DRC Team NimbRo Rescue: Flexible Driving-Stepping Locomotion and Human-like Manipulation with Mobile Manipulation Robot Momaro

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Autonomous Intelligent Systems

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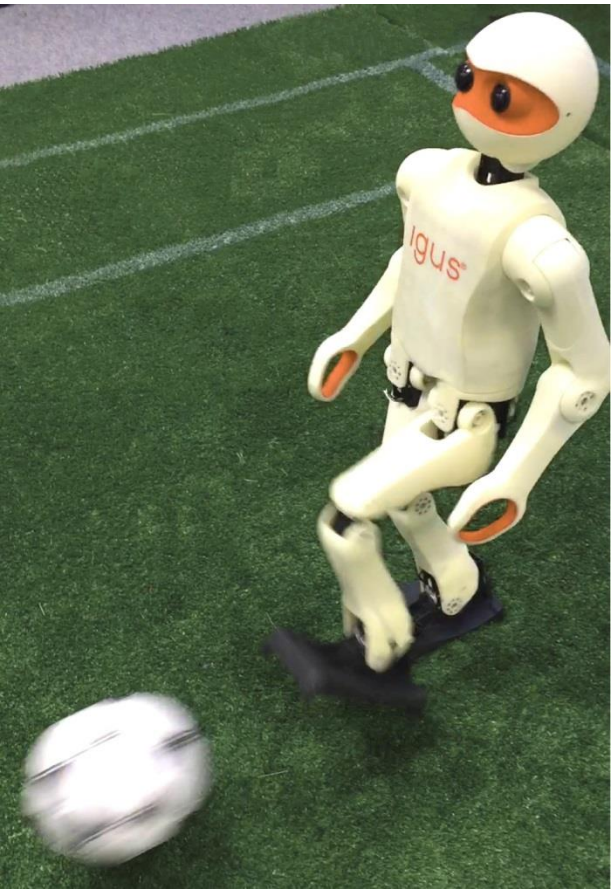
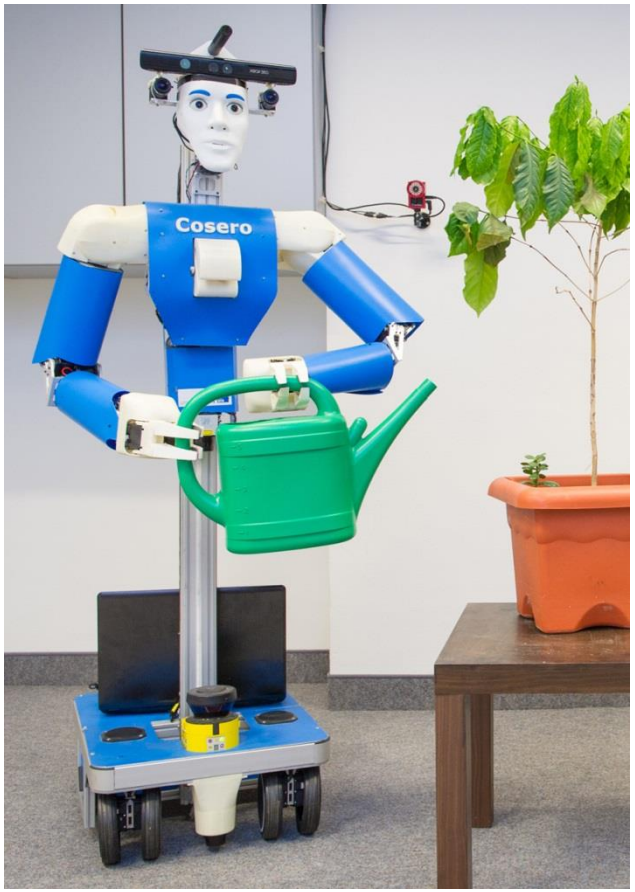
Our Previous Work

- Robots for playing soccer, domestic service tasks and mobile manipulation in rough terrain





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
  - 3 Panoramic cameras
  - Wide-angle camera
- Strong CPU (i7Quad 4 GHz)

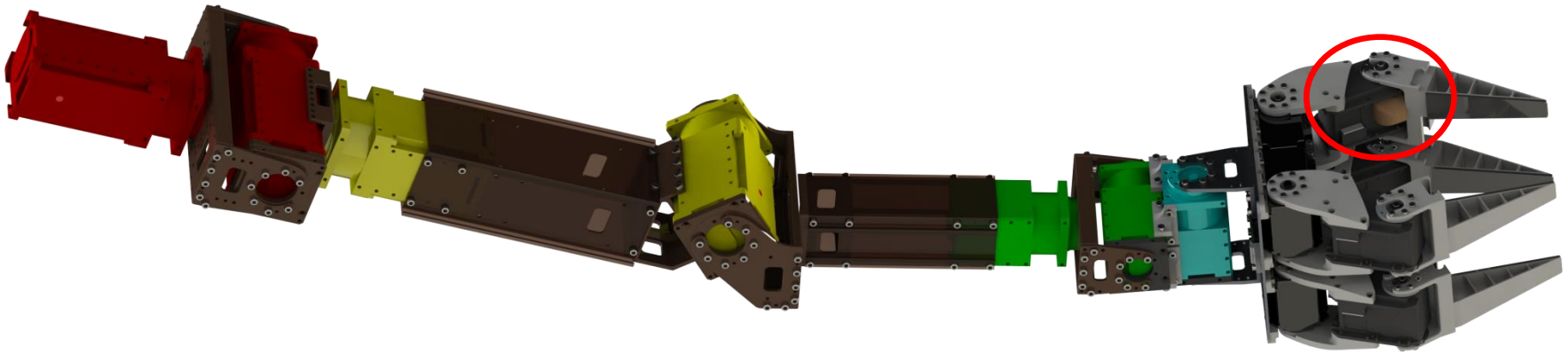
[Schwarz & Behnke, LBR, ICRA 2015; Rodehutskors et. al., Humanoids 2015]

