Hybrid Wheeled-Legged Locomotion in Semi-Structured Environments

Sven Behnke

Autonomous Intelligent Systems

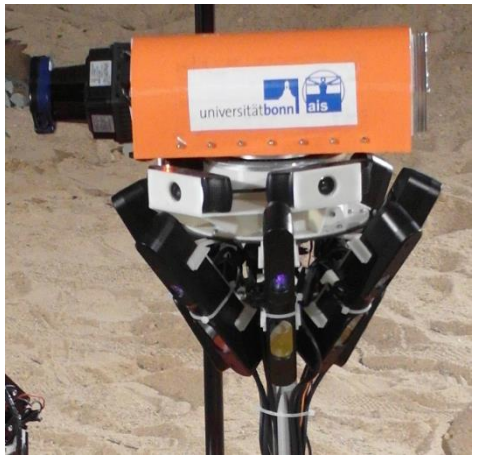
Mobile Manipulation Robot Momaro

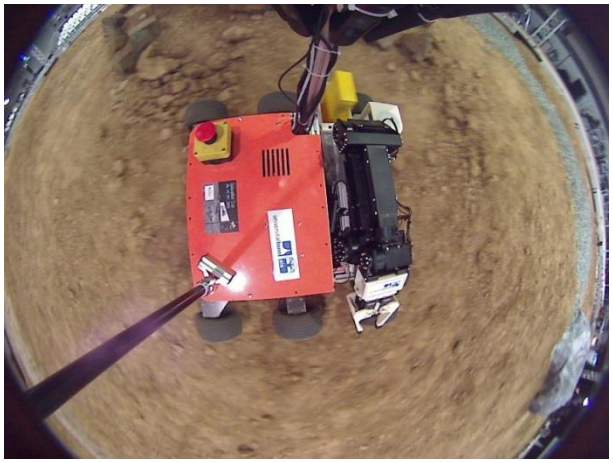
- Four legs ending in pairs of steerable wheels
- Anthropomorphic upper body
  - 7 DoF arms
  - Four-finger grippers
- Sensor head
  - 3D laser scanner
  - 8 RGB-D cameras
  - Panoramic cameras
  - Wide-angle camera
- Strong CPU (i7Quad 4 GHz)

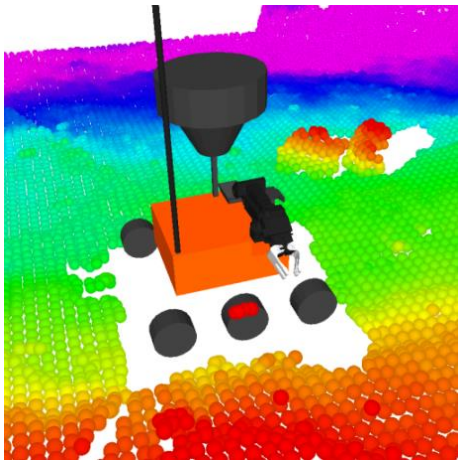
[Schwarz & Behnke, LBR, ICRA 2015; Rodehutskors et. al., Humanoids 2015]

Local Navigation Planning

- Local terrain model from omnidirectional RGB-D



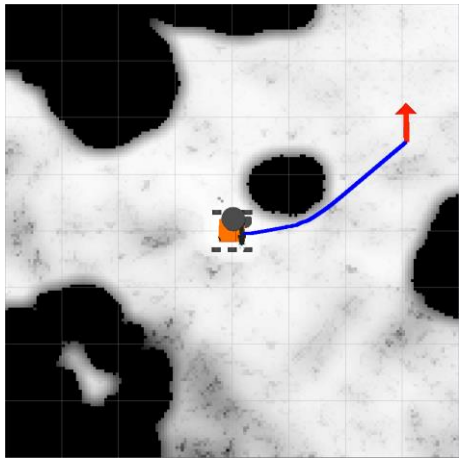


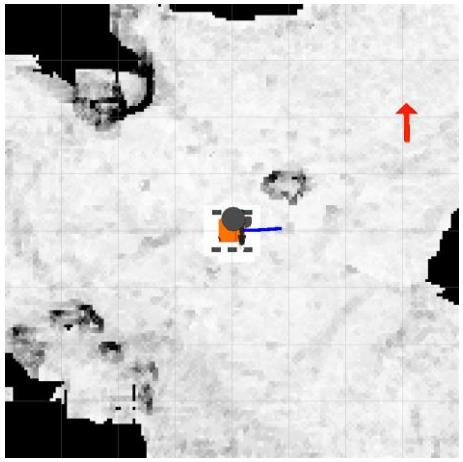


- Cell costs and planned path

[Schwarz, Behnke, Robotik 2014]

