

Advancing Robotics Research through Robot Competitions and Challenges

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Autonomous Intelligent Systems



Issues of Robotic Performance Evaluation

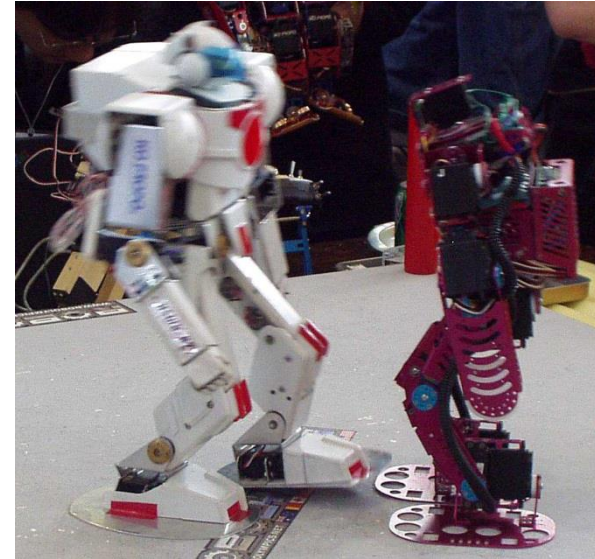
- **Benchmarking** robotics research inherently **difficult**
- Often, results reported only for a specific robotic system and a **self-chosen task**, solved in **own lab**
- Impossible to **compare** results
- Commonly used "**proof by video**" has same difficulties as "**proof by example**"



[Boston Dynamics: Handle]

Robot Competitions and Challenges

- Bring together researchers, students, and enthusiasts in the pursuit of a technological challenge
- Popular competitions include
 - RoboCup
 - DARPA Robotics Challenge
 - Amazon Robotics Challenge
 - International Aerial Robotics Competition
- Provide a **standardized test bed**
 - in a different environment
 - at a scheduled time
- **Directly compare** approaches

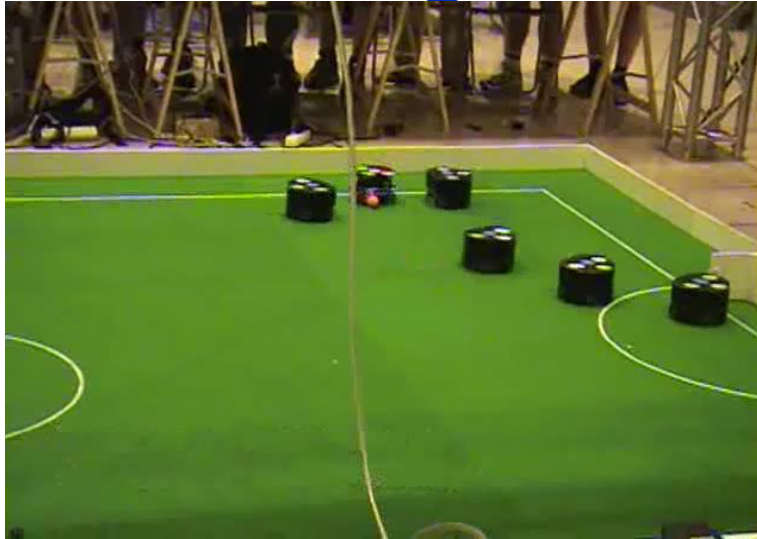
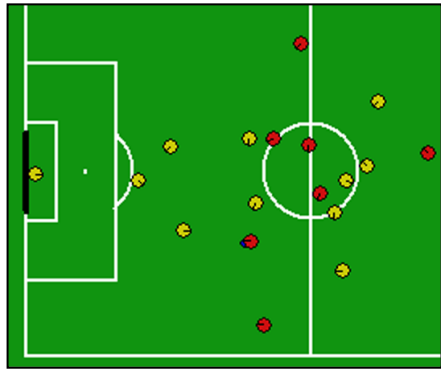


[Robo-one]

RoboCup Soccer Leagues



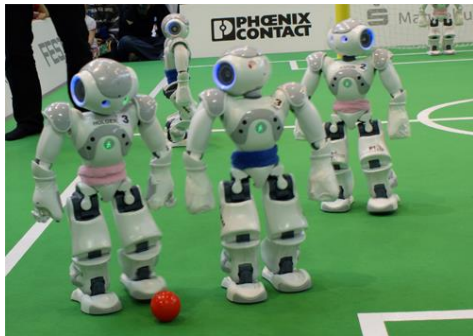
Simulation



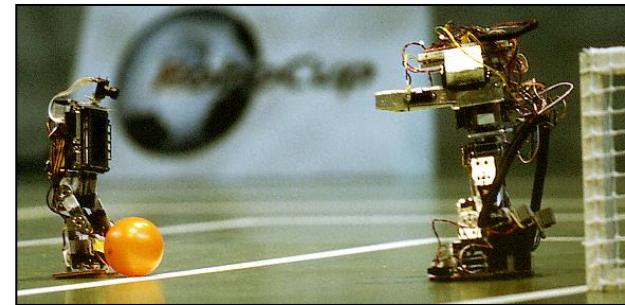
SmallSize



Standard Platform



Mid-Size



Humanoid

From RoboCup to Warehouse Automation



- Cornell Big Red team leader Raffaello D'Andrea co-founder of Kiva Systems

RoboCup 2016 TeenSize Final

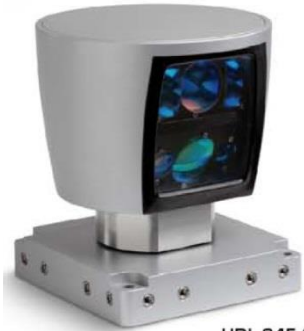


RoboCup 2017 AdultSize Final

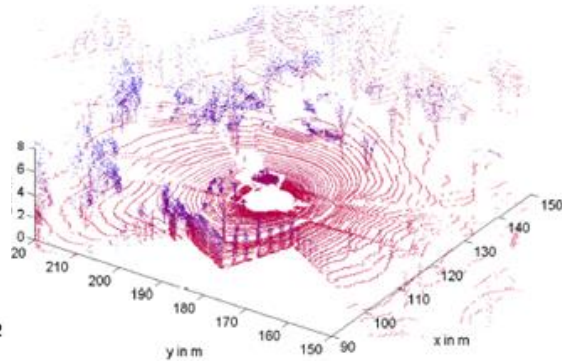


DARPA Urban Challenge 2007

- Autonomous driving in urban environment
- Obey traffic rules
- 3D lidar perception

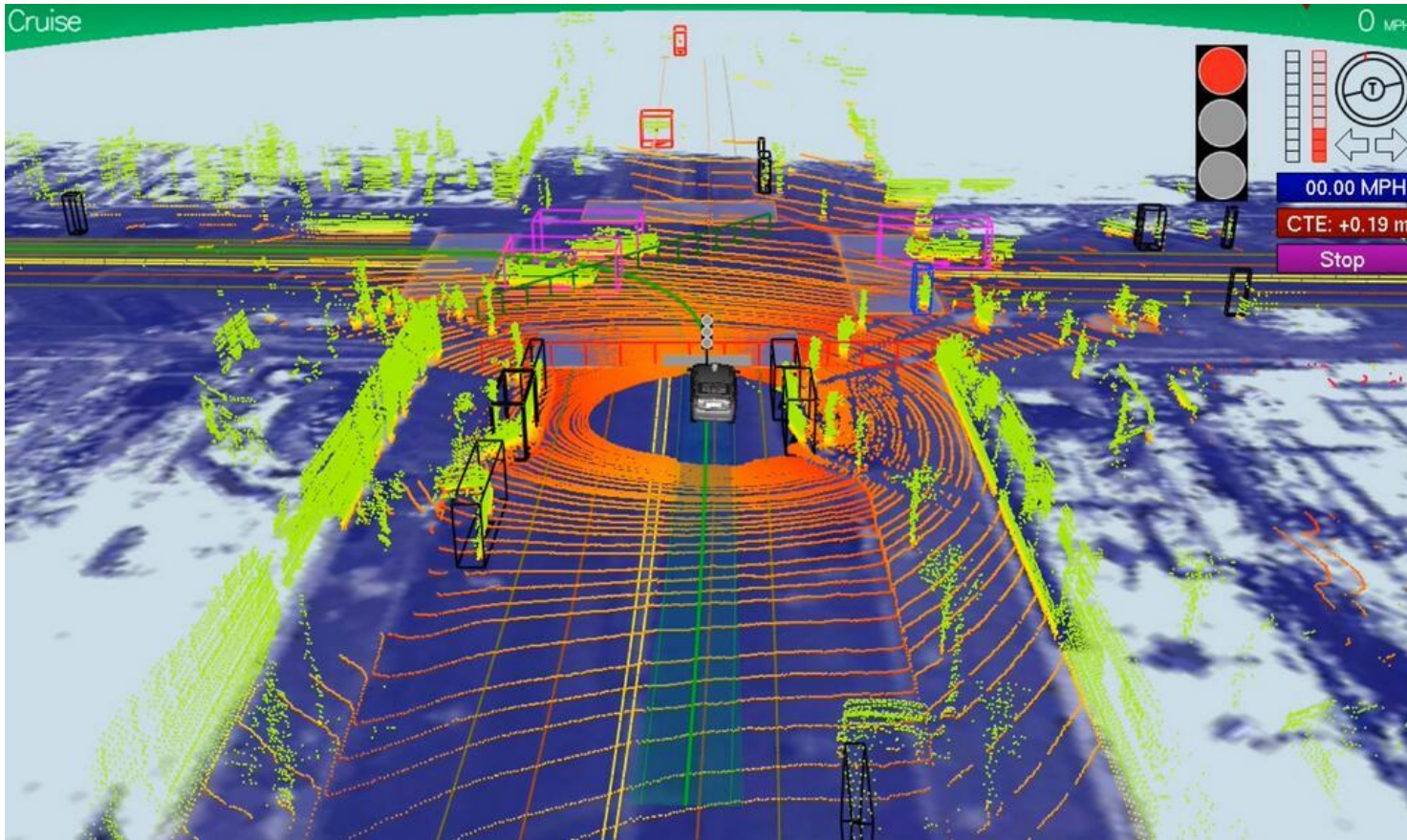


HDL-64E S2



[Team Berlin at DARPA Urban Challenge]

Environment Perception



[Google]

Google Self-driving Car



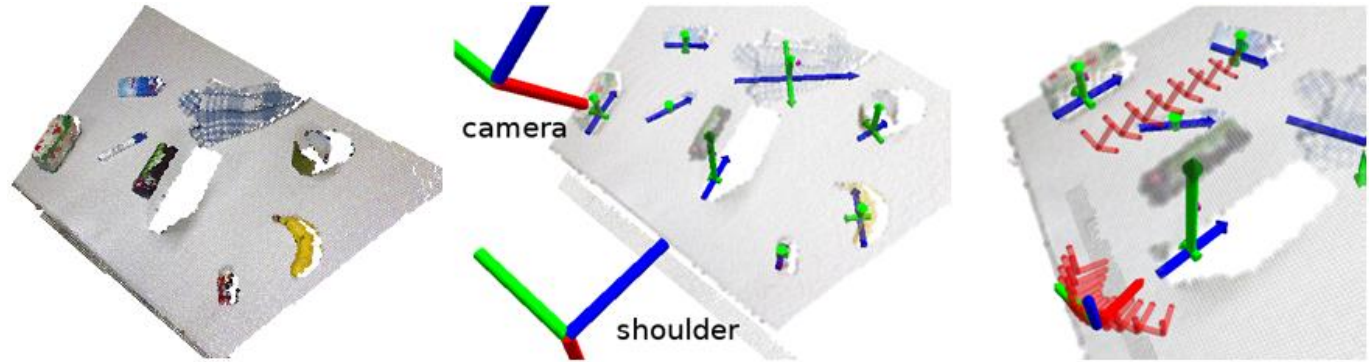
[Waymo]

RoboCup@Home

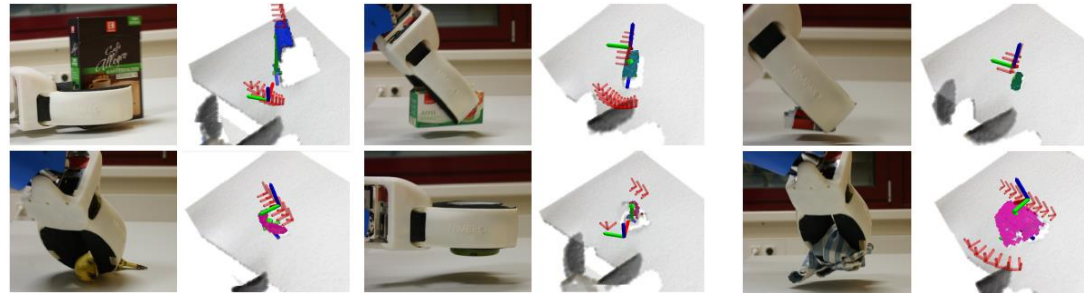


Table-top Analysis and Grasp Planning

- Detection of clusters above horizontal plane
- Two grasps (top, side)