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

Momaro Arm Design

- Seven Robotis Dynamixel Pro actuators
  - Shoulder roll & pitch 2x 44.2 Nm, yaw 25 Nm
  - Elbow 24.8 Nm
  - Wrist roll & pitch 6.3 Nm, yaw 1.4 Nm



- Four fingers with two Dynamixel actuators
  - Proximal 8.4 Nm, distal 6.0 Nm
  - Bump for pushing tool trigger

Getting Up from the Floor

Omnidirectional Driving

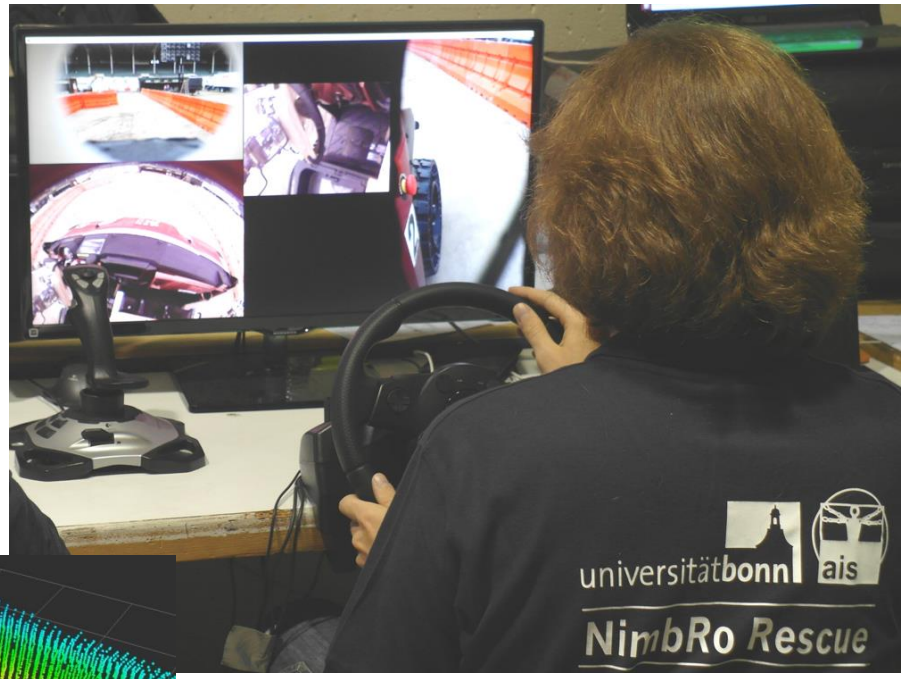
Climbing over an Obstacle

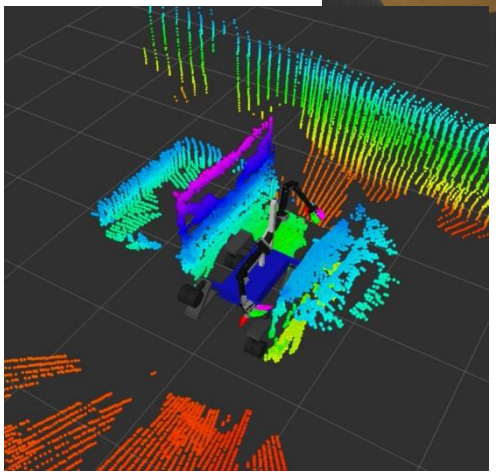
DRC Modifications

- Longer hind legs
- Lower computer box
- IMU in sensor head
- Removed RGB-D cameras

