Humanoide Roboter für den Einsatz in menschenfeindlichen Umgebungen

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Autonome Intelligente Systeme

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Einige unserer Humanoiden Roboter

- Ausgestattet mit zahlreichen Sensoren und Gelenken
- Demonstration in komplexen Szenarien

Kommunikation

Serviceaufgaben

Fußball


Fußball

Menschenfeind-
liche Umgebungen

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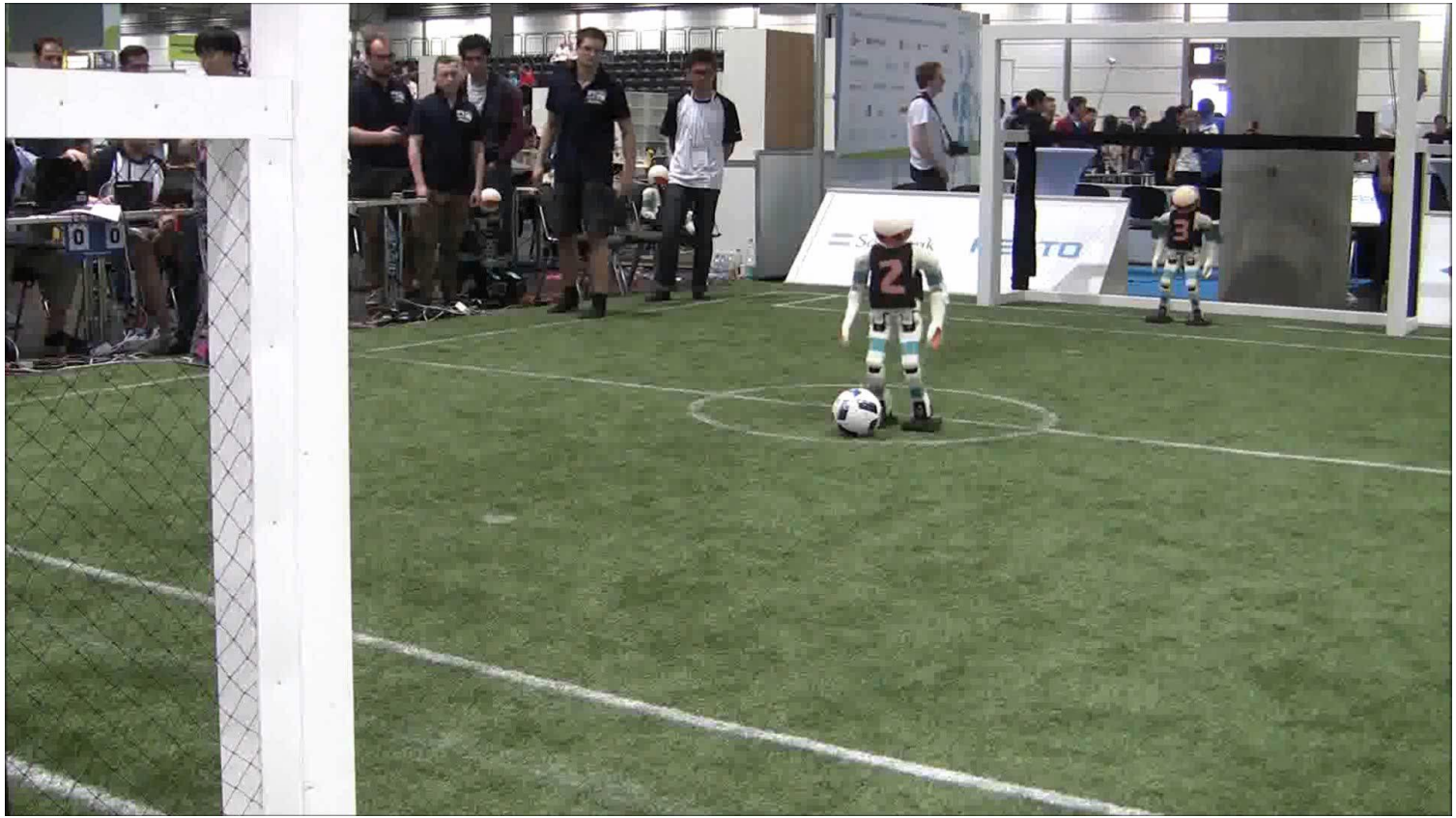
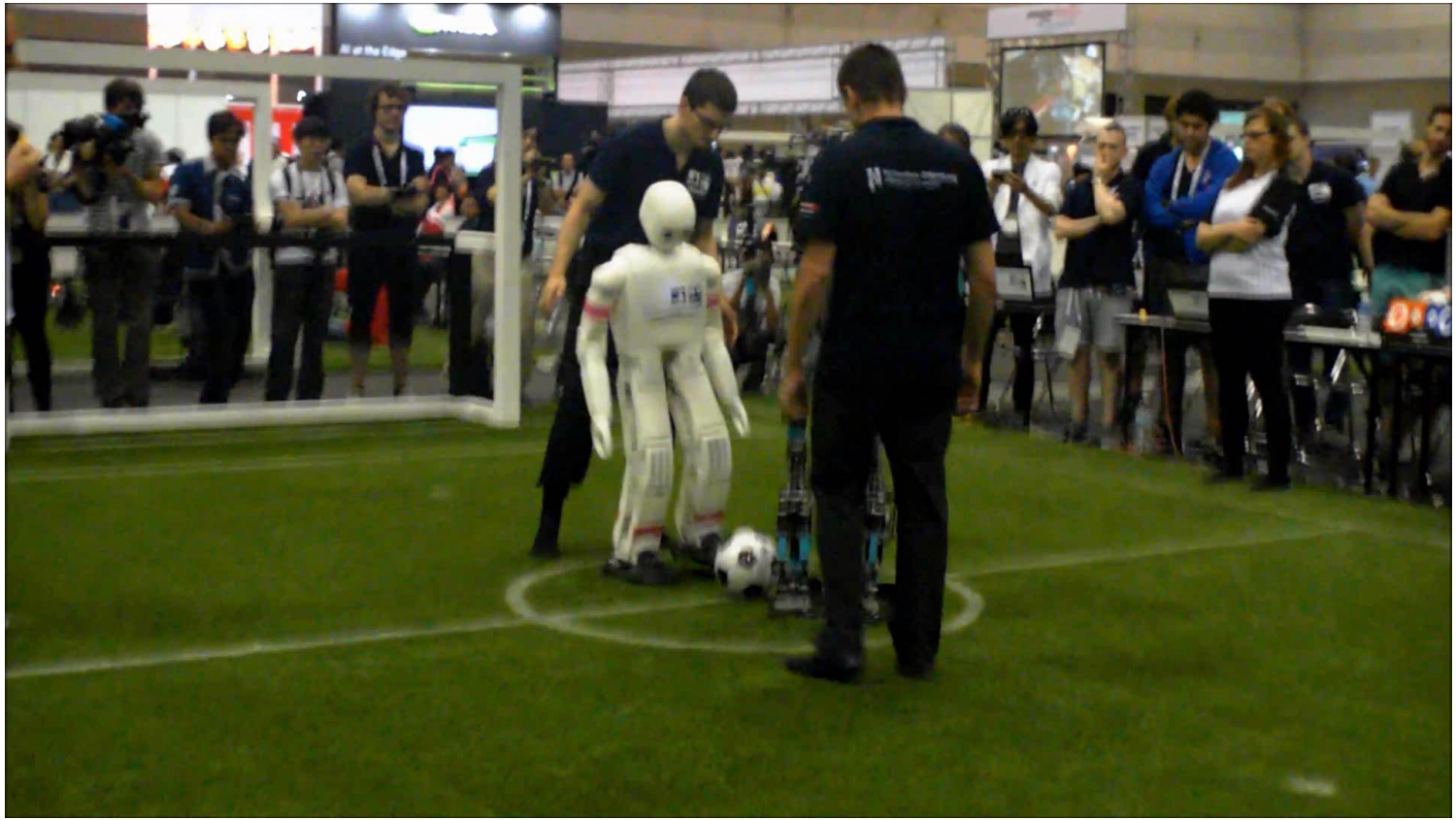
RoboCup 2016 TeenSize-Finale



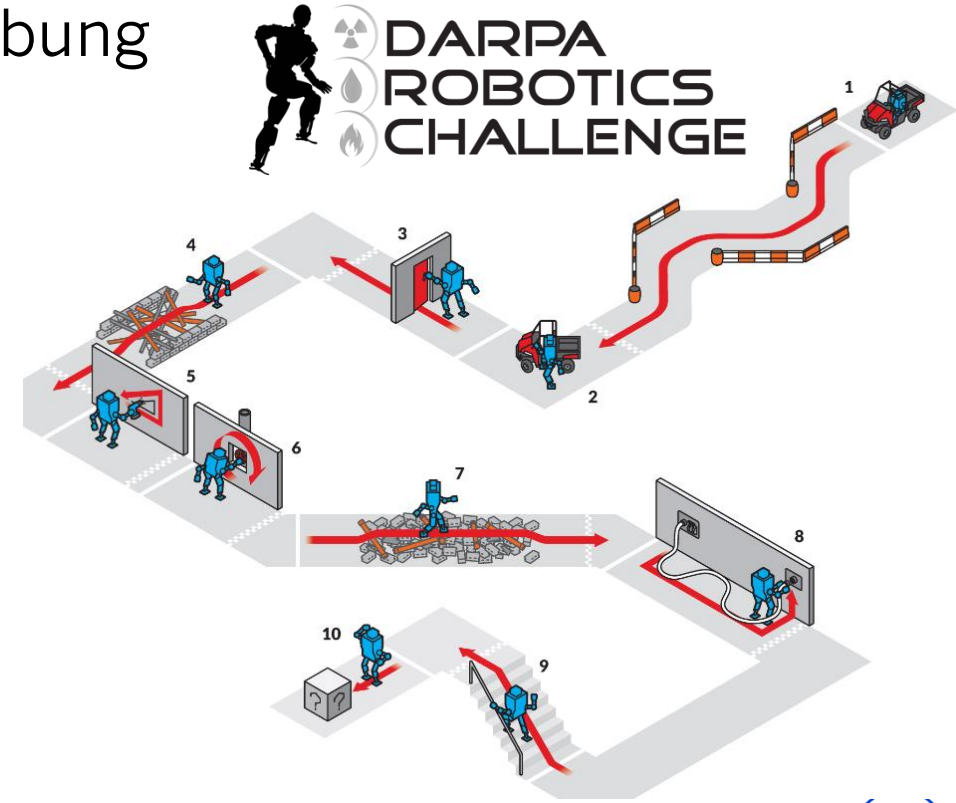
RoboCup 2017 AdultSize-Finale



Kognitiver Serviceroboter Cosero

DARPA Robotics Challenge

- Menschenfeindliche Umgebung
- Zahlreiche Aufgaben



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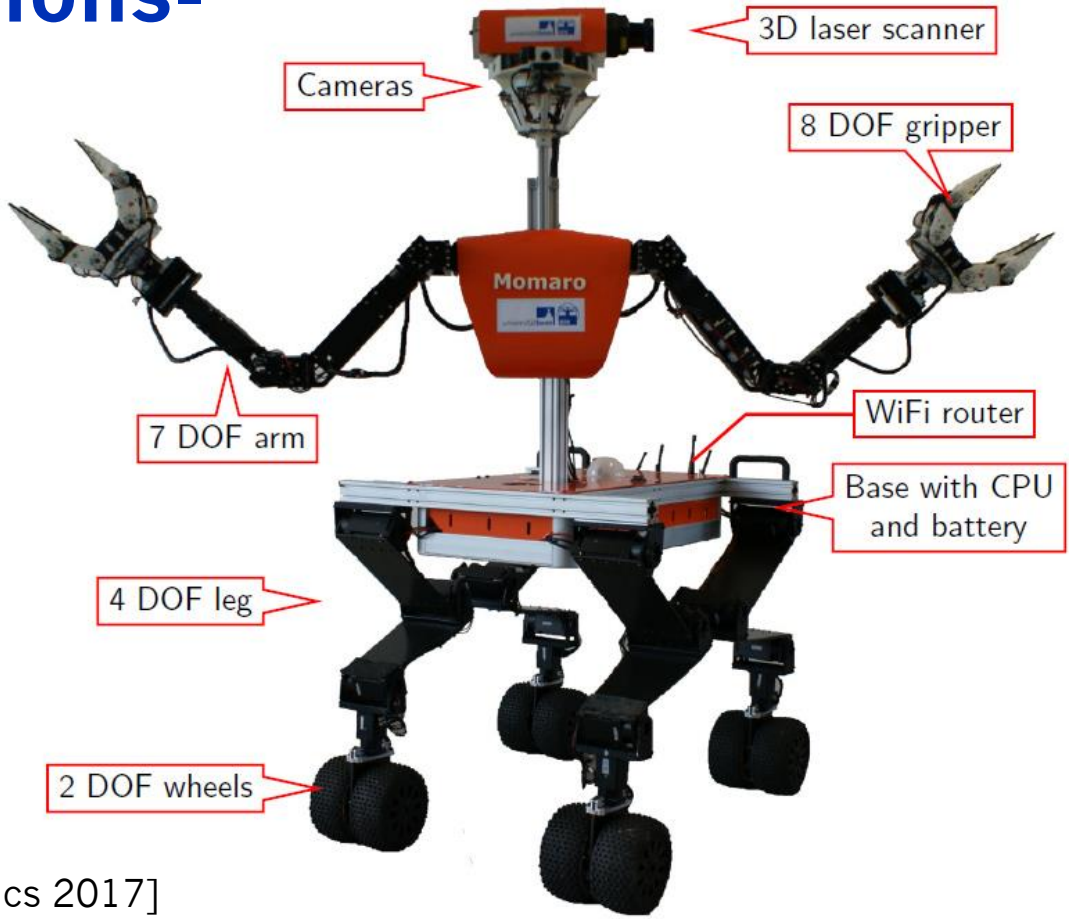
Mobiler Manipulations-Roboter Momaro

- Vier nachgiebige Beine mit lenkbaren Radpaaren
- Menschenähnlicher Oberkörper
- Sensorkopf
  - 3D-Laserscanner
  - IMU, Kameras



[Schwarz et al. Journal of Field Robotics 2017]

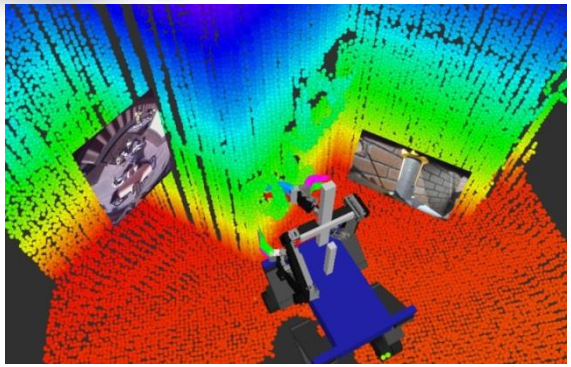
Führen eines Fahrzeugs

Ausstieg

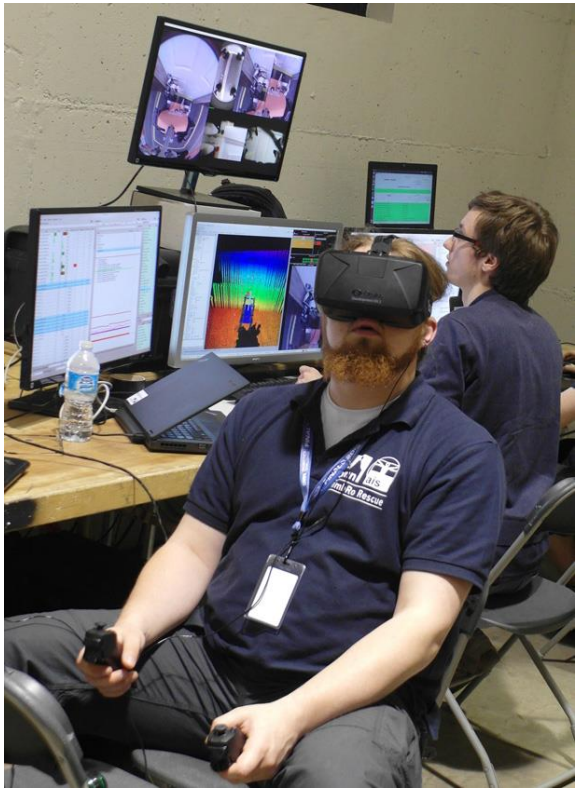
Operator-Interface für die Manipulation

- 3D-Head-mounted Display

- 3D-Umgebungs-modell + Bilder

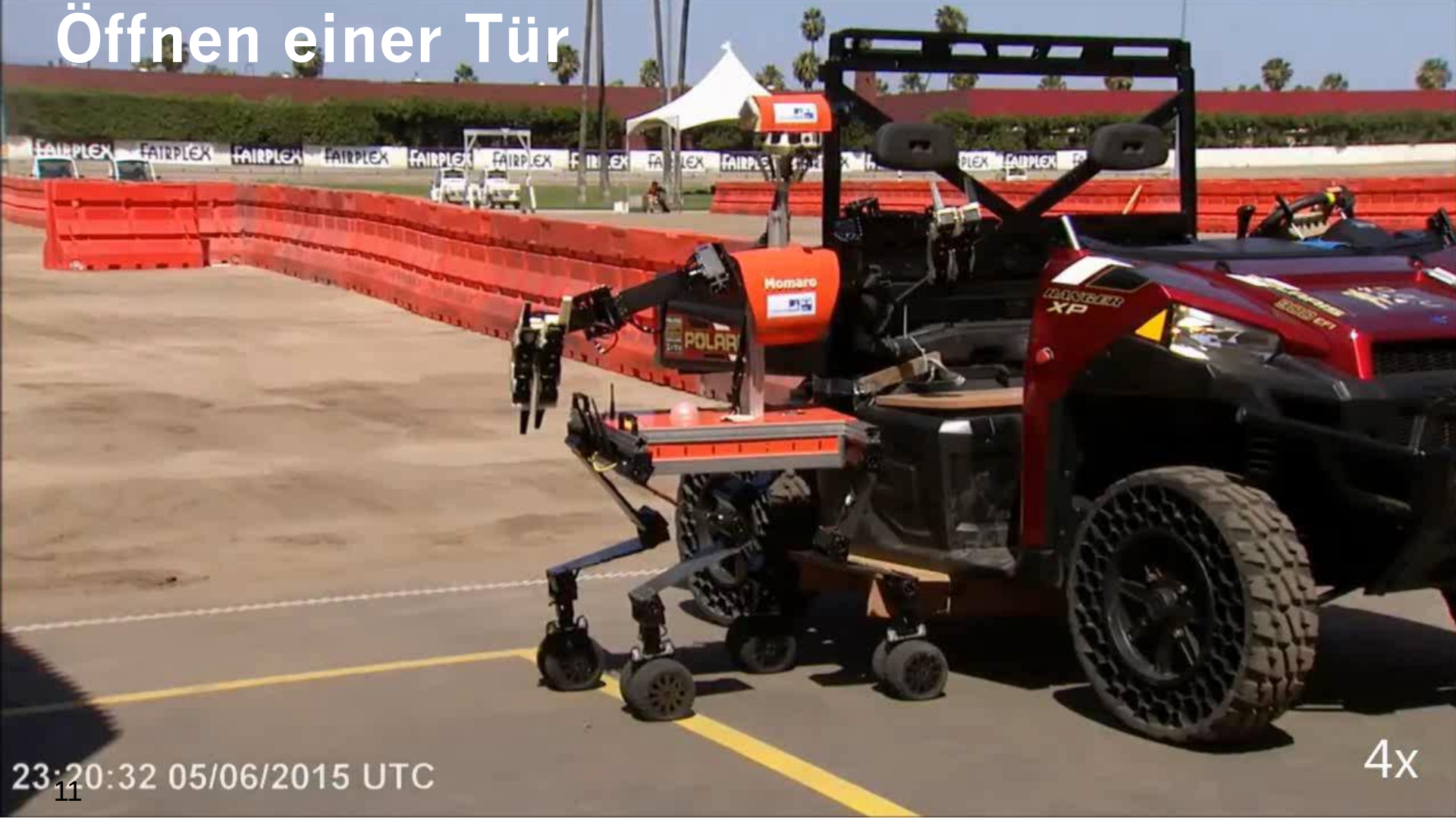


- 6D-Magnet-Tracker



[Rodehutskors et al., Humanoids 2015]