- Flexible grasping of many unknown objects

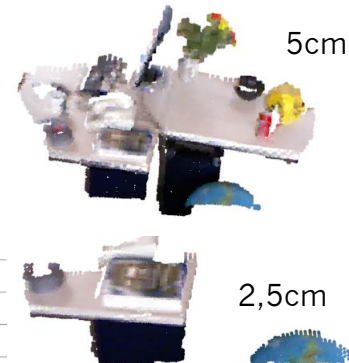
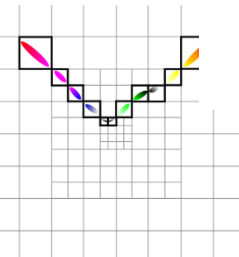
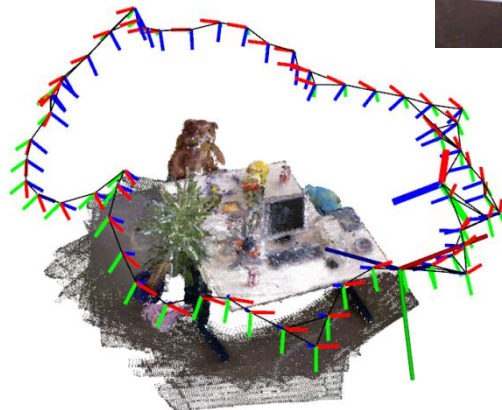


[Stückler et al, Robotics and Autonomous Systems, 2013]

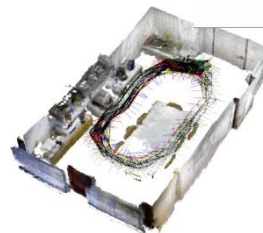
3D Mapping by RGB-D SLAM

[Stückler, Behnke:
Journal of Visual Communication
and Image Representation 2013]

- Modelling of shape and color distributions in voxels
- Local multiresolution
- Efficient registration of views on CPU
- Global optimization



- Multi-camera SLAM

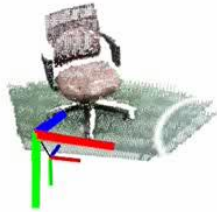


[Stoucken]

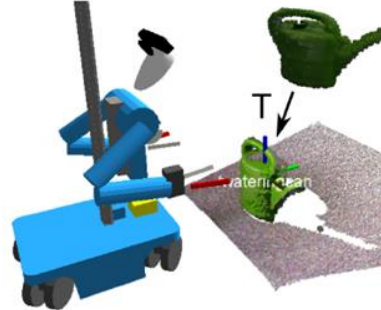


Learning and Tracking Object Models

- Modeling of objects by RGB-D-SLAM

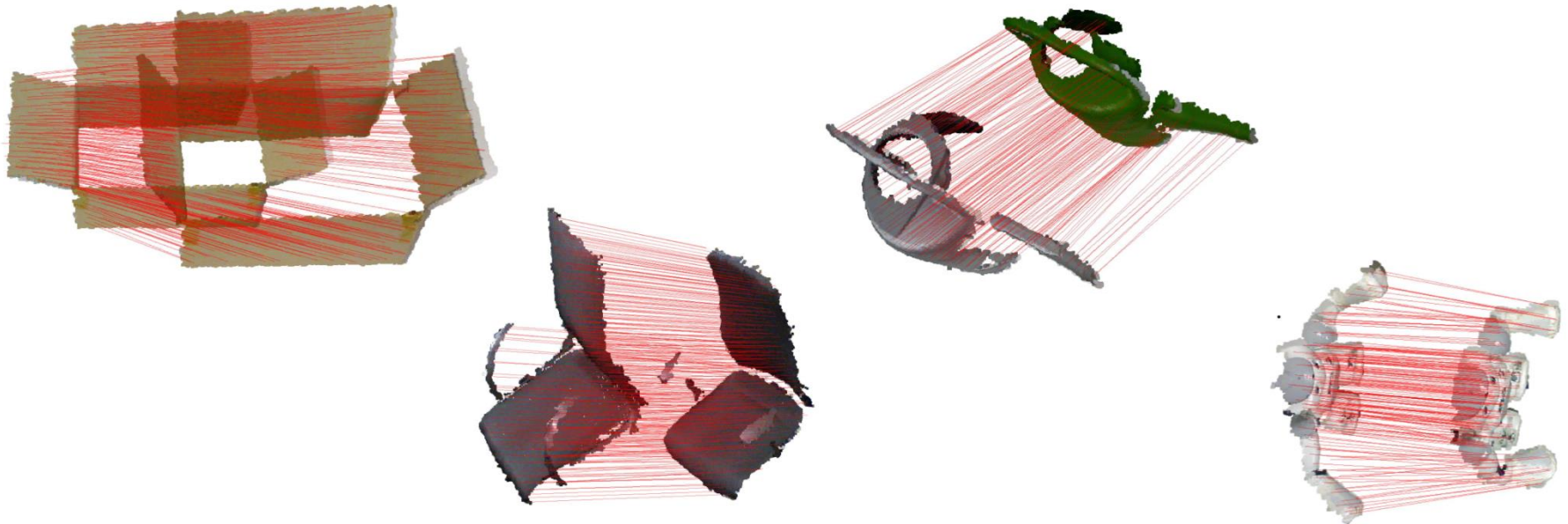


- Real-time registration with current RGB-D frame



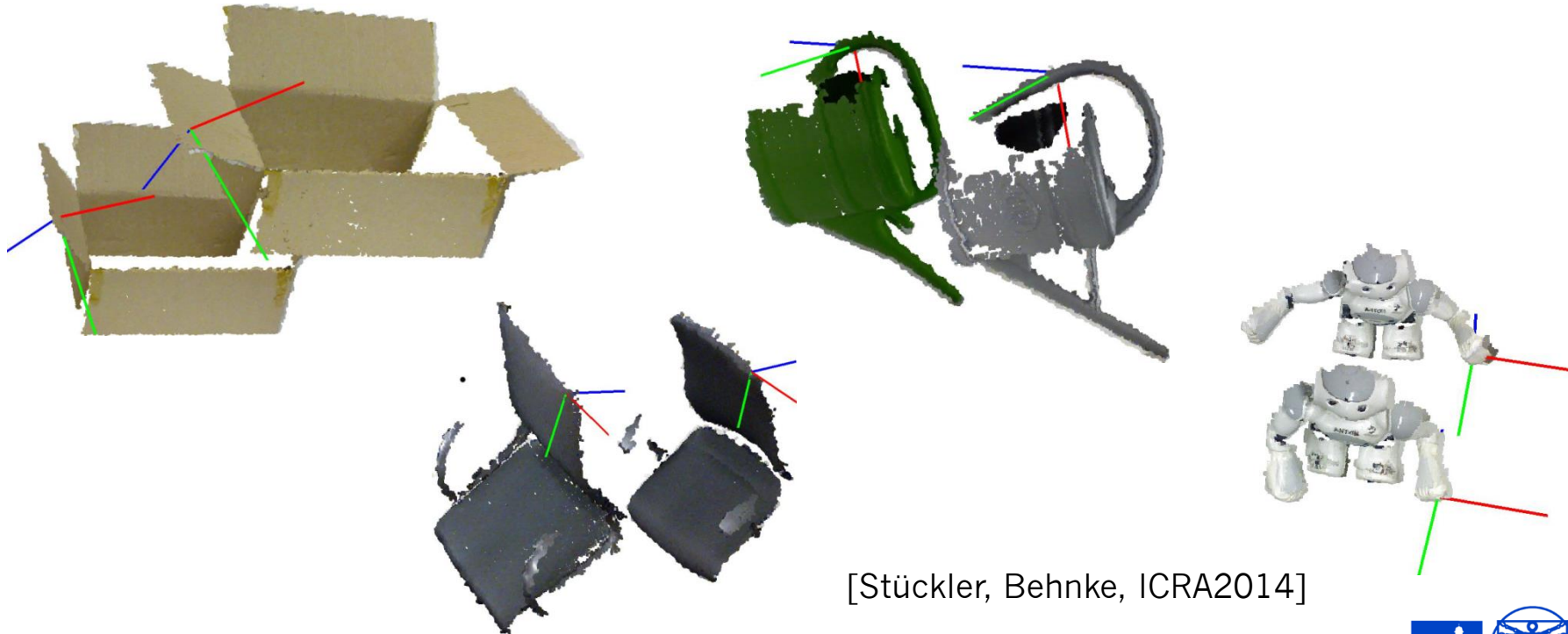
Deformable RGB-D-Registration

- Based on Coherent Point Drift method [Myronenko & Song, PAMI 2010]
- Multiresolution Surfel Map allows real-time registration



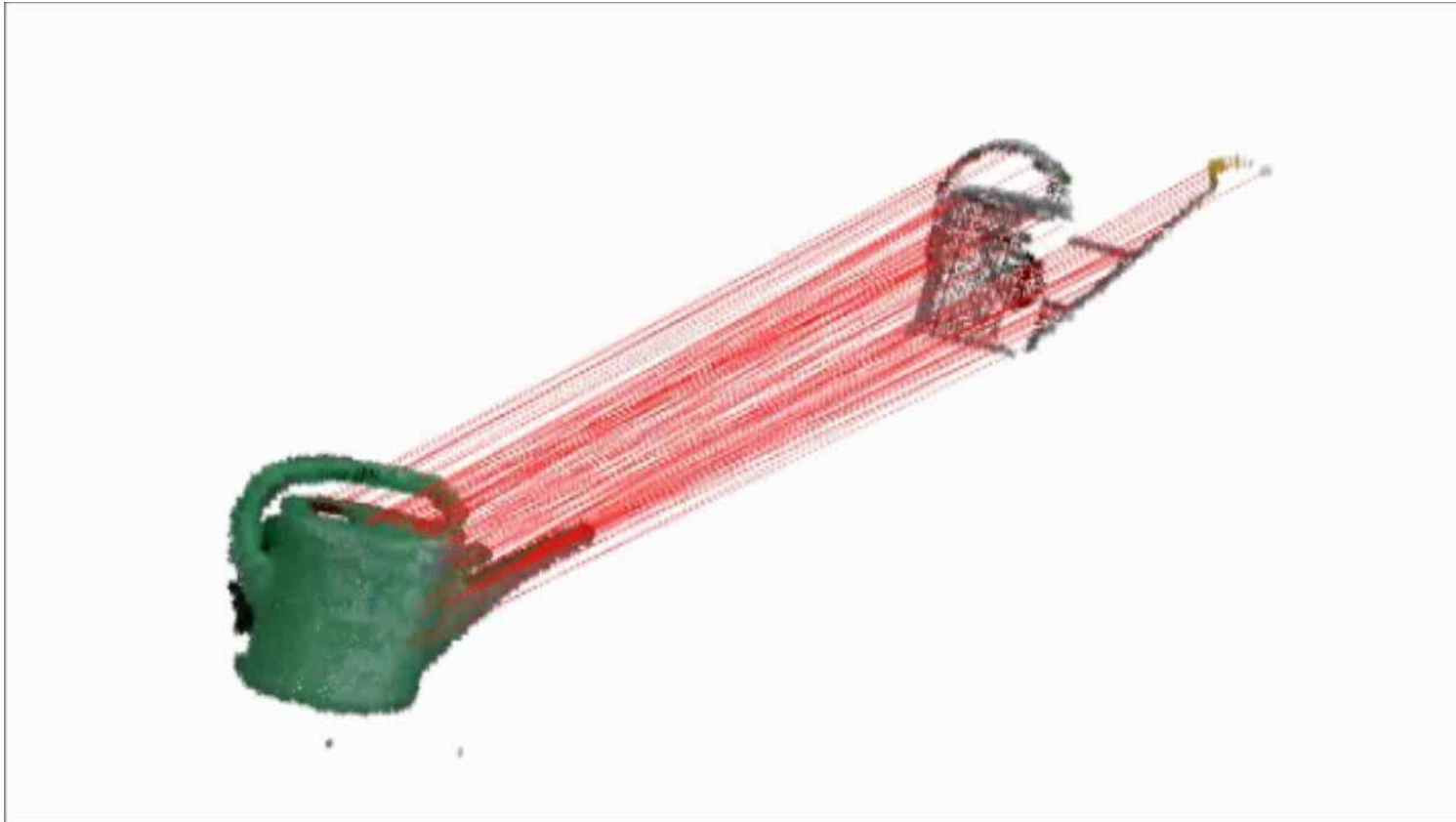
Transformation of Poses on Object

- Derived from the deformation field



[Stückler, Behnke, ICRA2014]