Car Driving Operator Interface

- Steering wheel and gas pedal directly mapped to car controls



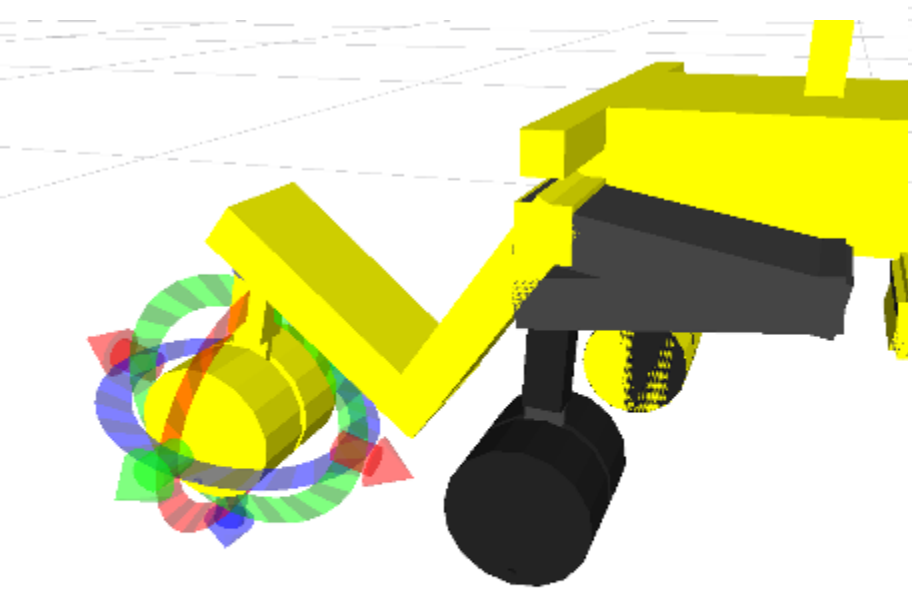


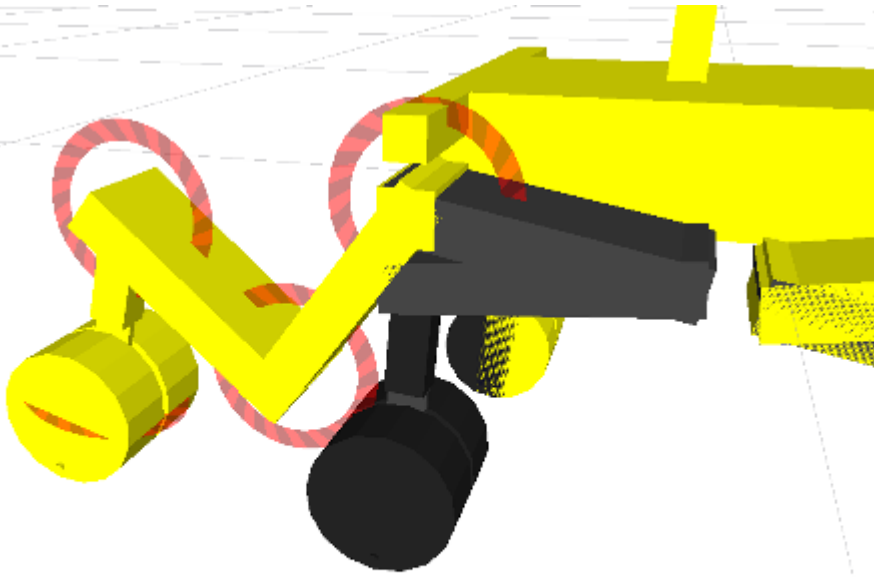
- Good situation awareness through cameras and 3D laser scanner

Car Driving at DRC

User Interface for Keyframes

- Cartesian
- Joint space

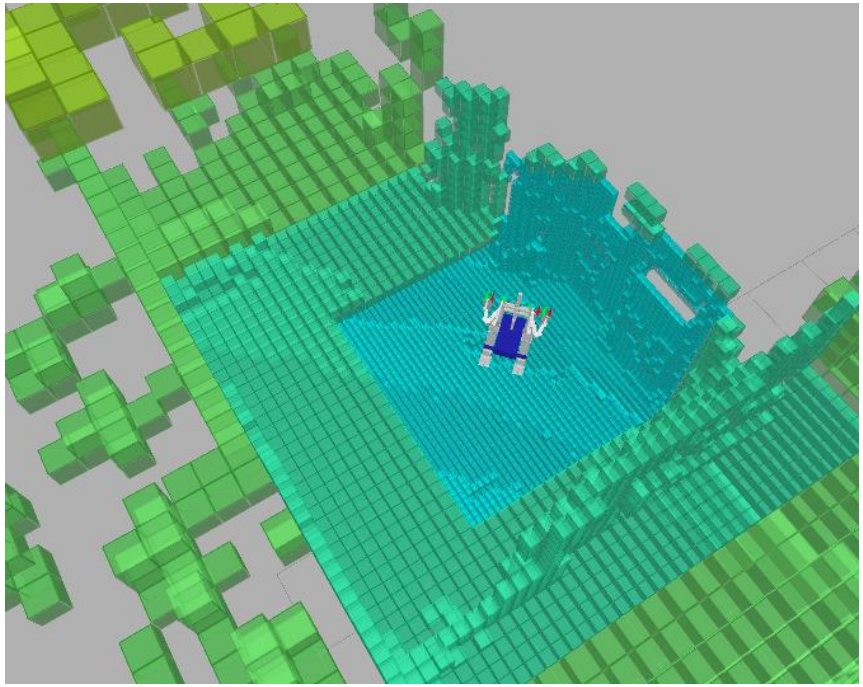


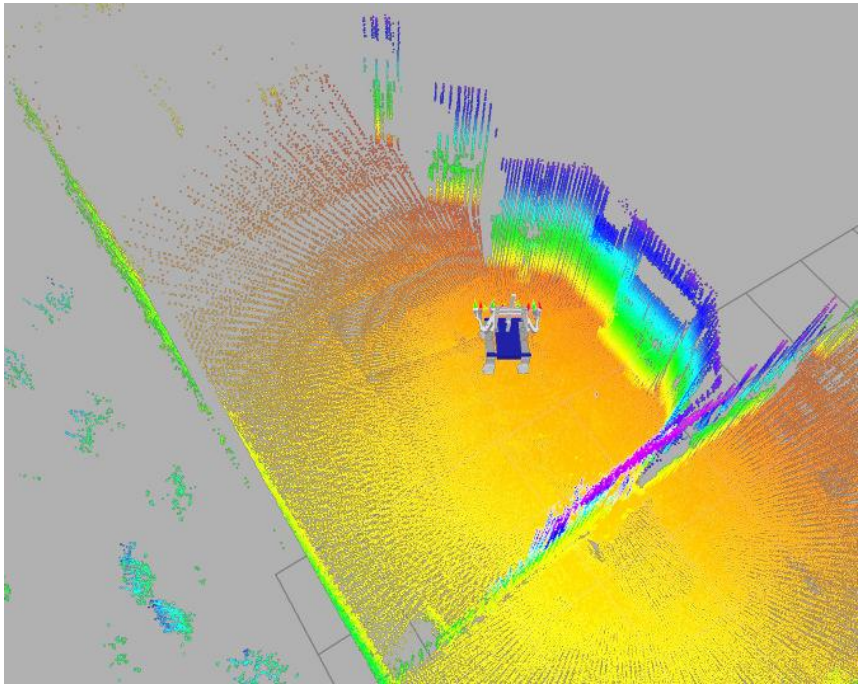


Egress the Car at DRC

3D Environment SLAM

- Compensate for sensor motion to assemble 3D scans
- Register and aggregate scans to local multiresolution surfel maps, localize in these

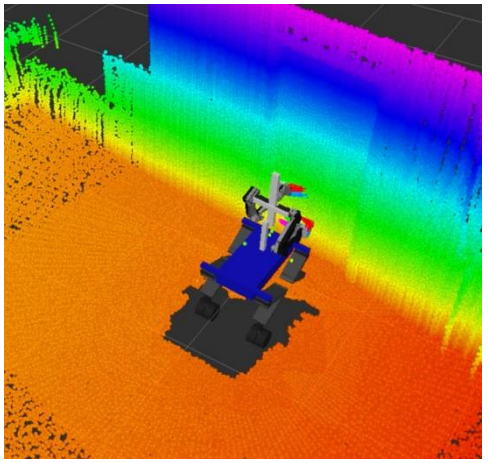




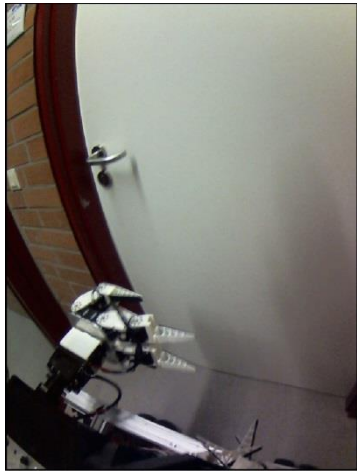
[Droeschel et al., ICRA 2014, IAS 2014]