A*

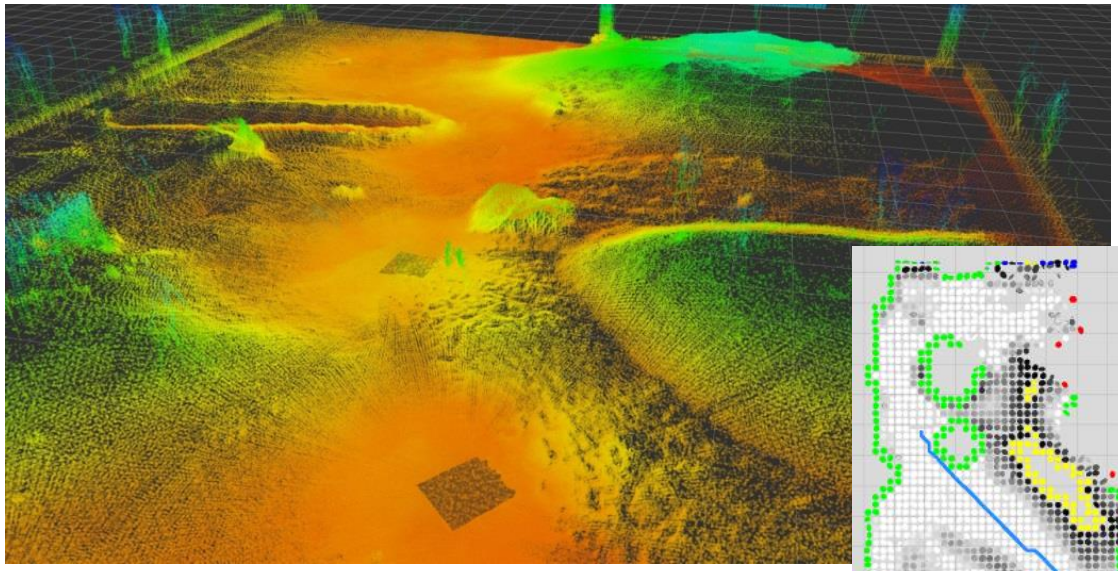




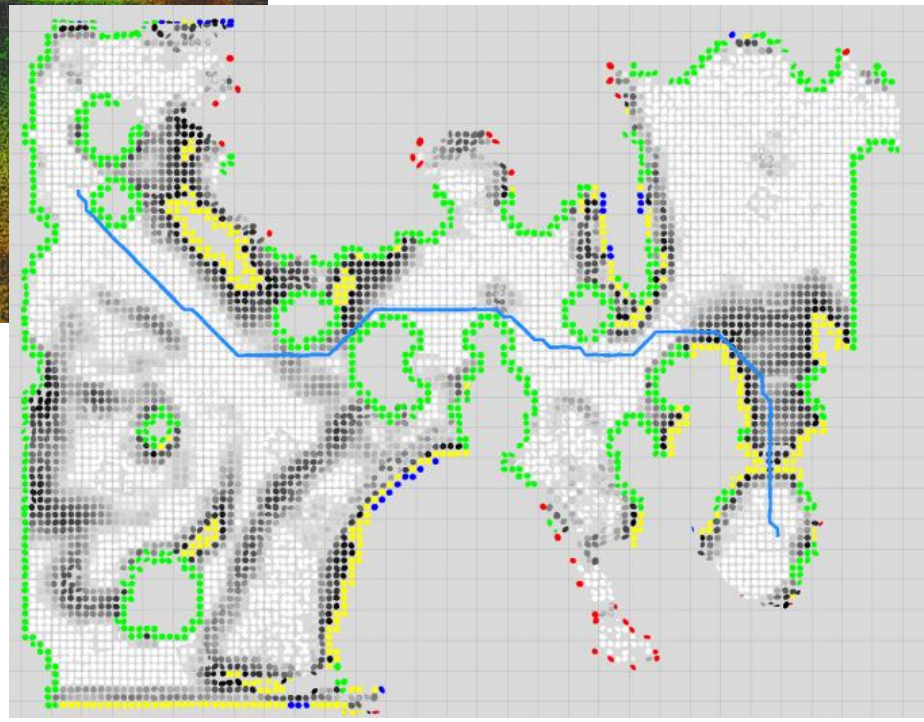
Rollout

Allocentric Path Planning

- 3D map from registered 3D laser scans



[Stückler et al. JFR 2015]



