From ground to space robotic manipulation

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DLR: Deutsches Zentrum für Luft- und Raumfahrt e.V.
German Aerospace Center

- Space Agency for Germany
- Project Management Agency
- Research Institution:
  - Aeronautics
  - Space
  - Energy
  - Transport
  - Digitalization
  - Defence & Security

DLR Site: Oberpfaffenhofen

Employees: Approx. 2500
Size of site: 245 000 m²

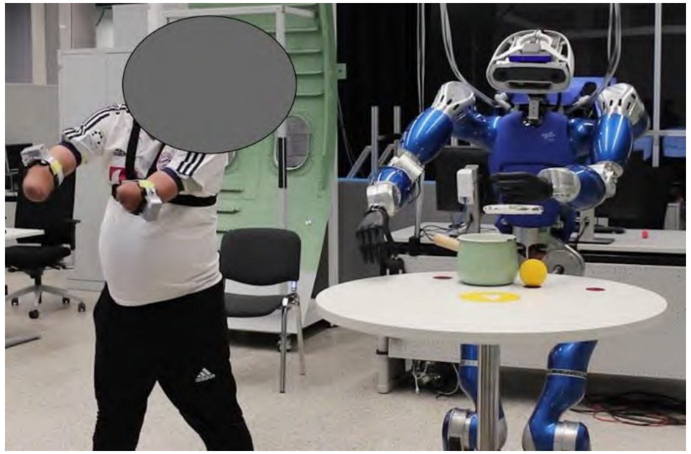
Research institutes and facilities:

- Microwaves and Radar Institute
- Institute of Communications and Navigation
- Institute of Atmospheric Physics
- Institute of Remote Sensing Technology
- ***Institute of Robotics and Mechatronics (RM)***
- Institute for Software Technology
- Institute of System Dynamics and Control
- Flight Experiments
- German Remote Sensing Data Center
- Space Operations and Astronaut Training
- Galileo Competence Center

RM-Research domains

I. GROUND MANIPULATION

Past and current projects in terrestrial/spatial manipulation



II. ROBOTIC HAND DEVELOPMENT: CLASH HAND

Warehouse picking

Robotic hands

Number of DOFs
Manipulation abilities
Cost
Control complexity

Applications in industry
Robustness

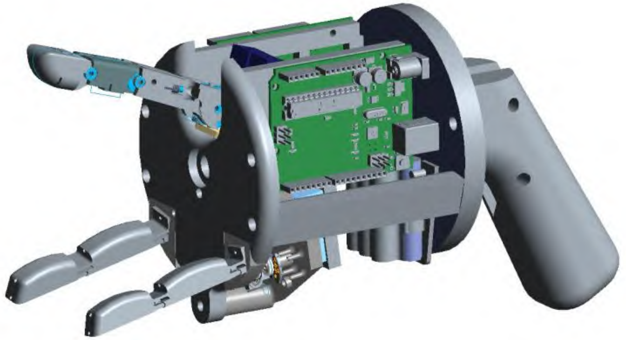
Hand-arm system (DAVID)

[Grebenstein et al., 2010]

Need for simplification

20 DOF
4,5 kg
>150.000 €

2N -> N+1
&
Underactuation
+ vsa



WHISG:Wearable hand to investigaste stiffness while grasping

[Friedl, Roa et al., 2016]

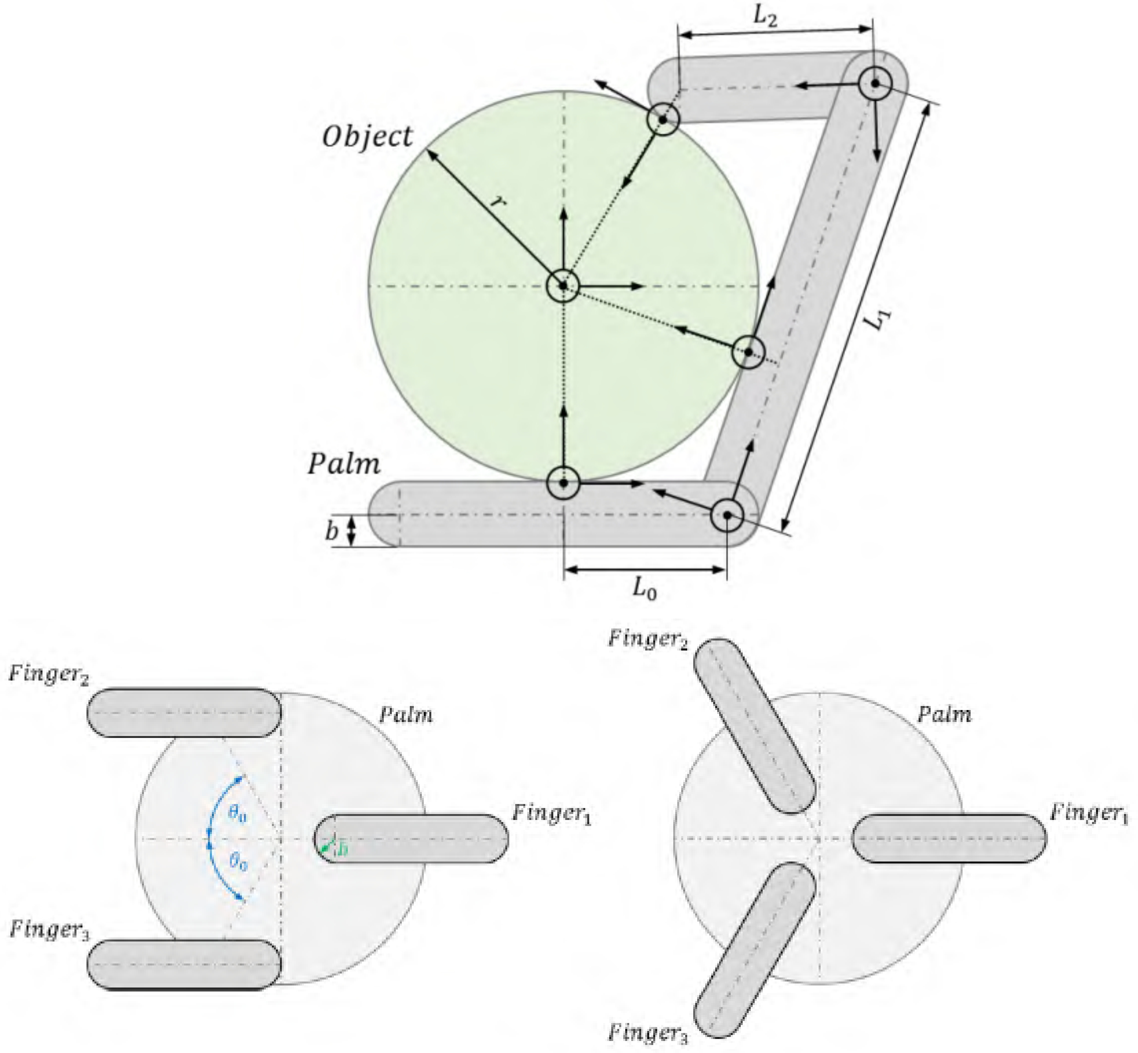
CLASH Compliant Low cost Antagonistic Servo Hand

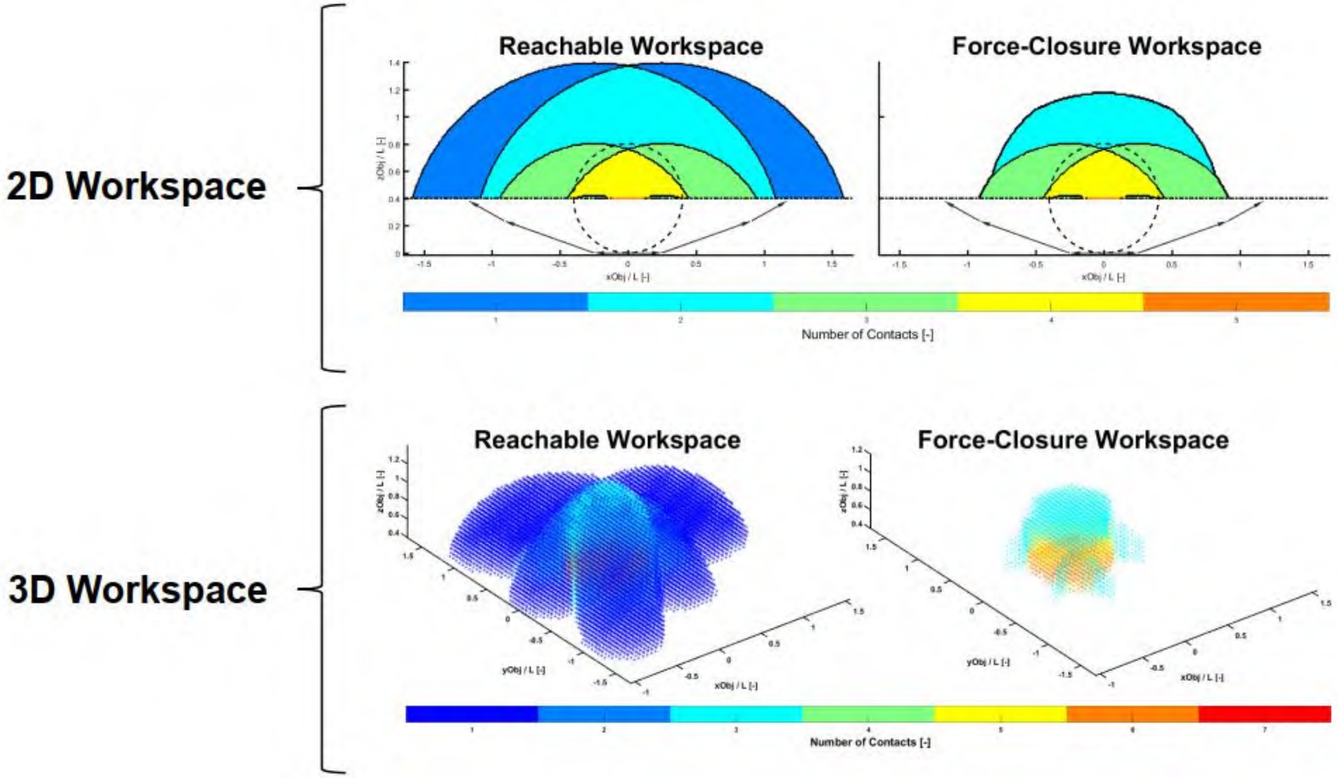
[Friedl, Roa et al., 2018]