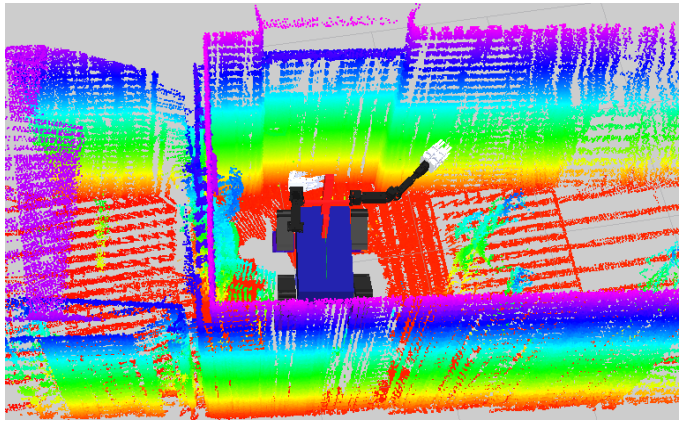
Door Opening

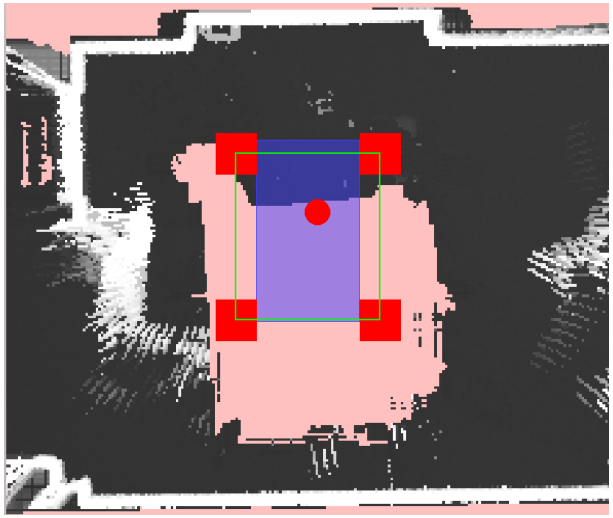
- Camera image
- 3D laser scan



- Omnidirectional height map

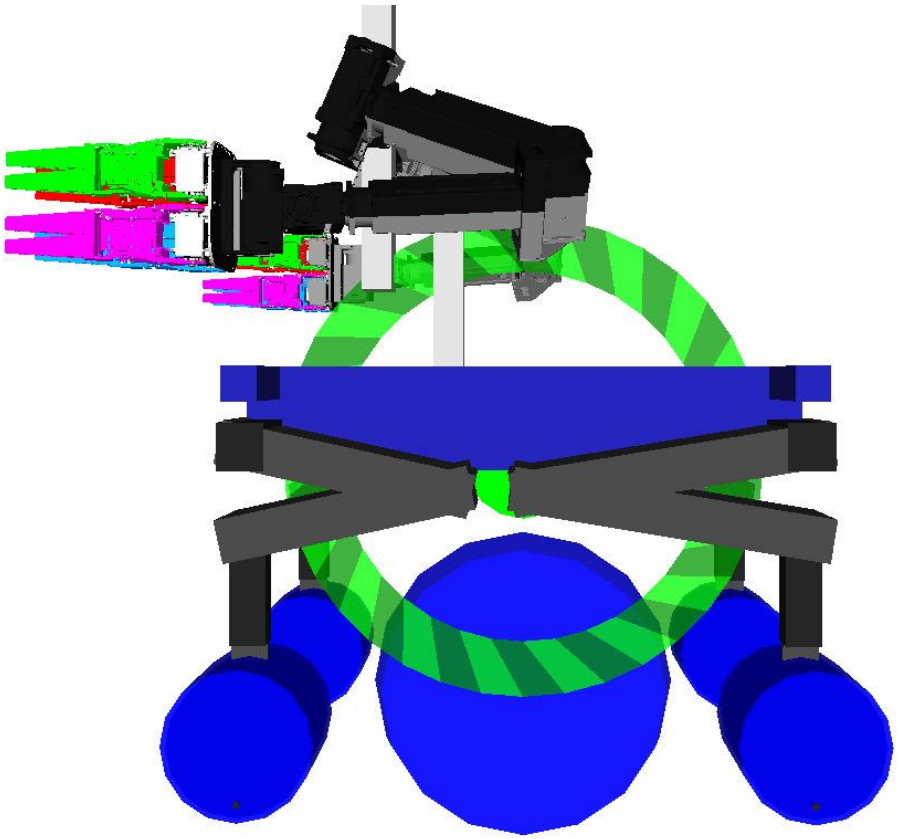






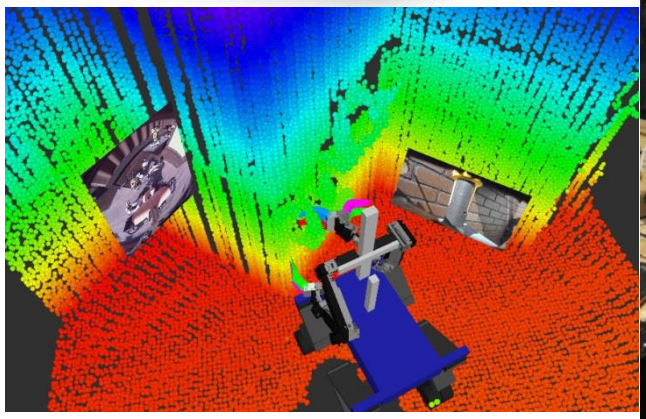
User Interface for Footprint and Attitude Control