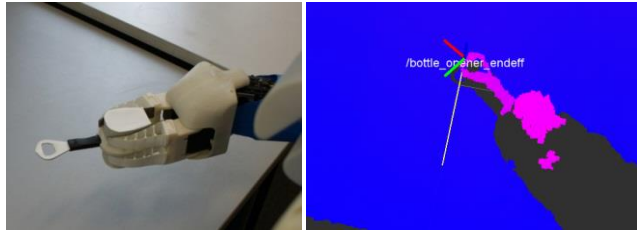
Grasp & Motion Skill Transfer



[Stückler,
Behnke,
ICRA2014]

Tool use: Bottle Opener

- Tool tip perception



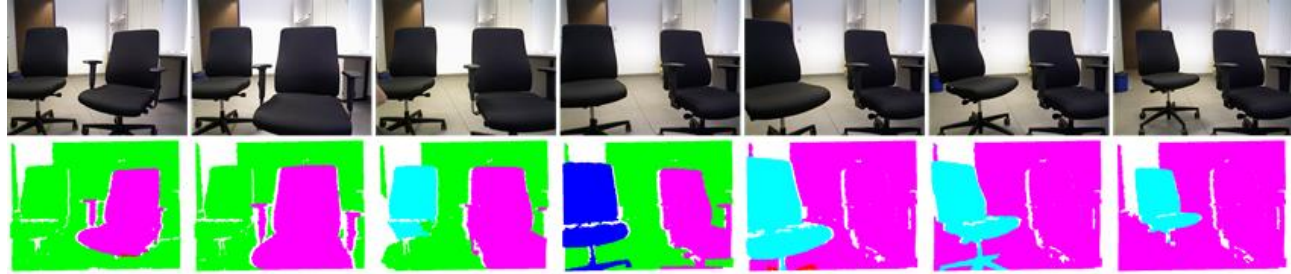
- Extension of arm kinematics
- Perception of crown cap
- Motion adaptation



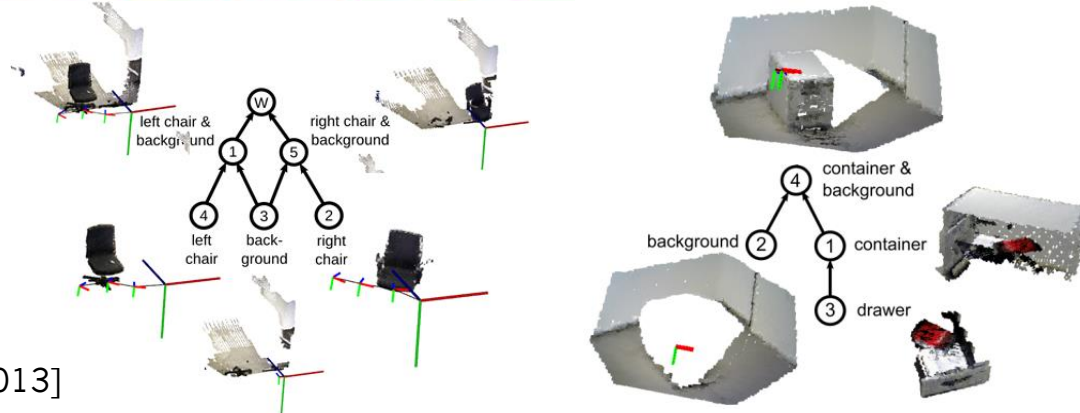
[Stückler, Behnke, Humanoids 2014]

Hierarchical Object Discovery through Motion Segmentation

- Simultaneous object modeling and motion segmentation

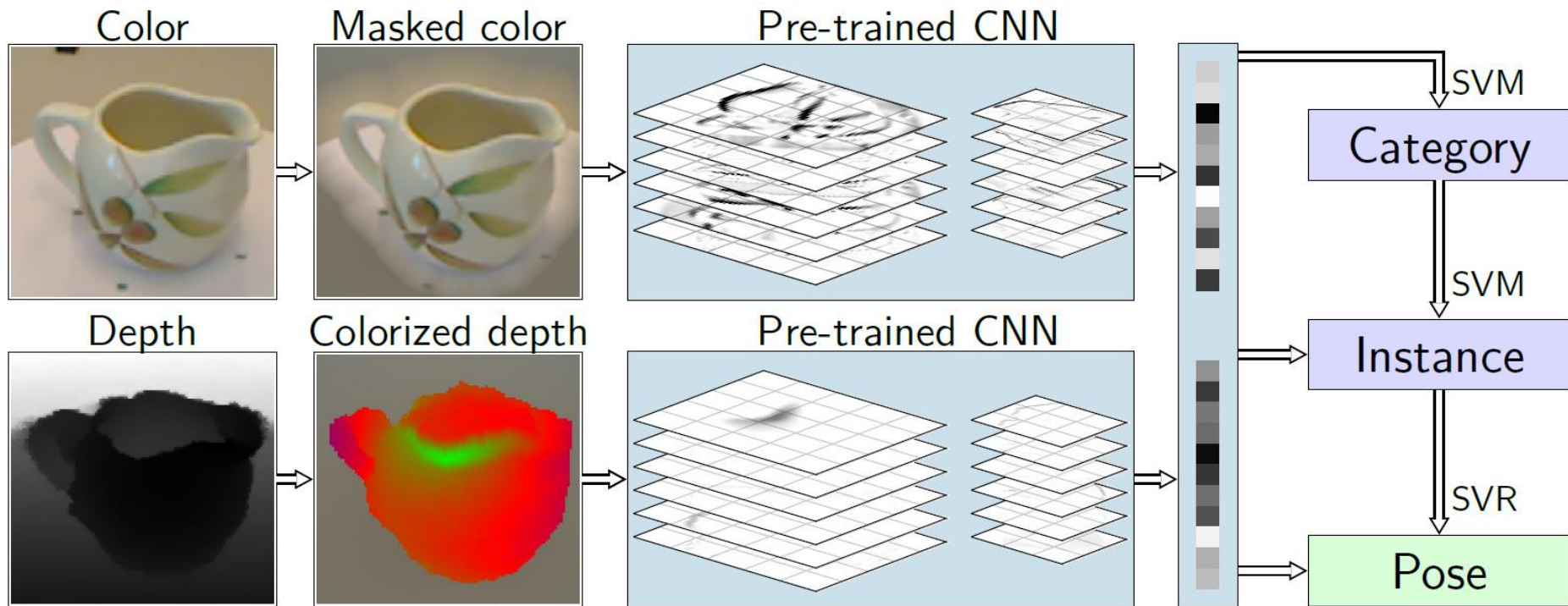


- Inference of a segment hierarchy



[Stückler, Behnke: IJCAI 2013]

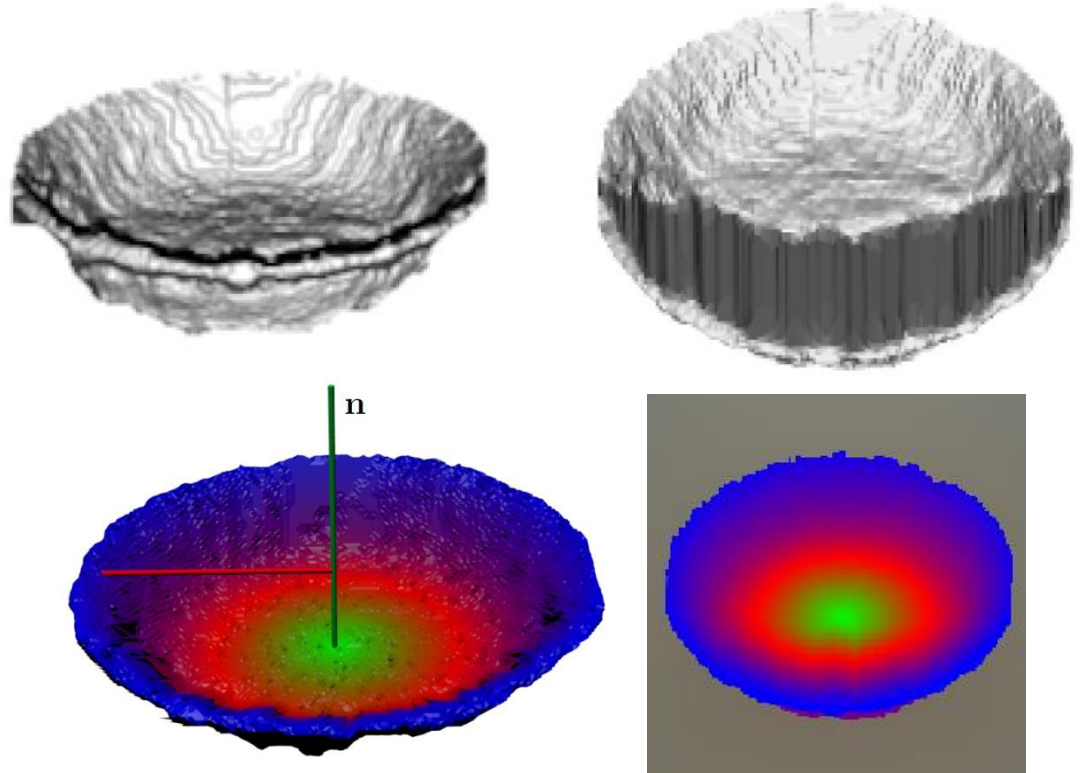
RGB-D Object Recognition and Pose Estimation



[Schwarz, Schulz, Behnke, ICRA2015]

Canonical View, Colorization

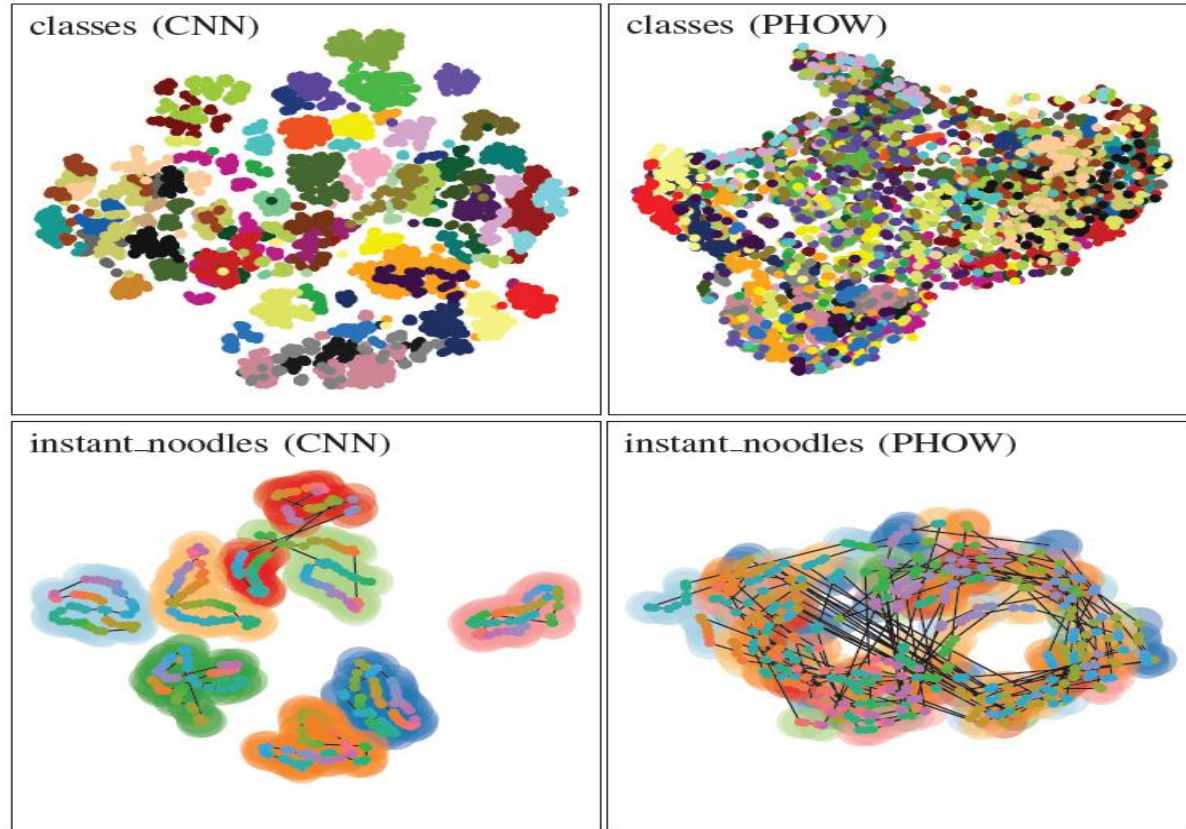
- Objects viewed from different elevation
- Render canonical view
- Colorization based on distance from center vertical



