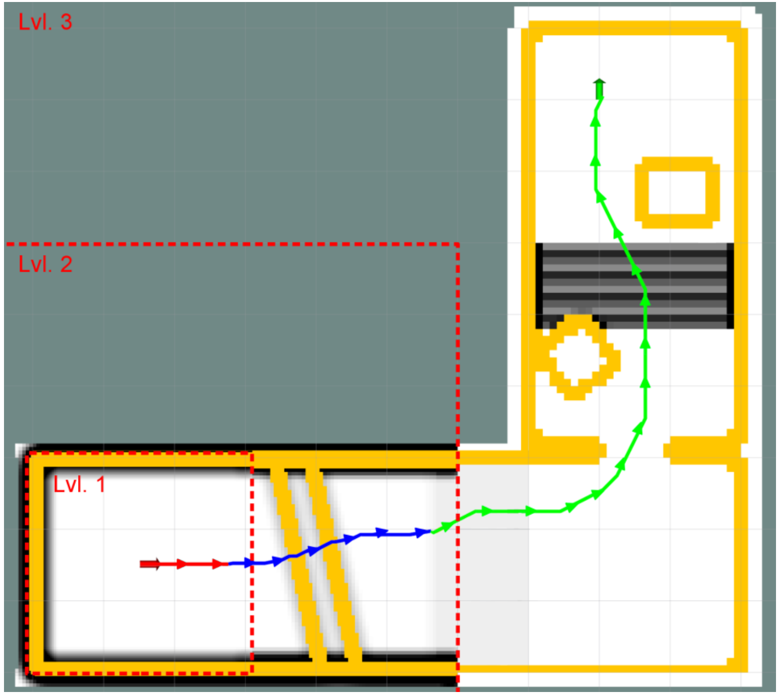
Level	Map Resolution	Map Features	Robot Representation	Action Semantics
1	• 2.5 cm • 64 orient.	• Height		• Individual Foot Actions
2	• 5.0 cm • 32 orient.	• Height • Height Difference		• Foot Pair Actions
3	• 10 cm • 16 orient.	• Height • Height Difference • Terrain Class		• Whole Robot Actions

- Combine planning with multiresolution and multiple robot representation dimensions
- Compensate information loss in coarser representations through additional semantics
- Combine all three levels in one planner

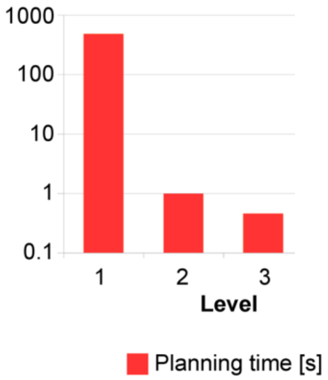


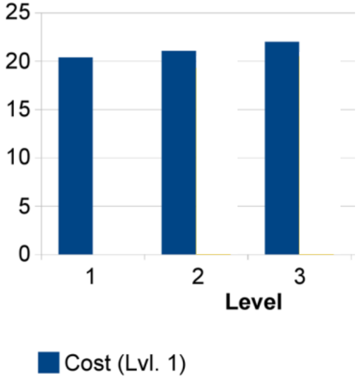
[Klamt and Behnke, ICRA 2018]