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

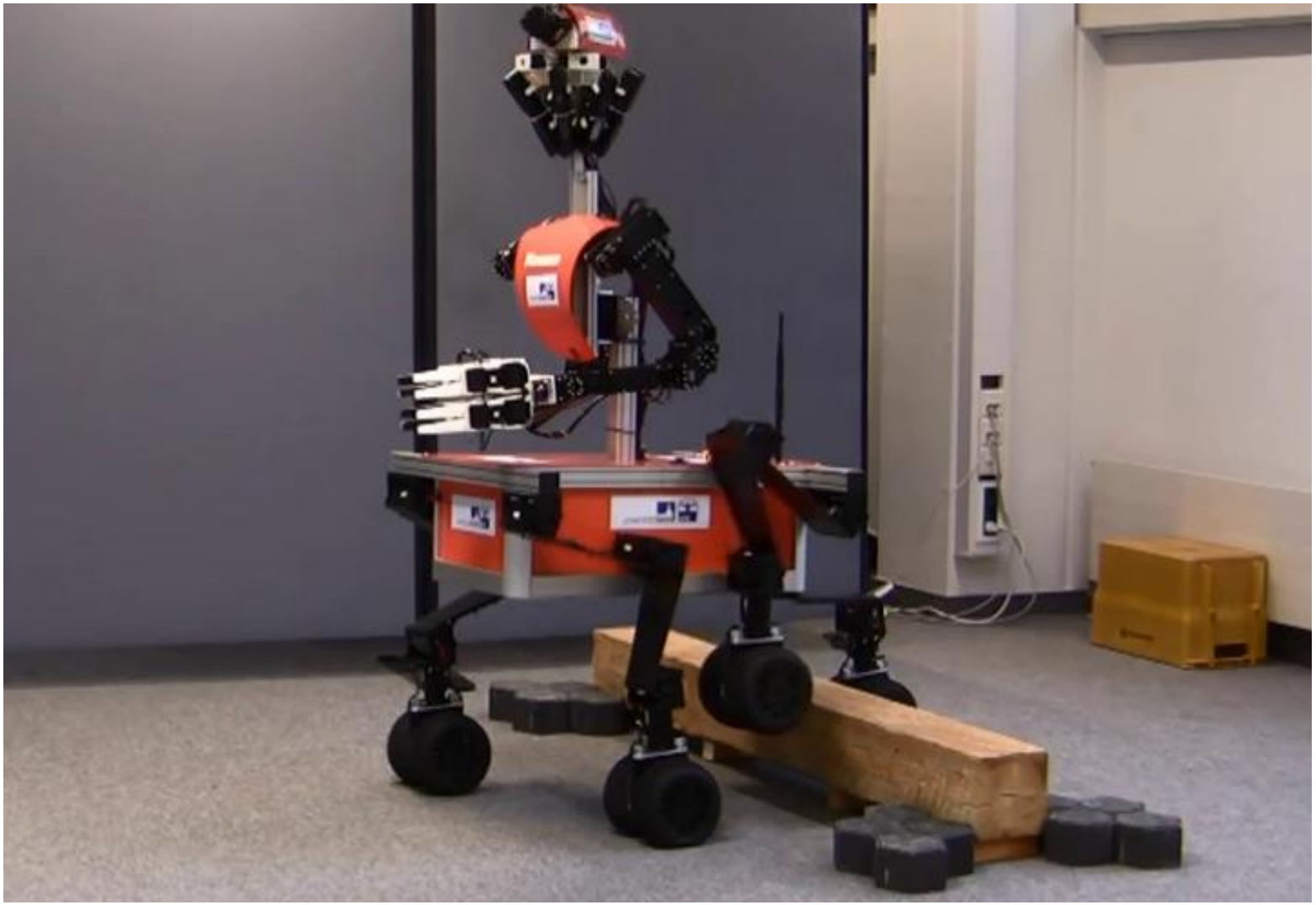
Momaro Leg Design

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

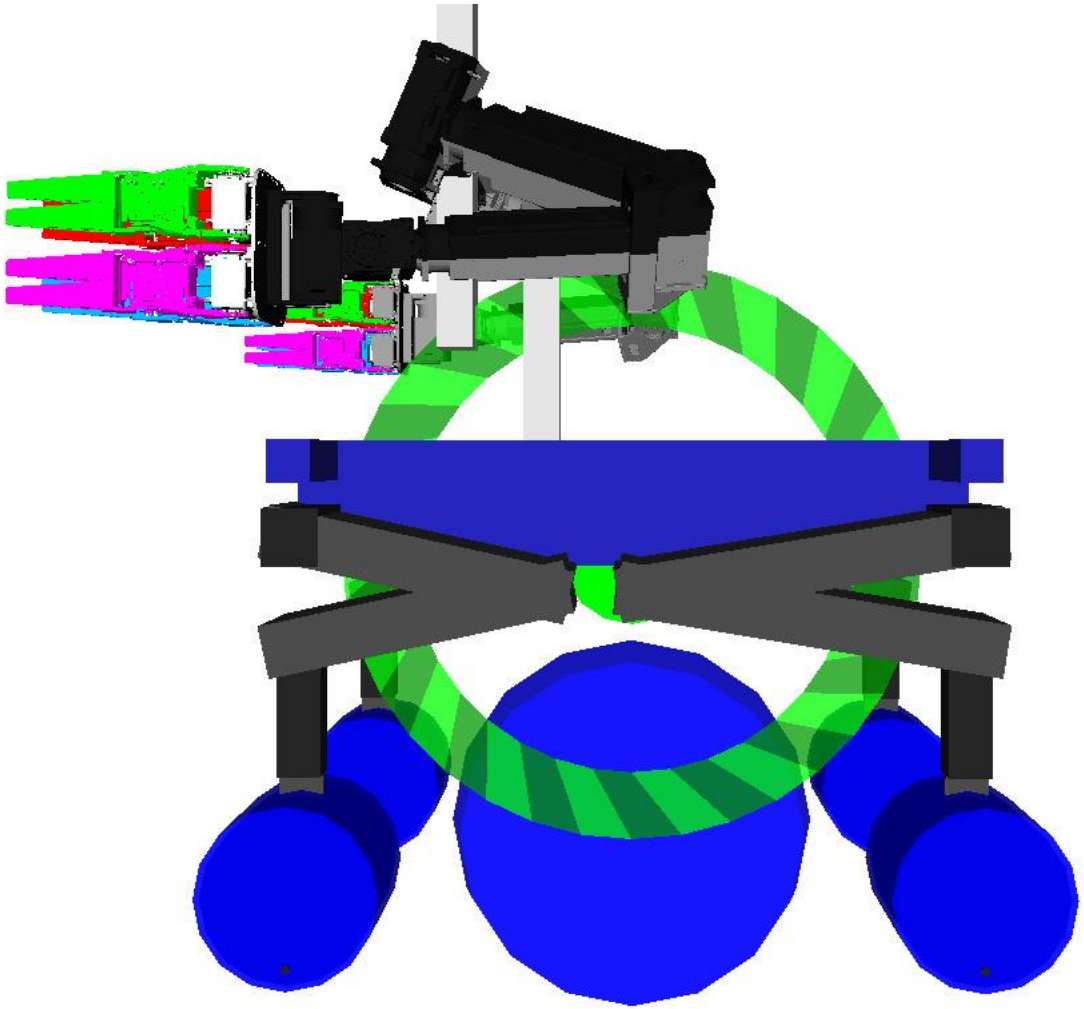