Öffnen einer Tür

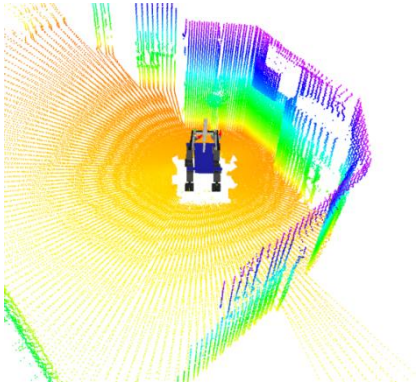


Lokale Multiresolutions-Surfel-Karten

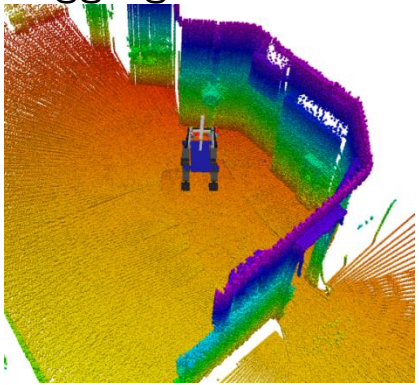
- Registrierung und Aggregation von 3D-Laserscans
- Lokales Multiresolutionsgrid
- Surfel in den Zellen

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

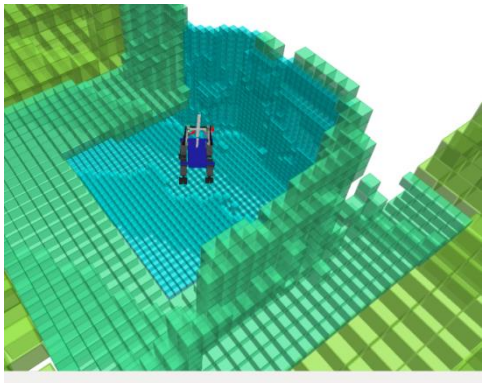
3D scan



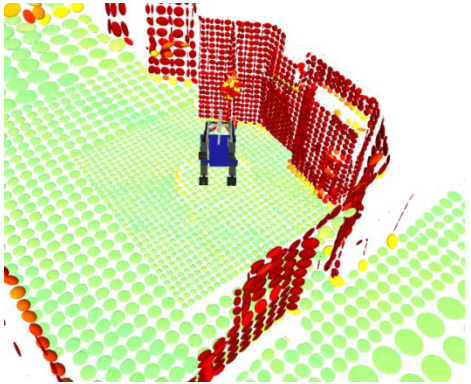
Aggregated scans



Multiresolution grid

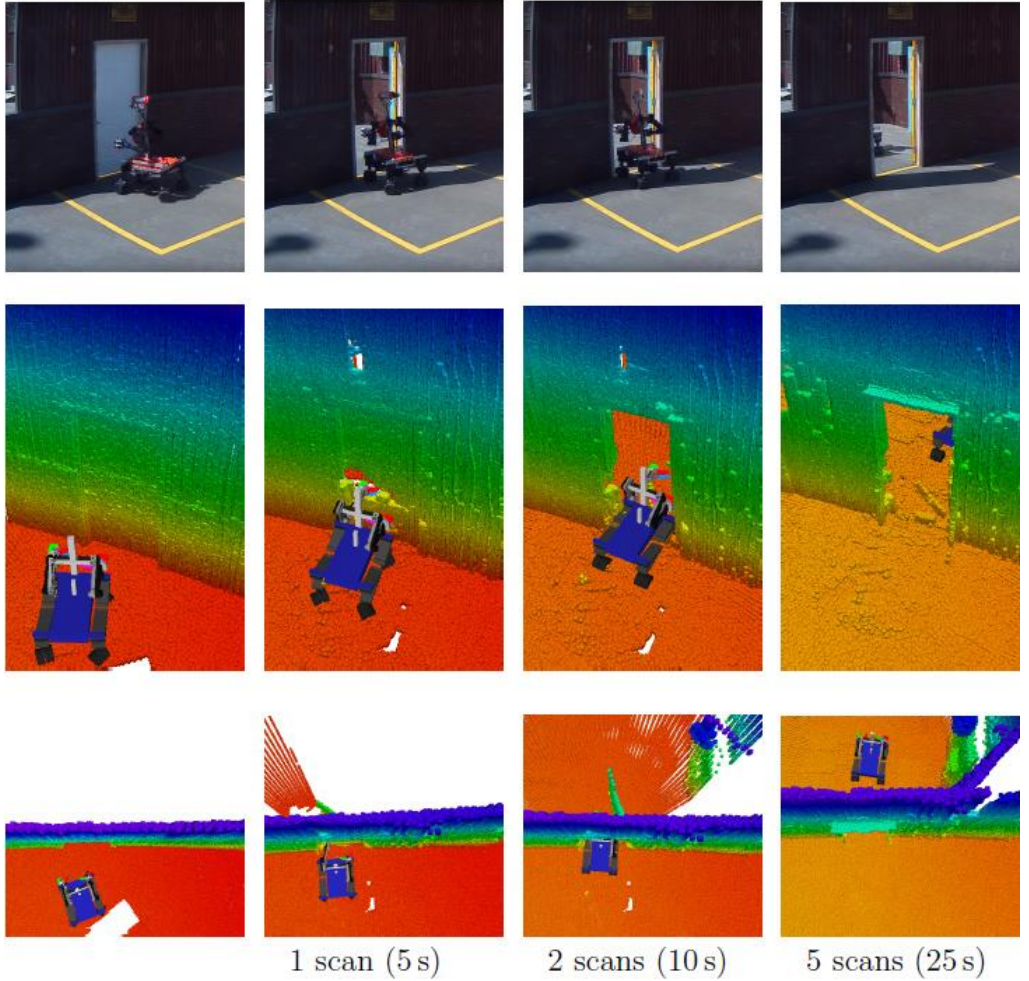


Surfels



Filterung beweglicher Objekte

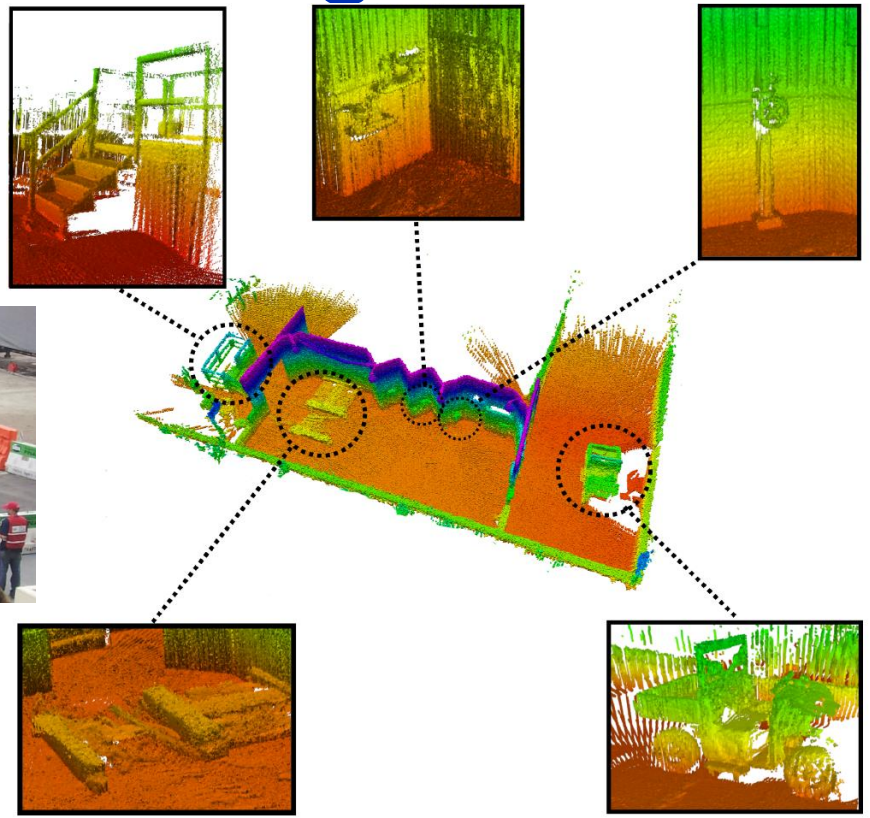
- Distanzmessungen sind auch Freimessungen
- Aktualisierung der Belegtheitsschätzung in jeder Zelle



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

Allozentrische 3D-Kartierung

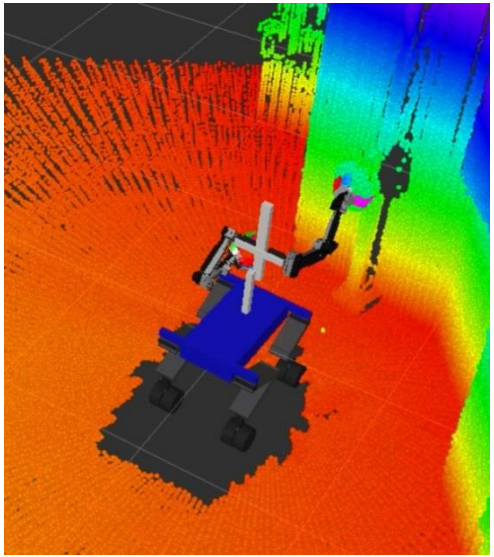
- Registrierung egozentrischer Karten durch Graphoptimierung



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

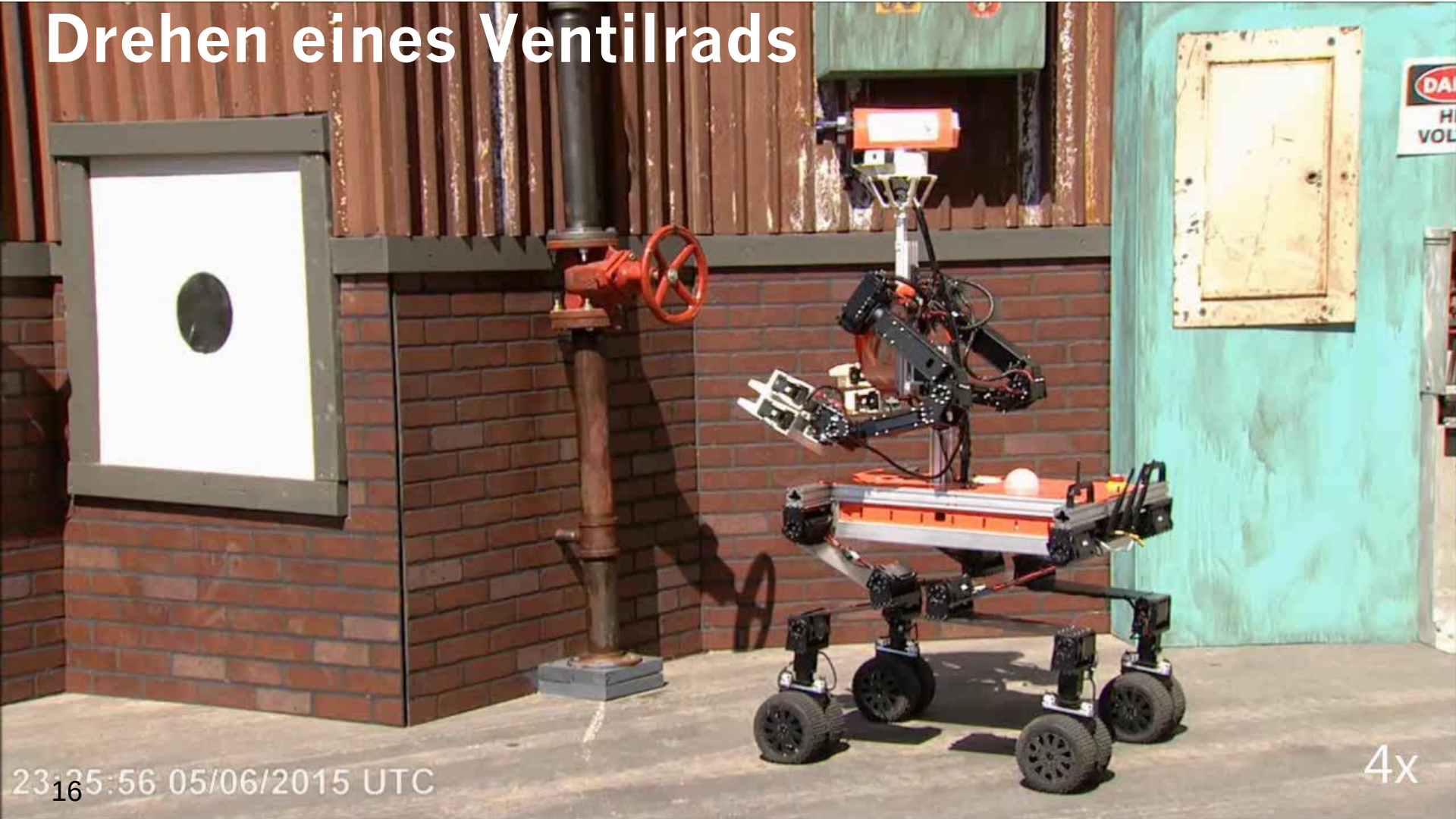
Schnittstelle zum Drehen des Ventilrads

- Interaktive Registrierung eines Radmodells mit der 3D-Karte



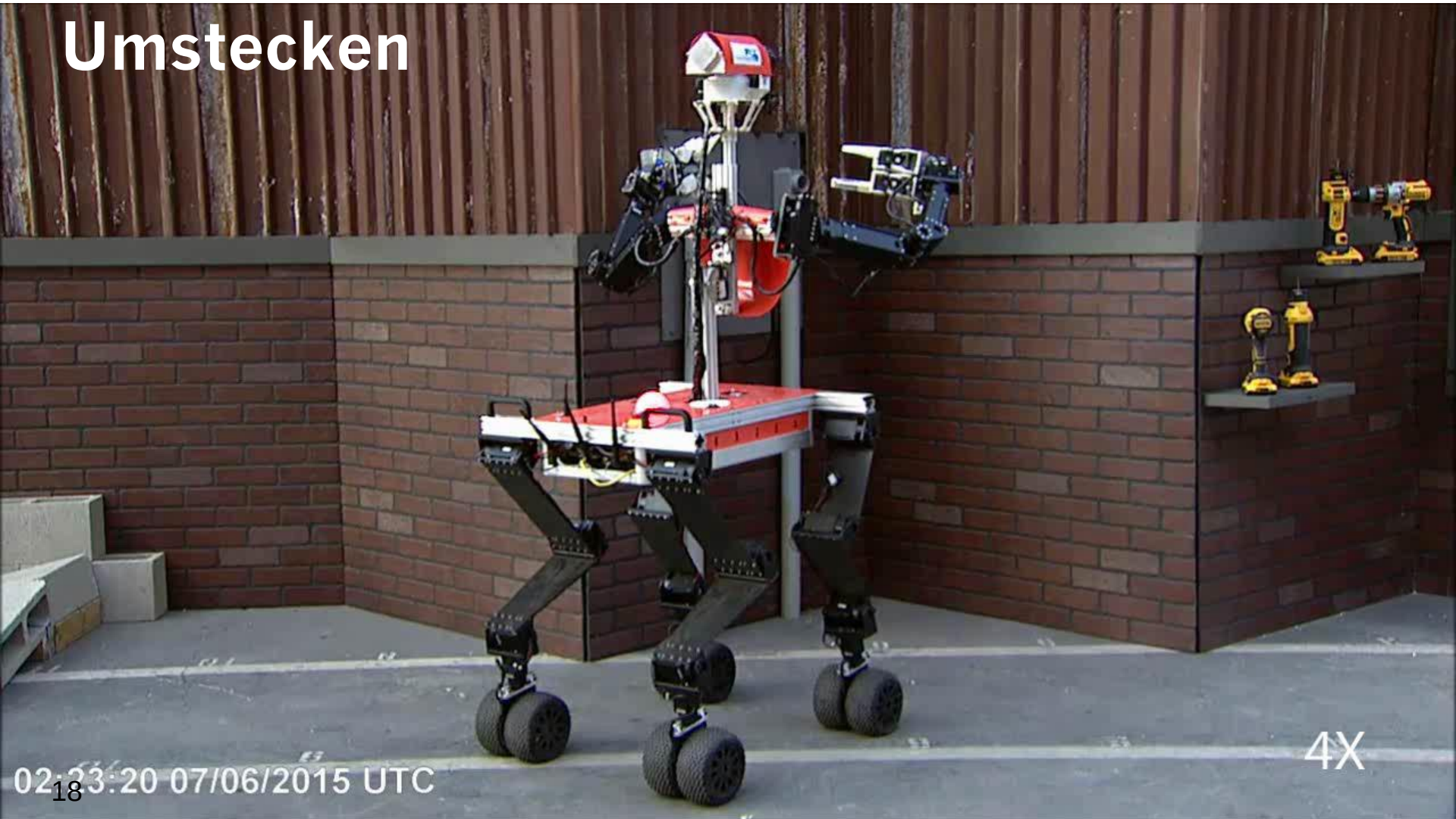
[Schwarz et al. Journal of Field Robotics 2017]