PLANNING EXPERIMENTS



Foot costs and result paths in different levels of representation

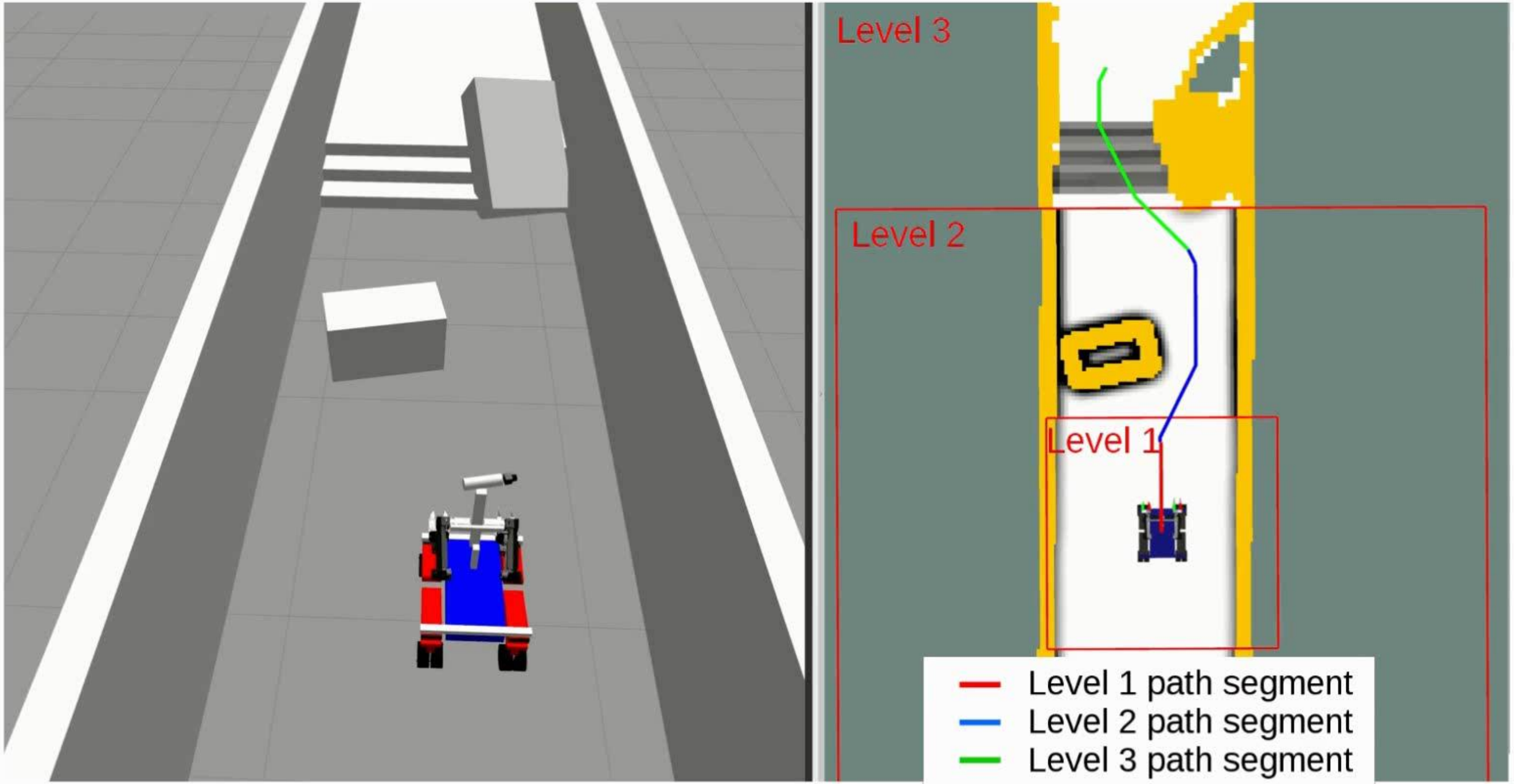




- Abstraction to higher levels significantly accelerates planning.
- Path quality is good in all levels.
- Planning on combined levels provides high quality paths in feasible time.

[Klamt and Behnke, ICRA 2018]