CLASH 3F - hand kinematics optimized for fruits/veggies

[Friedl, Roa et al, IROS18]

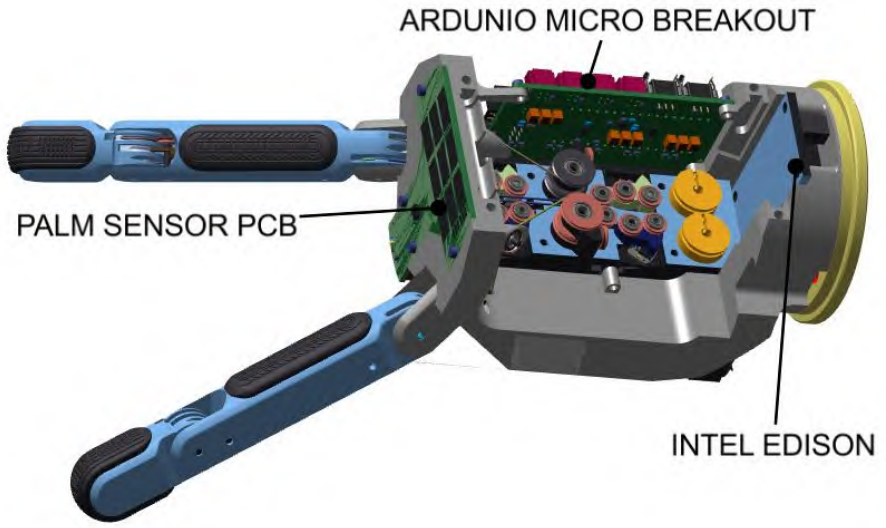
CLASH 3F - hand kinematics

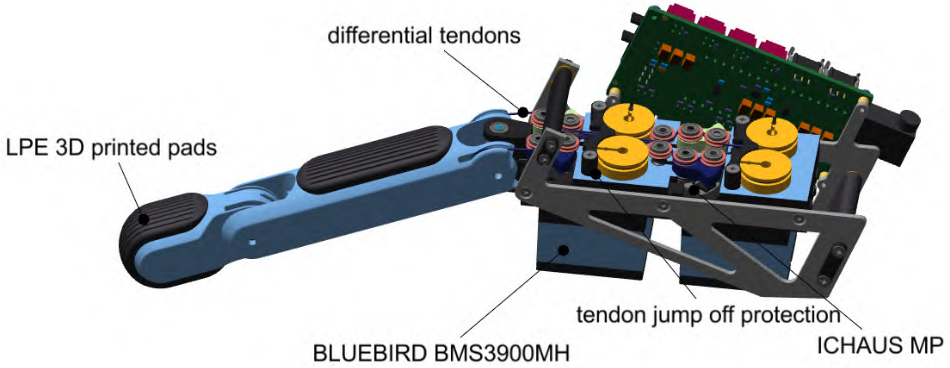




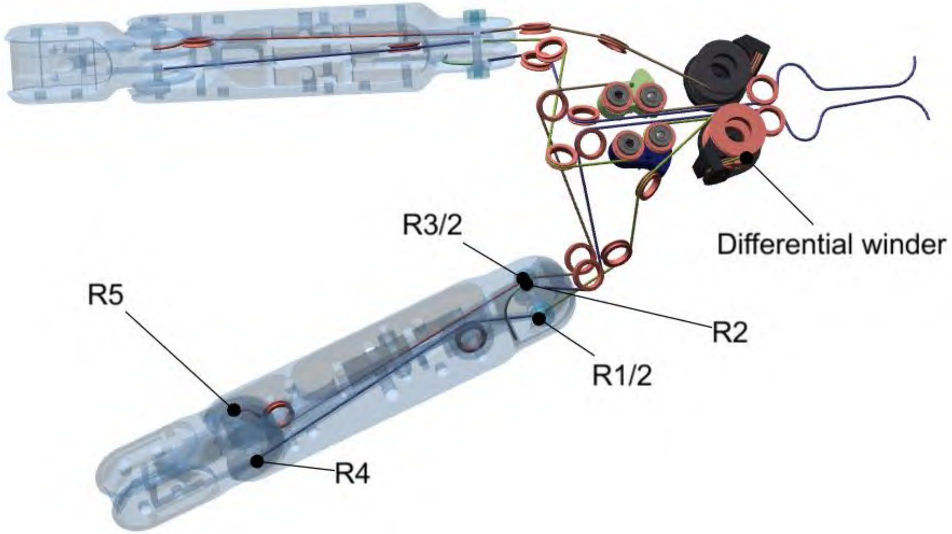
[Friedl, Roa et al., 2018]