[Schwarz, Schulz, Behnke, ICRA2015]

Pretrained Features Disentangle Data

- t-SNE embedding



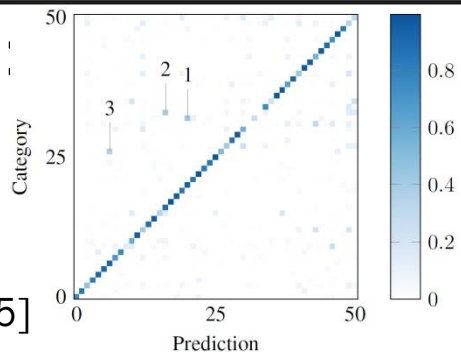
[Schwarz, Schulz,
Behnke ICRA2015]

Recognition Accuracy

- Improved both category and instance recognition

Method	Category Accuracy (%)		Instance Accuracy (%)	
	RGB	RGB-D	RGB	RGB-D
Lai <i>et al.</i> [1]	74.3 ± 3.3	81.9 ± 2.8	59.3	73.9
Bo <i>et al.</i> [2]	82.4 ± 3.1	87.5 ± 2.9	92.1	92.8
PHOW[3]	80.2 ± 1.8	—	62.8	—
Ours	83.1 ± 2.0	88.3 ± 1.5	92.0	94.1
Ours	83.1 ± 2.0	89.4 ± 1.3	92.0	94.1

- Confusion:



[Schwarz, Schulz, Behnke, ICRA2015]

1: pitcher / coffe mug

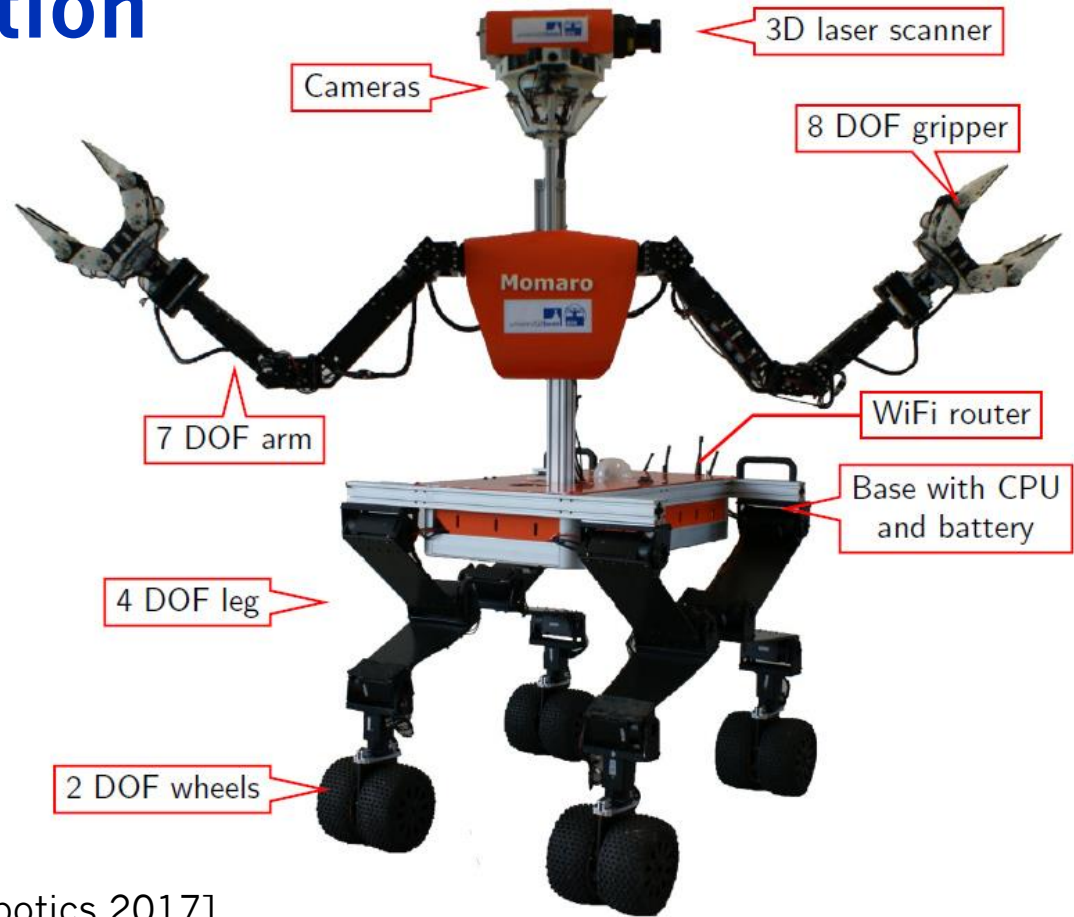


2: peach / sponge



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]

Driving a Vehicle



23:15:03 05/06/2015 UTC

4x

Egress



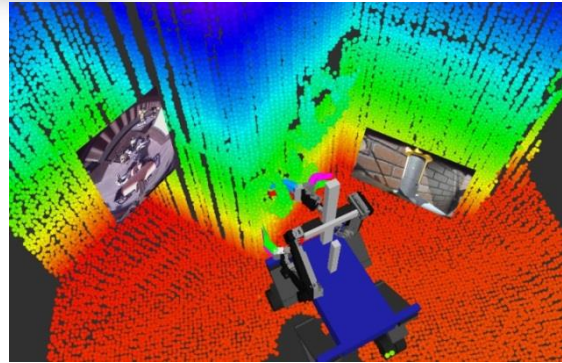
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4x

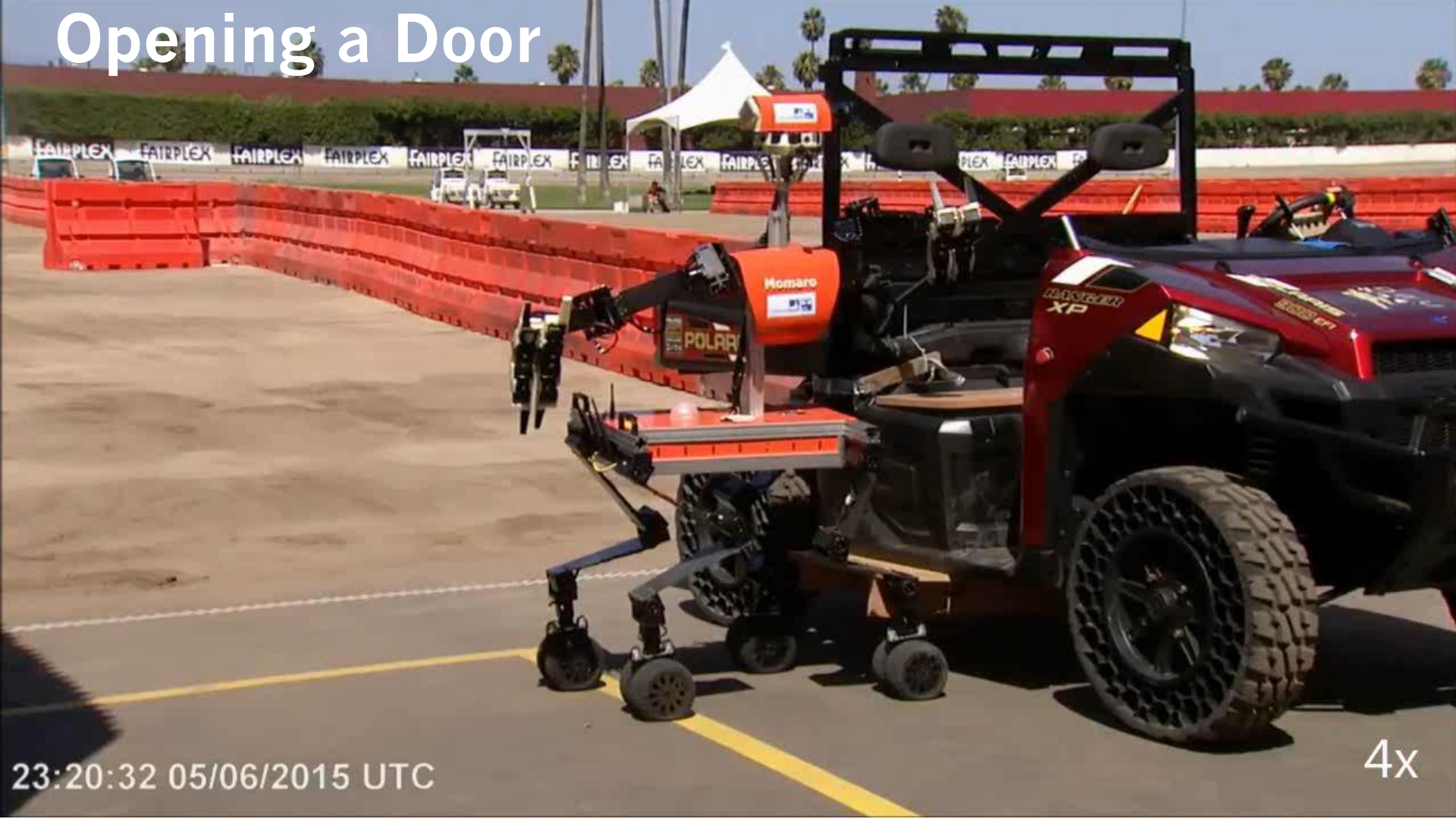
Manipulation Operator Interface

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

[Rodehuts Kors et al., Humanoids 2015]



Opening a Door



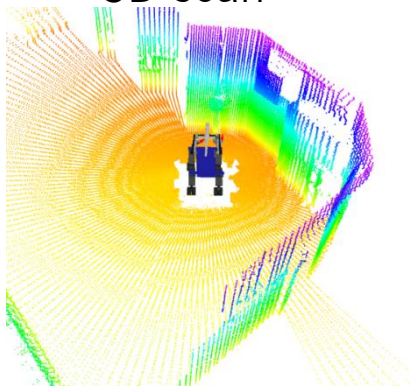
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4x

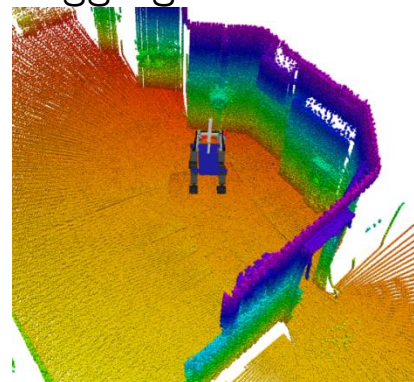
Local Multiresolution Surfel Map

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

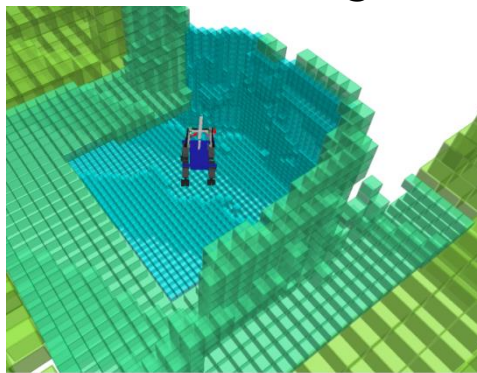
3D scan



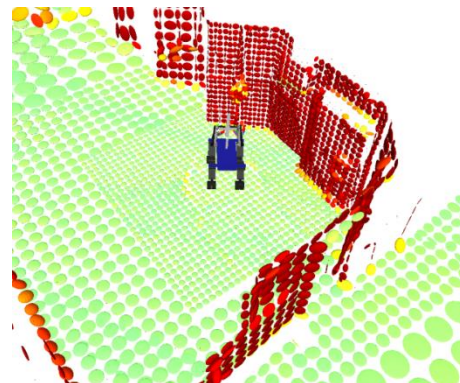
Aggregated scans



Multiresolution grid



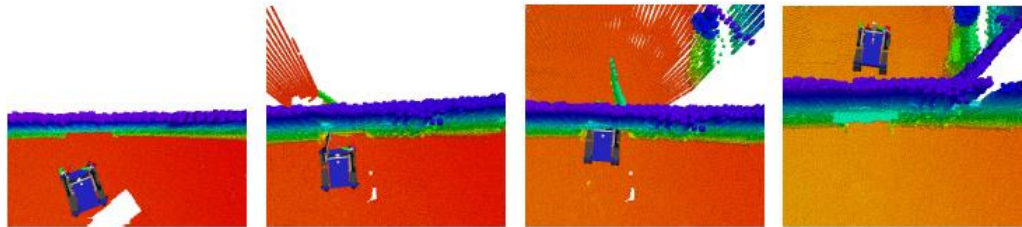
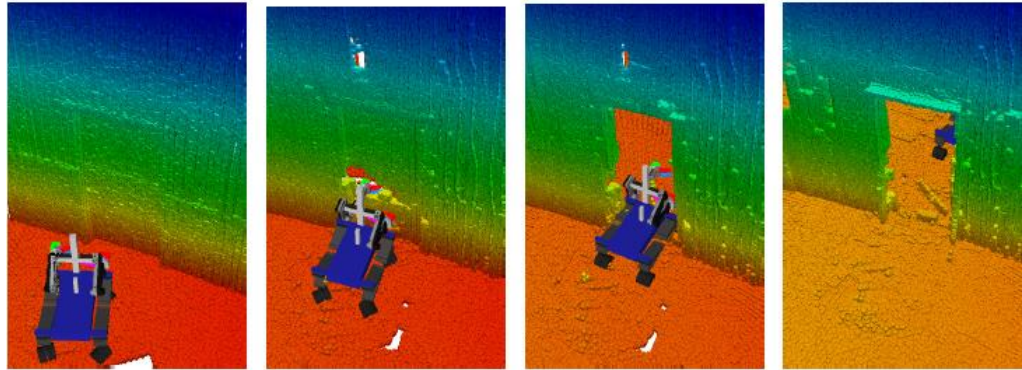
Surfels