Getting Up from the Floor

Omnidirectional Driving

Climbing over an Obstacle

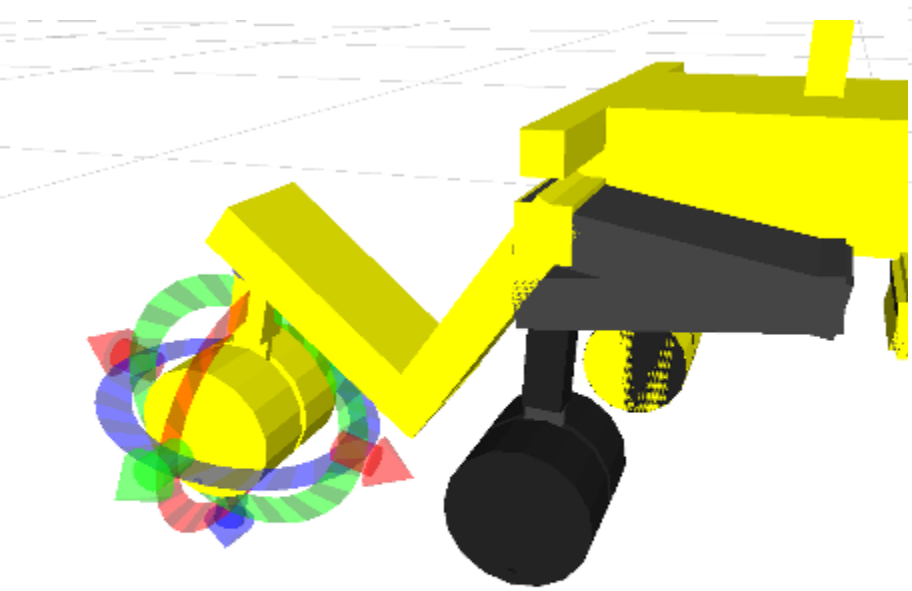


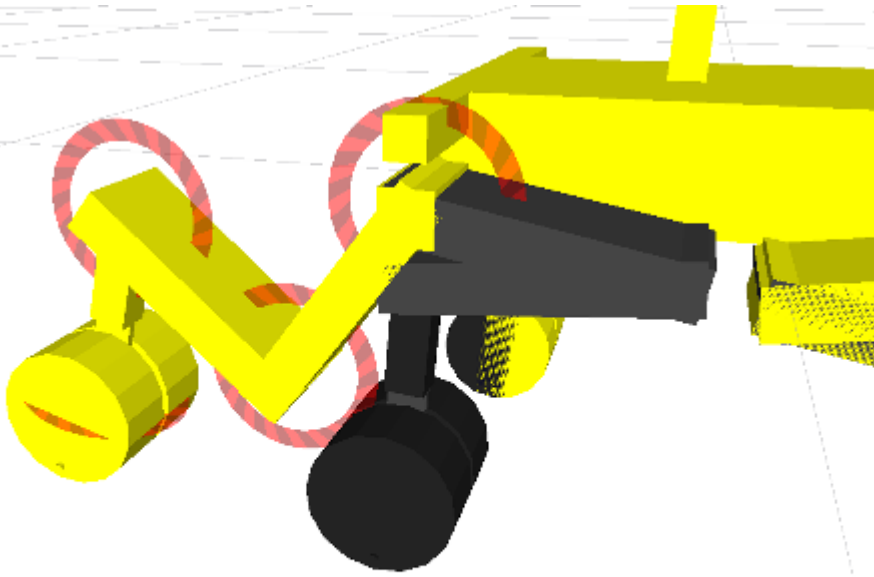
User Interface for Footprint and Attitude Control