CLASH 3F – mechatronic design

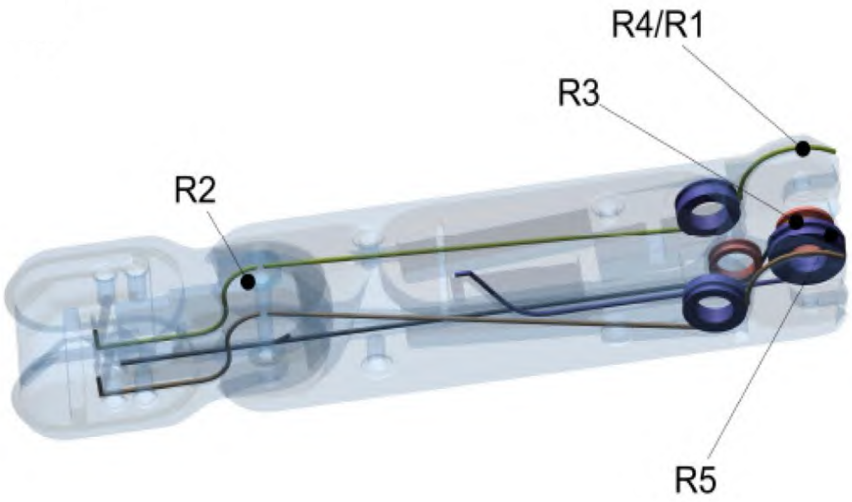




Parallel fingers

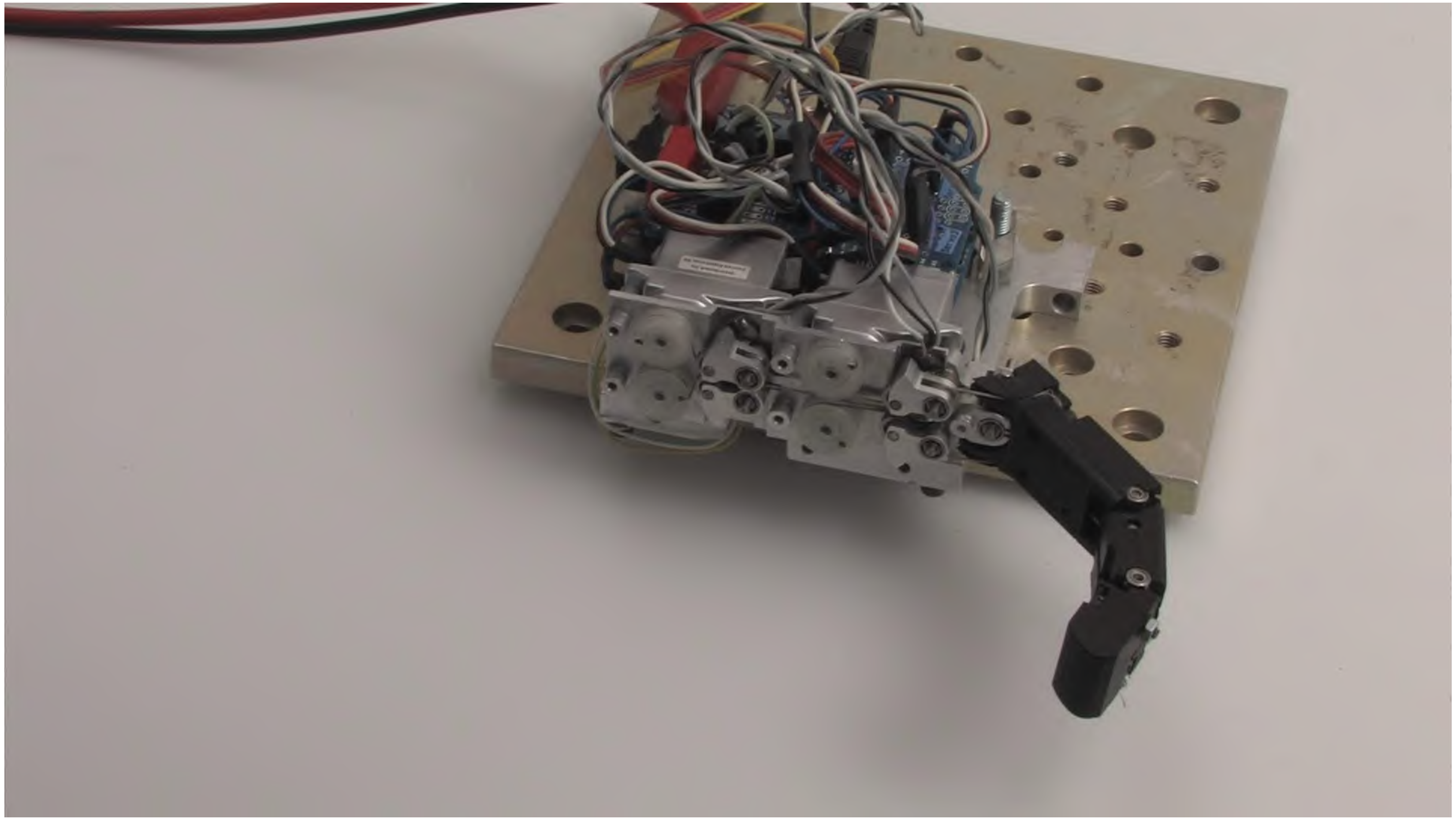


Thumb



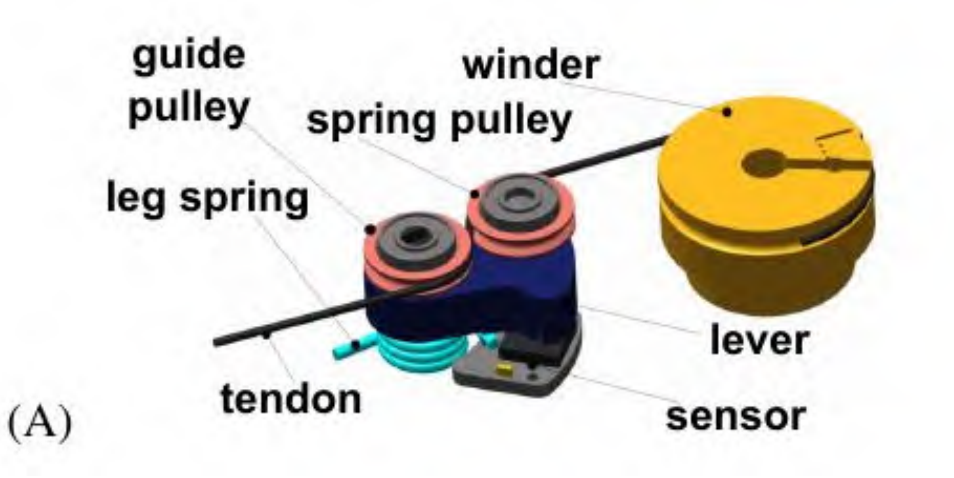
CLASH 3F - hand kinematics optimized for fruits/veggies

Adaptability



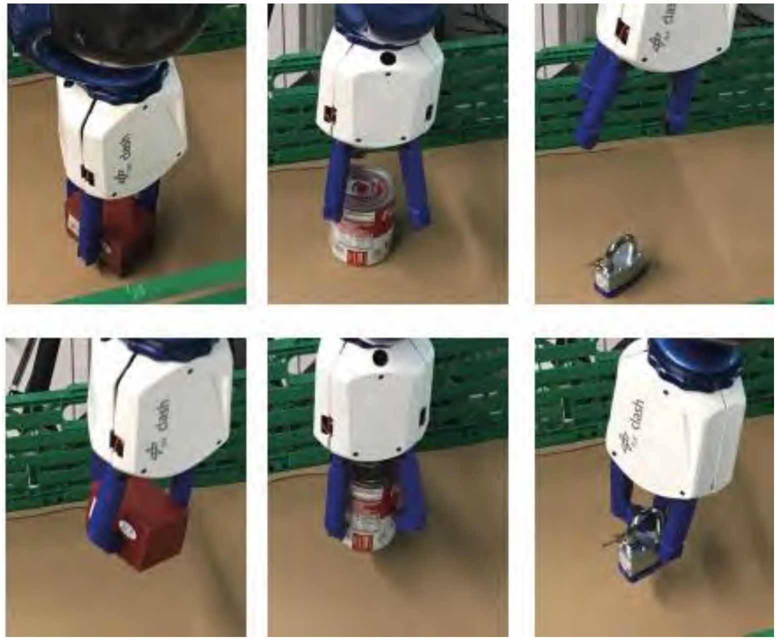
CLASH 3F - hand kinematics optimized for fruits/veggies

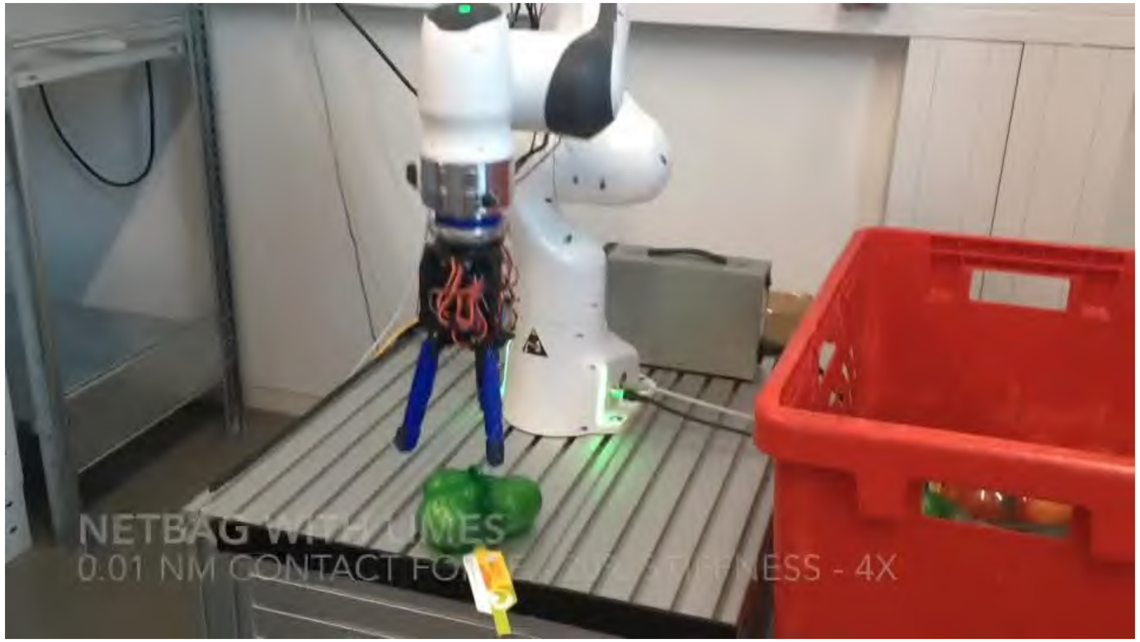
Robustness

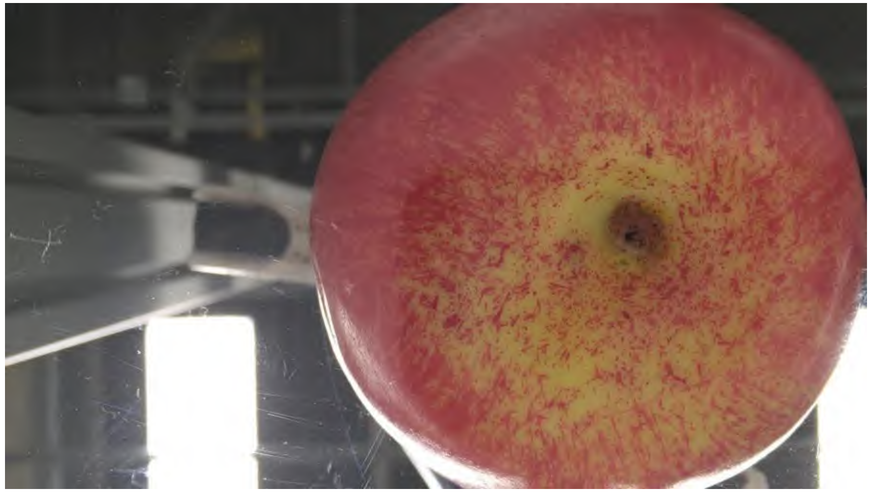


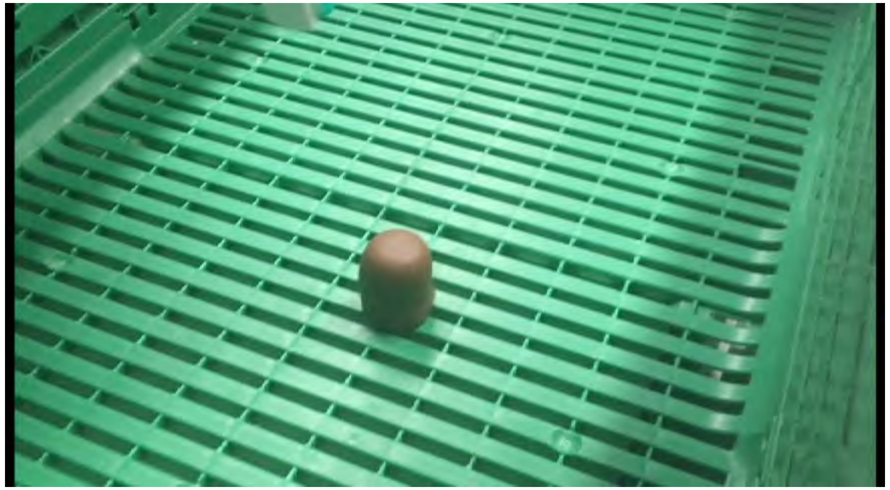
FAS Flexible Antagonistic Spring (IROS 2011)