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

Filtering Dynamic Objects

- Maintain occupancy in each cell



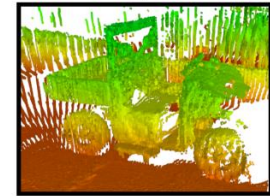
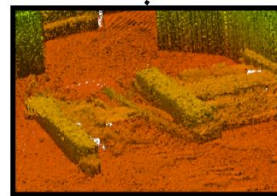
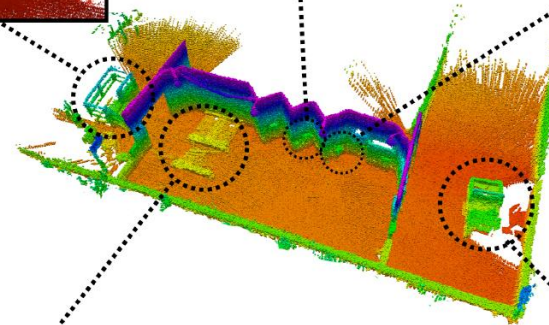
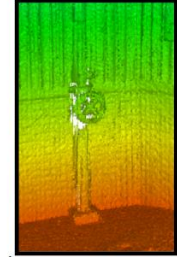
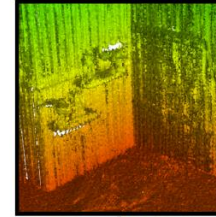
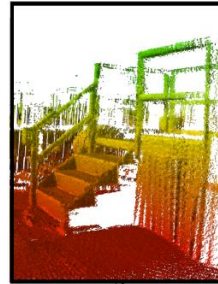
1 scan (5 s)

2 scans (10 s)

5 scans (25 s)