User Interface for Keyframes

- Cartesian
- Joint space





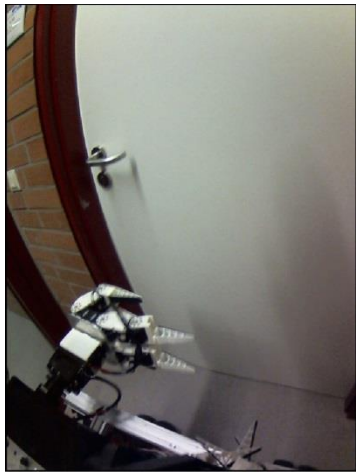
DARPA Robotics Challenge

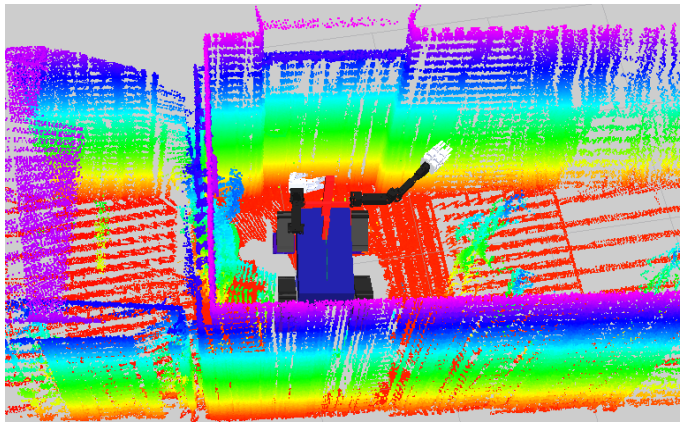
Climbing out of the Car