CLASH 3F – grasping abilities



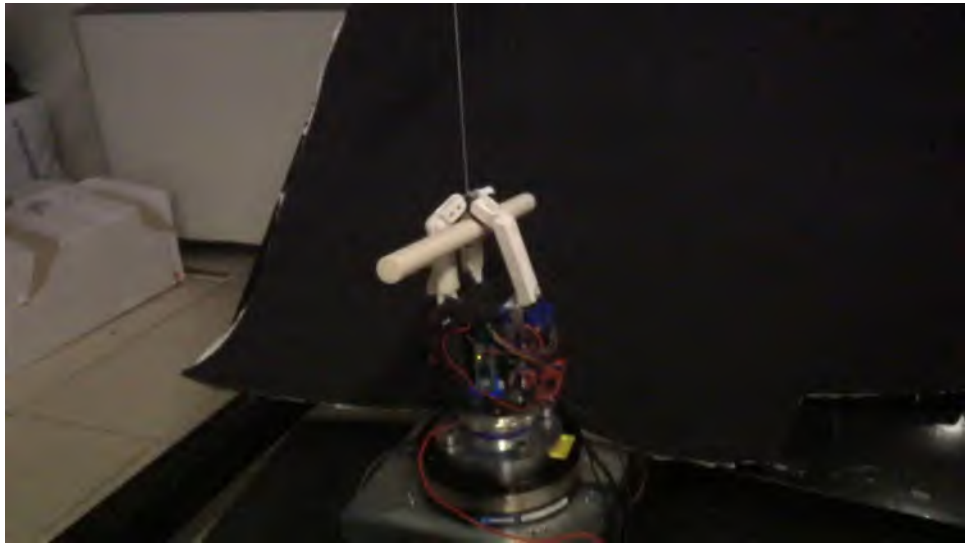


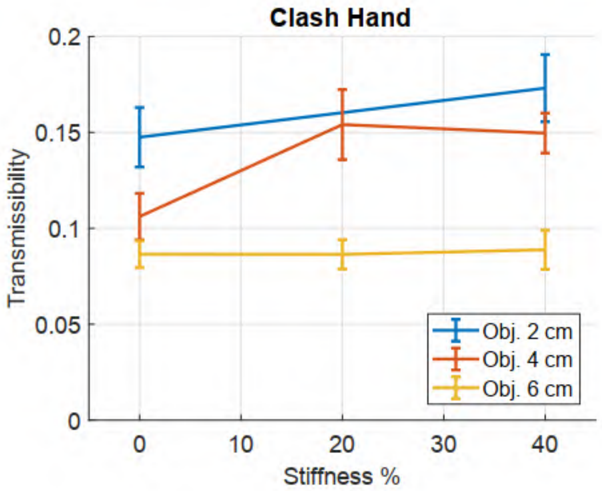


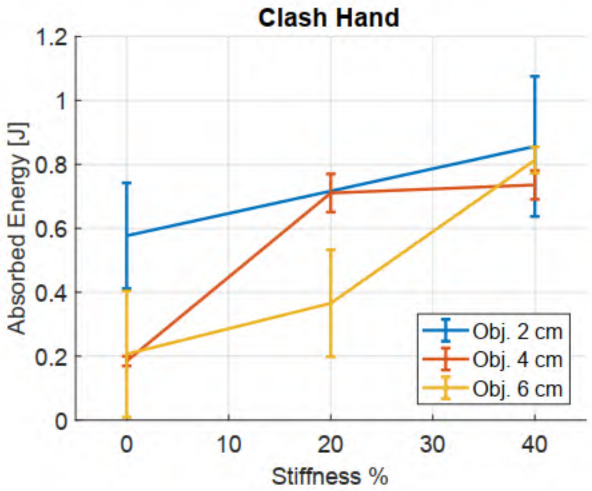


CLASH 3F – Exploiting environmental constraints

CLASH 3F – Hand and grasp resilience

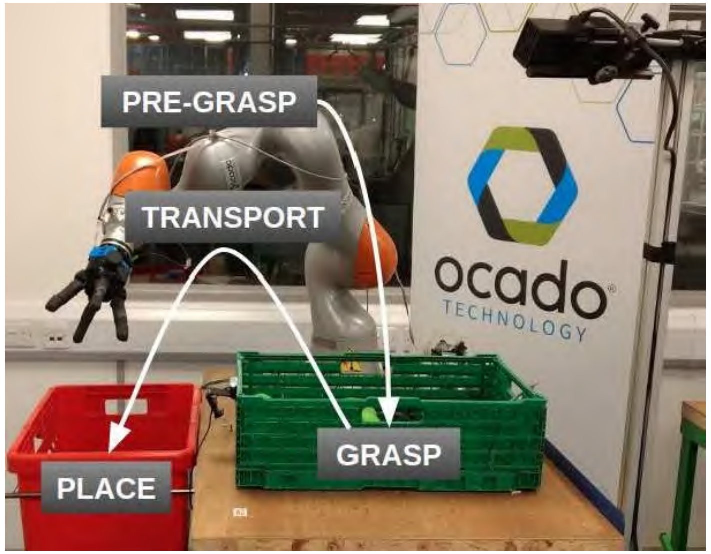






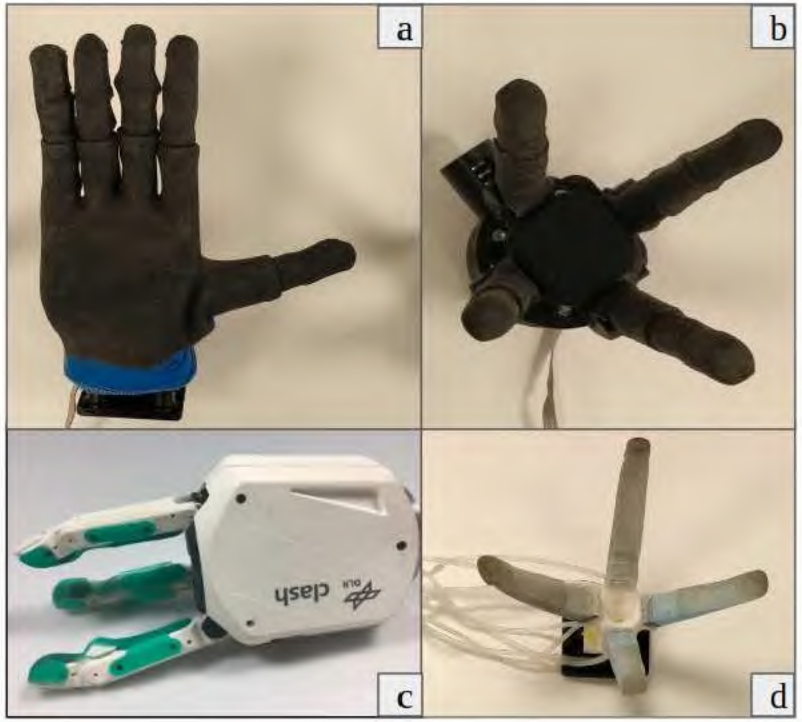
[“Benchmarking Hand and Grasp Resilience to Dynamic Loads”,. Negrello et al., RAL 2020]

Benchmarking Pick and Place Robotic Systems

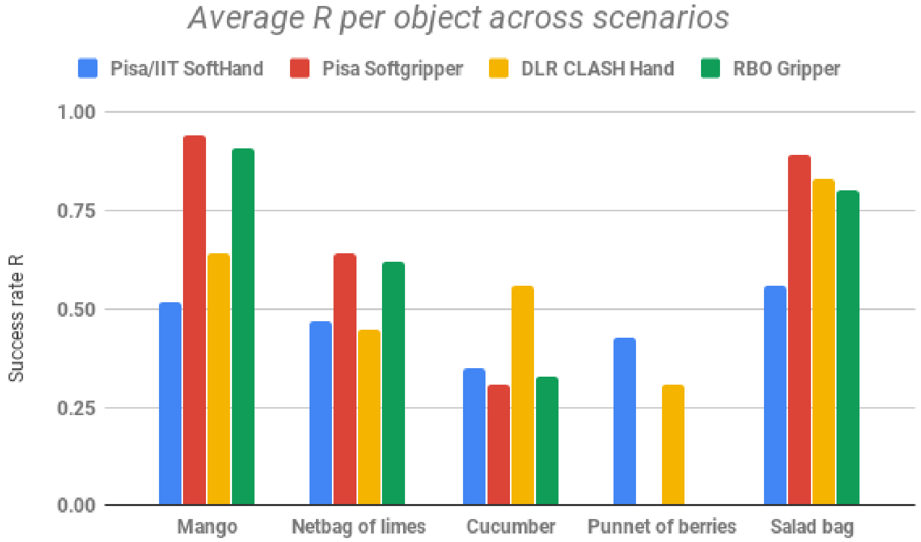


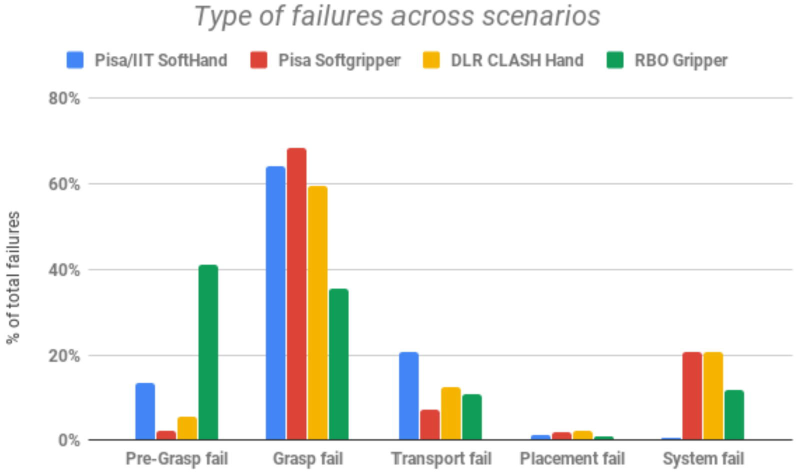
[“A Bin-Picking Benchmark for Systematic Evaluation of Robotic Pick-and-Place Systems”. Mnyusiwalla et al., RAL20]