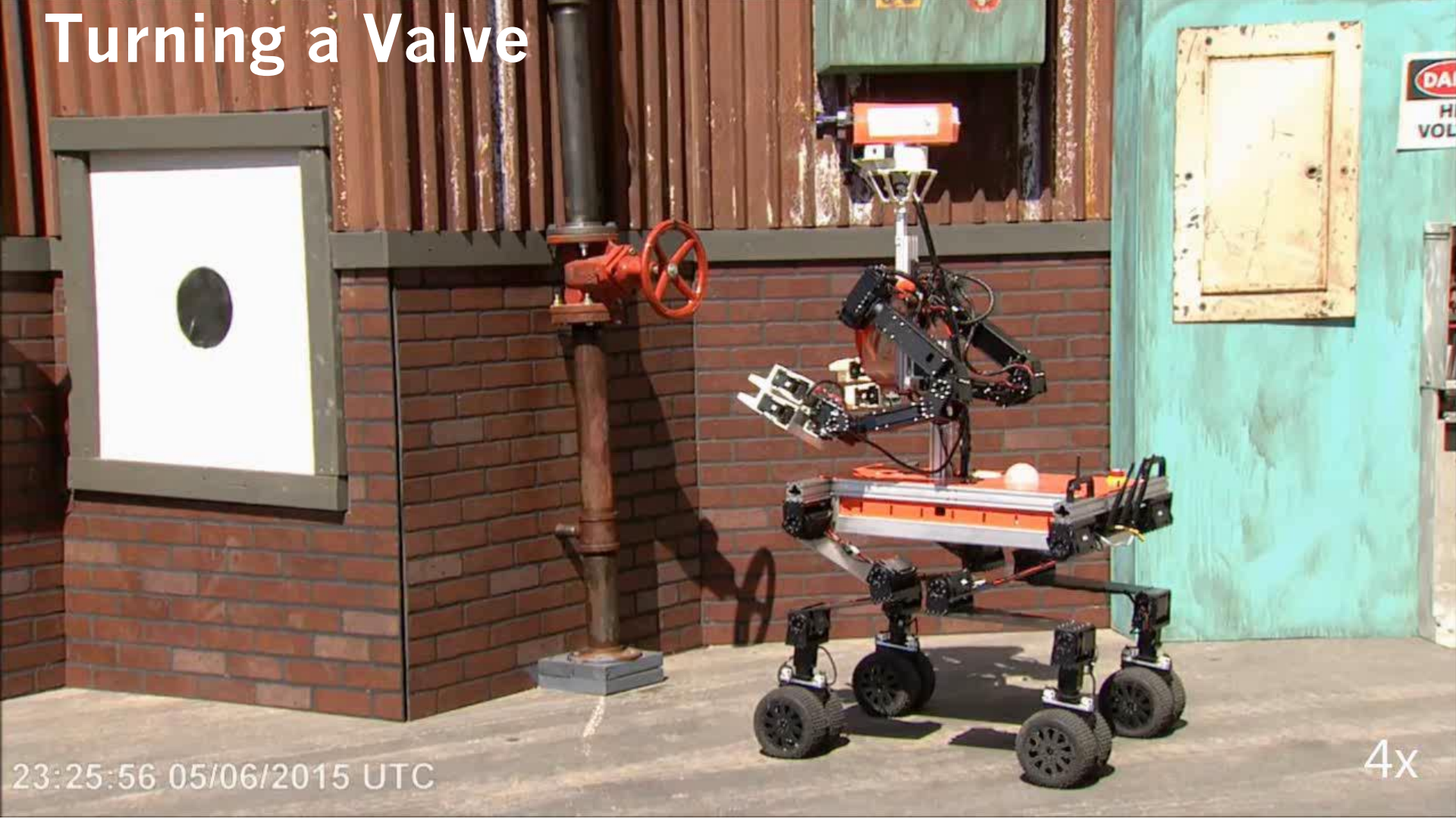
Allocentric 3D Mapping

- Registration of egocentric maps by graph optimization



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

Turning a Valve



23:25:56 05/06/2015 UTC

4x

Operating a Switch



23:28:21 05/06/2015 UTC

4x

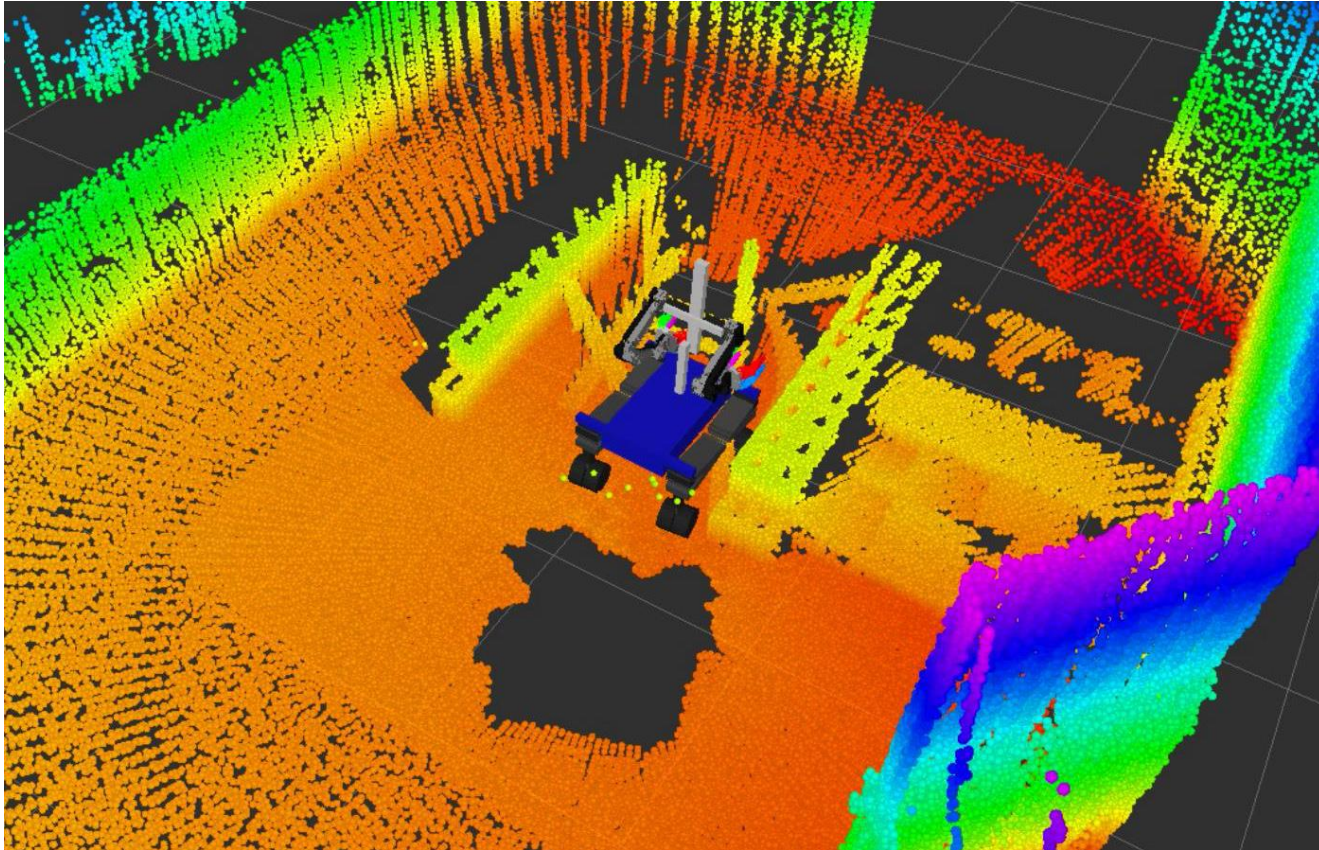
Plug Task



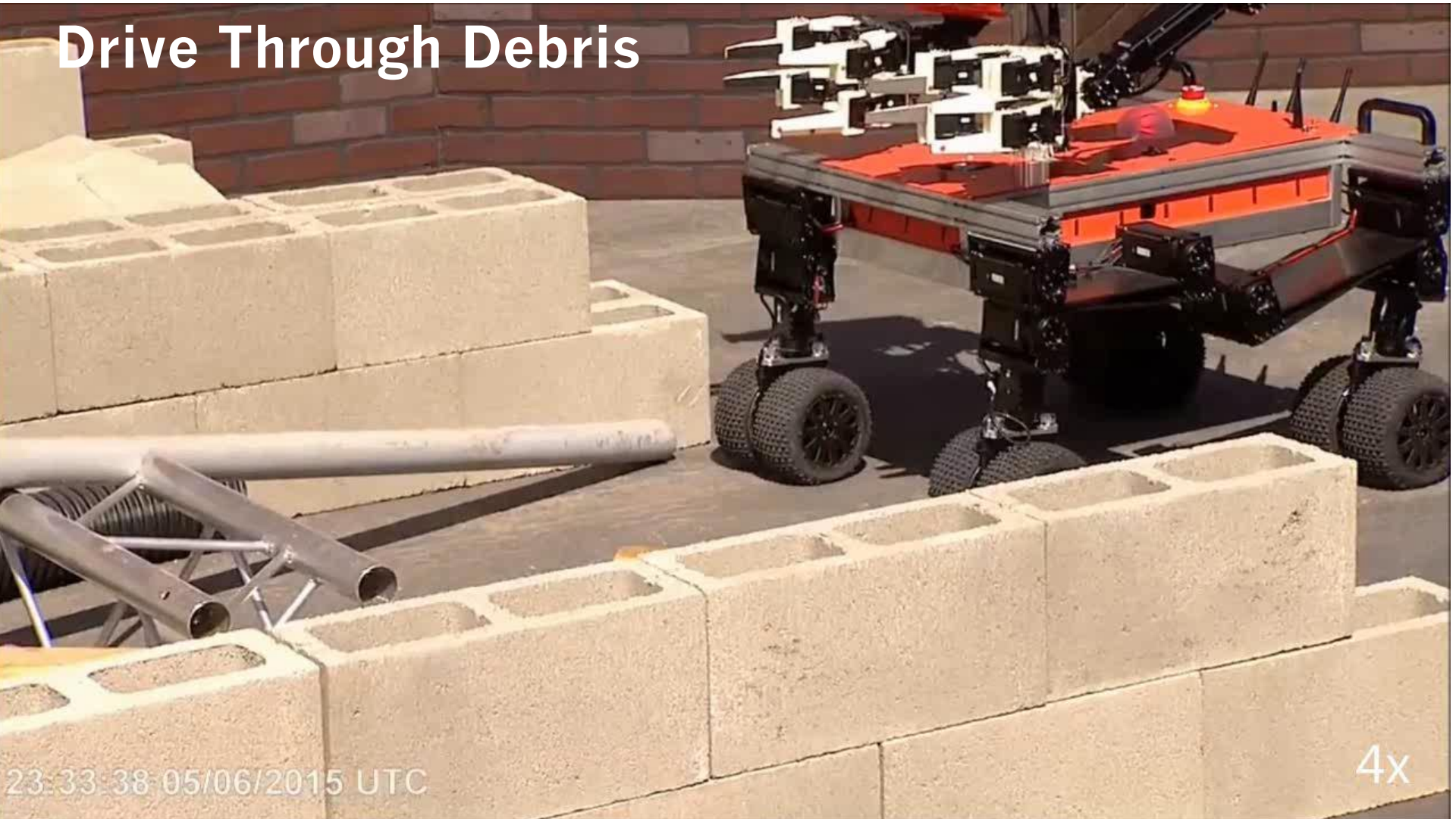
02:23:20 07/06/2015 UTC

4X

Debris Tasks



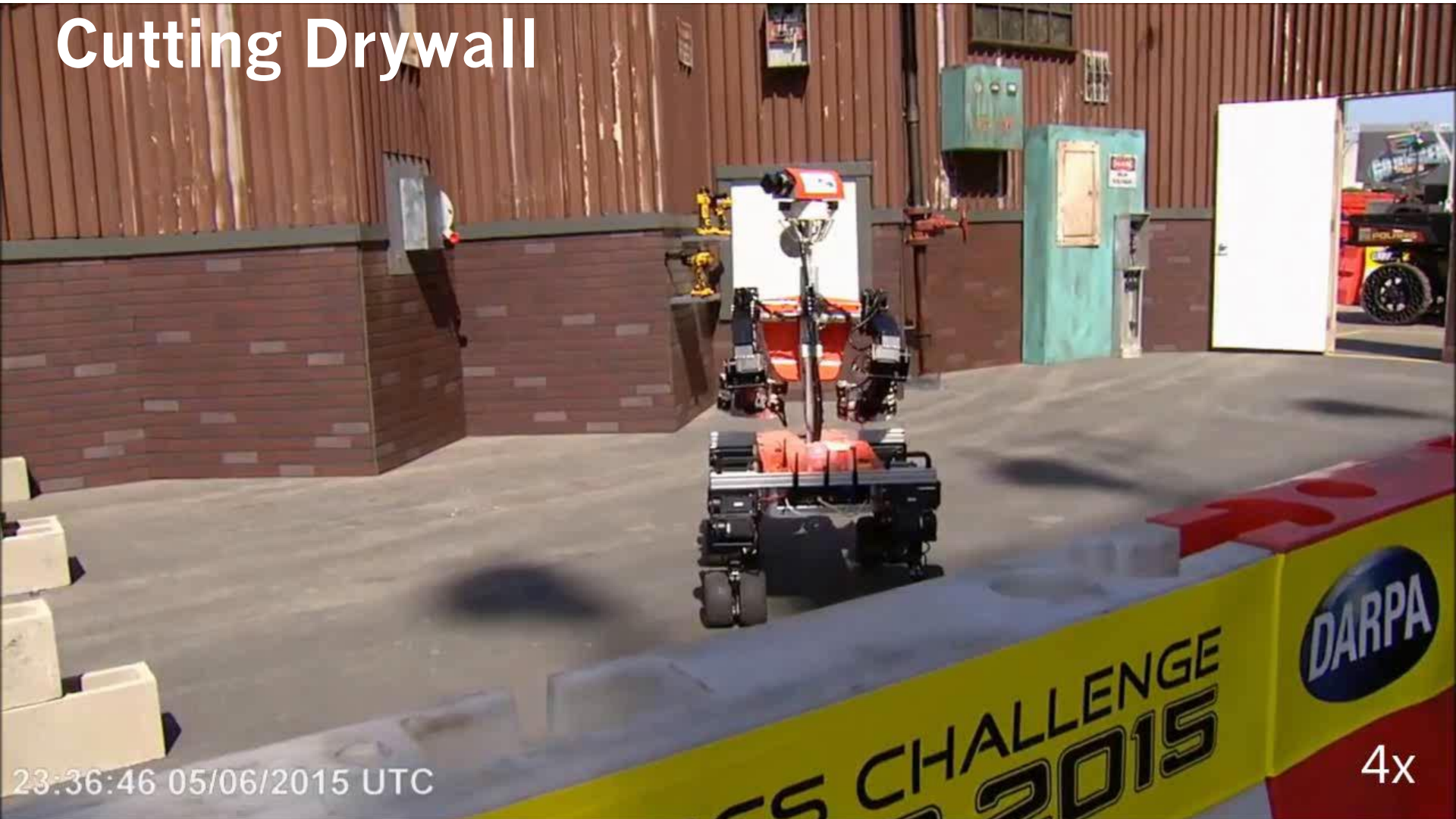
Drive Through Debris



23:33:38 05/06/2015 UTC

4x

Cutting Drywall



23:36:46 05/06/2015 UTC

CHALLENGE
2015

DARPA

4x

Team NimbRo Rescue

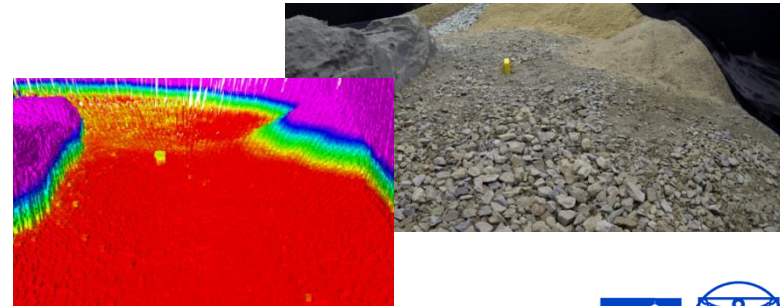
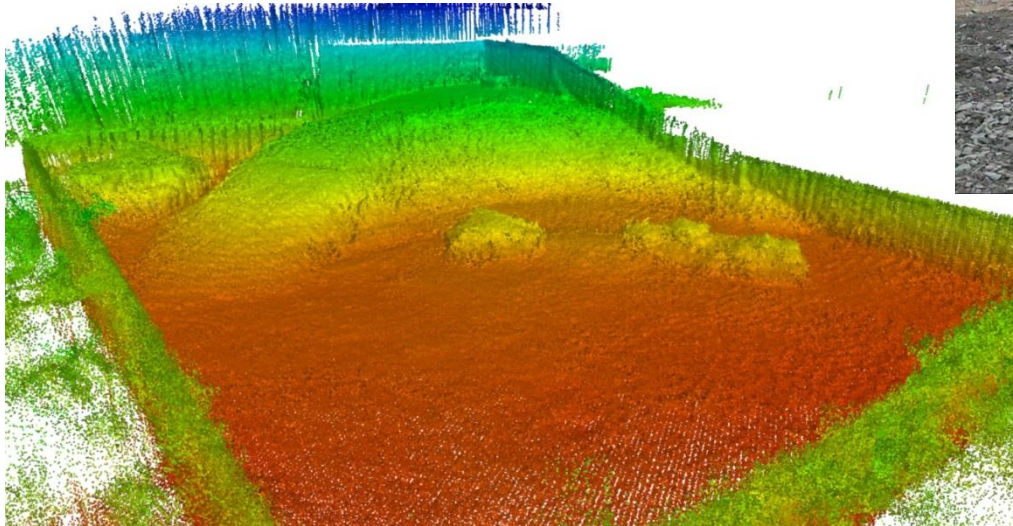


**Best European Team (4th place overall),
solved seven of eight tasks in 34 minutes**

DLR SpaceBot Cup 2015

- Mobile manipulation in rough terrain

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



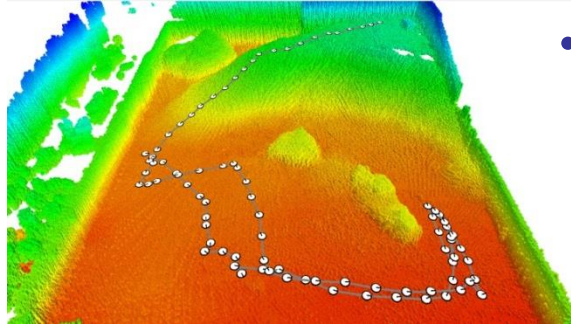
DLR SpaceBot Camp 2015



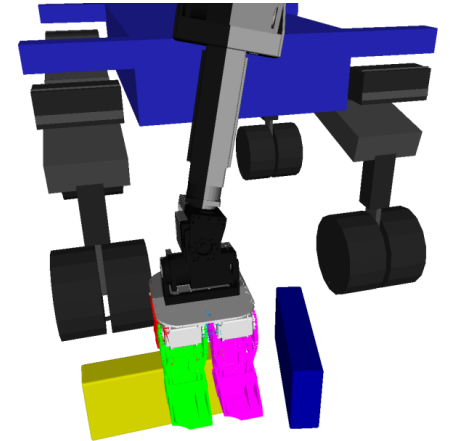
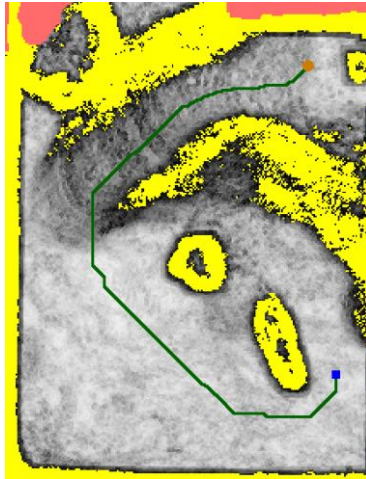
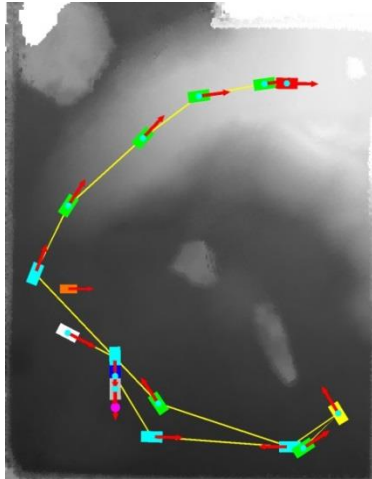
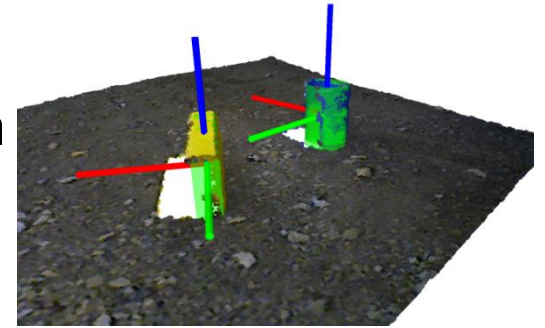
8X

Autonomous Mission Execution

- 3D mapping, localization, mission and navigation planning



- 3D object perception and grasping



[Schwarz et al. Frontiers 2016]