Drehen eines Ventilrads

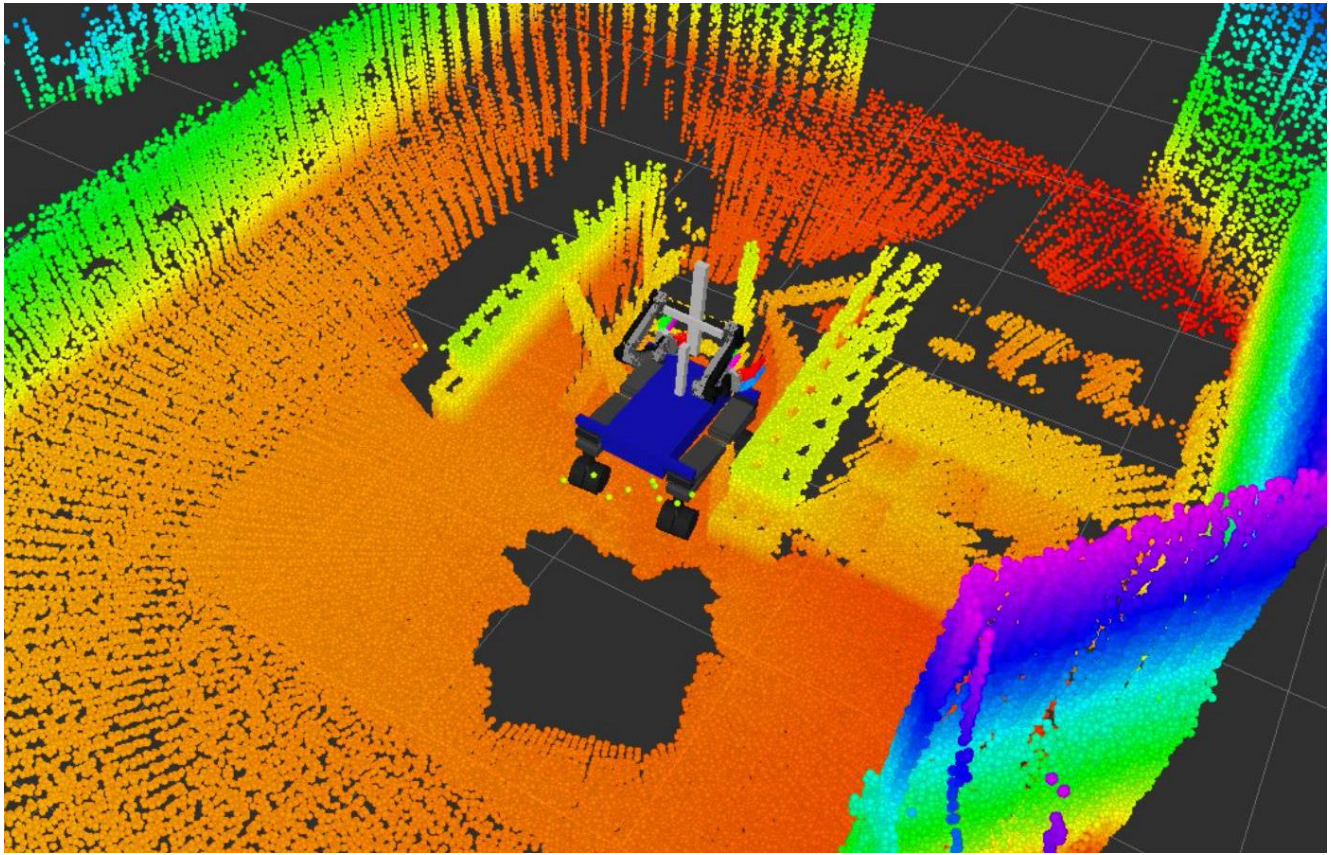


Umlegen eines Schalters

Umstecken

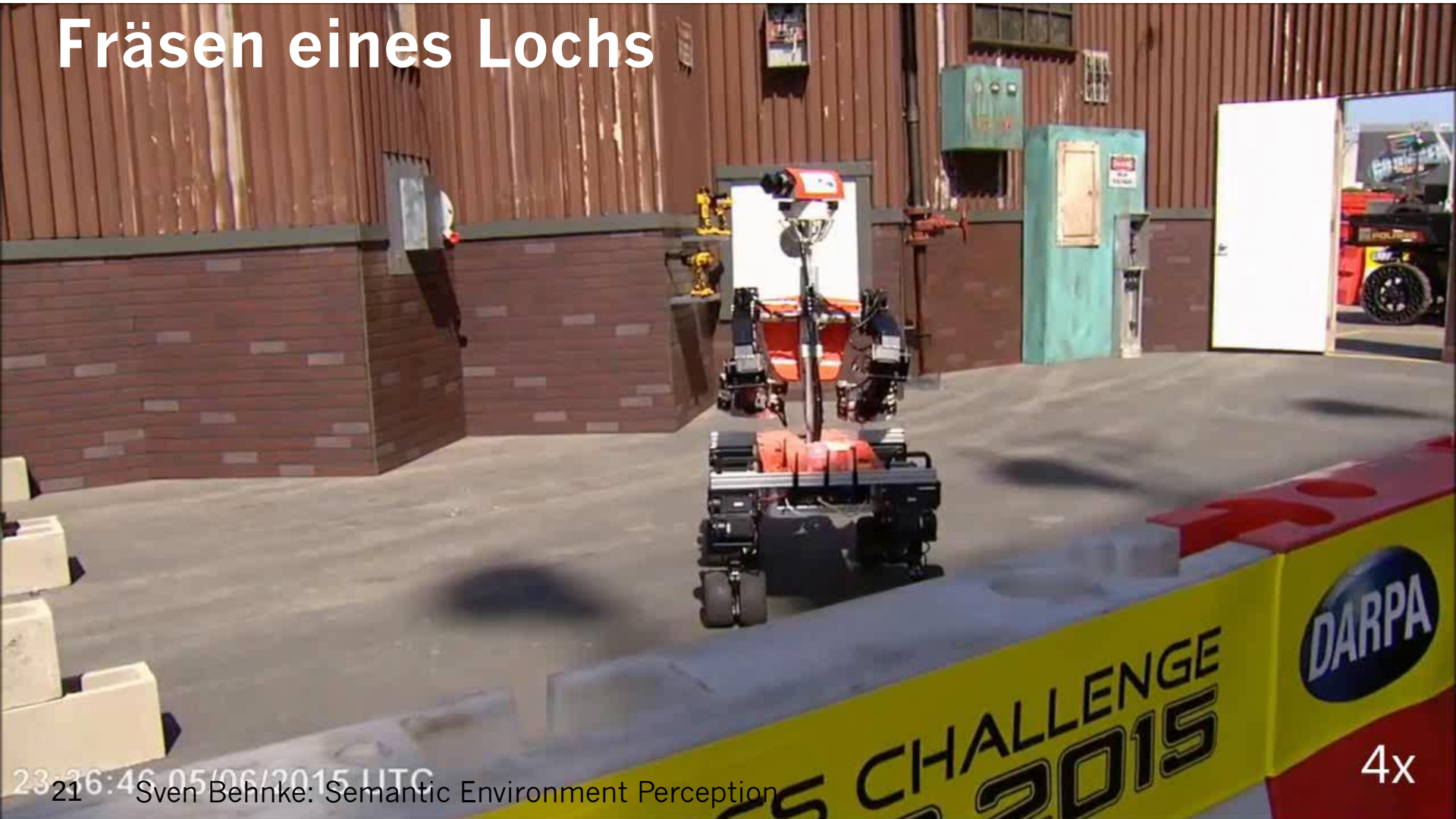


Überwindung von Hindernissen



Überwindung von Hindernissen

Fräsen eines Lochs

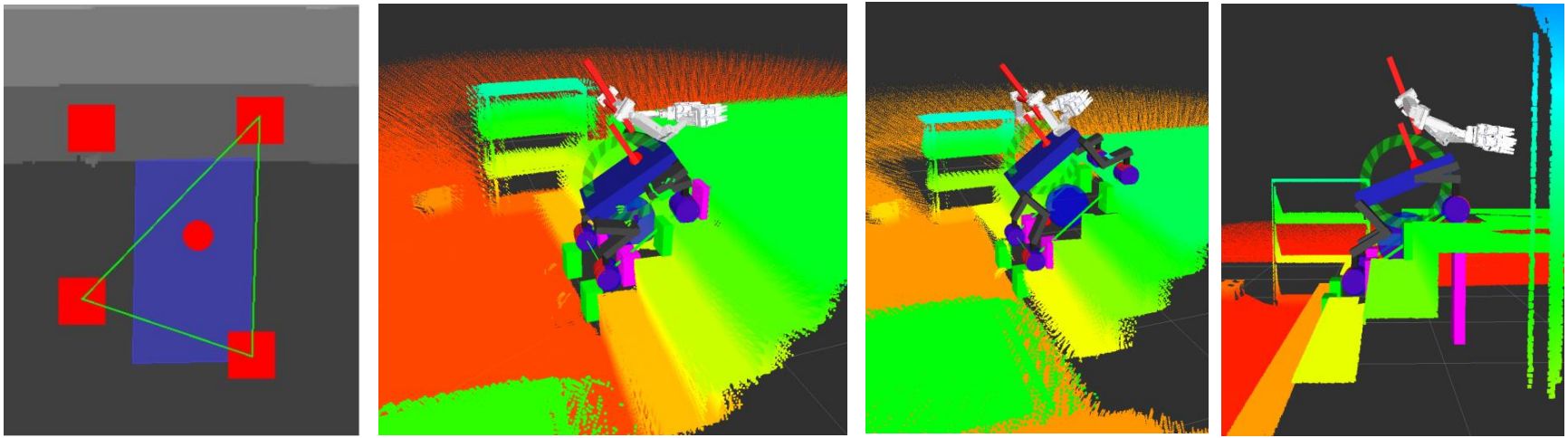


Team NimbRo Rescue

Bestes Europäisches Team (4. Platz)
Sieben von acht Aufgaben in 34 Min. gelöst

Treppensteigen

- Identifikation des Beines für den nächsten Schritt
- Gewichtsverlagerung: Sagittal, lateral, Raddrehungen
- Schritt auf horizontale Fläche nach Höhenunterschied



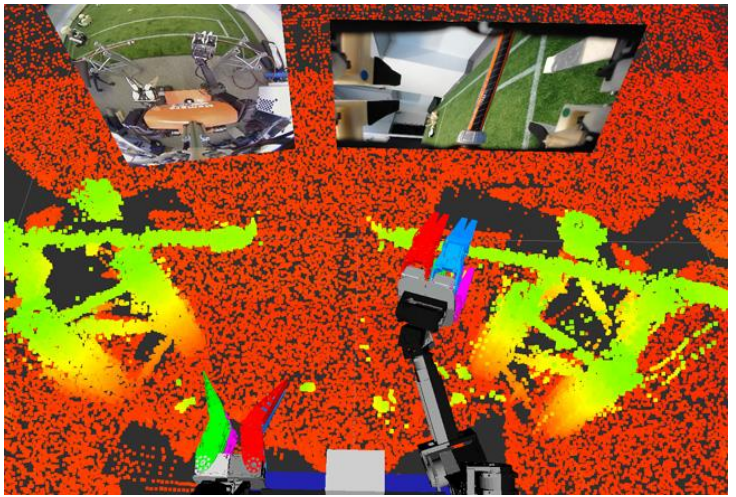
[Schwarz et al., ICRA 2016]

Treppen-Robben

Verbindung von Schläuchen

- Zweiarmige Aufgabe
  - Greifen des linken Schlauchs
  - Greifen des rechten Schlauchs
  - Verbindung beider Schläuche
- 10/11 Versuche erfolgreich
- Ausführungszeiten

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

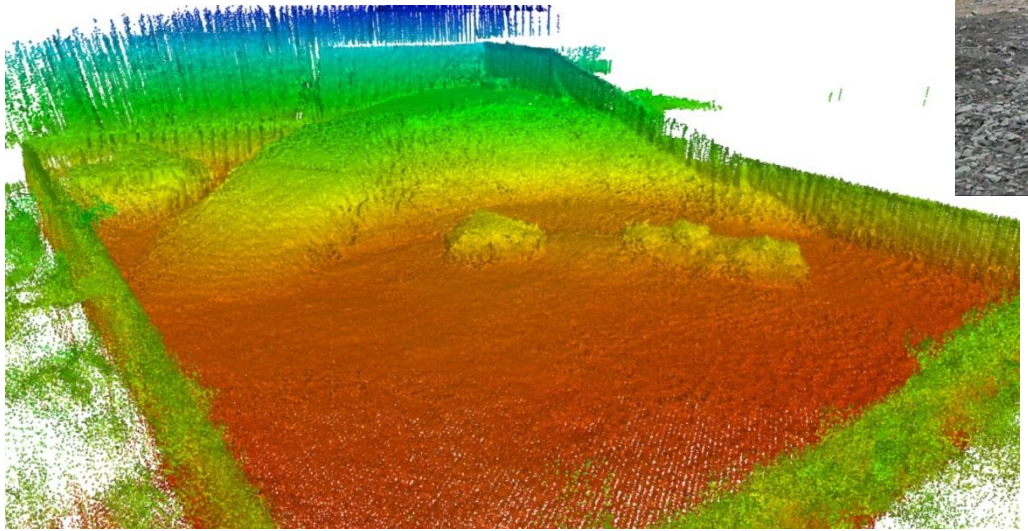


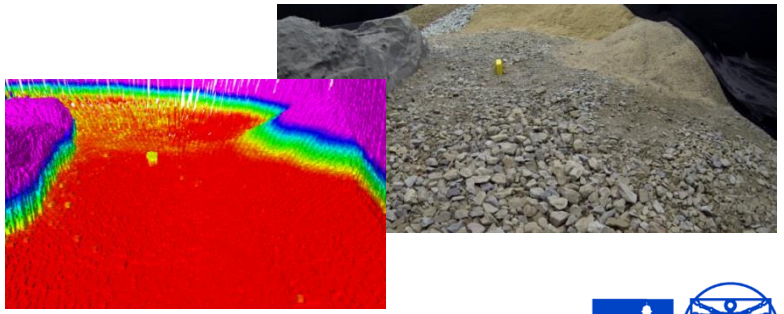
[Rodehutskors et al., Humanoids 2015]

DLR SpaceBot Cup 2015

- Mobile Manipulation im Gelände

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

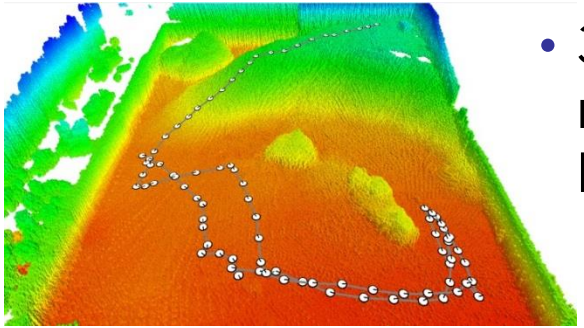


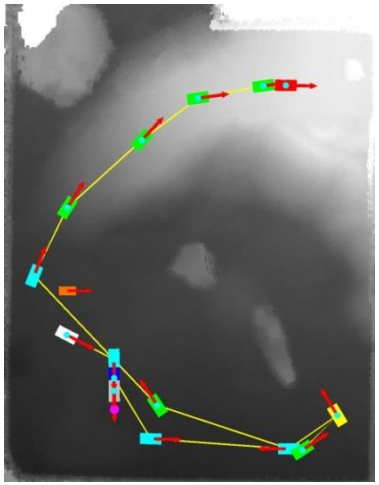


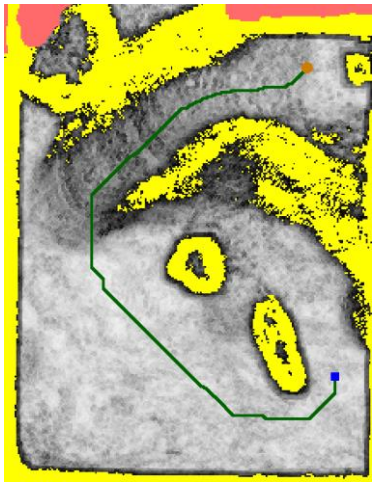
DLR SpaceBot Camp 2015

Autonome Missionsausführung

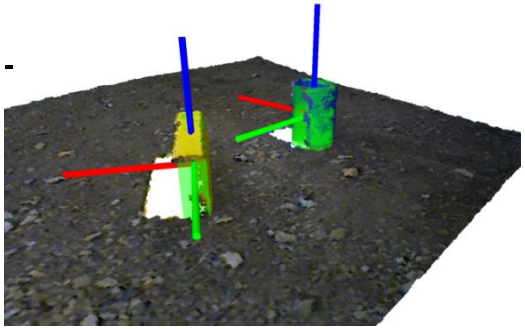
- 3D-Kartierung, Lokalisierung, Missions- und Navigations-planung

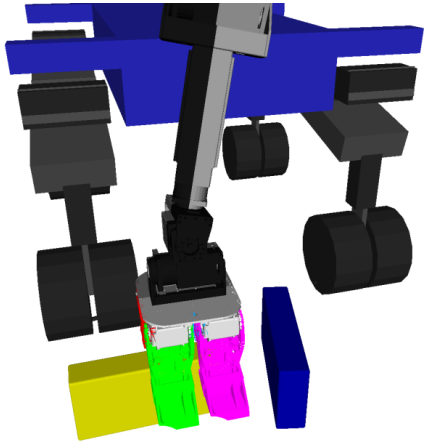






- 3D-Objektwahr-nehmung und Handhabung



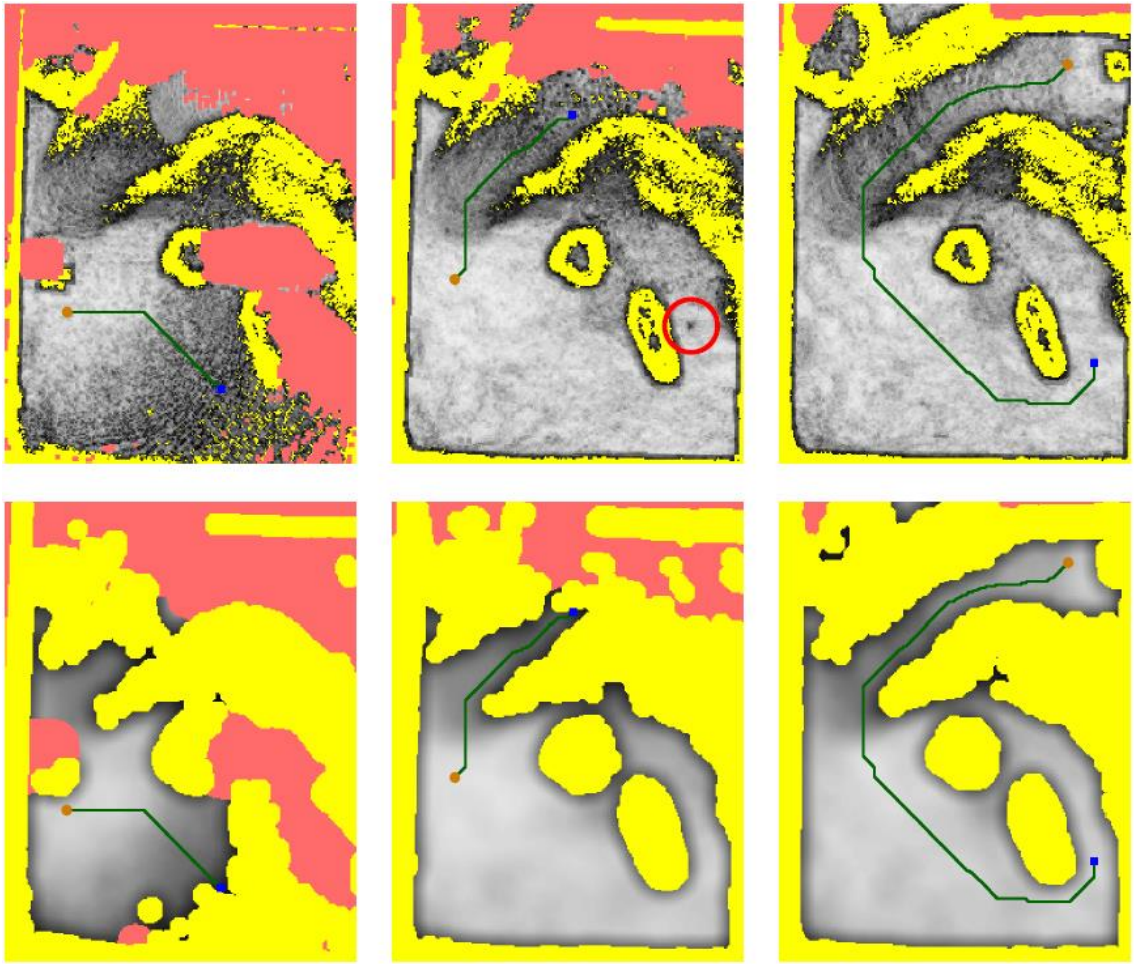


[Schwarz et al. Frontiers 2016]