Benchmarking Pick and Place Robotic Systems



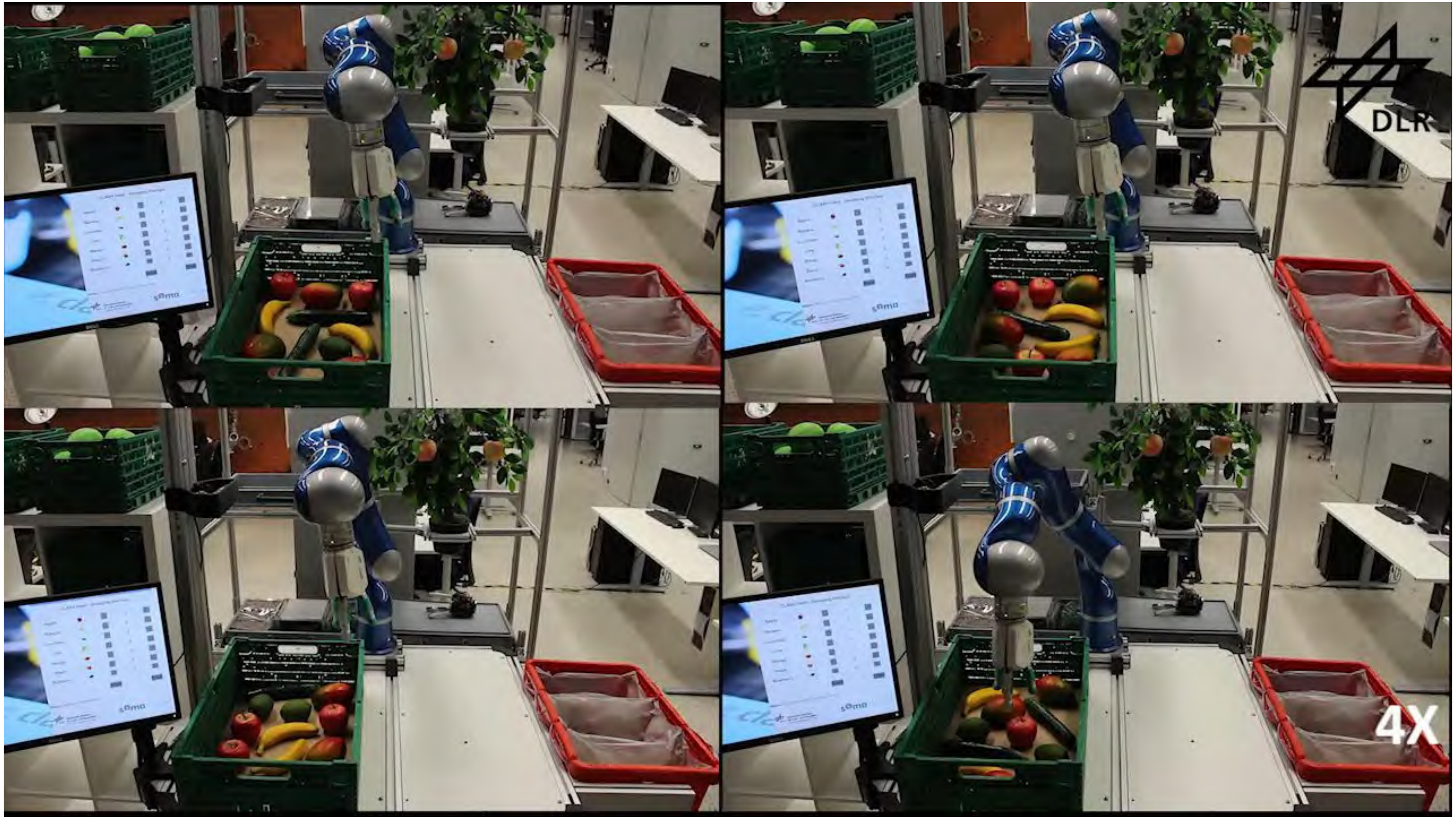
a: Pisa/IIT SoftHand b: Pisa Softgripper
c: CLASH hand d: RBO gripper





[Mnyusiwalla et al., RAL20]

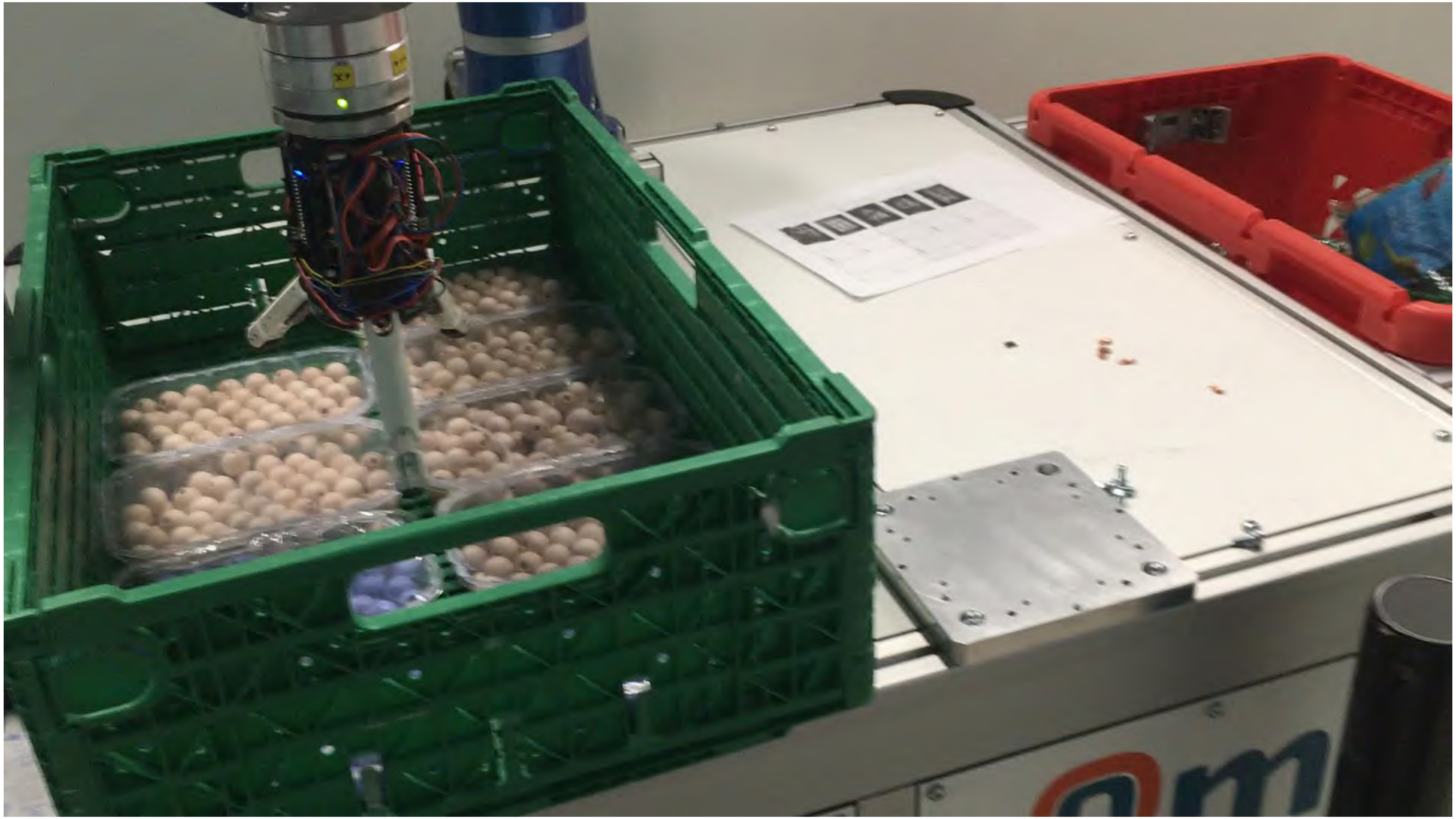
Environment-aware manipulation planning



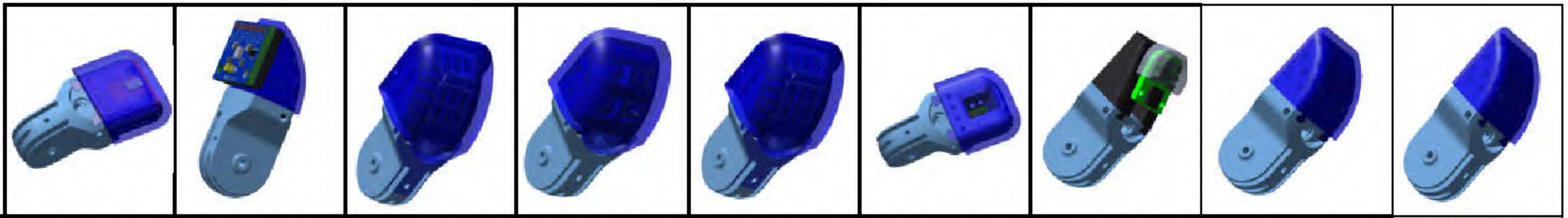
[“Environment-Aware Grasp Strategy Planning in Clutter for a Variable Stiffness Hand”
Sundaram et al., IROS20]

Current challenges

Planning and grasping in clutter….



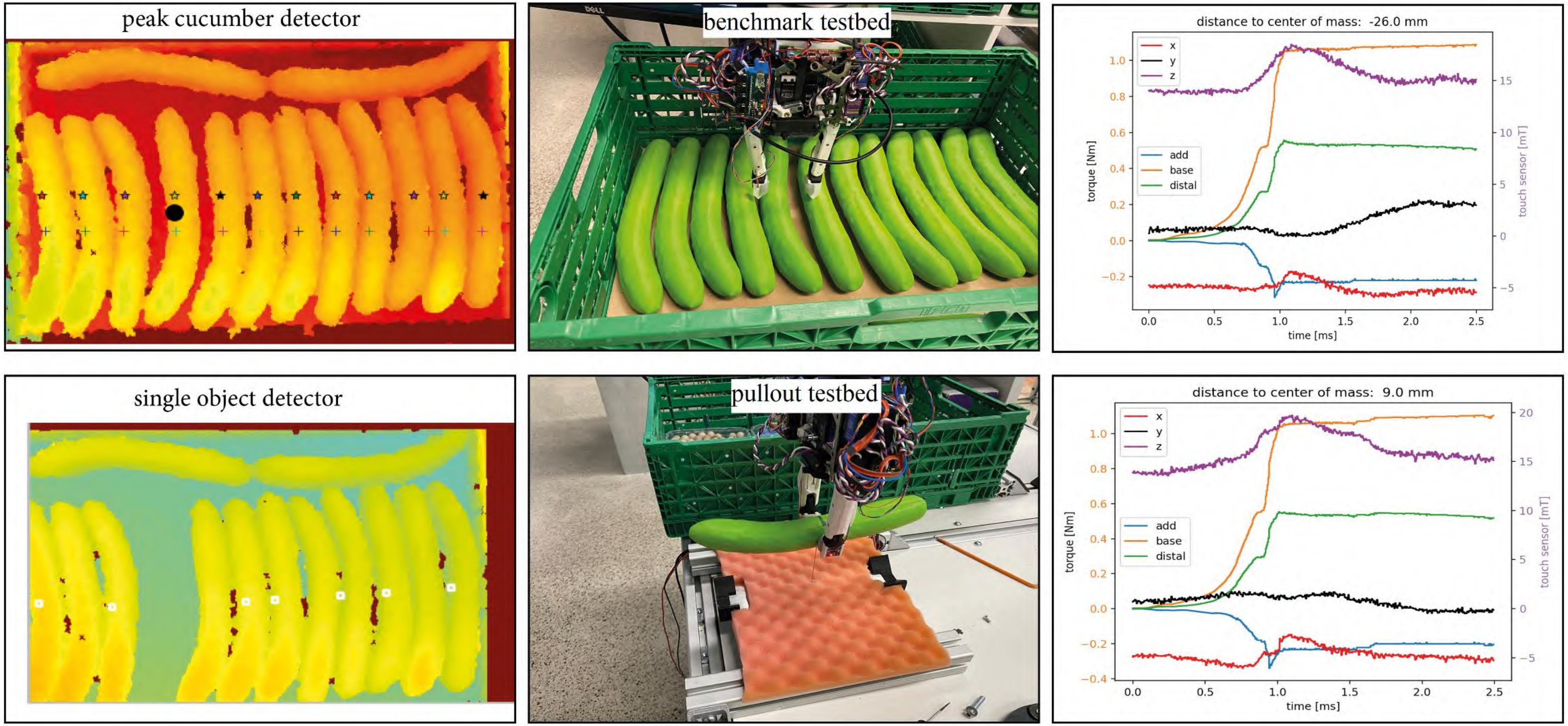
How to effectively integrate sensing?