MBZIRC Challenge 2

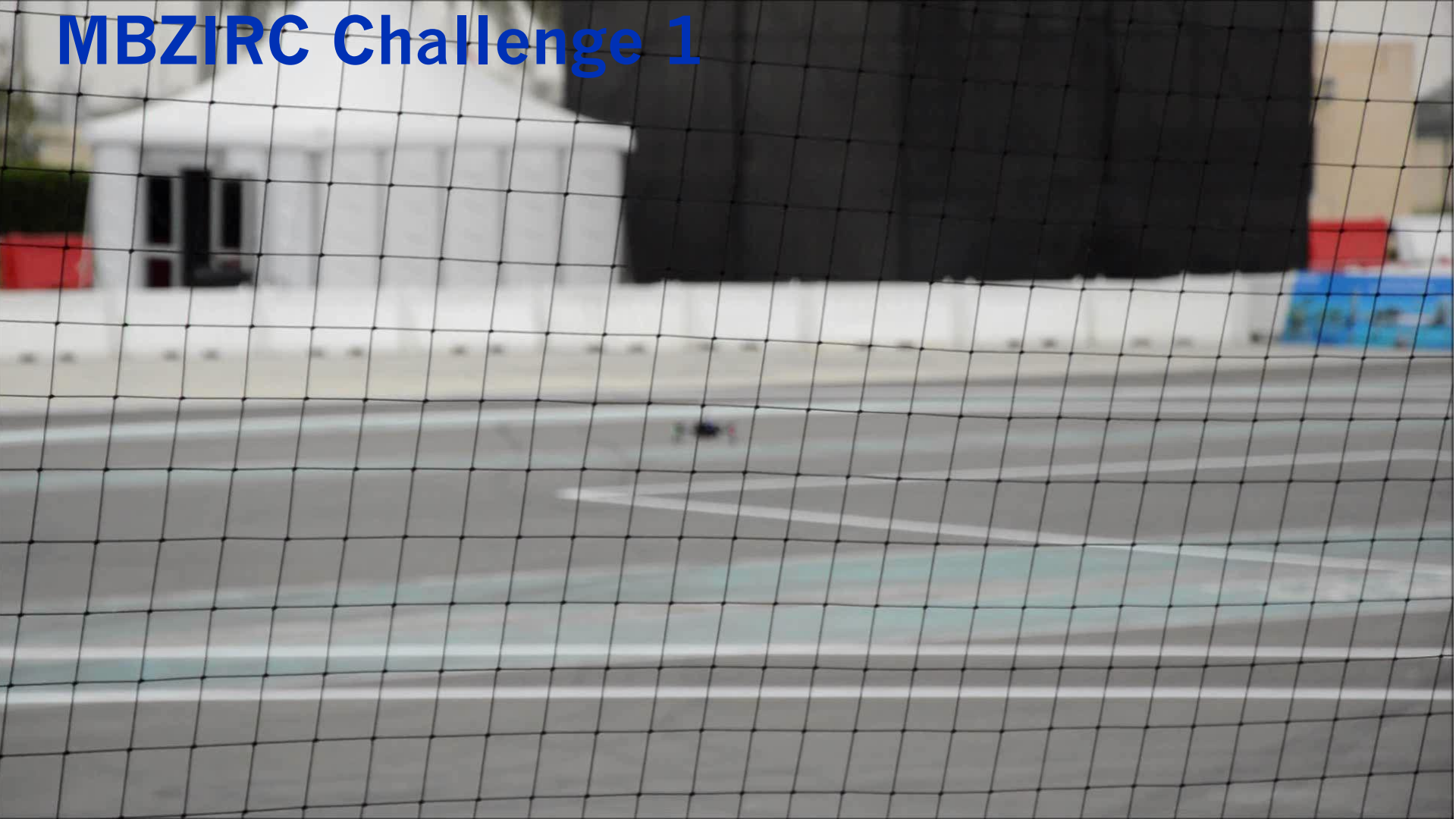


2x

Wrench Selection: Detection of Tool Ends

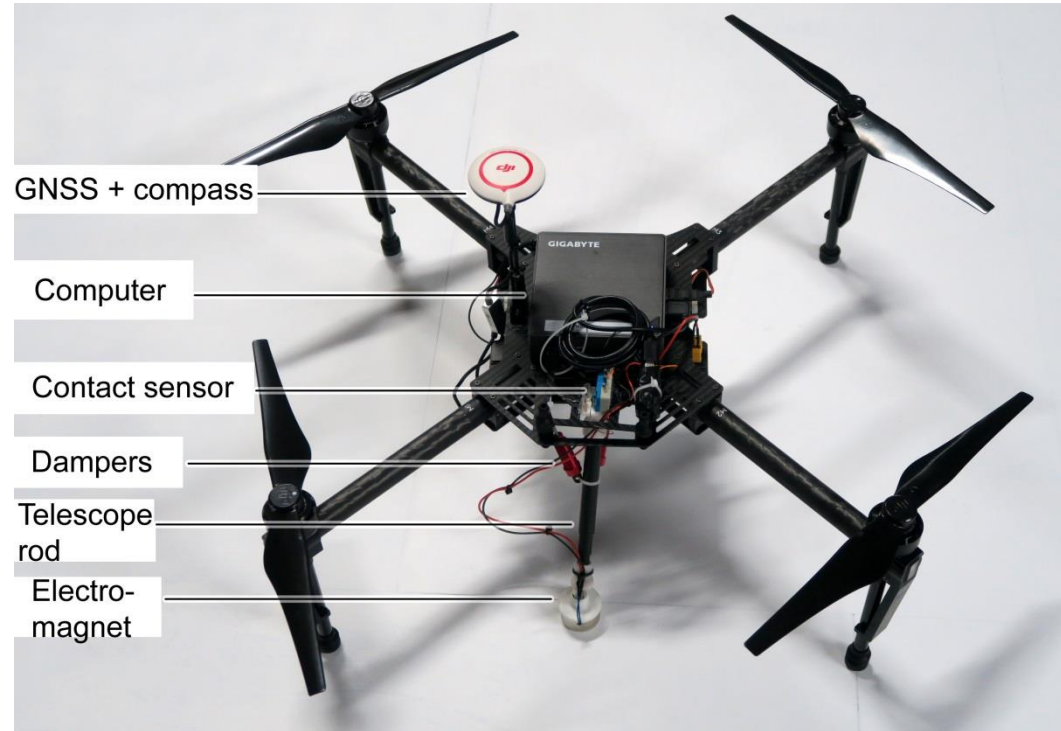


MBZIRC Challenge 1



Picking Copter DJI Matrice 100

- Wide-angle downward looking color camera
- Electromagnetic gripper
- Laser-distance sensor to ground
- Dual-core PC



7:13

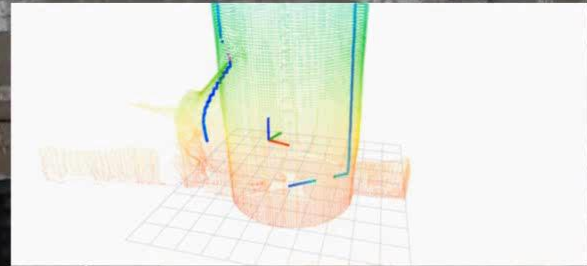
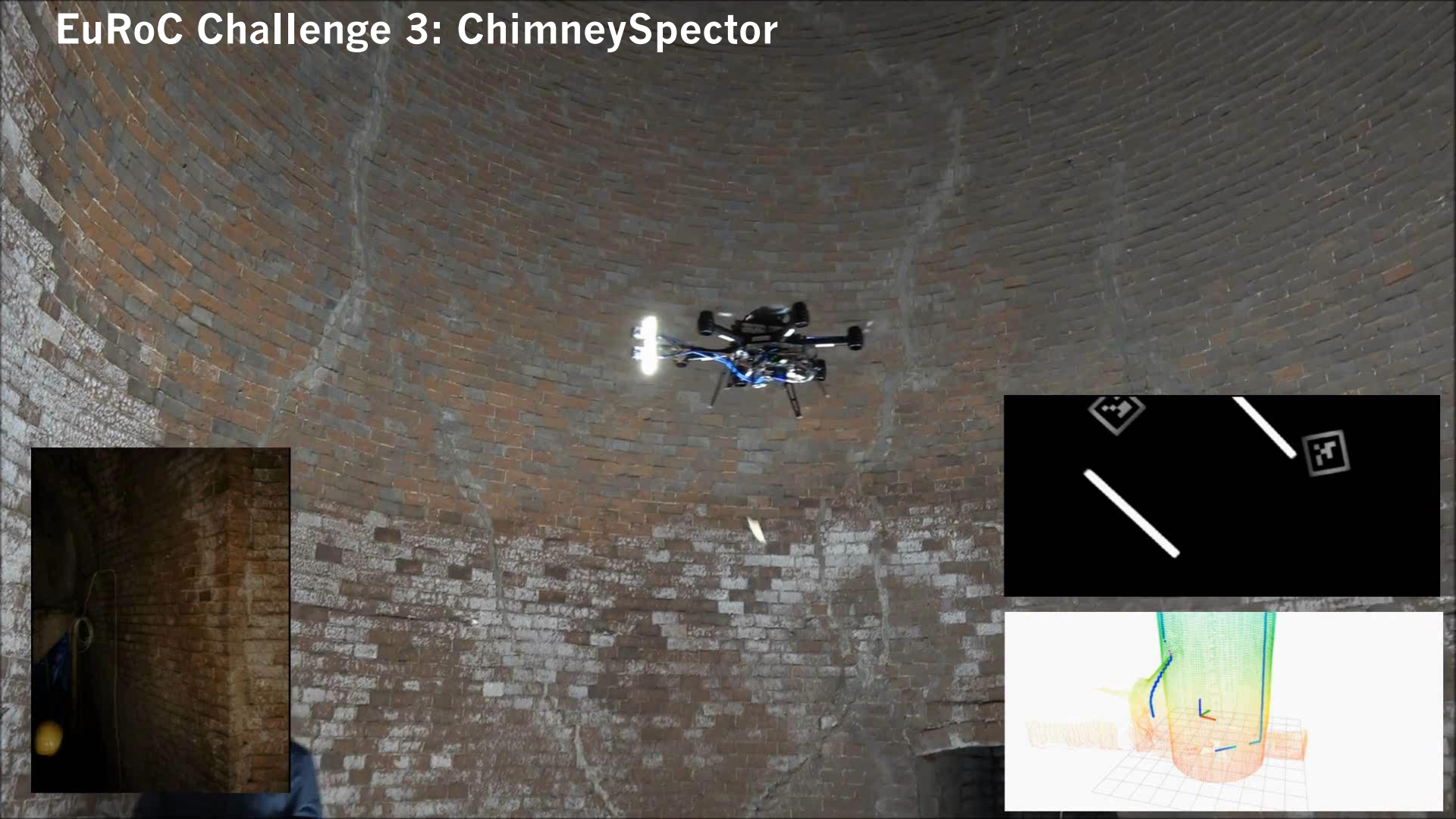
MBZIRC Challenge 3



MBZIRC Team NimbRo



EuRoC Challenge 3: ChimneySpector



DJI Matrice 600 with Velodyne Puck



Fast Autonomous Flight Near Structures



Fully Autonomous indoor flight without external tracking.