- Foot positions
- CoM
- Height
- Attitude



Manipulation Operator Interface

- 3D head-mounted display
- 3D environment model + images
- 6D magnetic tracker

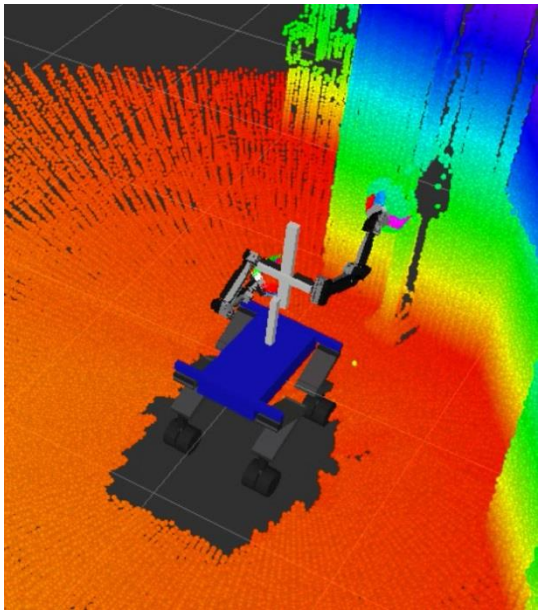


[Rodehutskors et al., Humanoids 2015]

Door Opening at DRC

Valve Turning Interface

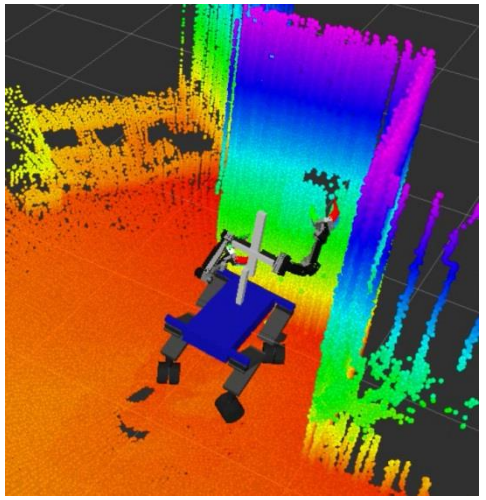
- Align wheel model with 3D points using interactive marker
- Turning motion primitive

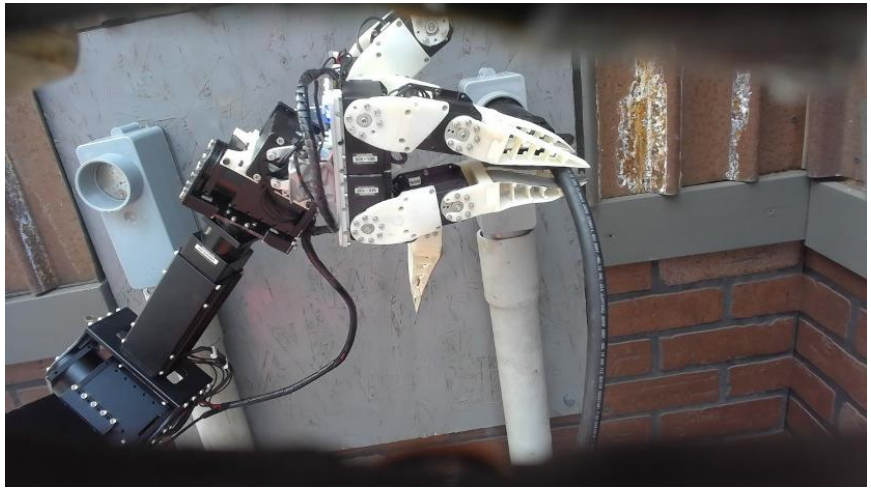


Valve Turning at DRC

Surprise Tasks

- Direct control of manipulation
- Open a cabinet and push a button
- Operate an electric switch
- Pull a plug and insert it into another socket