Name Company / Institution	pressure touch DLR	IMU touch DLR	single magnetic DLR	magnetic touch DLR	resitive touch DLR	TOF touch DLR	Robotic Finger Sensor v2 sparkfunc	tacterion tacterion	kinfinity kinfinity

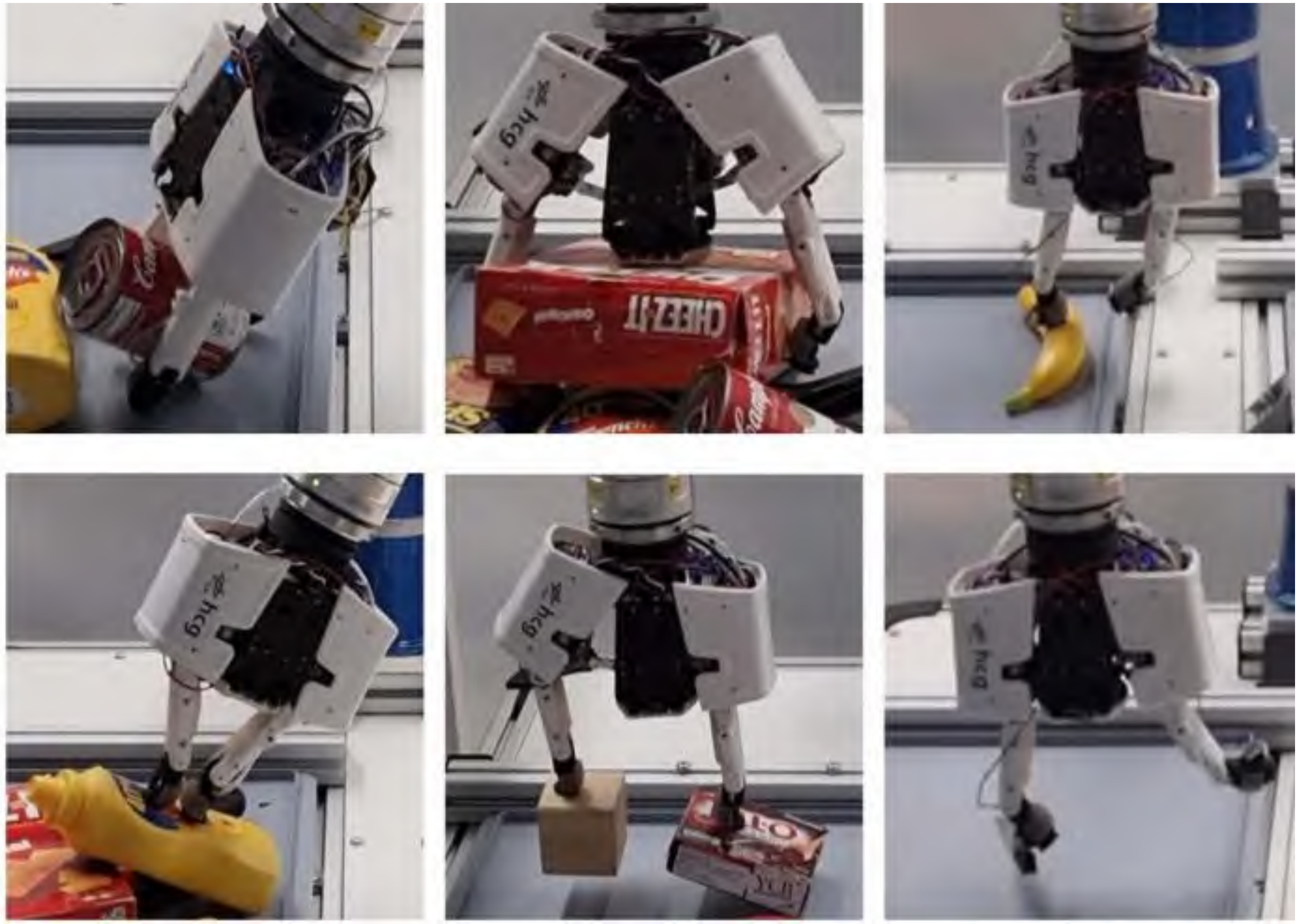
["Experimental evaluation of tactile sensors for compliant robotic hands"
Friedl and Roa, FRONTIERS21]

Fingertip sensing



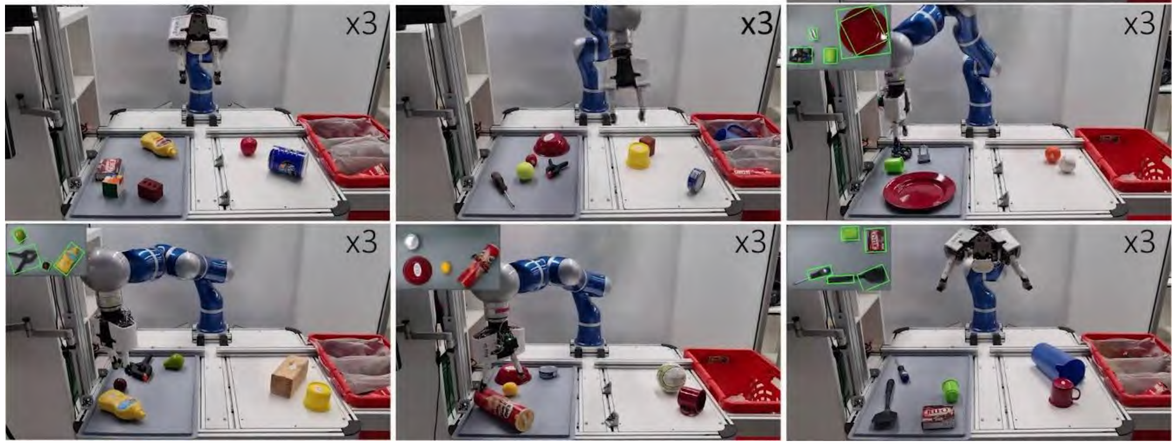
[Friedl and Roa, FRONTIERS21]

New concept: Hybrid Compliant Gripper



Multimodal grasp planner for hybrid grippers in cluttered scenes

success rate	# two-finger	# suction	# double suction	# magnetic
97%	35	16	10	3



[“Multimodal Grasp Planner for Hybrid Grippers in Cluttered Scenes”
D’Avella et al., RAL23]

Toward manipulation of deformable objects

SoftEnable

DLR

III. SPACE MANIPULATION: ORBITAL SERVICES

PULSAR: Prototype of an Ultra-Large Structure Assembly Robot

2019-2021

PULSAR Core Components

demonstrator of Precise Assembly of Mirror Tiles
dPAMT

demonstrator of Large Structure Assembly in Free Floating Environment
dLSAFFE

demonstrator of In-Space Assembly in Simulation
dISAS

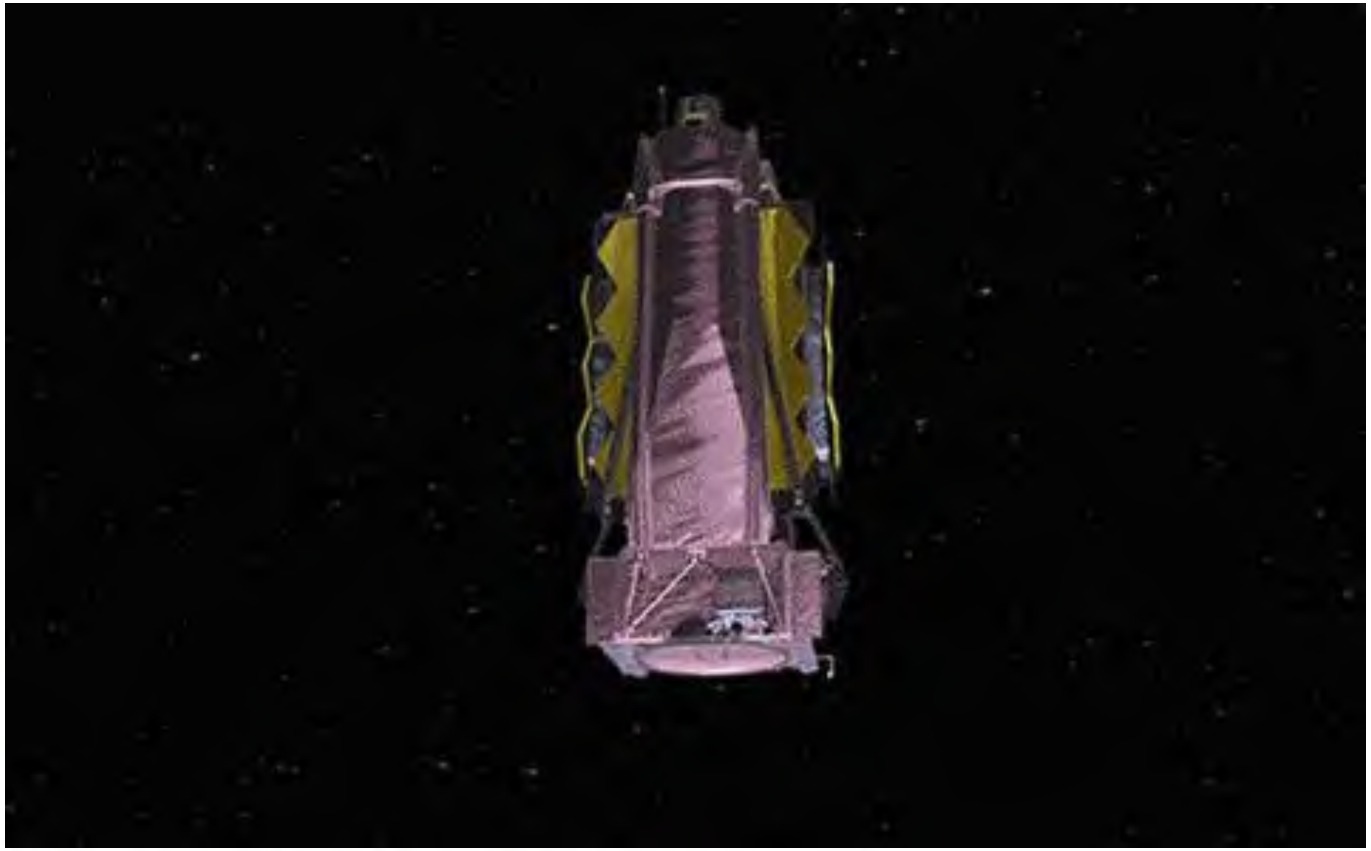
This project has received funding from the European Union’s H2020 research and innovation programme under grant agreement No 821858.