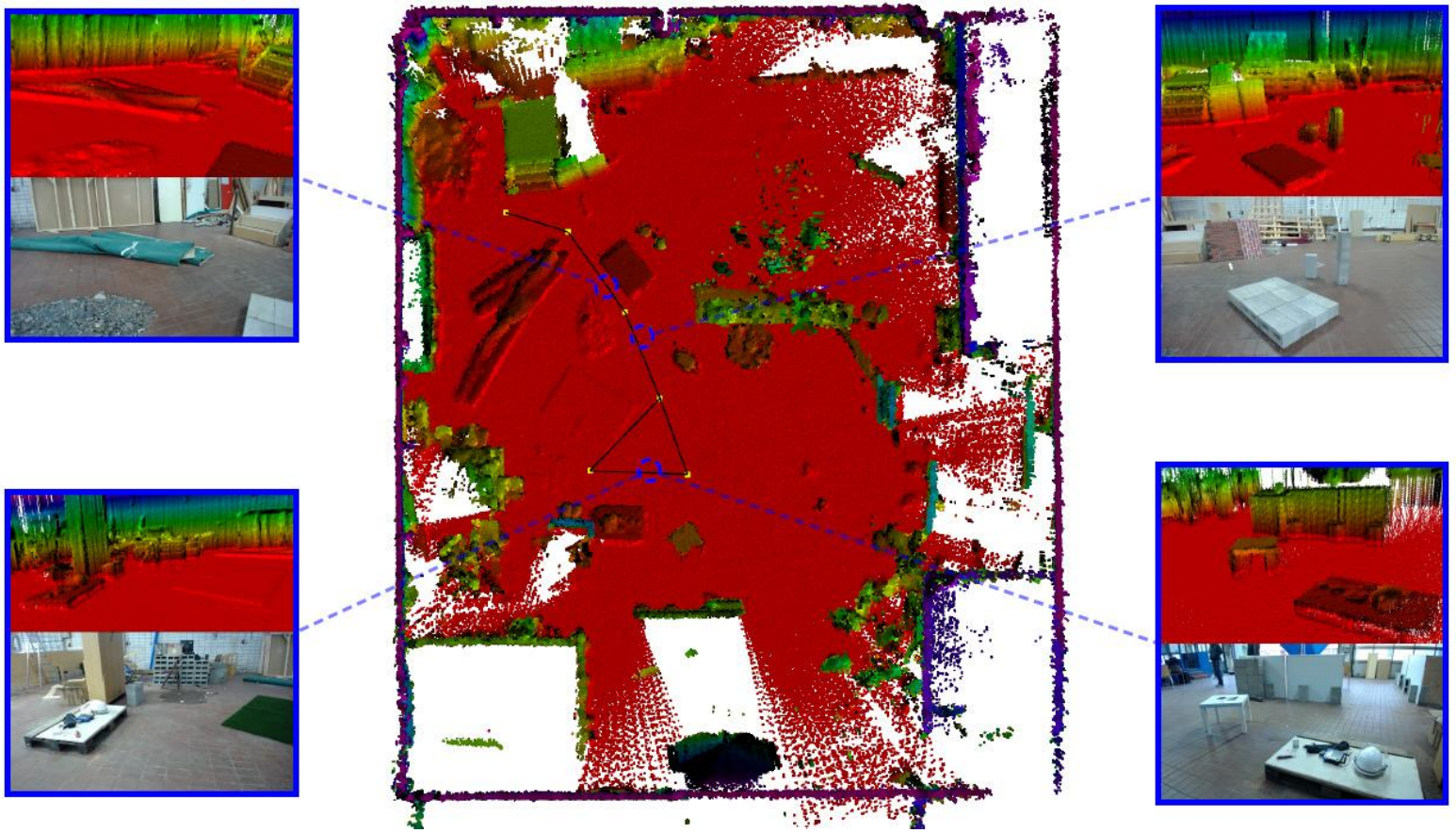
Navigations-planung

- Kosten aus lokalen Höhenunter-schieden
- A*-Pfadplanung

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



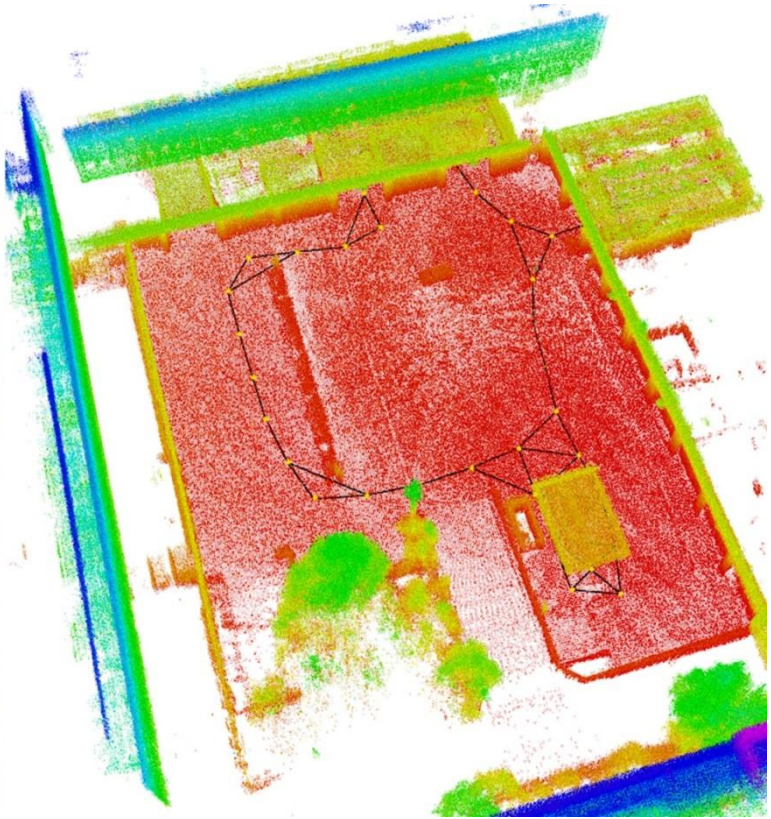
3D-Karte



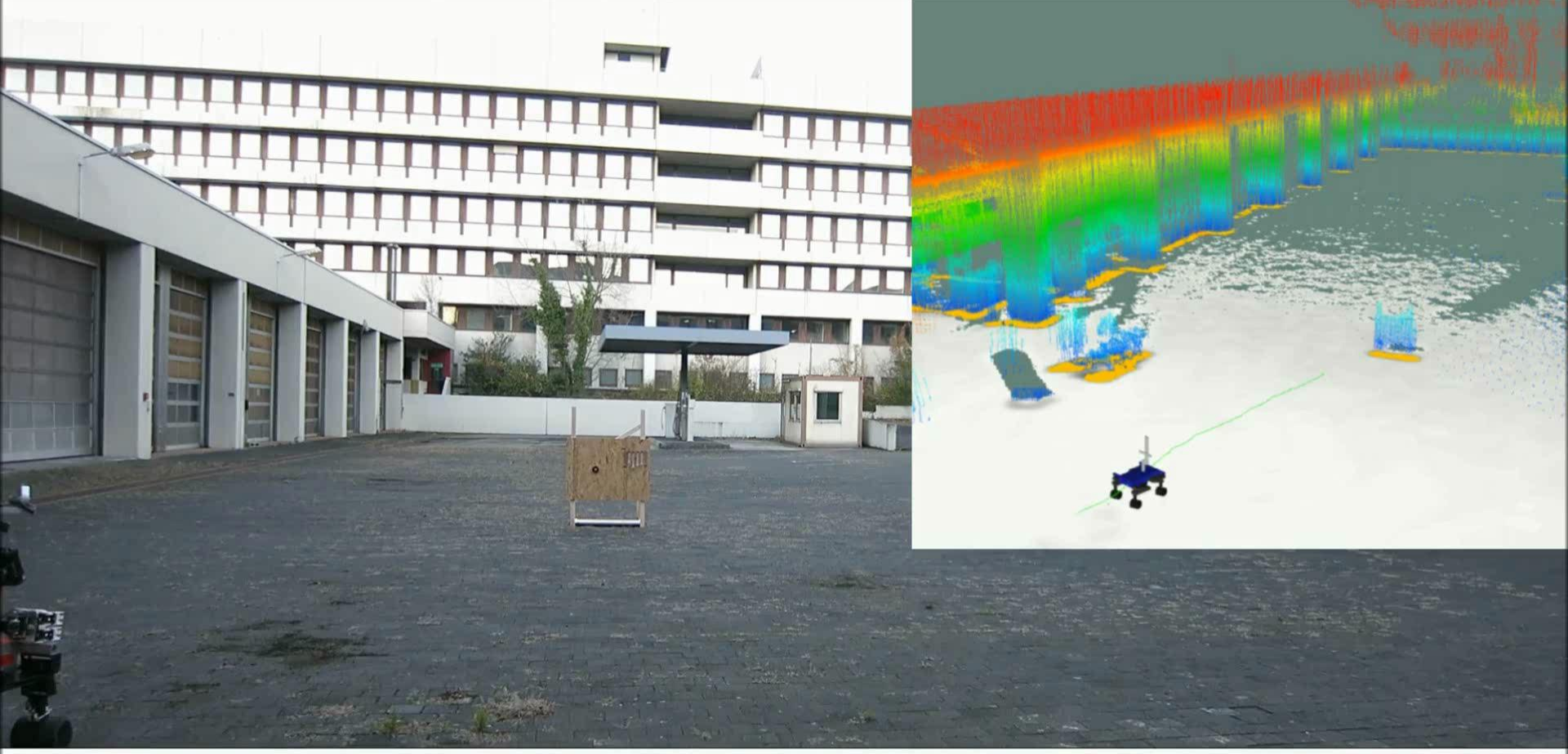
Neuer Sensorkopf

- Kontinuierlich rotierender Velodyne Puck VLP-16
  - 300,000 3D-Punkte/s
  - 100 m Messreichweite
  - Sphärisches Sichtfeld
- Drei weitwinklige Farbkameras (totales FoV 210×103°)
- Kinect V2 RGB-D-Kamera mit Schwenk- Neigegelenk

3D-Karte unseres Innenhofs

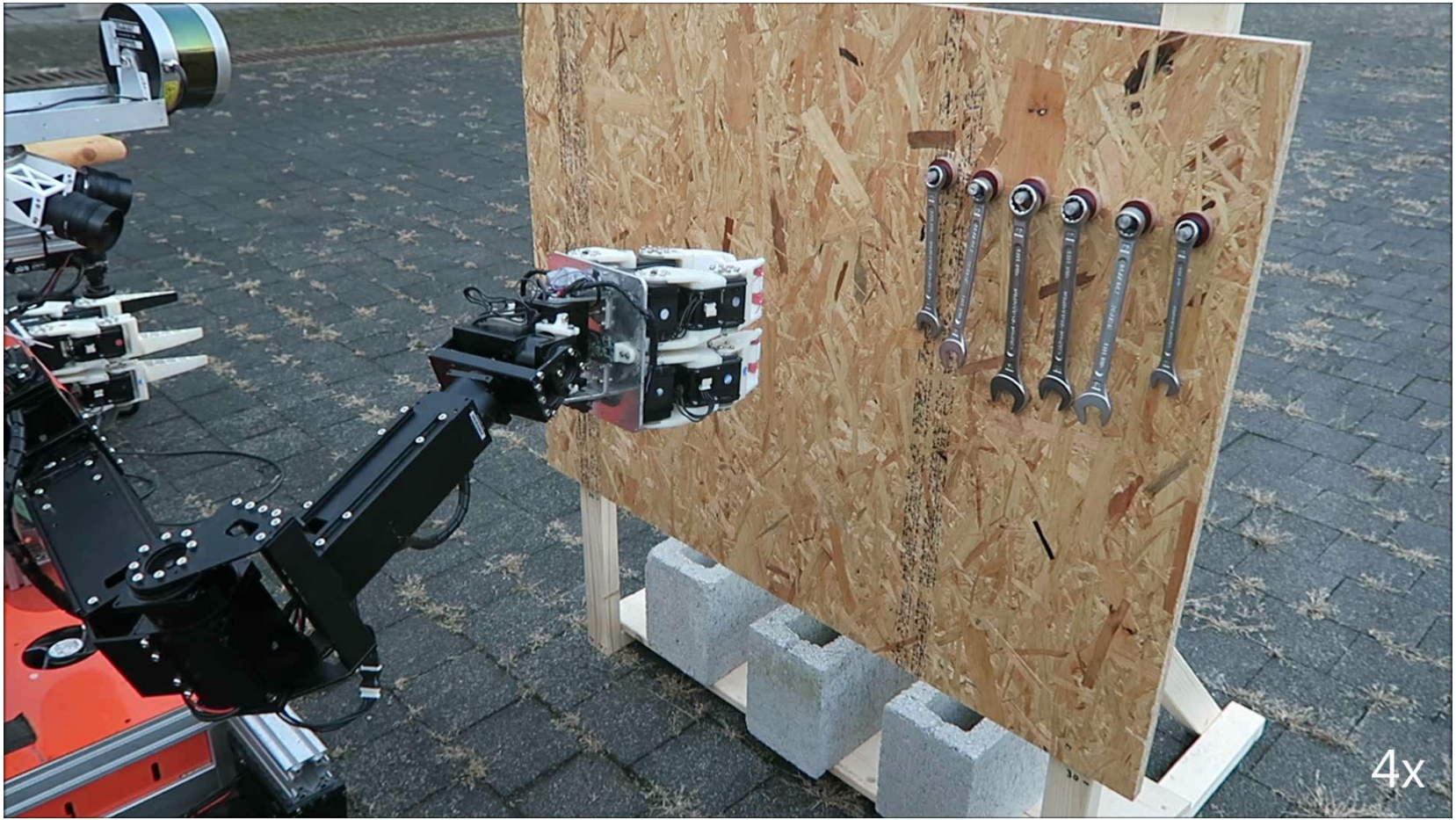


[Droeschel et al., Robotics and Autonomous Systems 2017]



Navigation in allocentric laser map (colored points)

Gebrauch eines Maulschlüssels



H2020 Project CENTAURO

Robust Mobility and Dexterous Manipulation in Disaster Response by Fullbody Telepresence in a Centaur-like Robot

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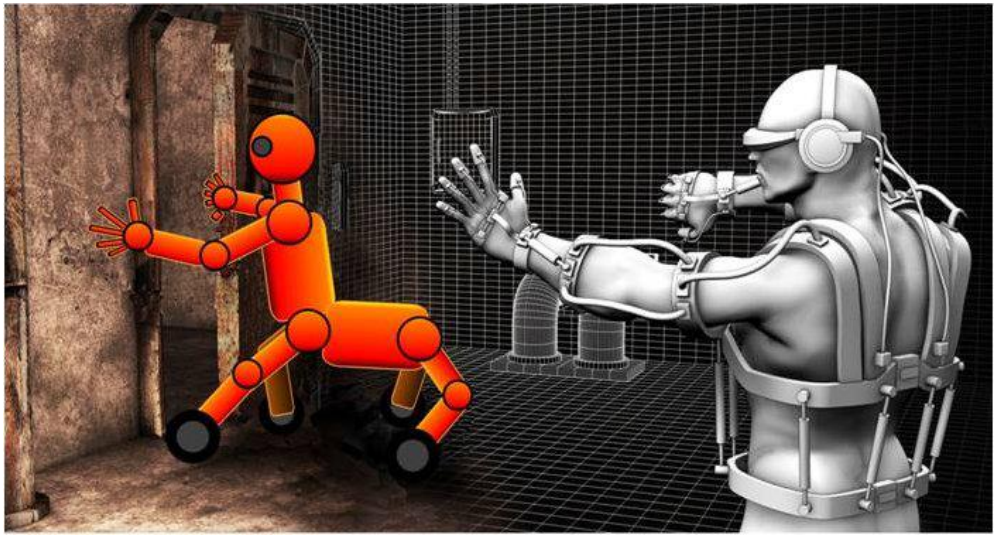
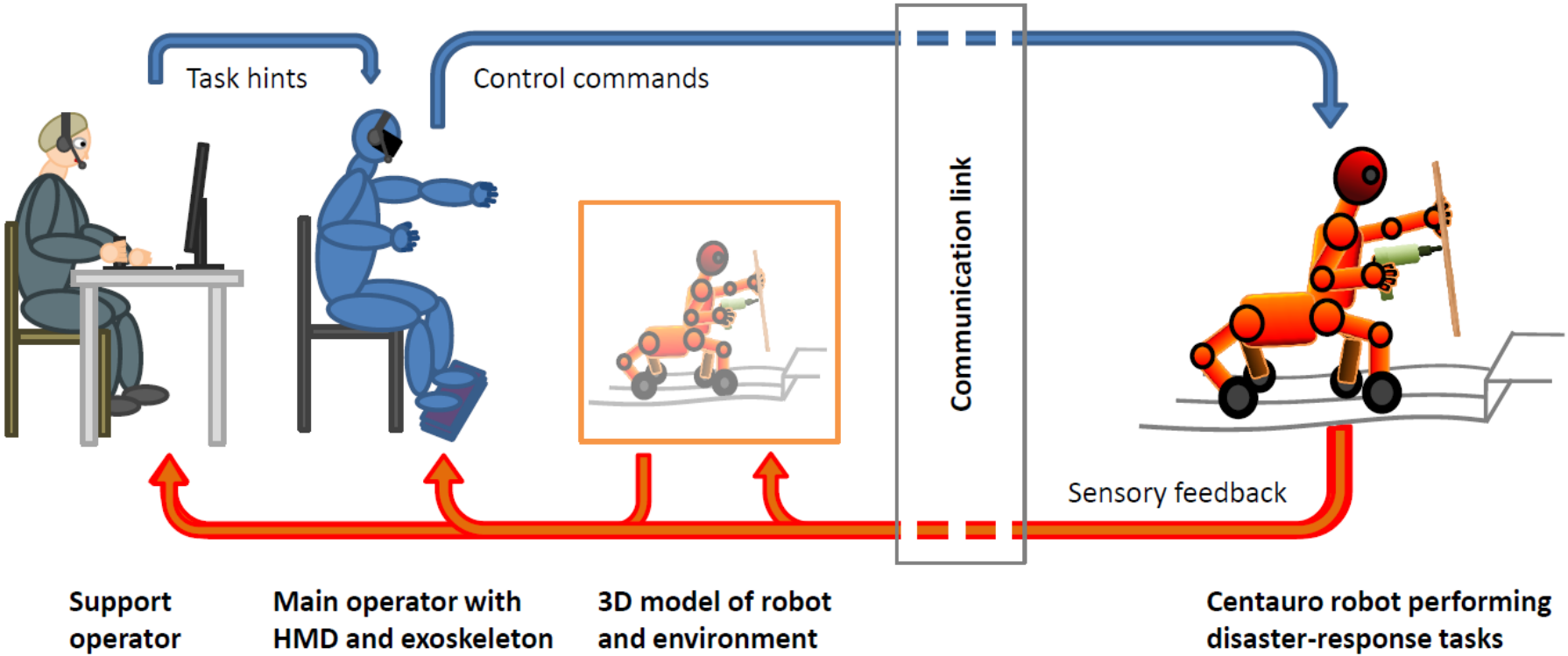
CENTAURO Objective

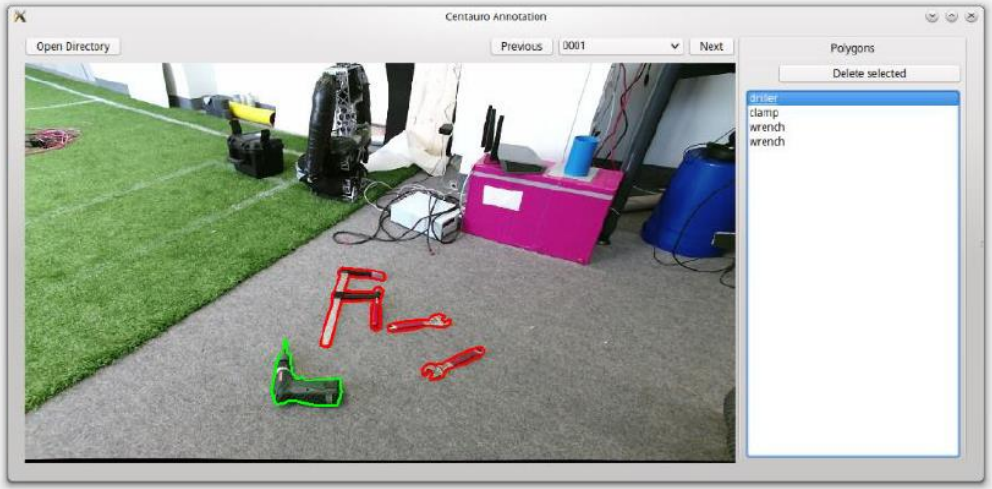
Development of a Human-robot system where a human operator is telepresent with its whole body in a Centaur-like robot, which is capable of robust locomotion and dexterous manipulation in the rough terrain and austere conditions characteristic of disasters



CENTAURO Approach



CENTAURO Workspace Perception Data Set



129 frames, 6 object classes

https://www.centauro-project.eu/data_multimedia/tools_data

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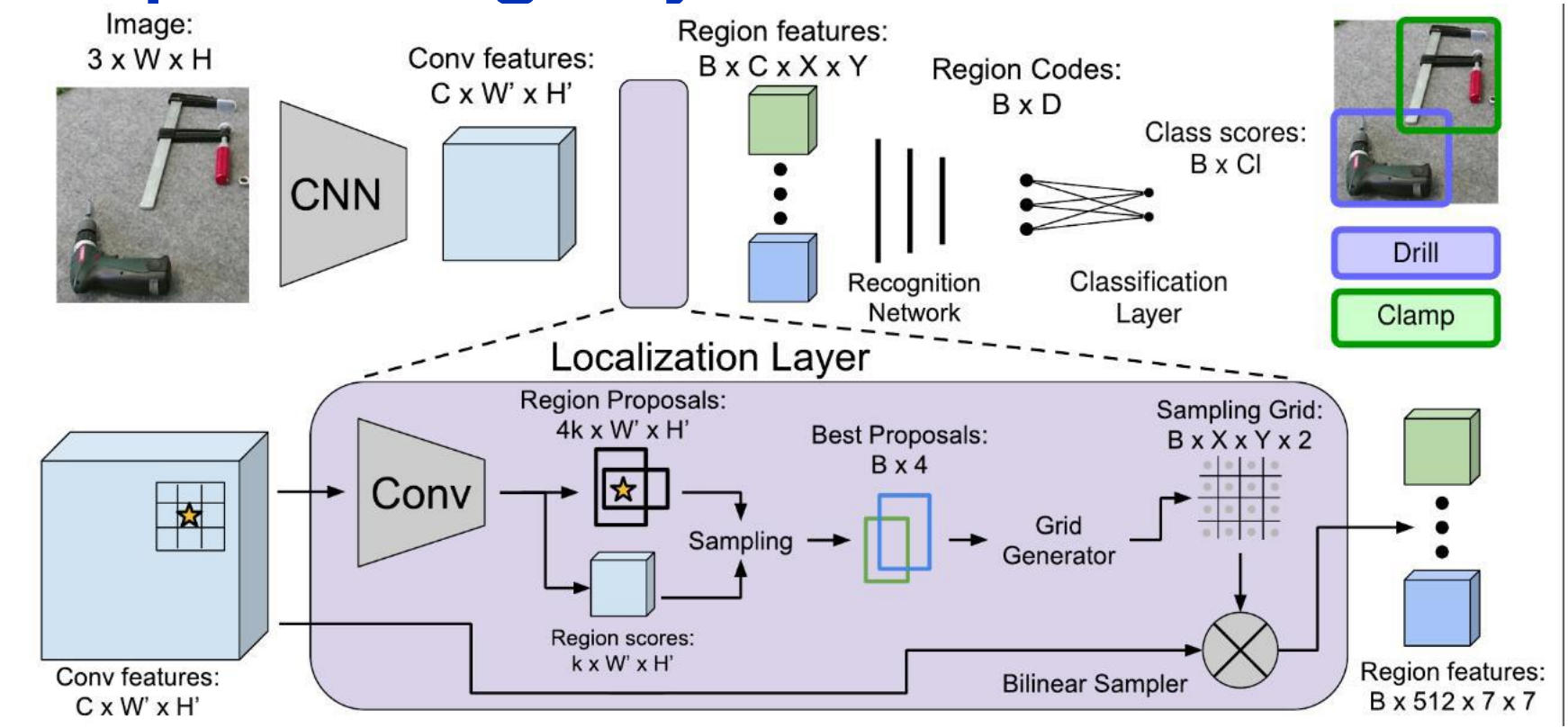
Deep Learning Object Detection