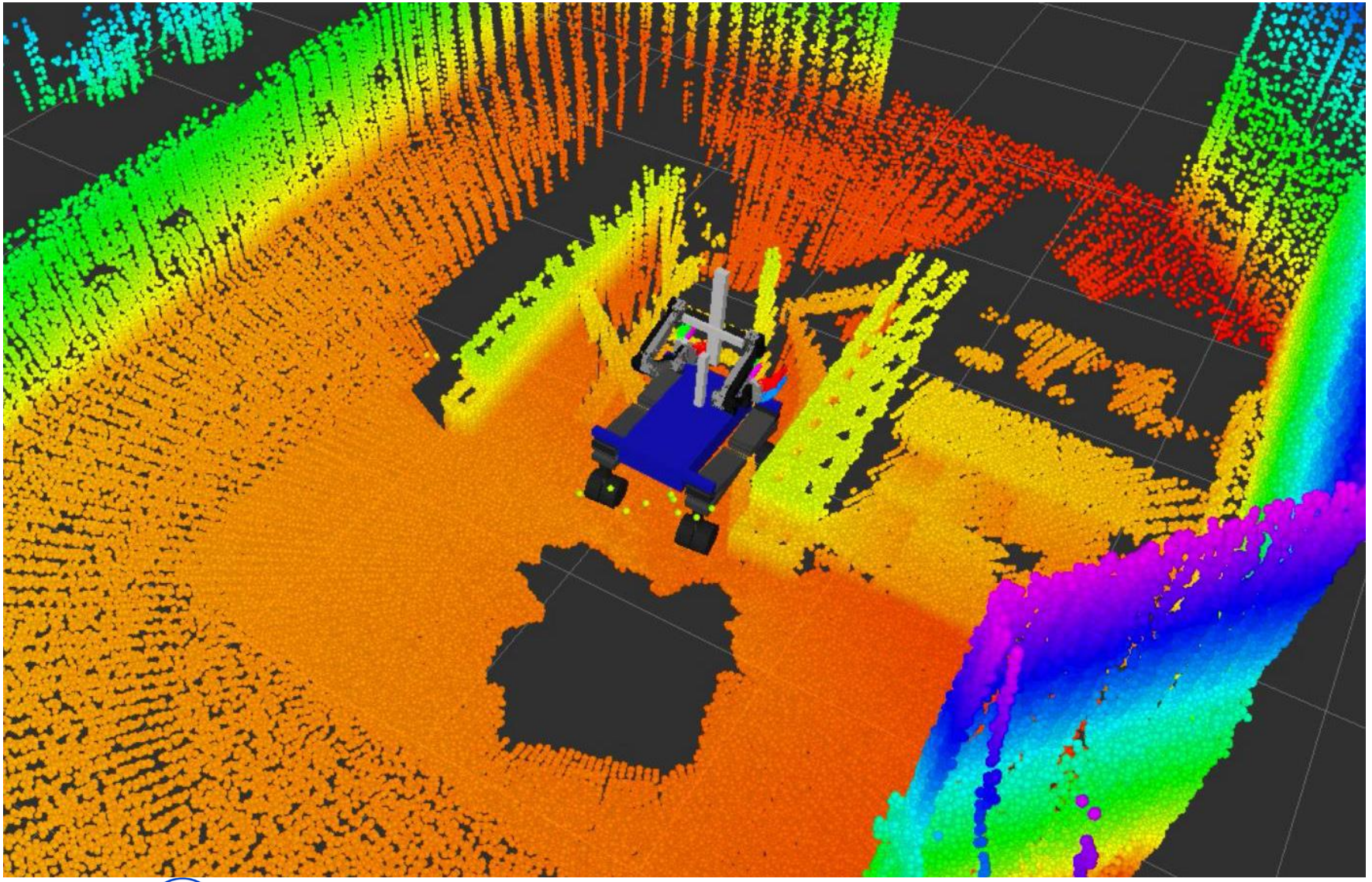




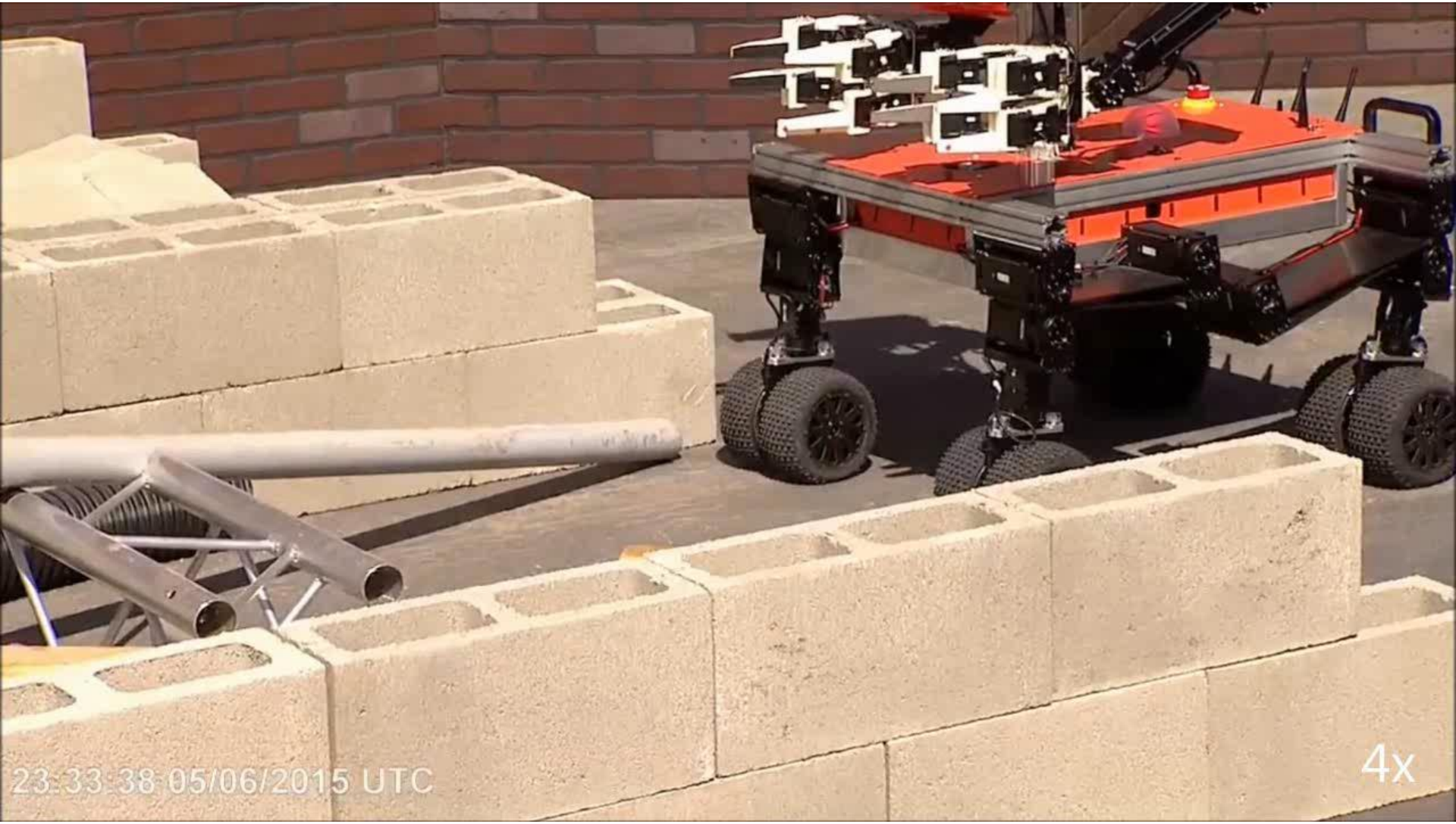
Operating a Switch at DRC

Plug Task at DRC

Debris Task

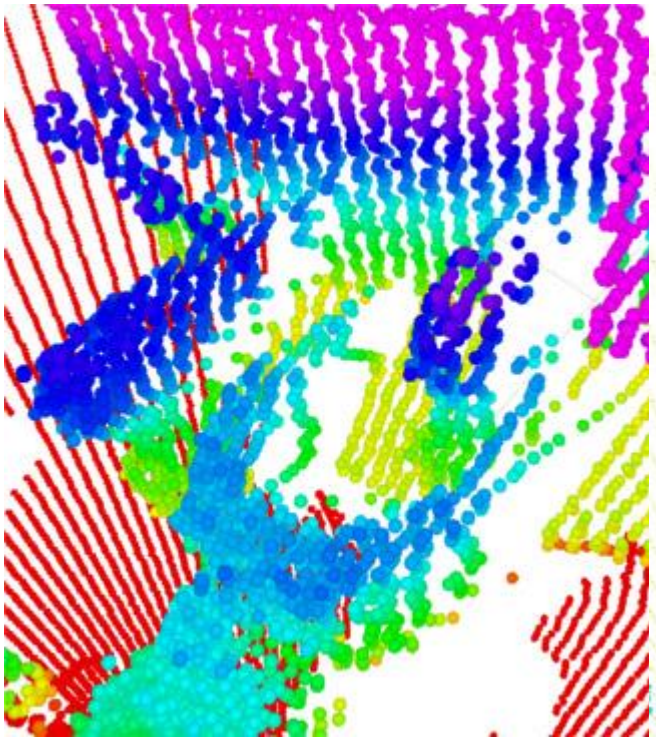


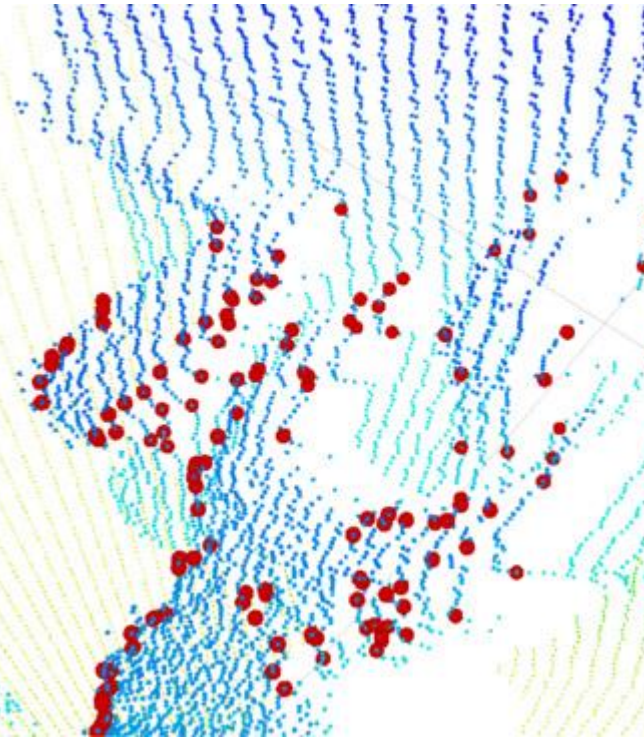
Traversing Debris at DRC



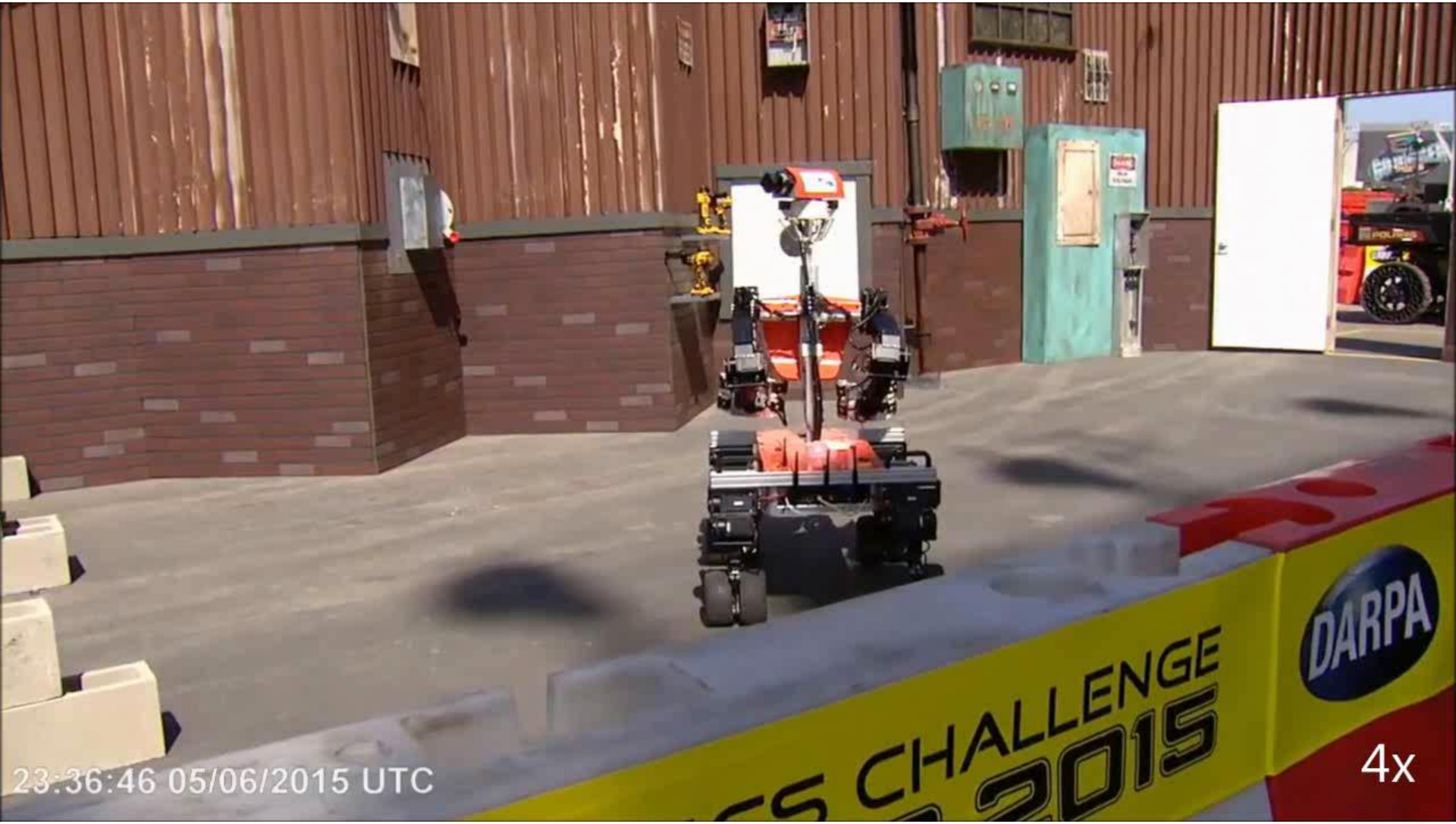
Low-bandwidth Feedback

- Compressed image stream
- Edge points in 3D laser scans
- Joint angles, IMU, temperature, audio level, …





Cutting Drywall at DRC

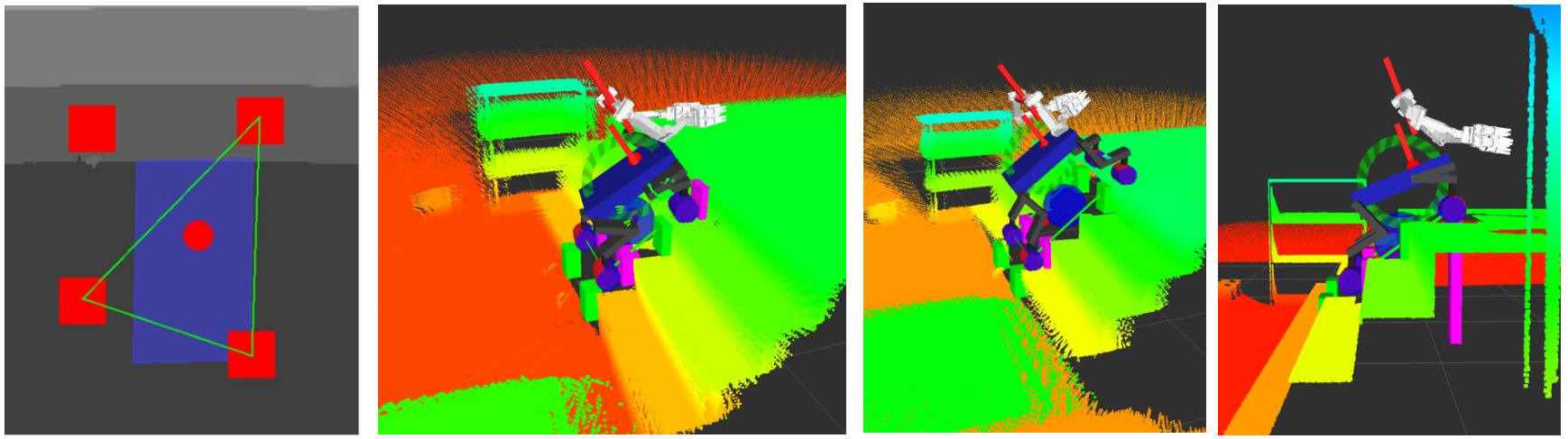


Team NimbRo Rescue

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