[Rognant et al., EUCASS 2019]

Foldable structures

James Webb Space Telescope

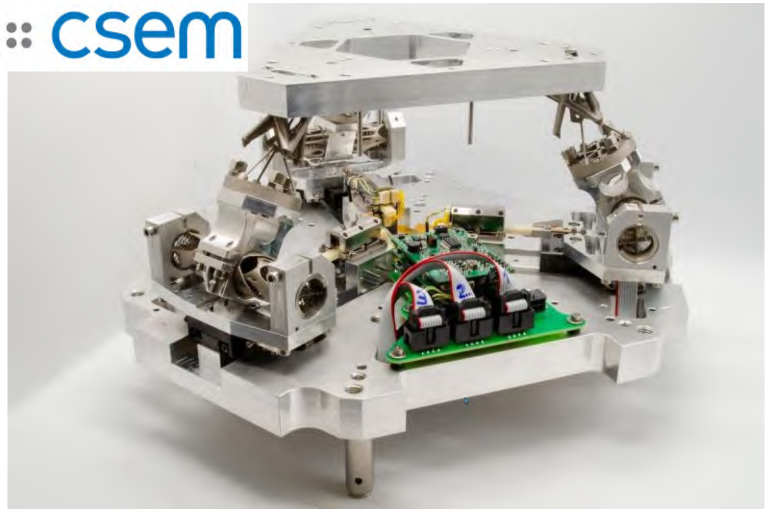
Ariane 5 (4.6 m fairing)



Falcon Heavy (5.2 m fairing) – 9 m telescope
SLS Block I (8 m fairing) – 12 m telescope
SLS Block II (10 m fairing) – 15 m telescope
? – > 15 m telescope

[ESA/NASA]

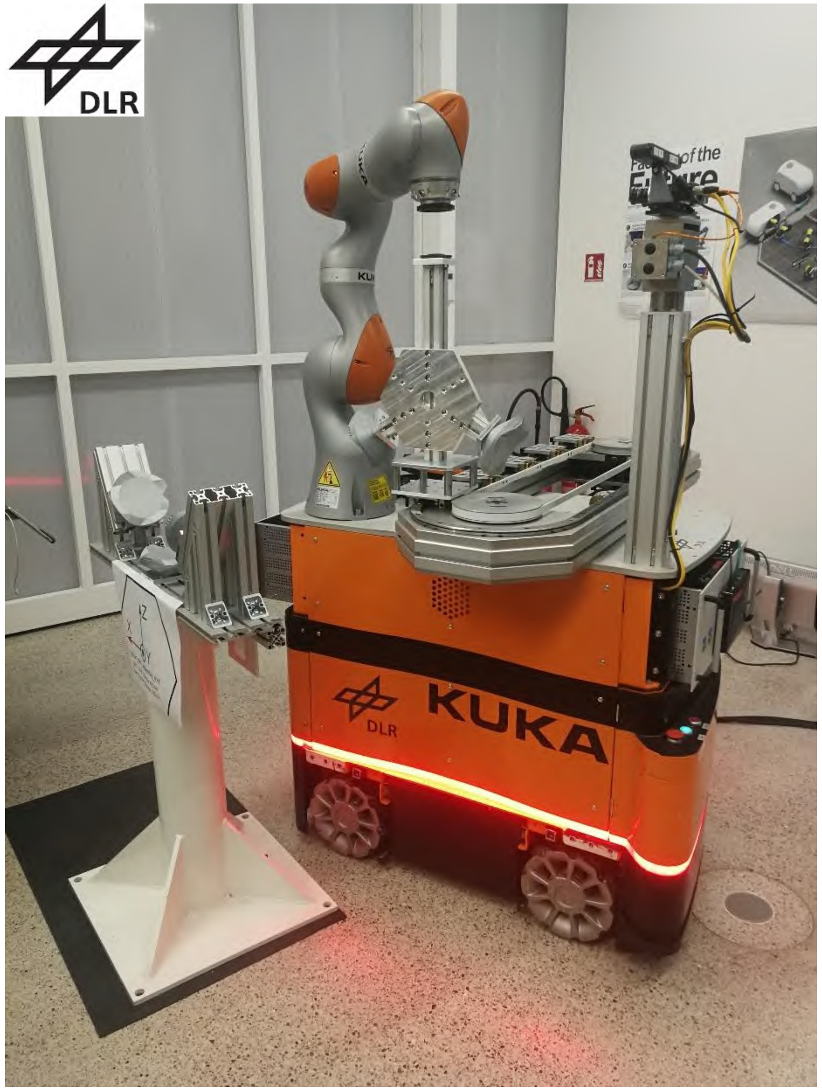
dPAMT - Components



Segmented Mirror Tile, SMT

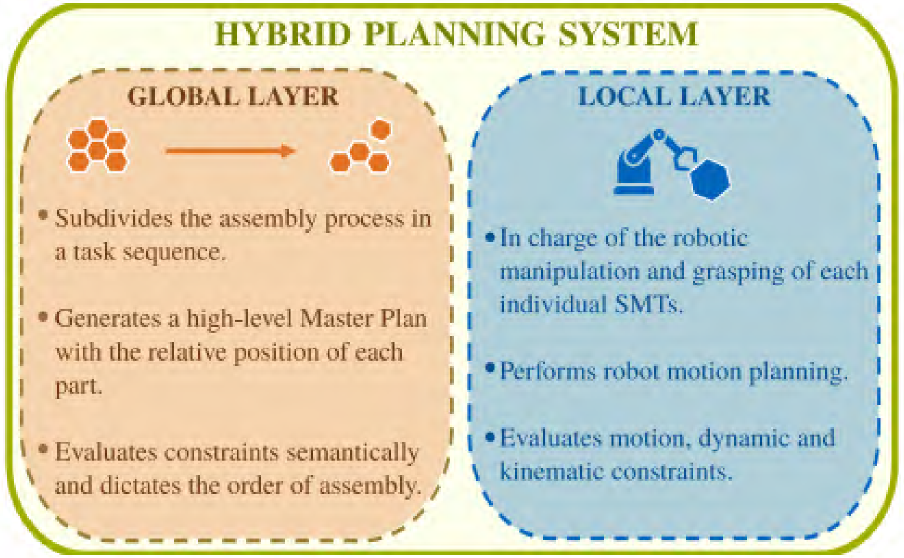
HOTDOCK Standard Interface

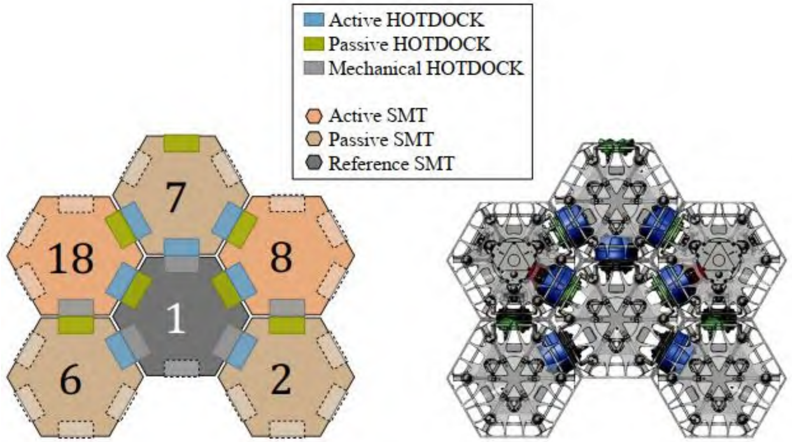
[Letier et al., IAC 2020]