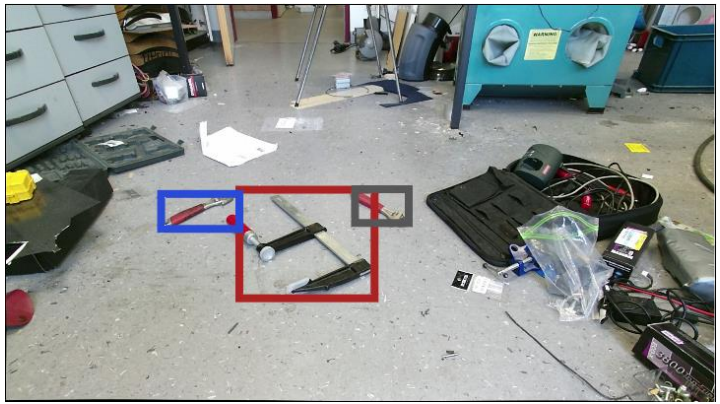
[Johnson et al. 2015]

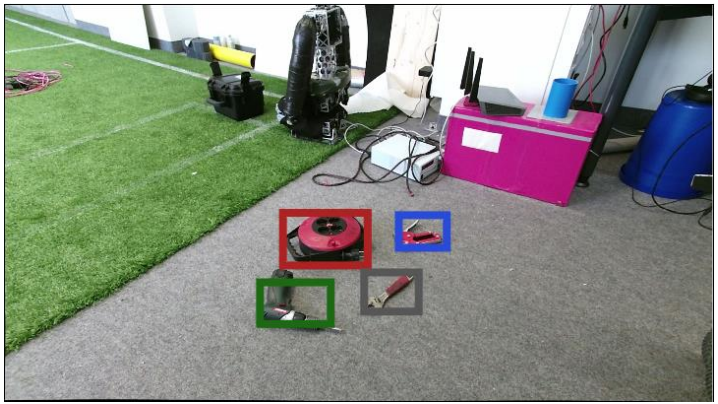
Tool Detection Results

[Schwarz et al. IJRR 2017]

Resolution	Clamp	Door handle	Driller	Extension	Stapler	Wrench	Mean
	AP / F1	AP / F1	AP / F1	AP / F1	AP / F1	AP / F1	AP / F1
720×507	0.881/0.783	0.522/0.554	0.986/0.875	1.000/0.938	0.960/0.814	0.656/0.661	0.834/0.771
1080×760	0.926/0.829	0.867/0.632	0.972/0.893	1.000/0.950	0.992/0.892	0.927/0.848	0.947/0.841
1470×1035	0.913/0.814	0.974/0.745	1.000/0.915	1.000/0.952	0.999/0.909	0.949/0.860	0.973/0.866

Tools Detection Examples

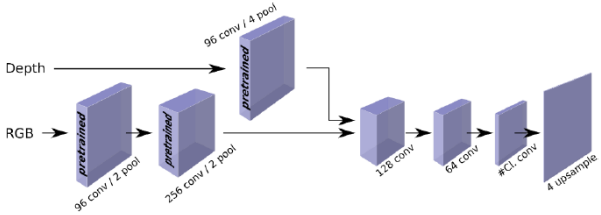




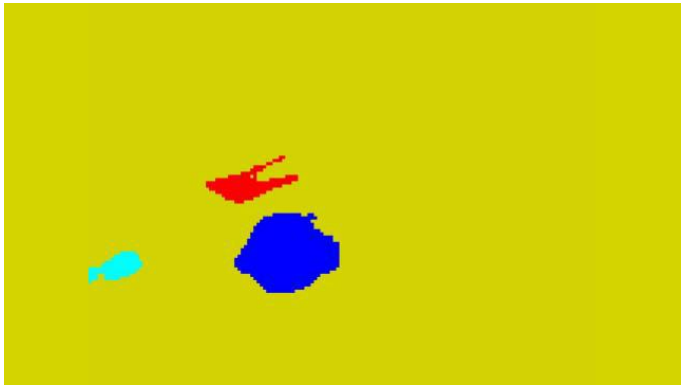
[Schwarz et al. IJRR 2017]

Semantic Segmentation

- Deep CNN



[Husain et al. RA-L 2016]

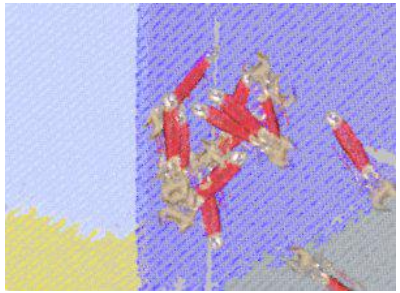


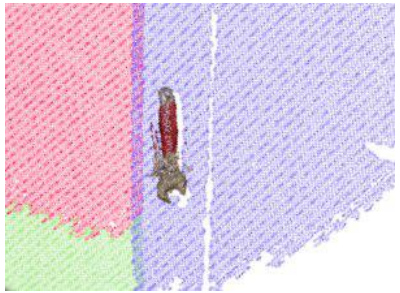
Pixel-wise accuracy:

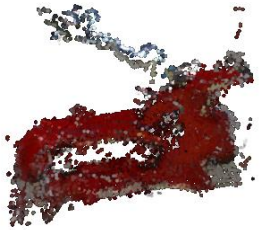
Clamp	Door handle	Driller	Extension	Stapler	Wrench	Background	Mean
0.727	0.751	0.769	0.889	0.775	0.734	0.992	0.805

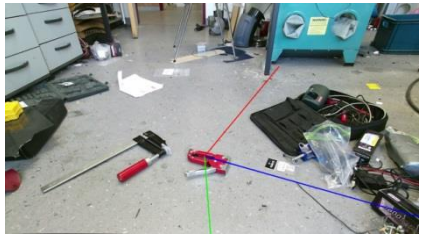
3D Object Modeling and 6D Pose Estimation

- Build 3D model on turn table
- Generate proposals
- Register to test image





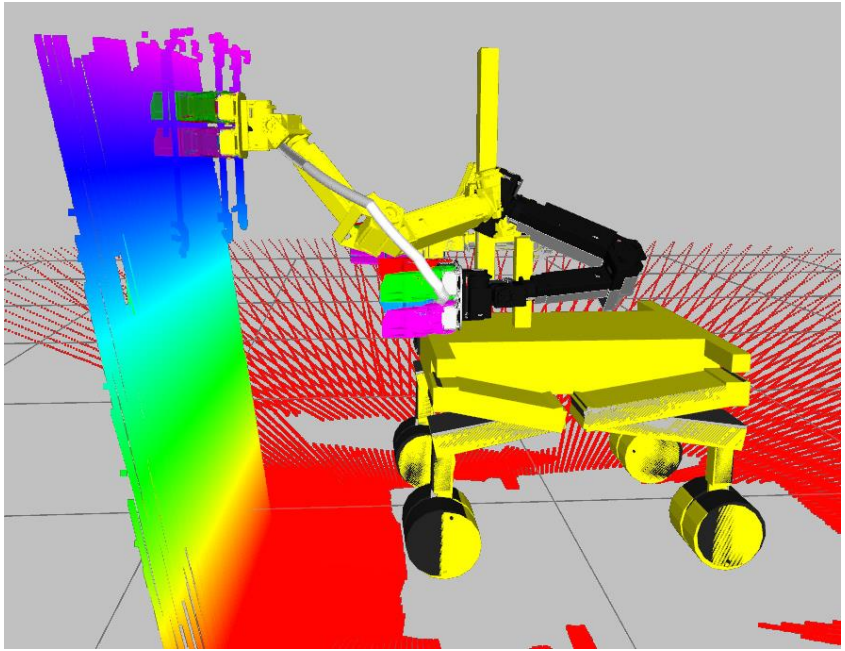


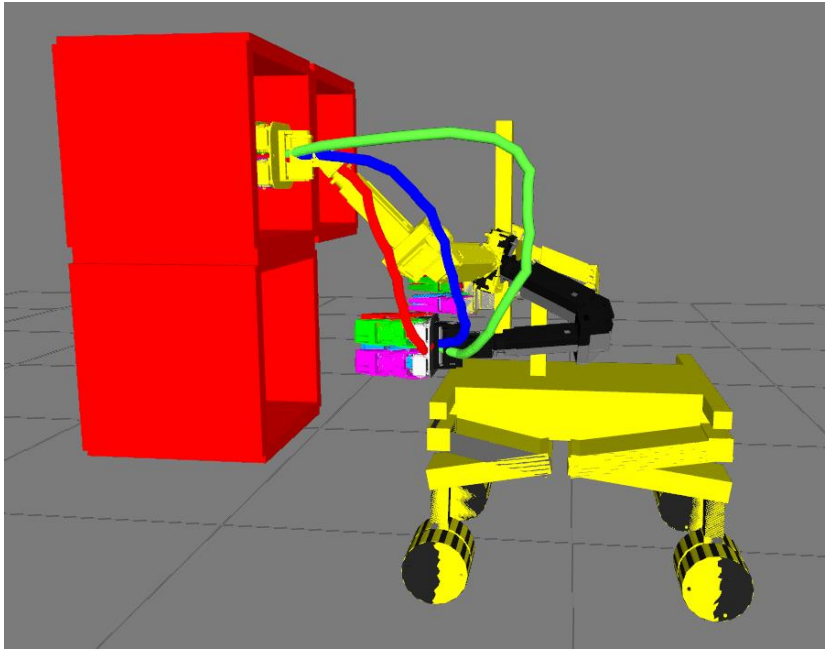


[Aldoma et al., ICRA 2013]

Manipulation Trajectory Optimization

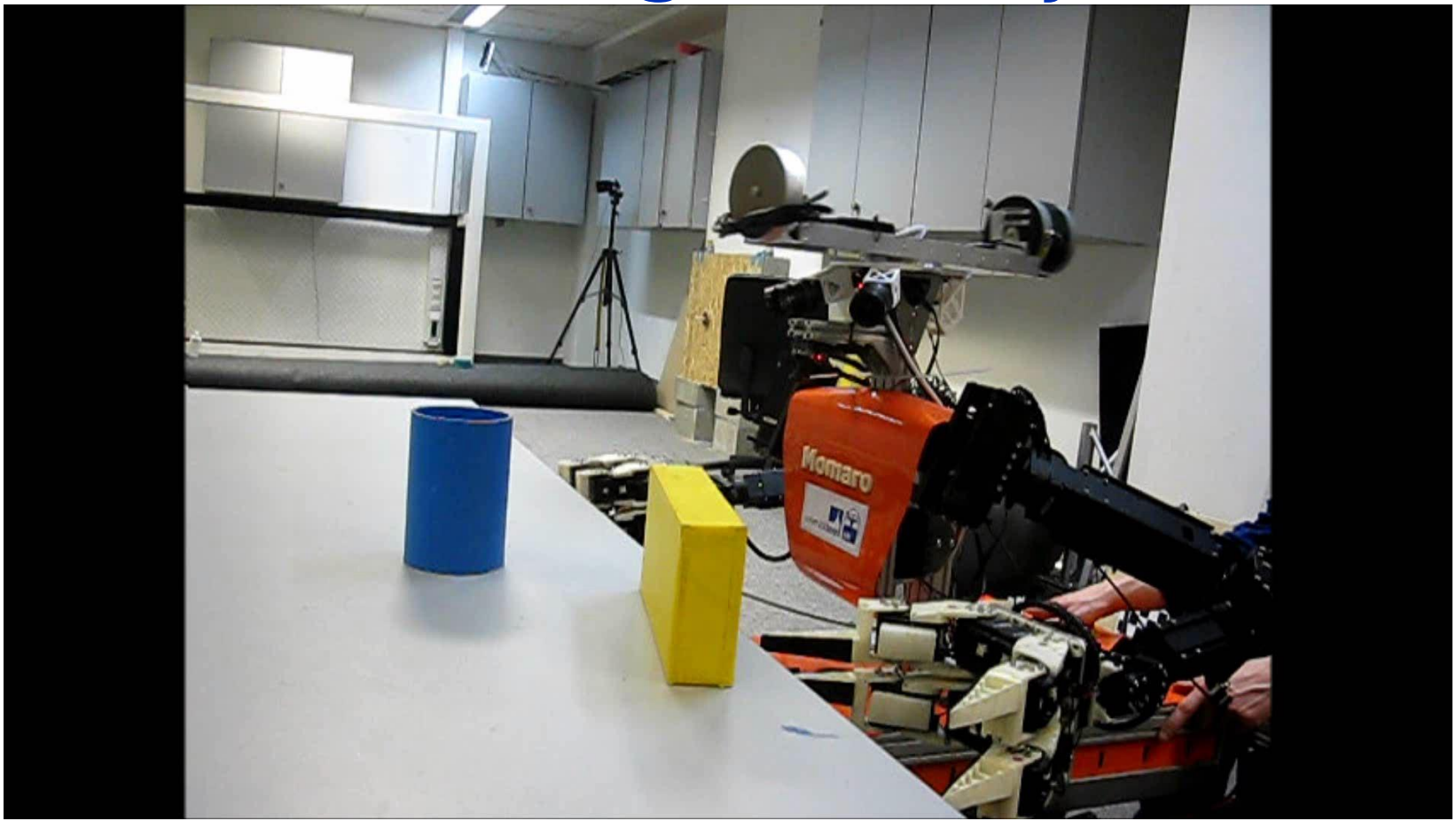
- Extended stochastic trajectory optimization (STOMP), 8 DoF
- Weighting multiple objectives, e.g. speed, obstacles, torque, ...





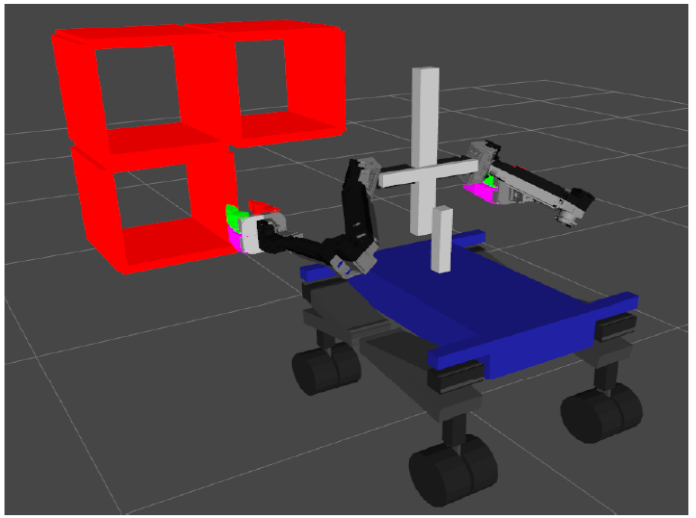
[Pavlichenko and Behnke, IROS 2017]

Momaro Reaching for an Object



Shelf Experiment

[Pavlichenko and Behnke, IROS 2017]

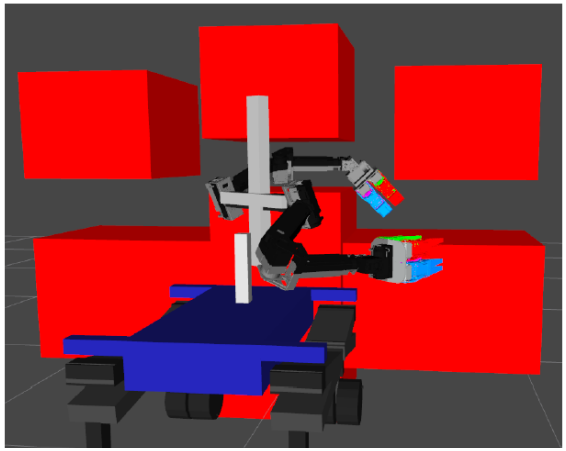


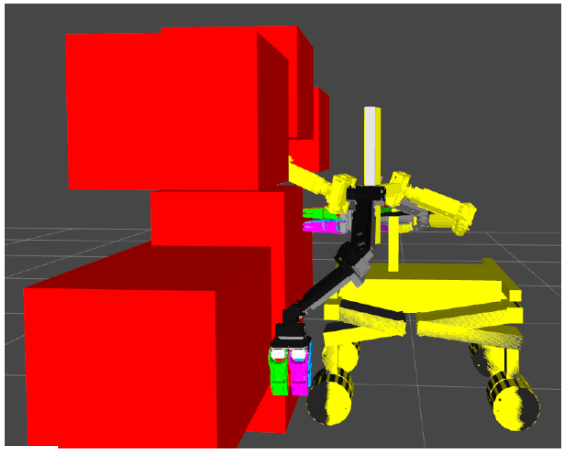
- Four configurations
  - 12 planning tasks
  - 100 executions for each task
- 3 difficulty levels:
  - Easy
  - Hard (gripper deeper)
  - Hard constrained (endeffector orient.)

	Difficulty level					
	Easy		Hard		Hard constrained	
Algorithm	success rate	runtime [s]	success rate	runtime [s]	success rate	runtime [s]
LBKPIECE	0.94	2.47 ± 1.08	0.93	2.46 ± 0.85	-	-
STOMP-Industrial	0.87	0.87 ± 0.86	0.76	1.47 ± 1,01	-	-
RRTConnect	0.97	0.29 ± 0.18	0.96	0.85 ± 0.58	0.97	1.22 ± 1.04
STOMP-New	1.0	0.09 ± 0.02	1.0	0.18 ± 0.11	0.99	0.28 ± 0.21

Corridor Experiment

- Two difficulty levels:
  - Easy
  - Hard
- 100 trials each

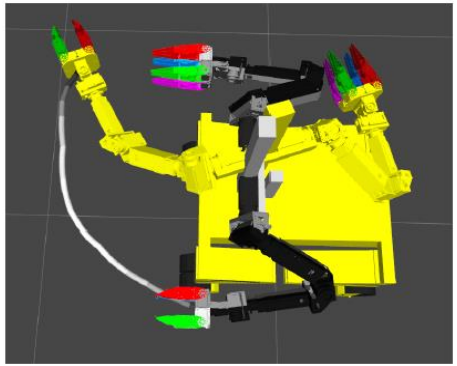


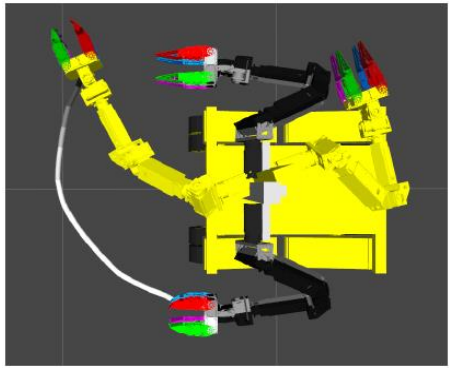


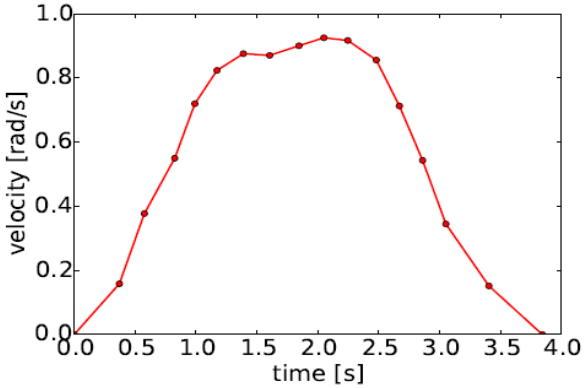
	Difficulty level			
	Easy		Hard	
Algorithm	success rate	runtime [s]	success rate	runtime [s]
LBKPIECE	0.65	6.97 ± 2.58	0.50	7.82 ± 2.58
RRTConnect	0.08	9.64 ± 1.27	0.06	9.71 ± 1.56
STOMP-Industrial	0.00	2.82 ± 0.07	0.00	2.85 ± 0.08
STOMP-New	0.78	1.89 ± 1.44	0.18	3.64 ± 1.29