Experiment: Planning on Combined Levels of Representation



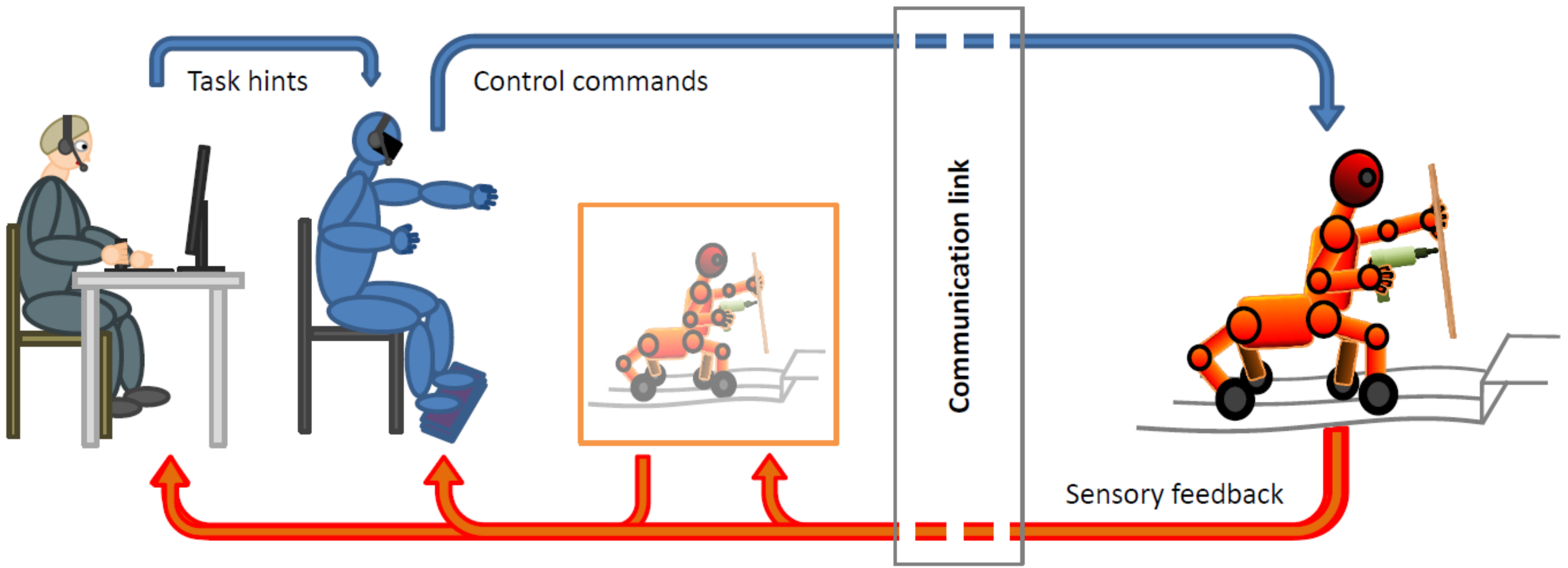
[Klamt and Behnke, ICRA 2018]

H2020 RIA CENTAURO

ROBUST MOBILITY AND DEXTEROUS MANIPULATION IN DISASTER RESPONSE BY FULLBODY TELEPRESENCE IN A CENTAUR-LIKE ROBOT

universitätbonn ISTITUTO ITALIANO DI TECNOLOGIA Scuola Superiore Sant'Anna di Studi Universitari e di Perfezionamento KTH ROYAL INSTITUTE OF TECHNOLOGY LINKÖPINGS UNIVERSITET RWTH AACHEN UNIVERSITY progenox KHG universitätbonn ais