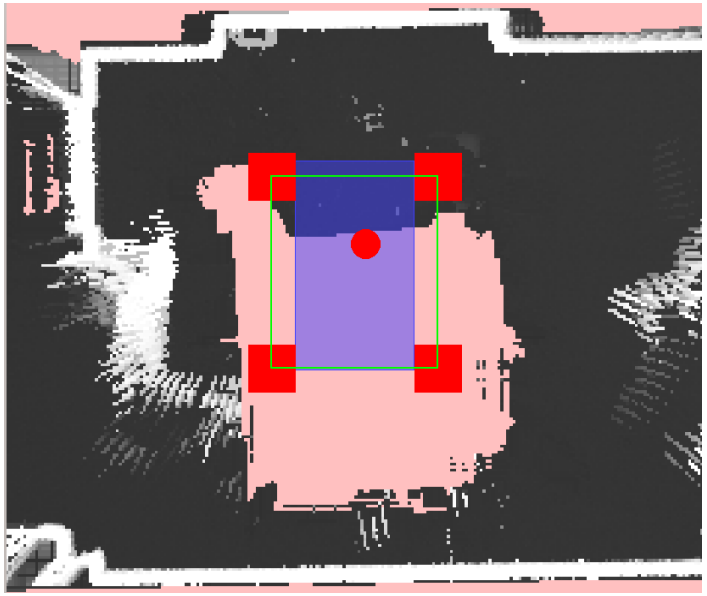
Traversing Debris

Door Opening

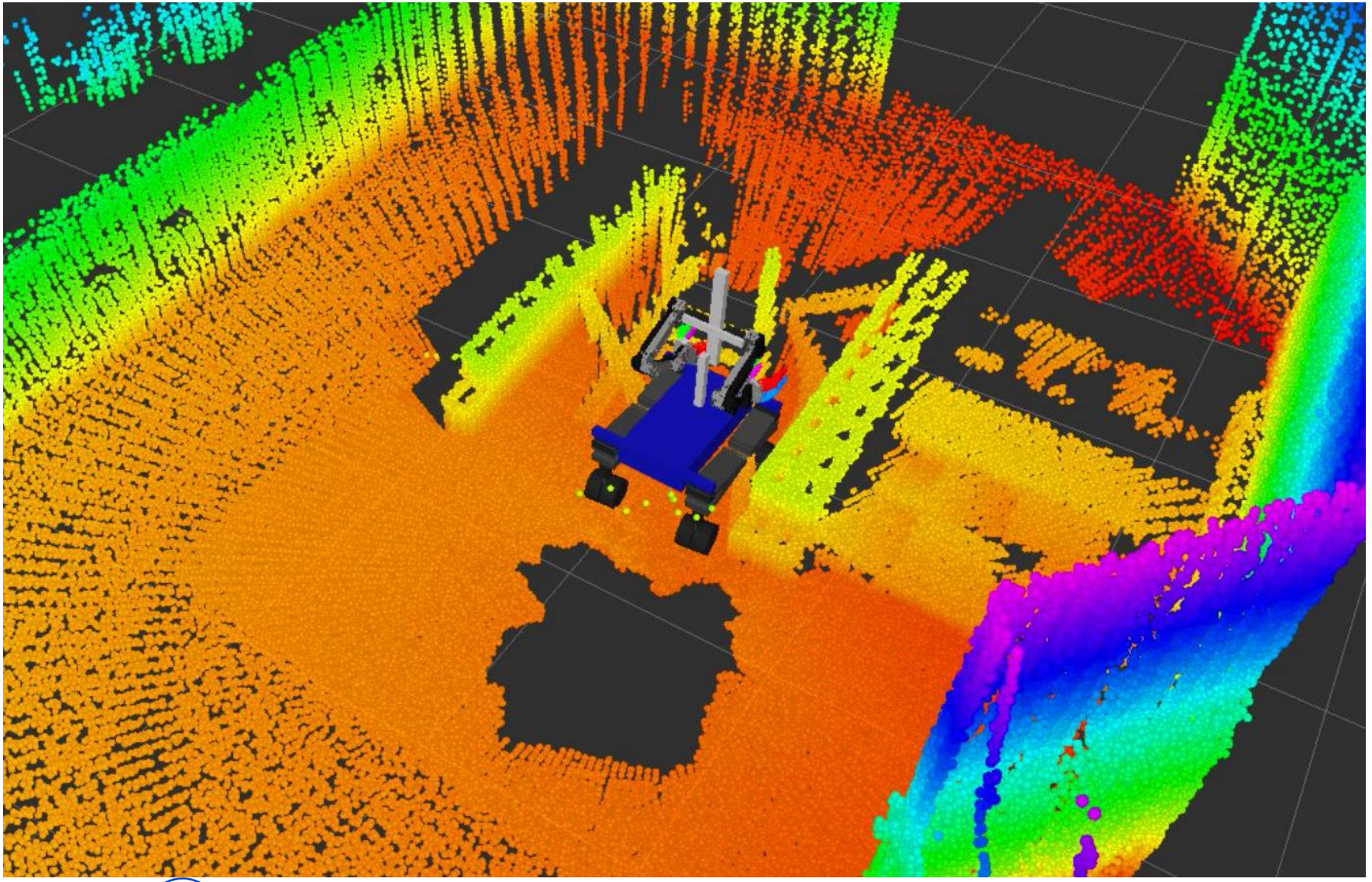
- Camera image
- 3D laser scan
- Omnidirectional height map