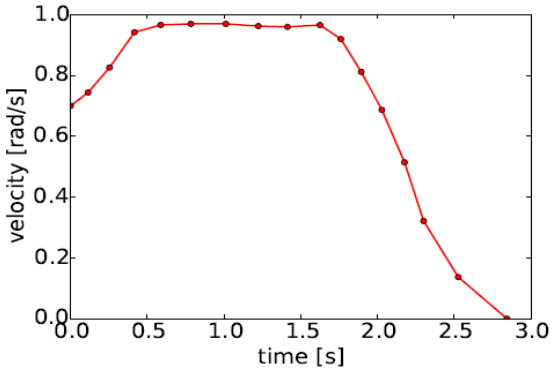
Velocity Profiles

- Start pose can have velocity
- Continuous replanning possible





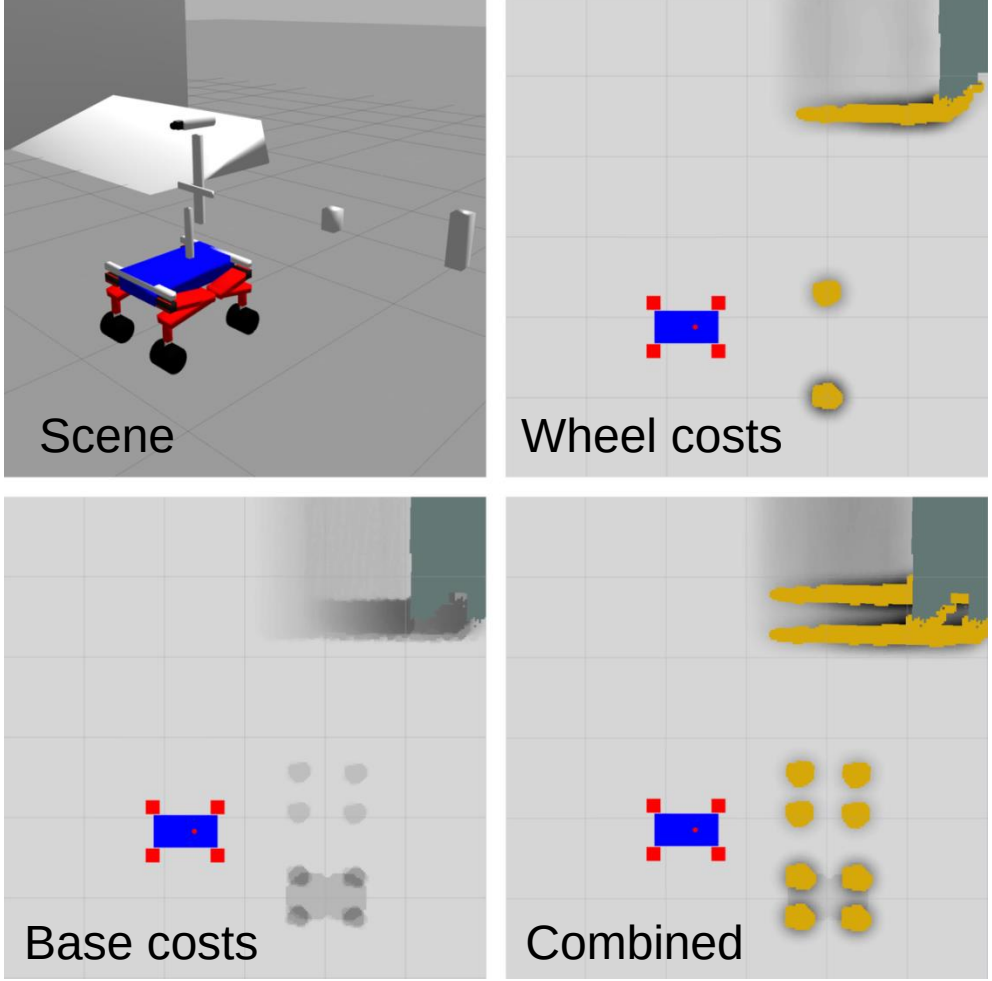




Locomotion Planning Considering Robot Footprint

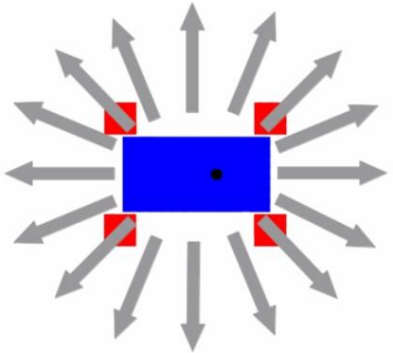
- Costs for individual wheel pairs from height differences
- Base costs
- Non-linear combination yields 3D (x, y, θ) cost map

[Klamt and Behnke, IROS 2017]

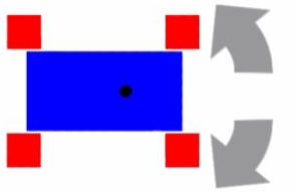


3D Driving Planning (x, y, θ): A*

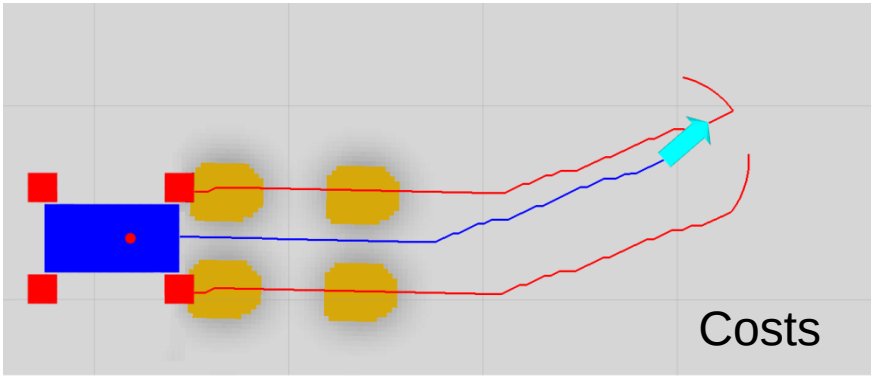
- 16 driving directions

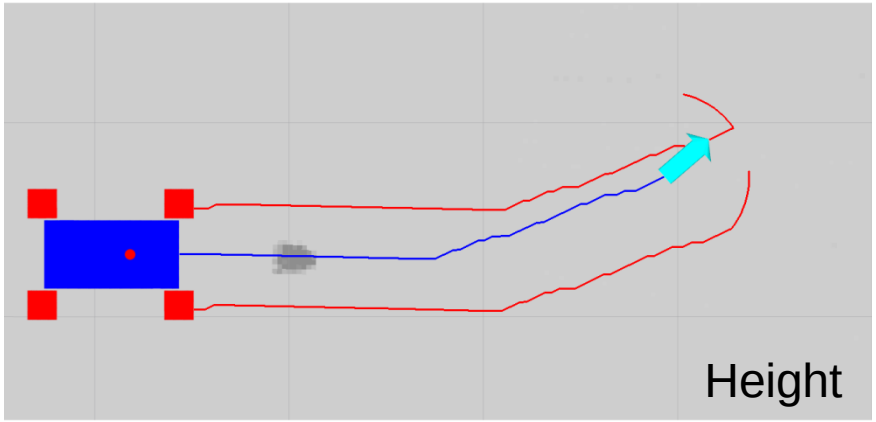


- Orientation changes



=> Obstacle between wheels

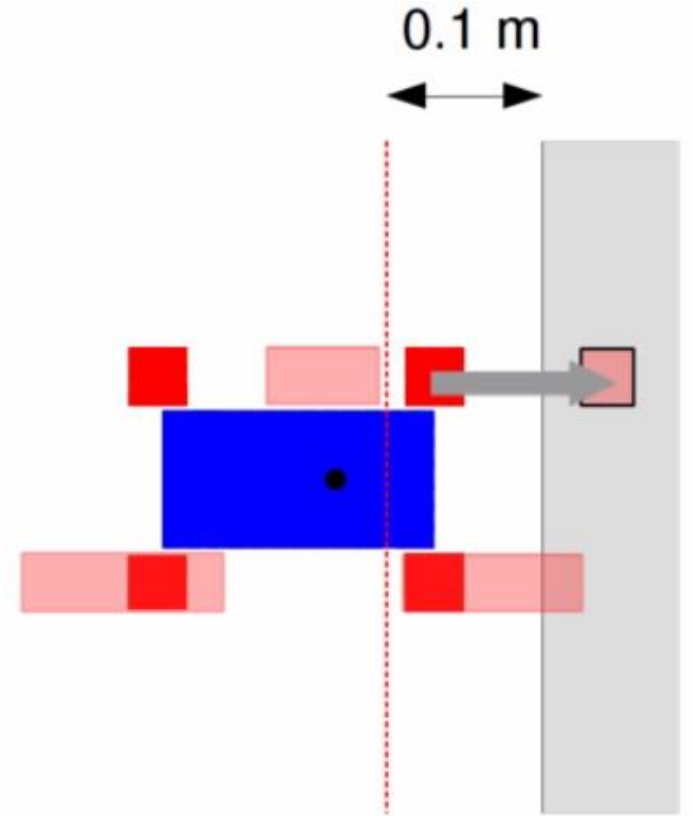




[Klamt and Behnke, IROS 2017]

Making Steps

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

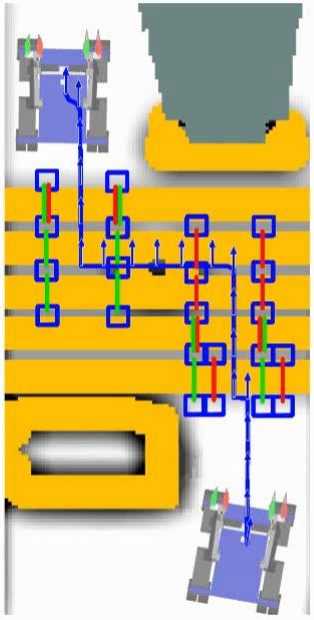


[Klamt and Behnke: IROS 2017]

Expanding Abstract Steps to Detailed Motion Sequences

[Klamt and Behnke: IROS 2017]

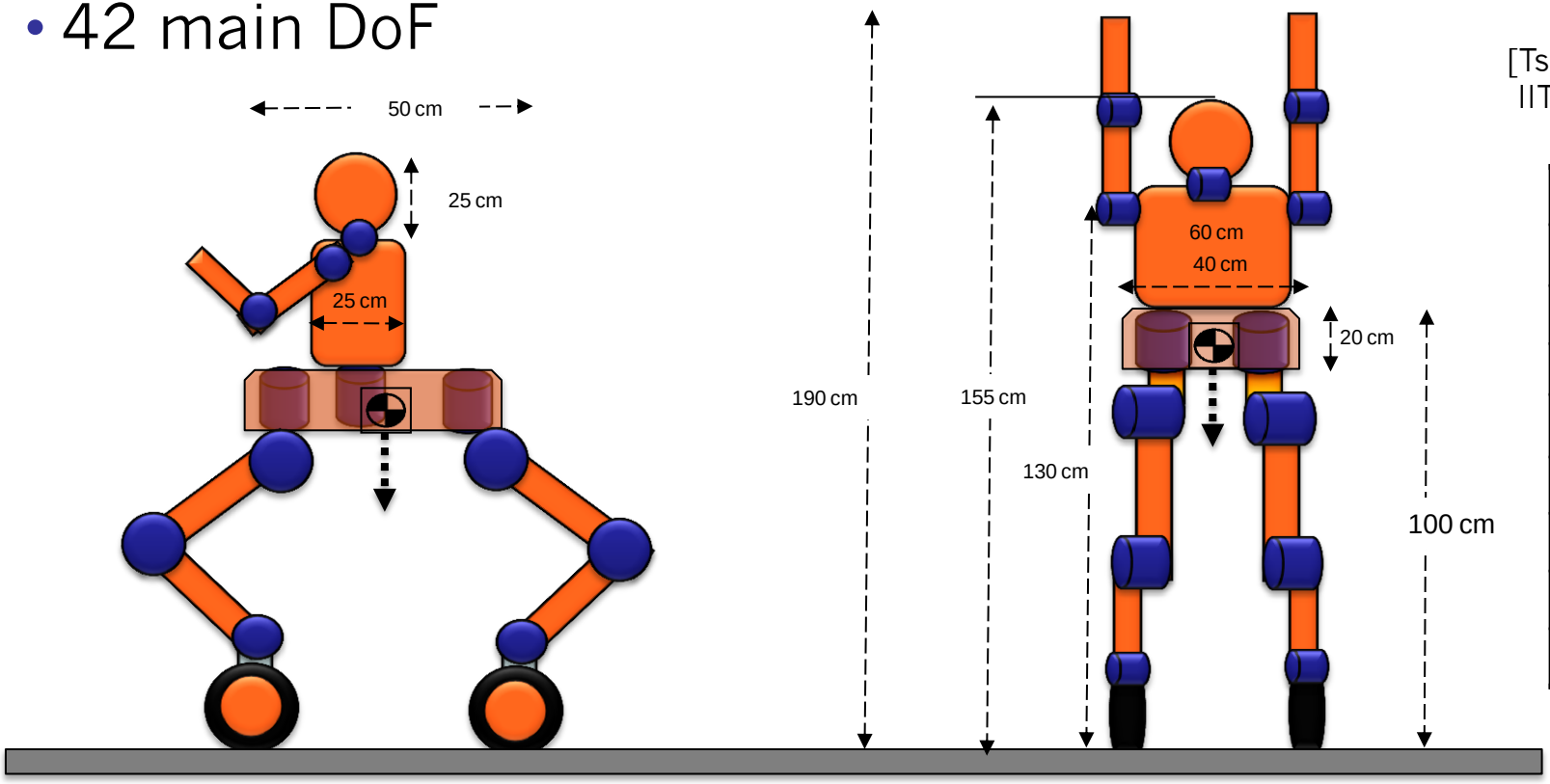
Planning for Challenging Scenarios



[Klamt and Behnke: IROS 2017]

Centauro Robot Kinematic Concept

- 42 main DoF



[Tsagarakis et al., IIT 2017]

Joint	DoF
Ankle	2
Knee	1
Hip	2
Waist	1
Shoulder	3
Elbow	1
Wrist	3
Neck	2

Centauro Robot Upper Body

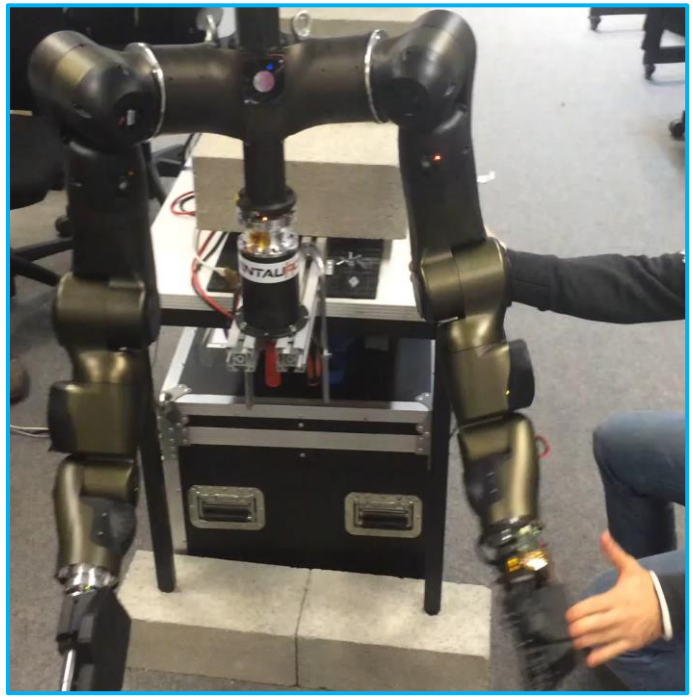
- Strong

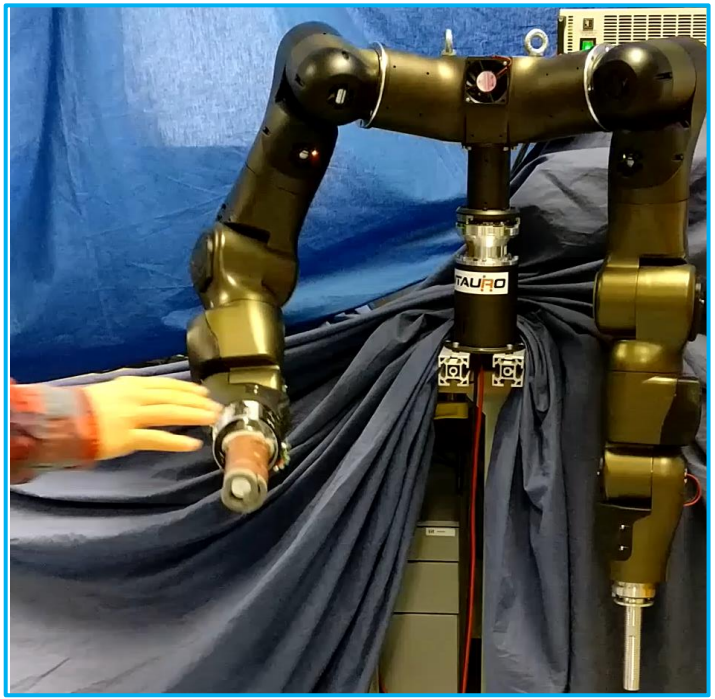
- Fast

[Giusti et al. ICRA 2017]

Centauro Robot Upper Body

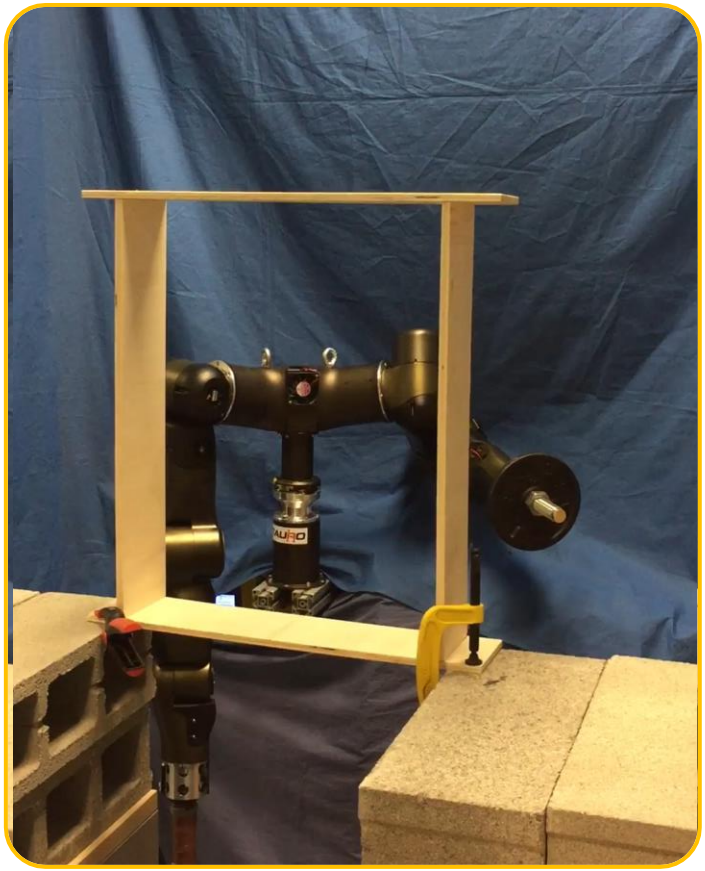
- Serial-elastic actuators (SEA) => Compliant & adaptive

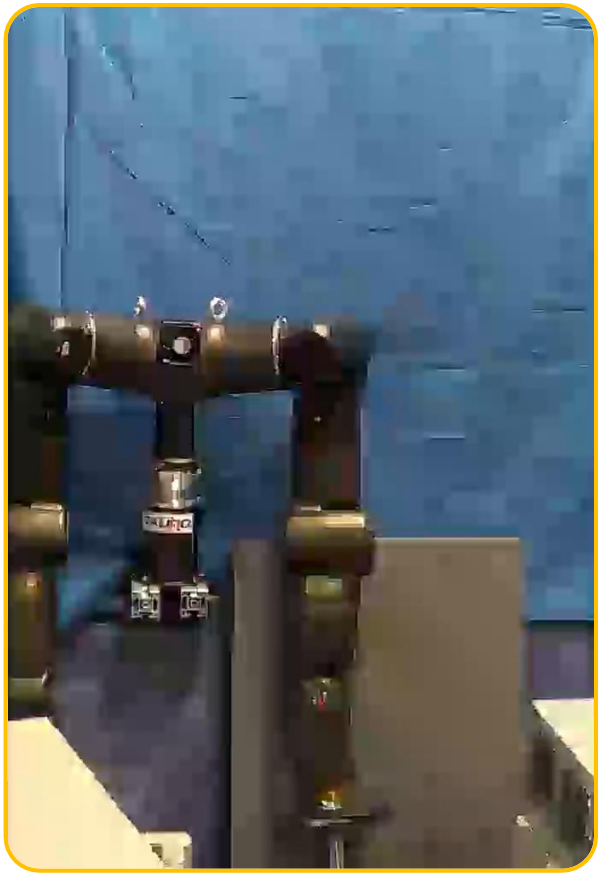




[Giusti et al. ICRA 2017]