CENTAURO APPROACH



Support operator

Main operator with HMD and exoskeleton

3D model of robot and environment

Centauro robot performing disaster-response tasks

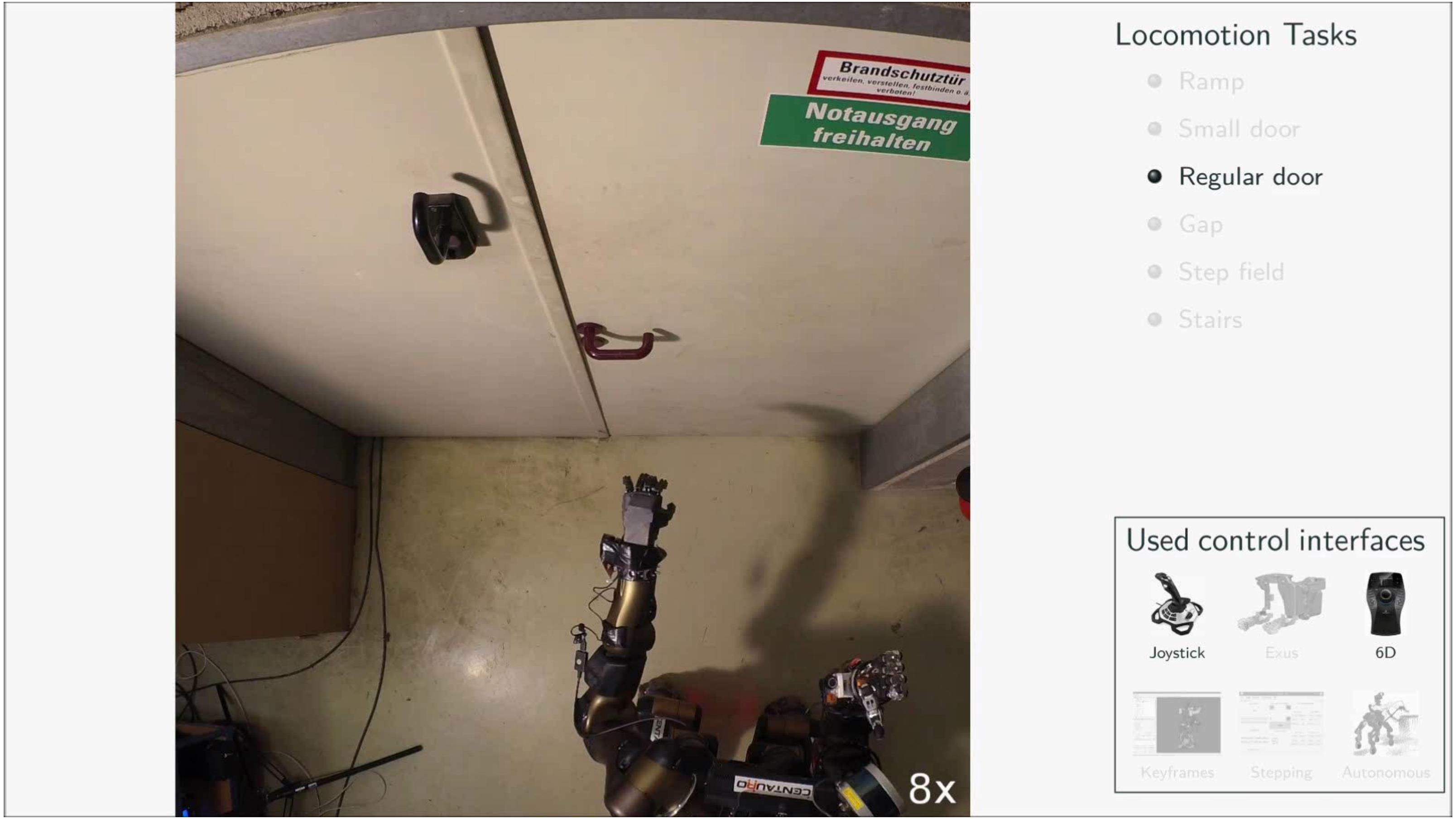
1ST CENTAURO ROBOT

CENTAURO

- Serial elastic actuators
- 42 main DoFs
- Schunk hand
- 3D laser
- RGB-D camera
- Color cameras
- Two GPU PCs

[Tsagarakis et al., IIT 2017]

OPENING AND GOING THROUGH A DOOR



CLIMBING OVER A GAP

WALKING OVER A STEP FIELD

CONCLUSIONS

- Hybrid driving-stepping locomotion combines advantages of wheels and legs
  - Omnidirectional driving on flat terrain
  - Overcoming height differences
- Two demonstrators: Momaro and Centauro
- 3D environment mapping
- Efficient coarse-to-fine locomotion planning
- Demonstrated a variety of locomotion tasks
- Valuable insights for further development
- Plan to demonstrate integrated missions

CENTAURO TEAM