  - 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

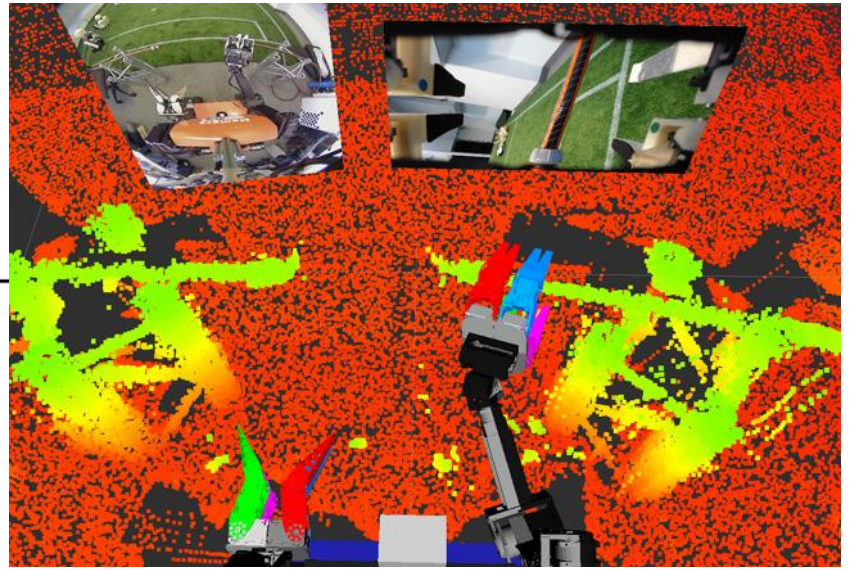


[Schwarz & Behnke, LBR, ICRA 2015]

Faster Stair Climbing

Hose Connecting Task

- Bimanual task
  - Grab the left hose with the left gripper,
  - Grab the right hose with the right gripper, and
  - Connect both hoses
- 10/11 trials successful
- Execution time



Task	Time [min:s]				
	Avg.	Median	Min.	Max.	Std. Dev.
Left grasp	0:44	0:38	0:27	1:20	0:16
Right grasp	0:45	0:40	0:34	1:04	0:10
Connect	1:36	1:32	1:07	2:04	0:21
Total	3:04	2:57	2:21	3:51	0:28

[Rodehutskors et al., Humanoids 2015]

DLR SpaceBot Cup Qualification

Conclusions

- Compliant wheeled-legged base allows for flexible locomotion using omnidirectional driving, terrain adaptation, and making steps when necessary
- Anthropomorphic upper body with large workspace and flexible grippers
- Rich sensors for environment perception
- Intuitive teleoperation interfaces
- Solved seven of eight tasks in 34 minutes
- Future work: More autonomous functions

Team NimbRo Rescue @ DRC

http://www.nimbro.net/Rescue