Centauro Upper Body: Resilient





[Giusti et al. ICRA 2017]

1st Centauro Robot

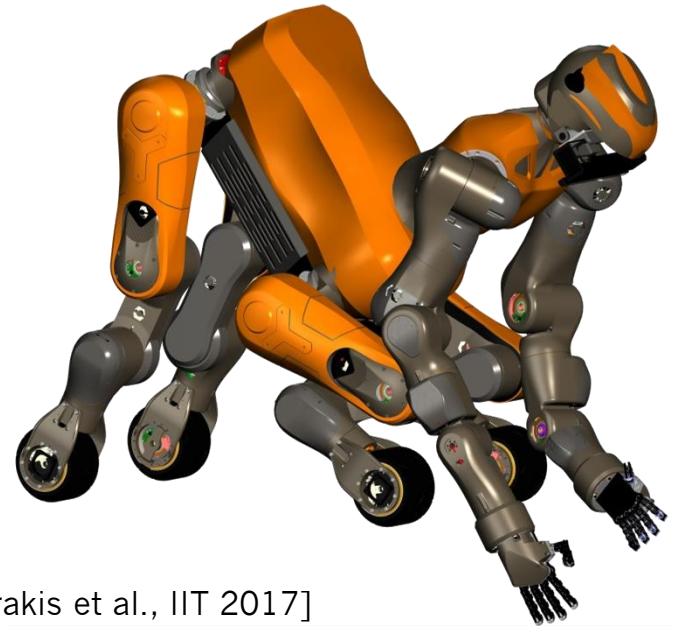
- Serial elastic actuators
- 42 main DoFs
- Schunk hand
- 3D laser
- RGB-D camera
- Color cameras
- Two GPU PCs

[Tsagarakis et al., IIT 2017]

Centauro Robot: Knee Configurations

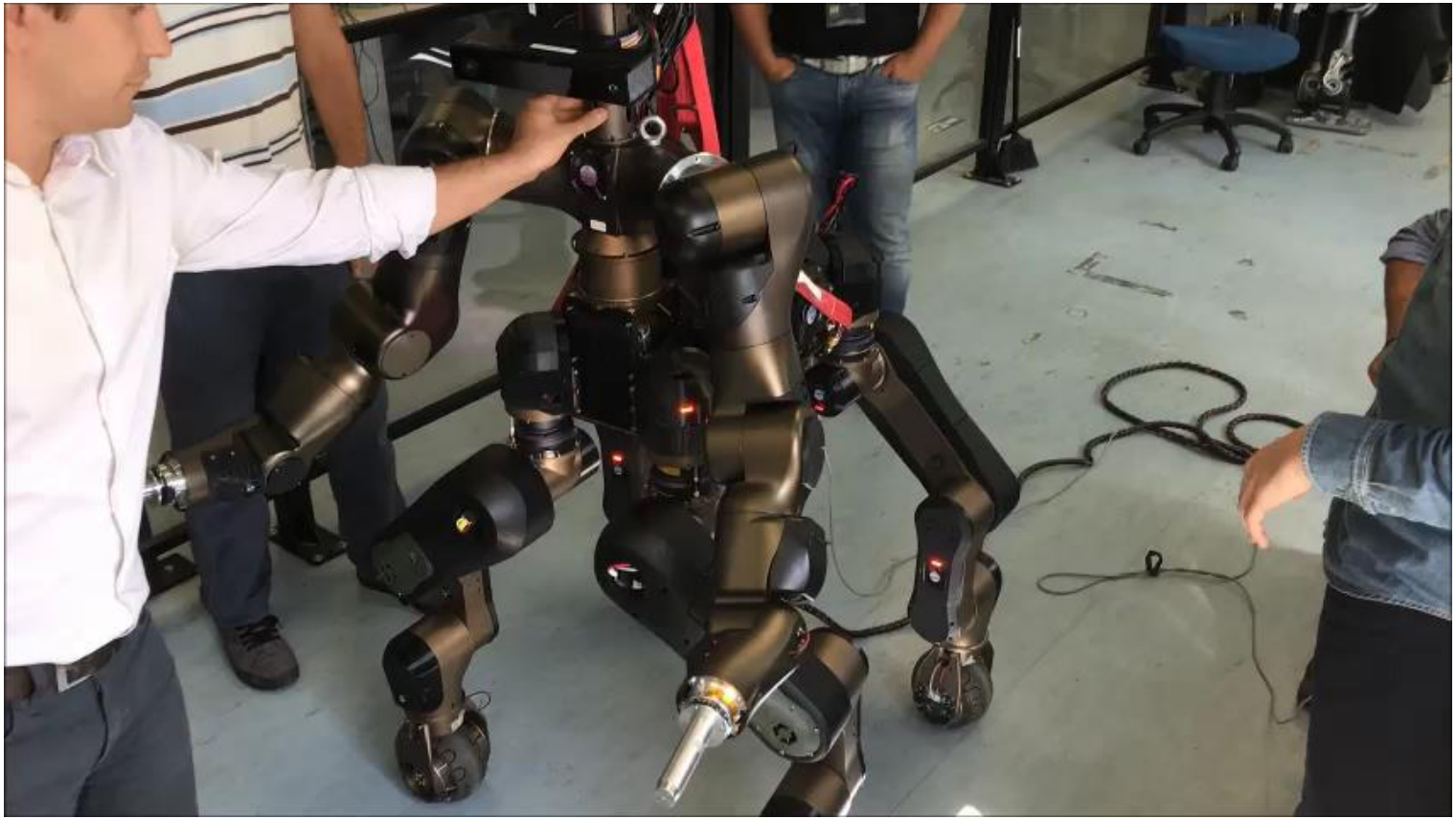
[Tsagarakis et al., IIT 2017]

Centauro Robot: Reaching the Ground

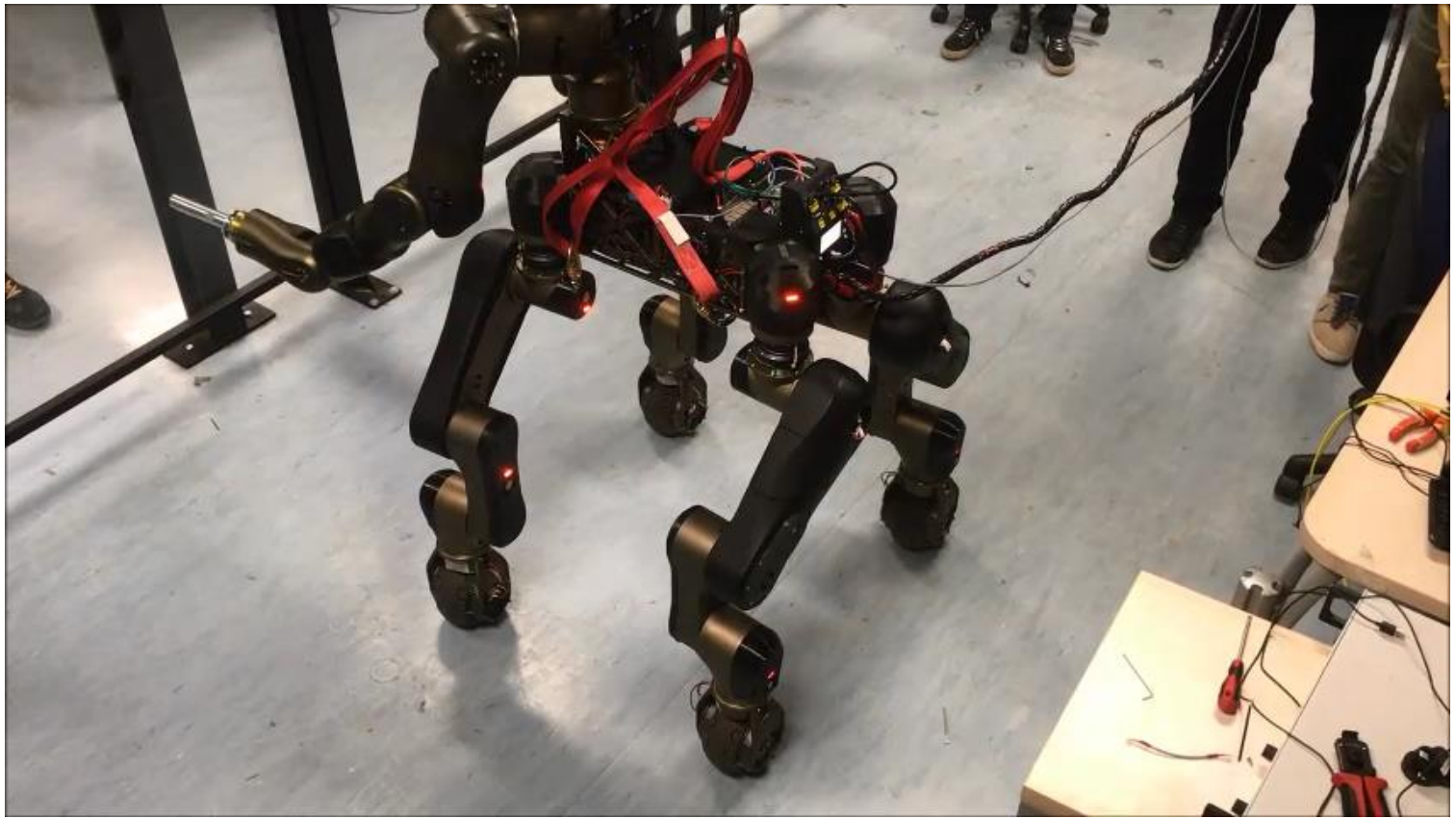


[Tsagarakis et al., IIT 2017]

Centauro: Whole Body Impedance Control

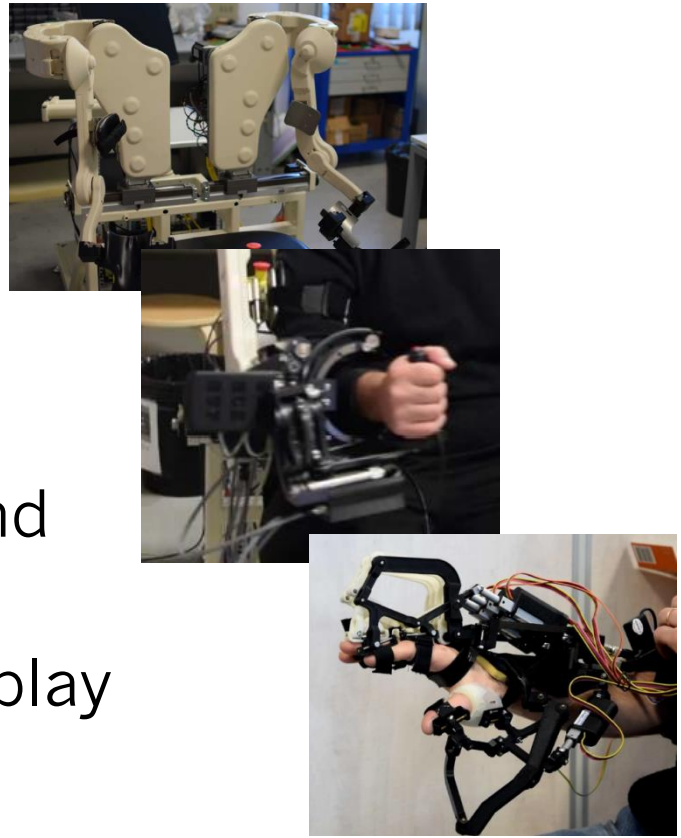


CENTAURO Robot: Omnidirectional Driving



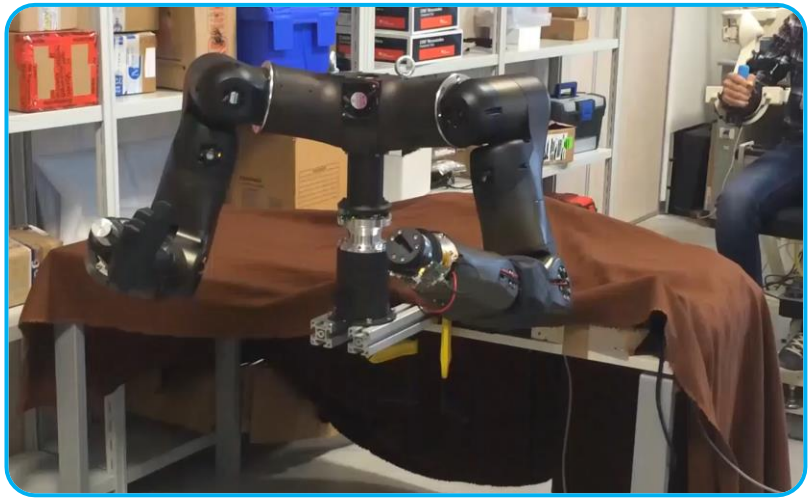
Main Operator Telepresence Interface

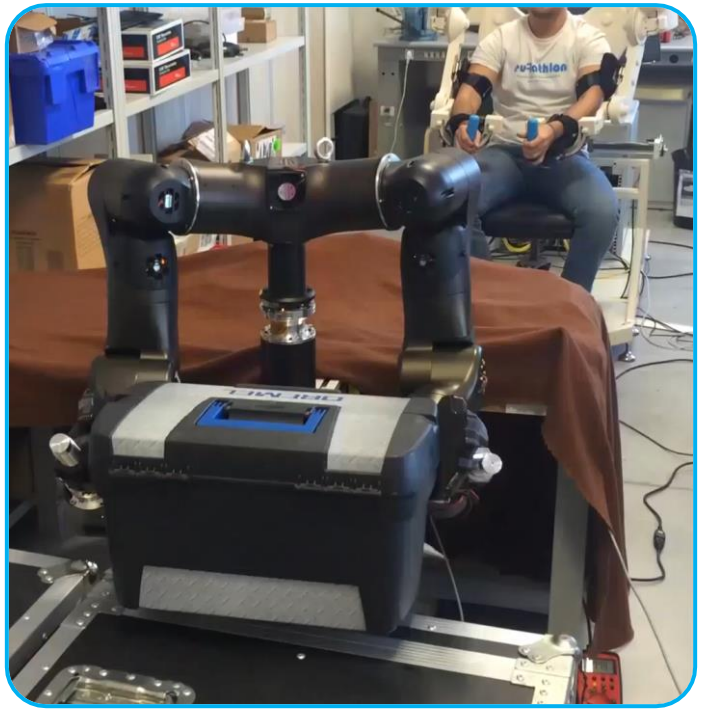
- Tendon-driven dual-arm exoskeleton
- Active wrist with differential tendon transmission
- Underactuated hand exoskeleton
- Head-mounted display
- Foot pedals



[Frisoli et al., SSSA 2017]

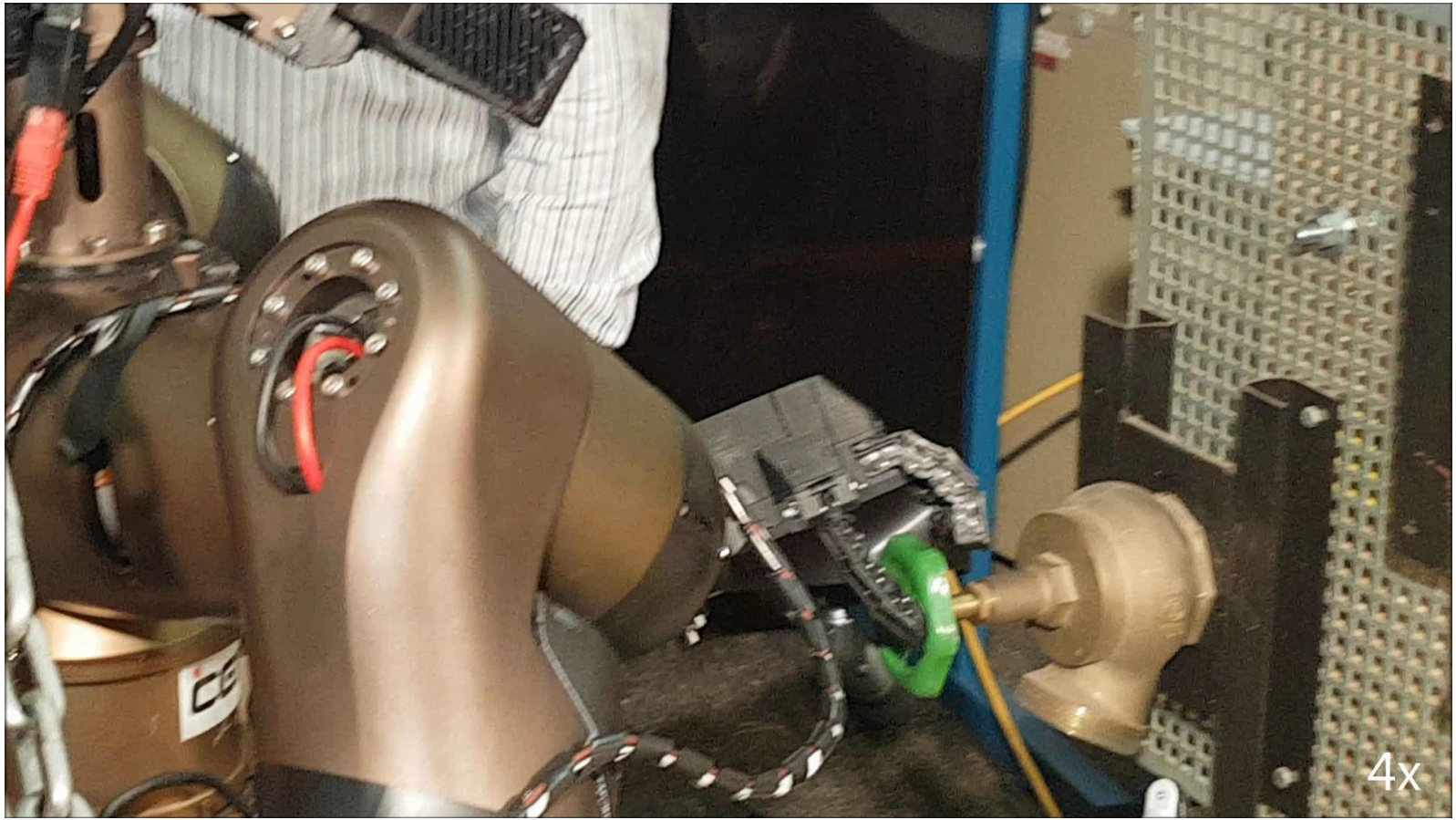
Centauro Upper Body Bi-manual Teleoperation