Amazon Picking Challenge

- Large variety of objects
- Unordered in shelf or tote
- Picking and stowing tasks



[Schwarz et al. ICRA 2017]

Deep Learning Semantic Segmentation

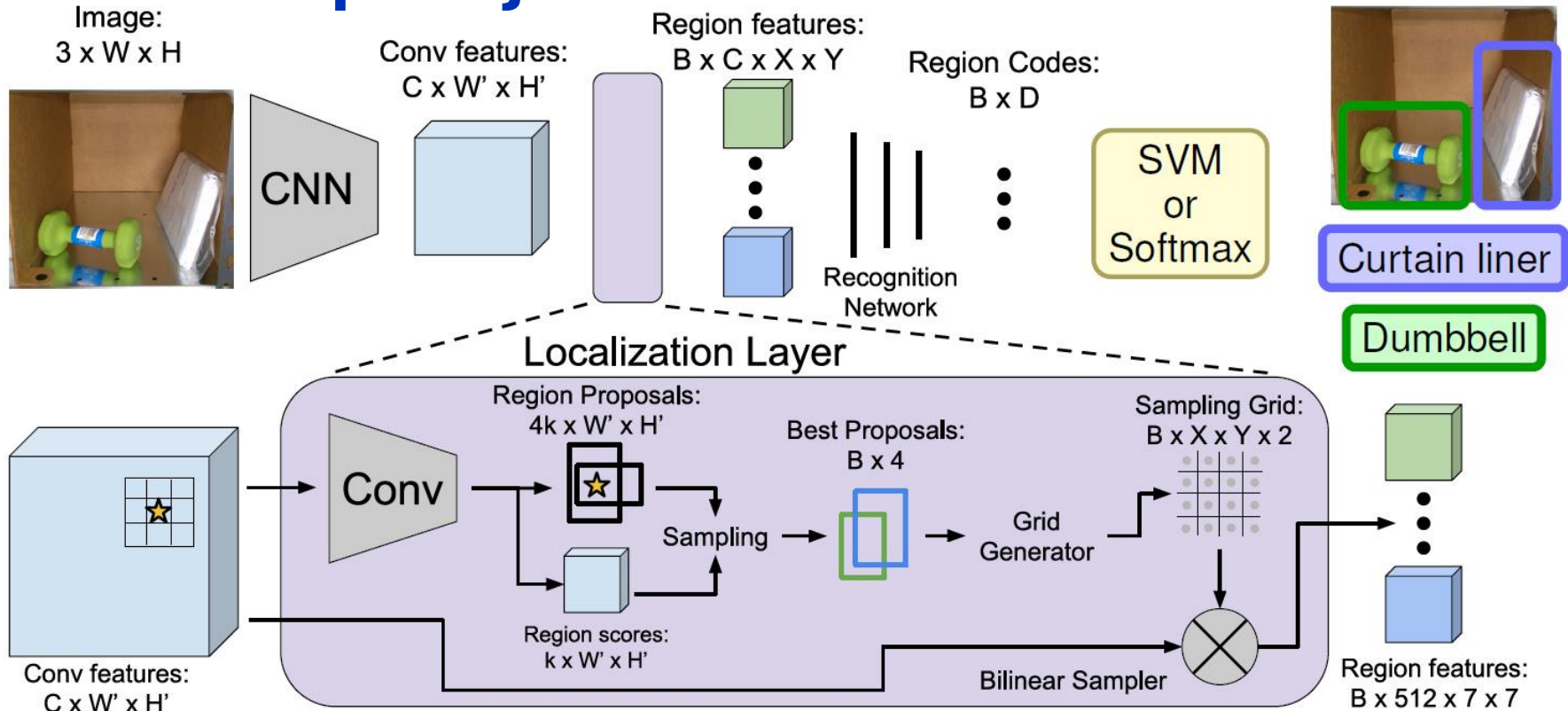
- Adapted from our segmentation of indoor scenes [Husain et al. RA-L 2016]



[Schwarz et al. ICRA 2017]



DenseCap Object Detection

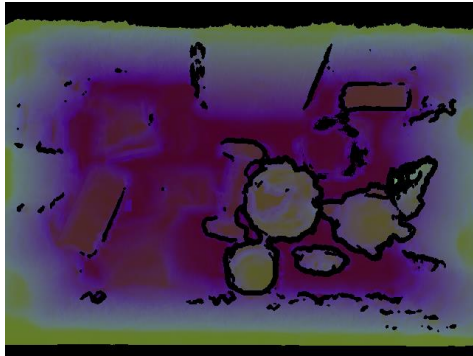
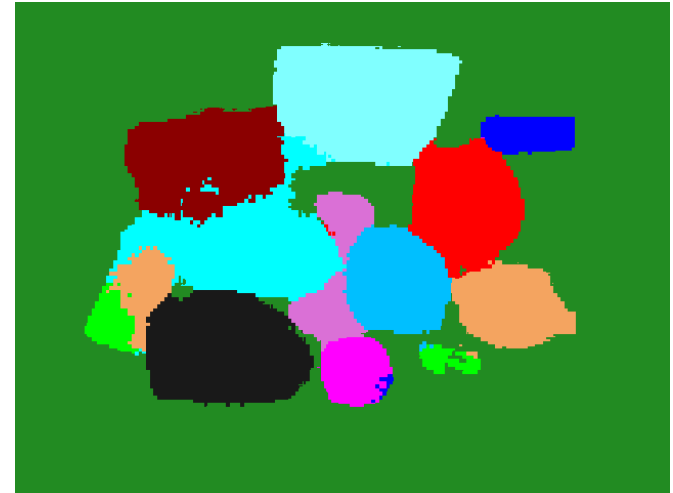
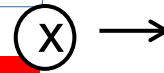


[Schwarz et al. ICRA 2017]

[Johnson et al. CVPR 2016]

Combined Detection and Segmentation

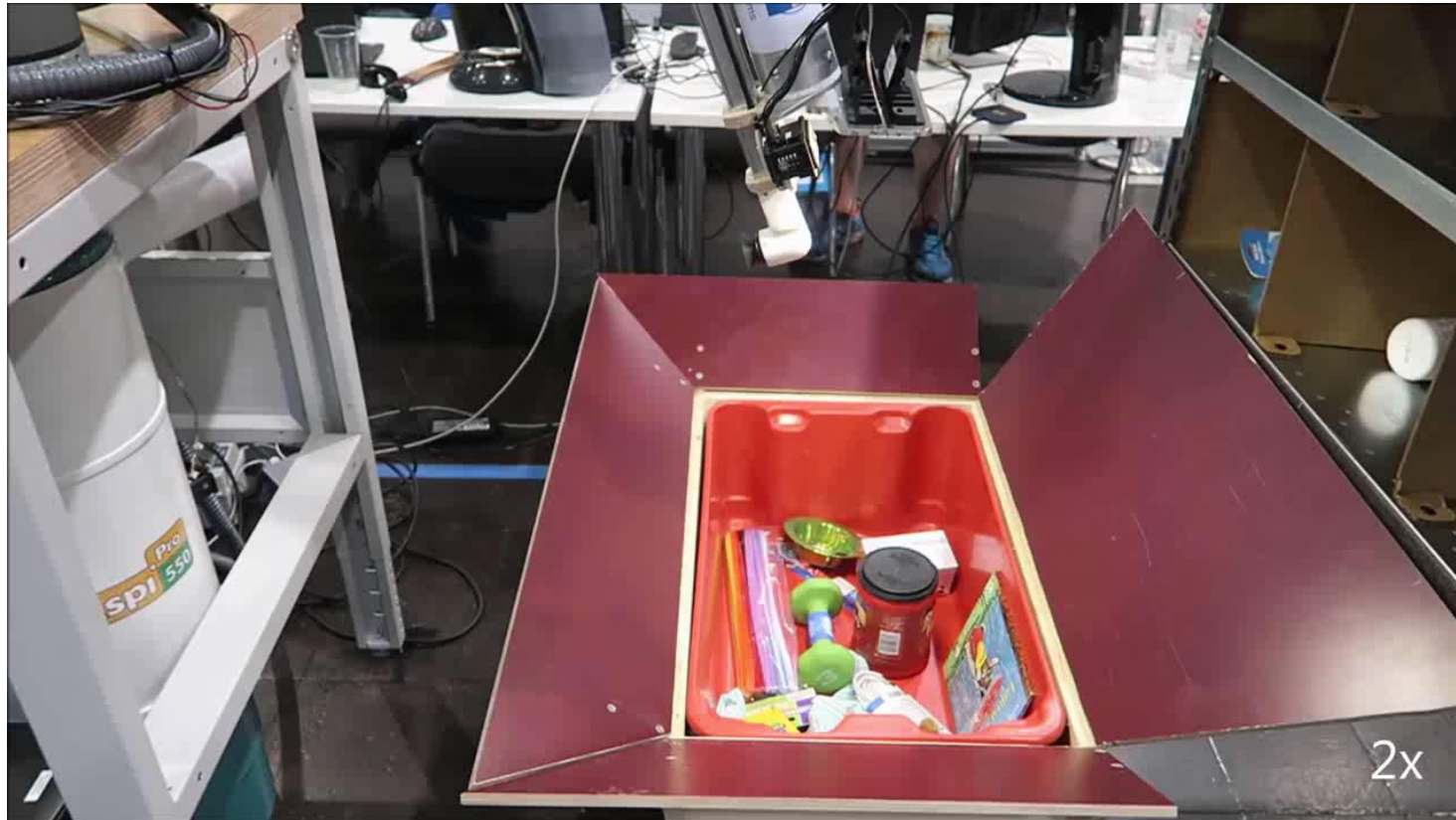
Detection



Segmentation

[Schwarz et al. IJRR 2017]

Stowing



Picking



4x

NimbRo Picking APC 2016 Results



- 2nd Place Stowing
- 3rd Place Picking



[Schwarz et al. IJRR 2017]

Amazon Robotics Challenge 2017

- Quick learning of novel objects
- Training with rendered scenes

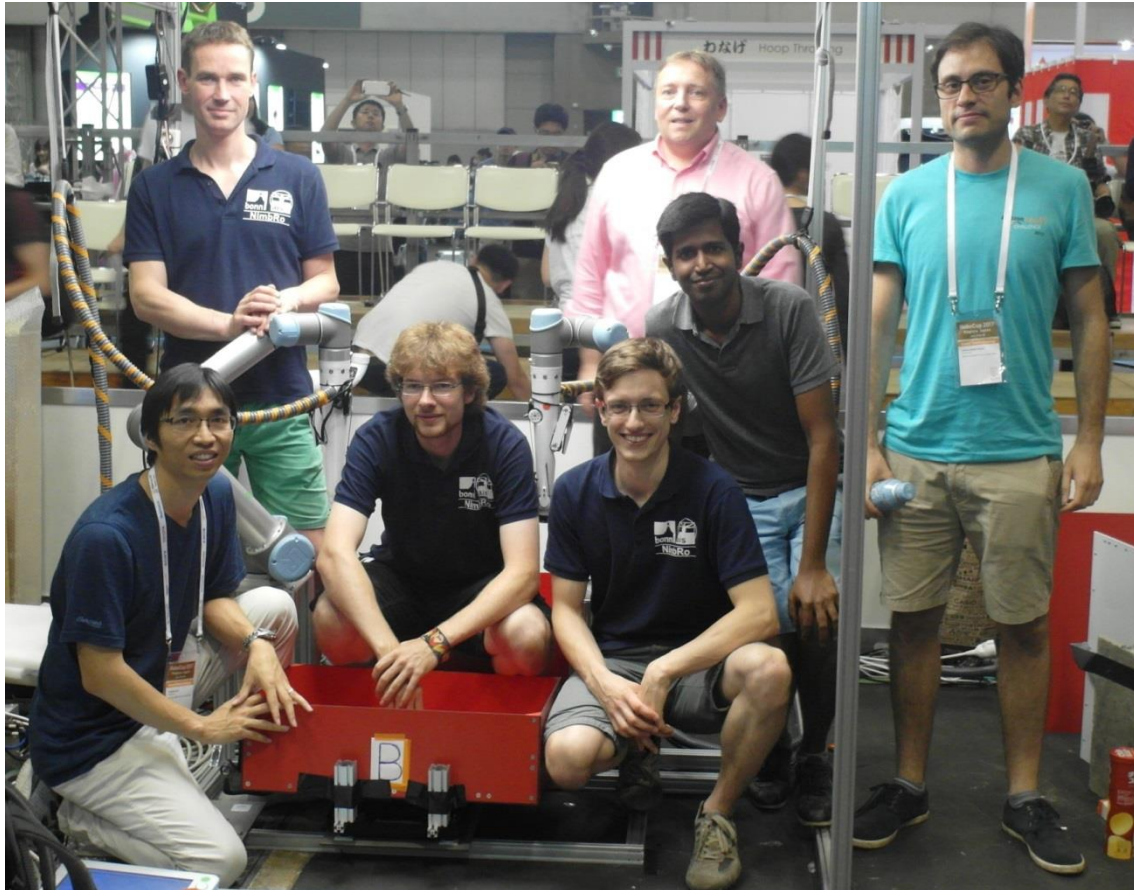


Amazon Robotics Challenge 2017 Final



NimbRo Picking 2017 Team

- 2nd place Pick
- 2nd place Stow-and-Pick Final



Conclusions

- Robot competitions **driving force** of technological development
- Direct comparison of different approaches to solving a task
- Outside own lab, at scheduled time
- Unleash **huge energies** and foster the **exchange** of ideas
- **Rules must be developed** to keep the challenges challenging
 - Meaningful for many research groups
 - Challenging, but not too hard
- Competitions **evaluate entire systems**
 - Unclear, to which component performance should be attributed to
 - => include specific tests for subsystems
- Help **identifying issues**
 - Weakest component must be improved
 - Starting point for research

We are Hiring!

- PhD students and postdocs
- ais.uni-bonn.de/jobs.html