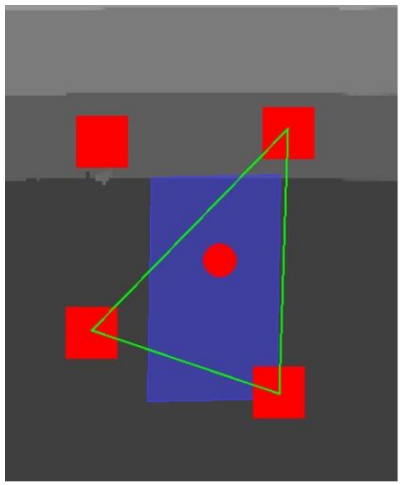
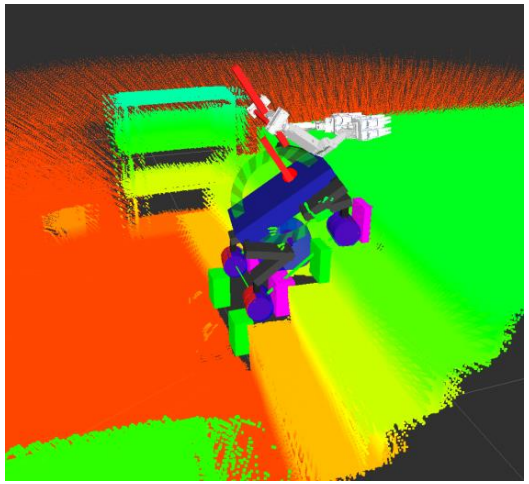
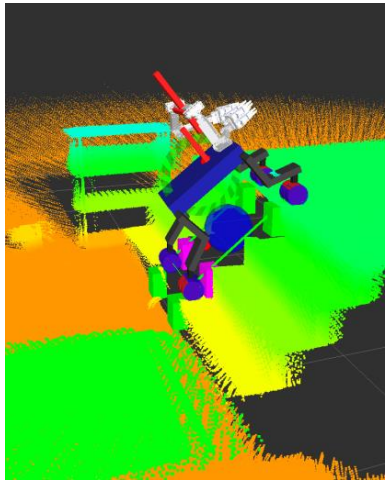
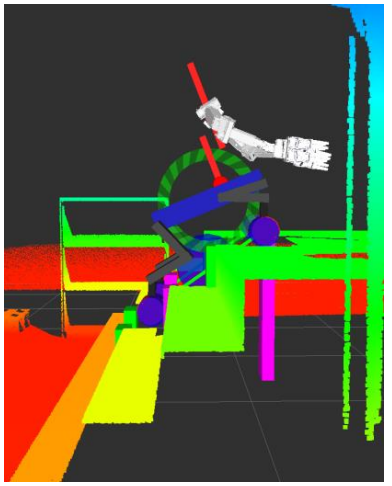


Debris



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

Faster Stair Climbing

DLR SpaceBot Cup Qualification

Conclusions

- Compliant wheeled-legged base
- Large adjustable support polygon
- Steerable wheels allow for omnidirectional driving
- Legs support terrain adaptation, weight shifts, and making steps when necessary
- Demonstrated mobile manipulation tasks
- Future work will focus on more autonomous functions

Team NimbRo Rescue @ DRC

http://www.nimbro.net/Rescue