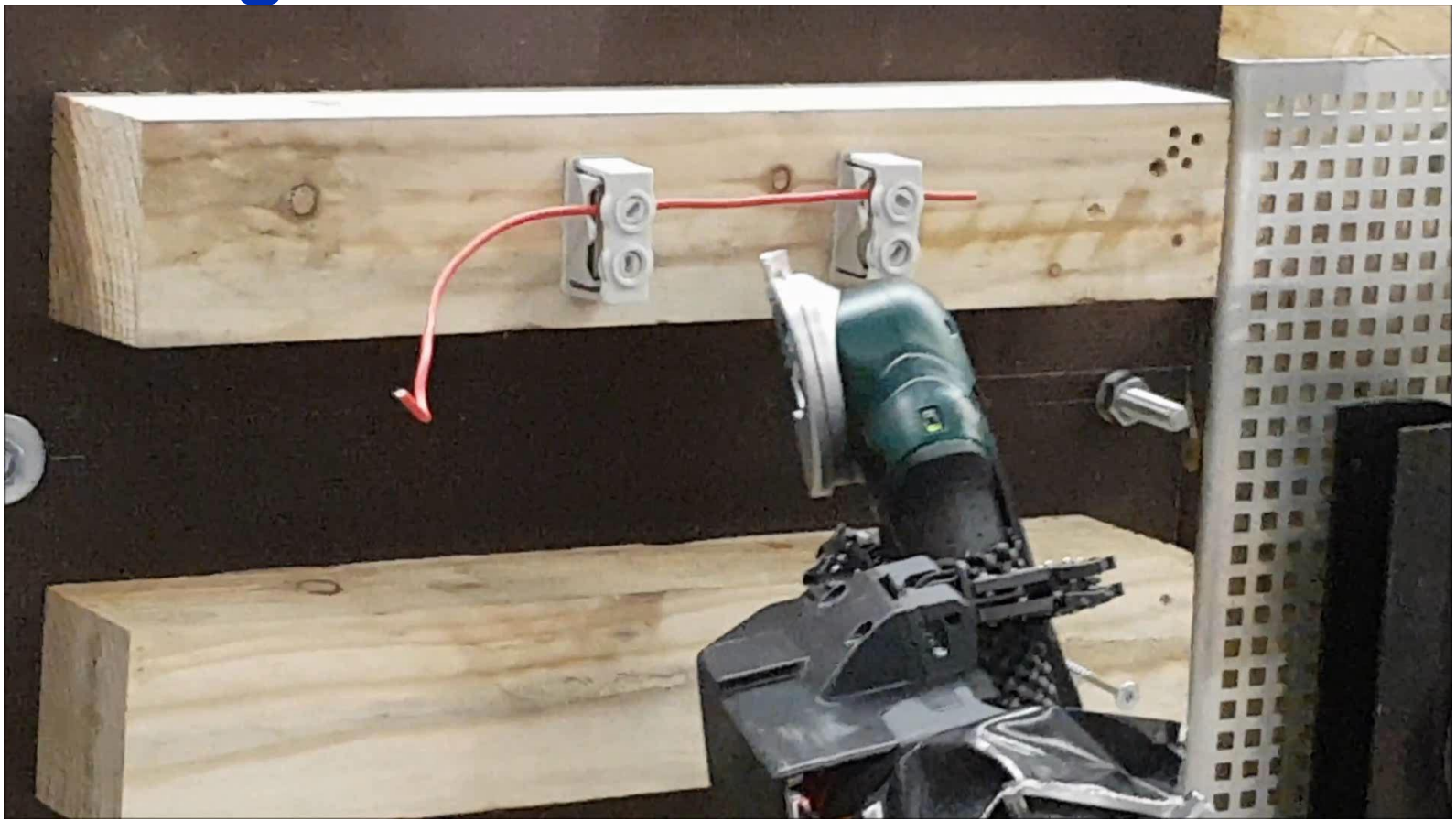


[Tsagarakis et al. (IIT) + Frisoli et al. (SSSA), 2016]

Turning a Valve



Cutting a Wire



Climbing over a Gap

Walking over a Step Field

Transfer of Manipulation Skills

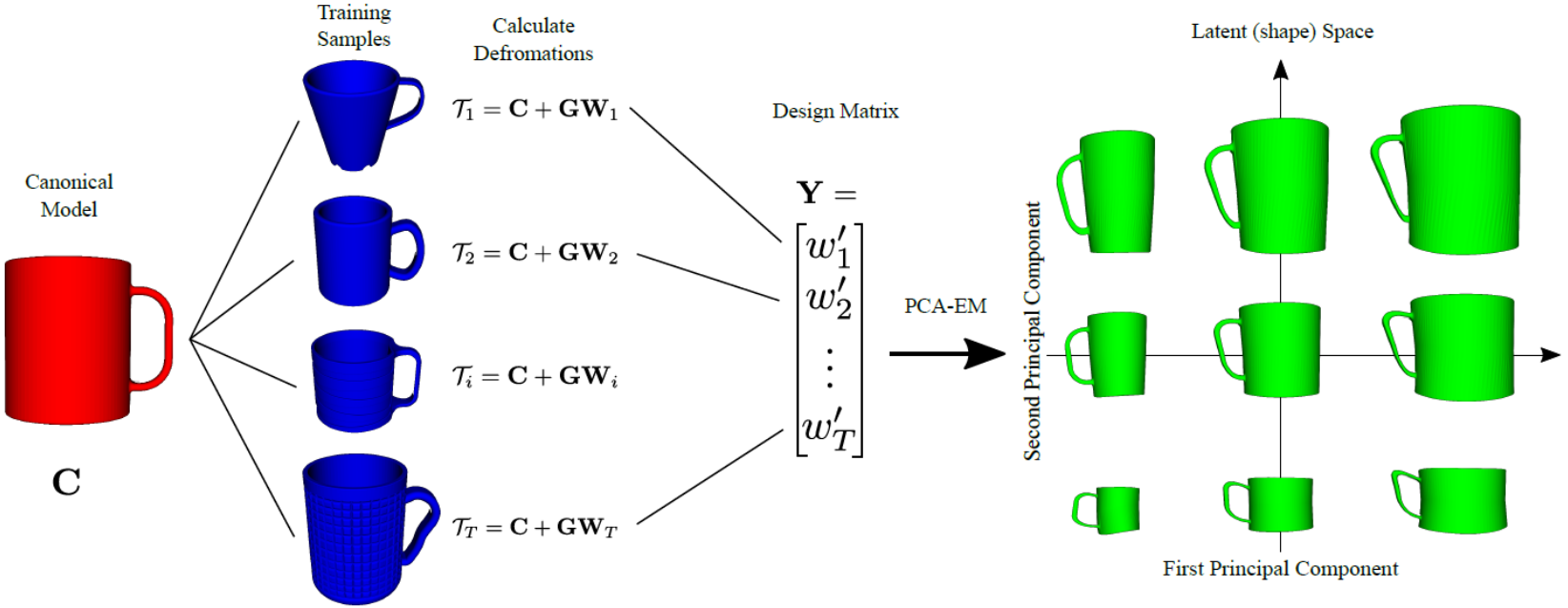
- Objects belonging to the same **category** can be handled in a very similar manner.

Transfer of Manipulation Skills

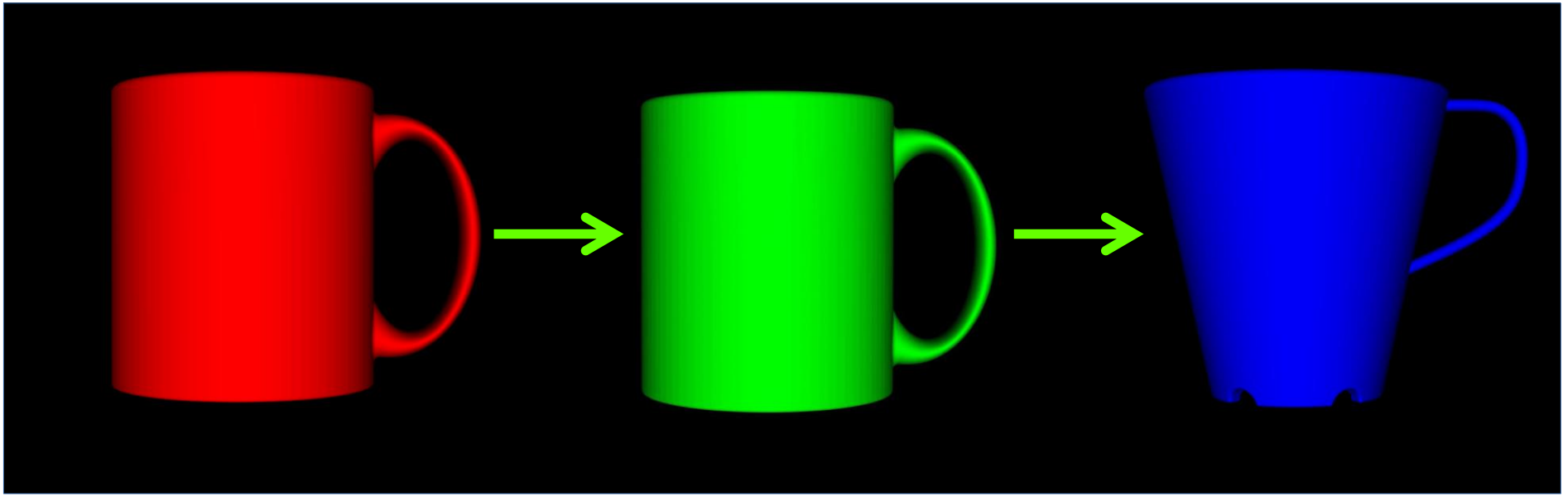
Knowledge Transfer

Learning a Latent Shape Space

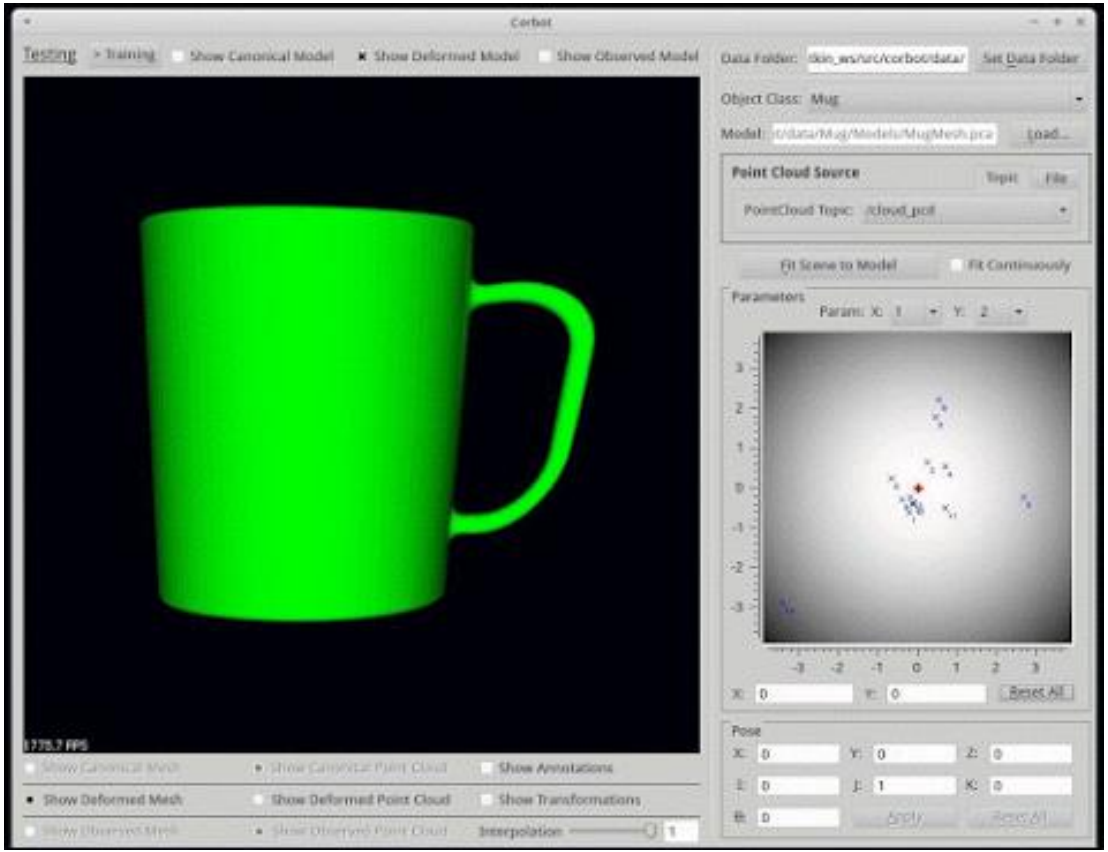
- Non-rigid registration of instances and canonical model
- Principal component analysis of deformations



Interpolation in Shape Space

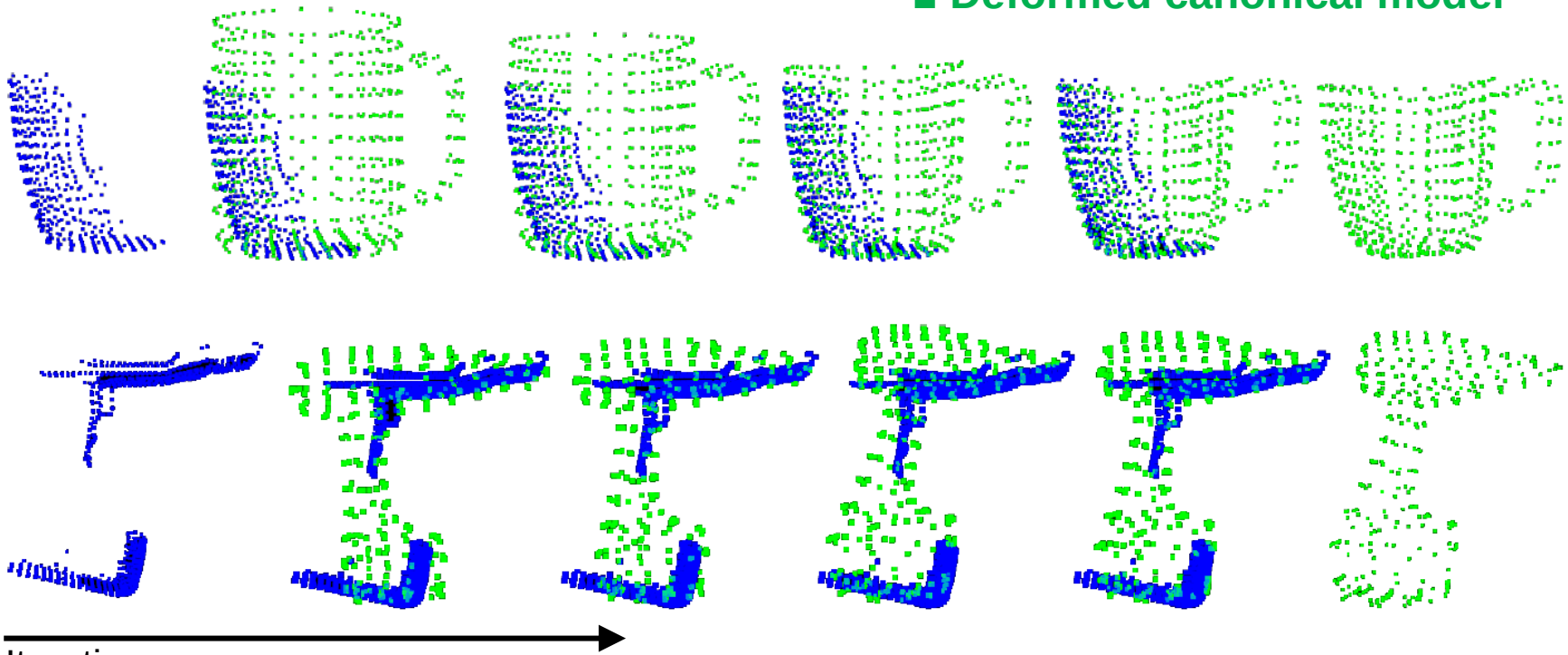


Interpolation in Shape Space



Shape-aware Non-rigid Registration

- Partial view of novel instance
- Deformed canonical model



Iterations

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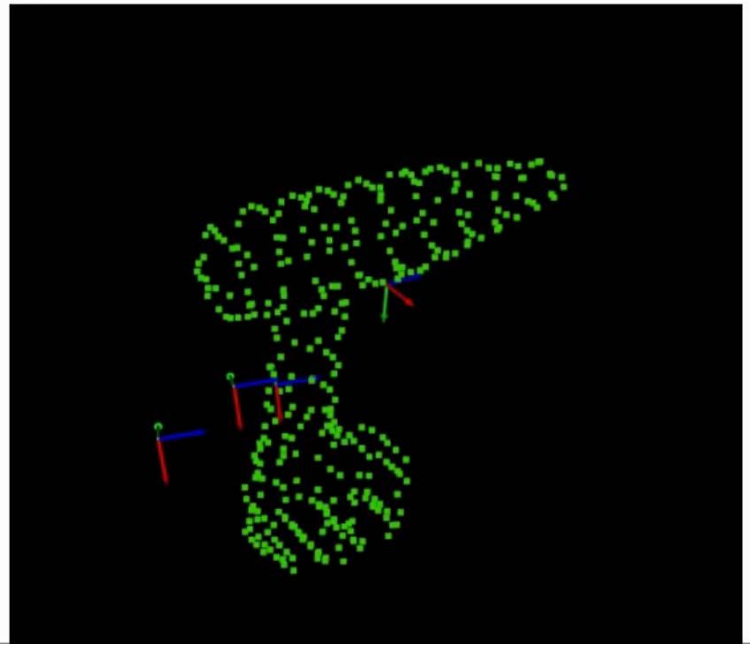
Transference of Grasping Skills

Warp grasping information



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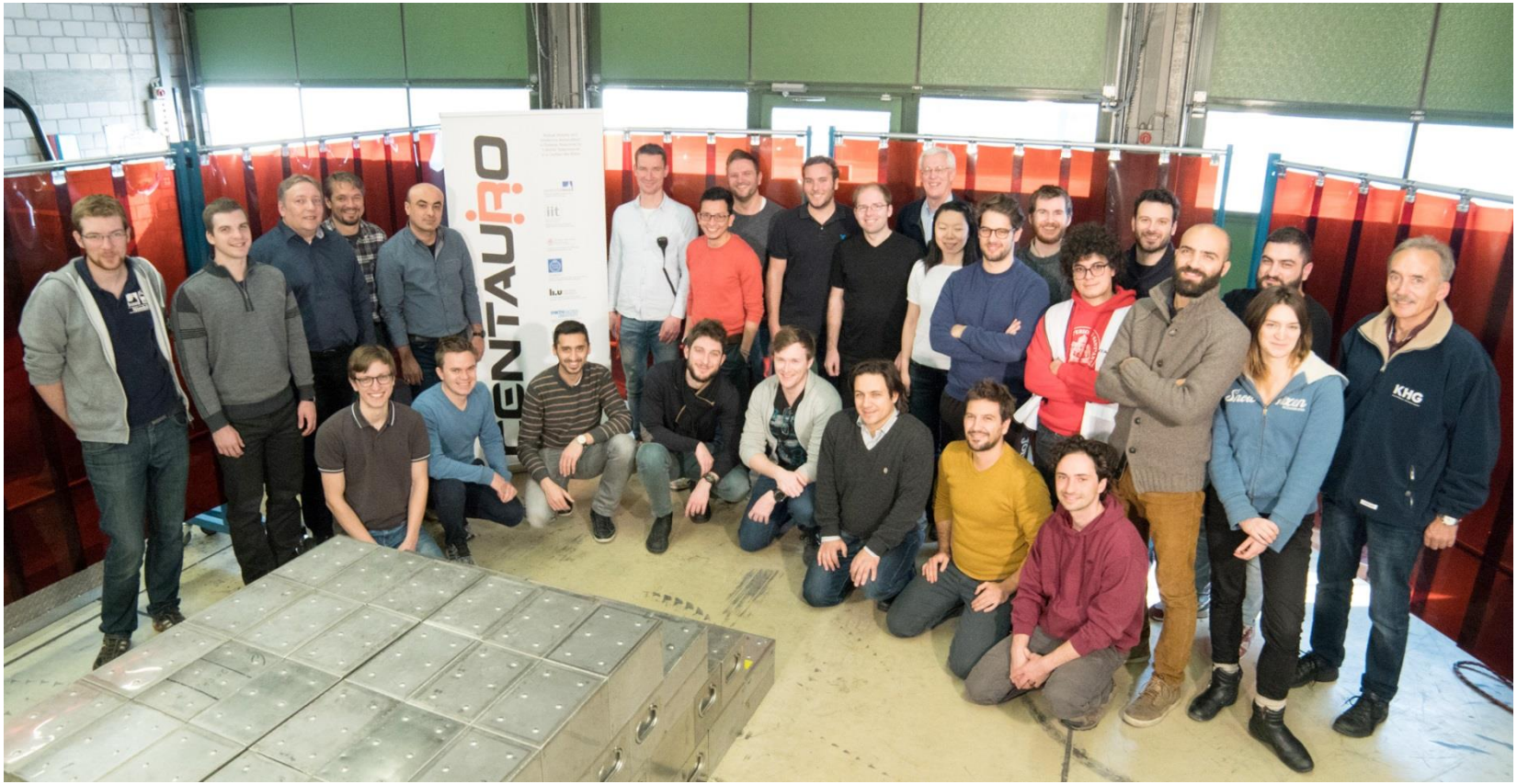
Grasping an Unknown Power Drill

Fastening a Screw

CENTAURO Team



Zusammenfassung

- Leistungsfähige Roboter für menschenfeindliche Umgebungen
  - Mobiler Manipulationsroboter Momaro
  - Centauro-Roboter
- Teleoperation ist flexibel, aber belastend und fehleranfällig
- Autonome Assistenzfunktionen für wiederkehrende Navigations- und Manipulationsaufgaben benötigt
- Herausforderungen dafür beinhalten
  - 3D-Kartierung
  - Semantische Szeneninterpretation
  - Hochdimensionale Bewegungsplanung

We are Hiring!

- Doktoranden und Postdocs
- **ais.uni-bonn.de/jobs.html**

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Questions?