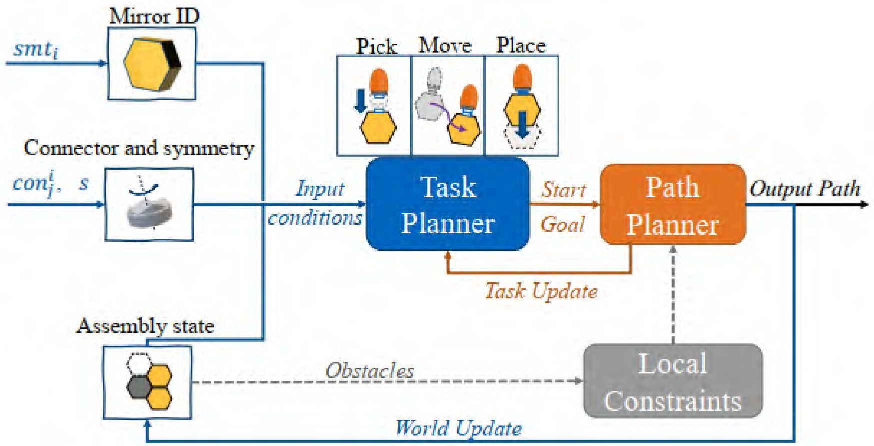
Robotic system

dPAMT - Assembly planner





Semantic constraints

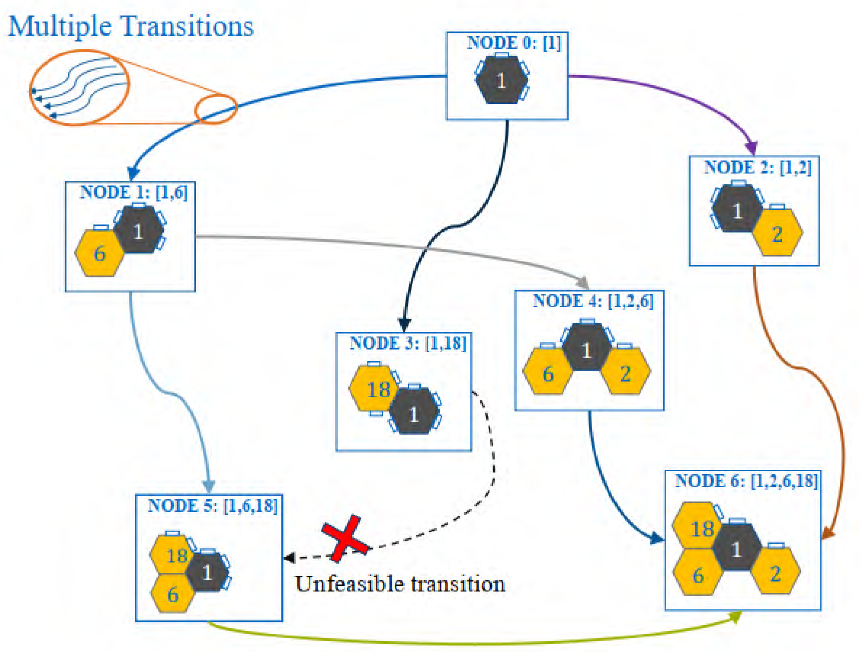


Optimization-based path planner (based on STOMP)

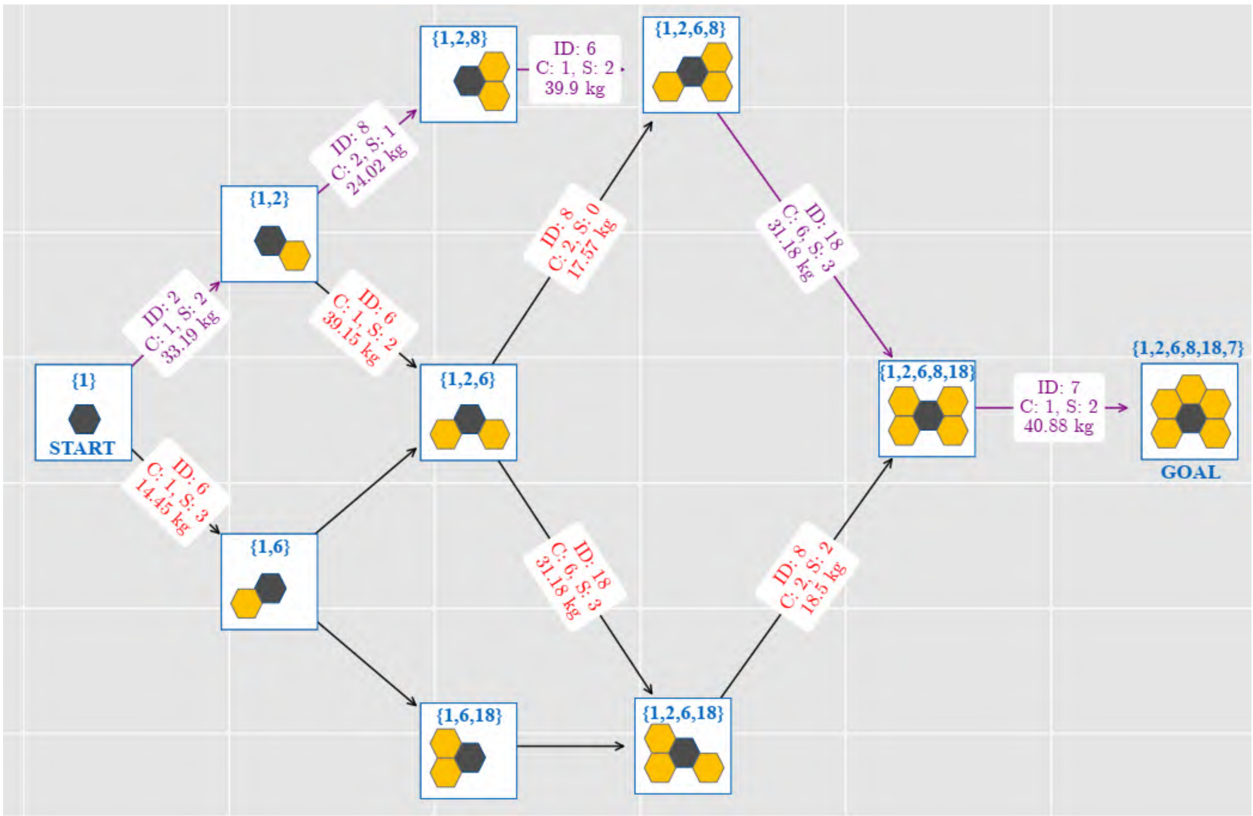
[Martinez et al., Aeroconf 2021]

dPAMT - Assembly planner

Exploration and pruning



Feasible sequences

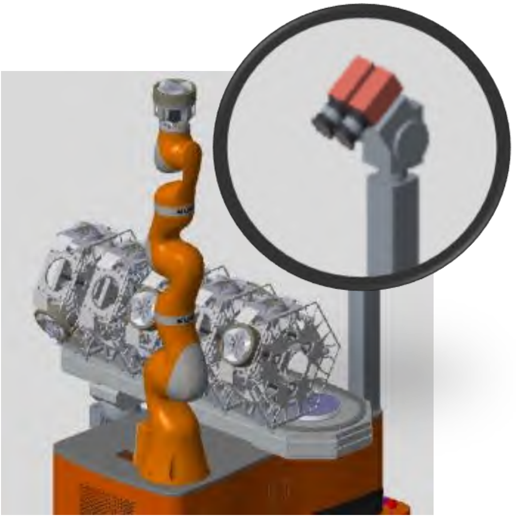


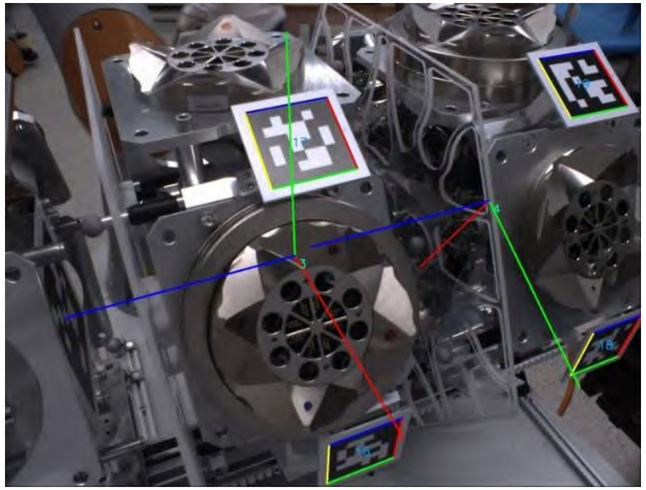
[Martinez et al., Aeroconf 2021]

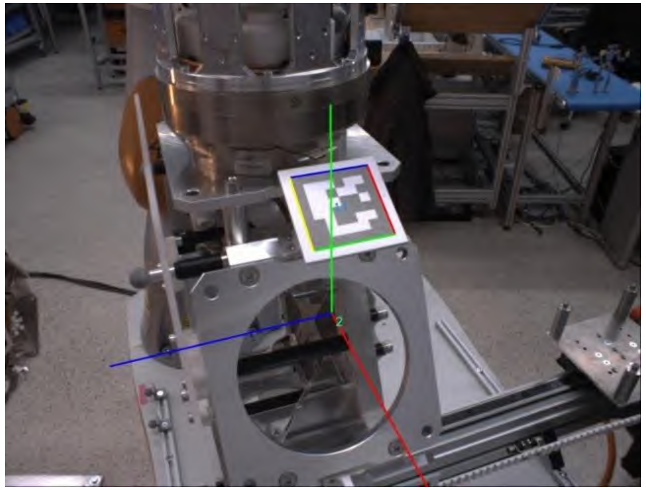
dPAMT - Perception

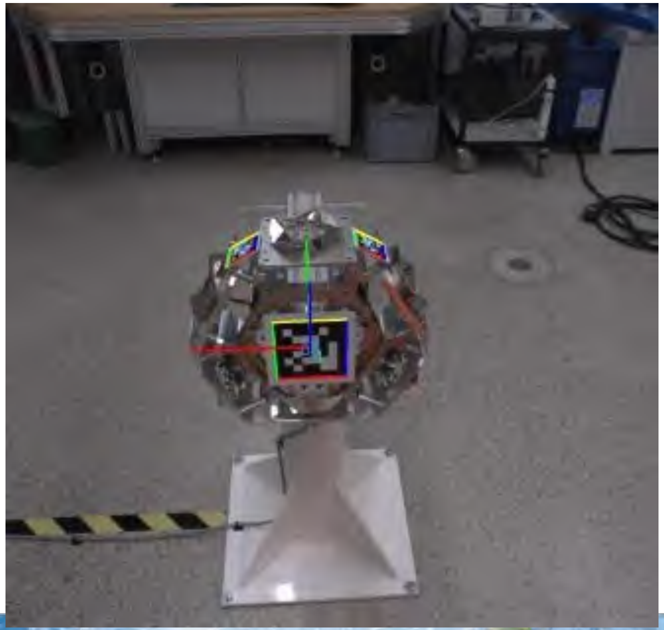
Perception and localization

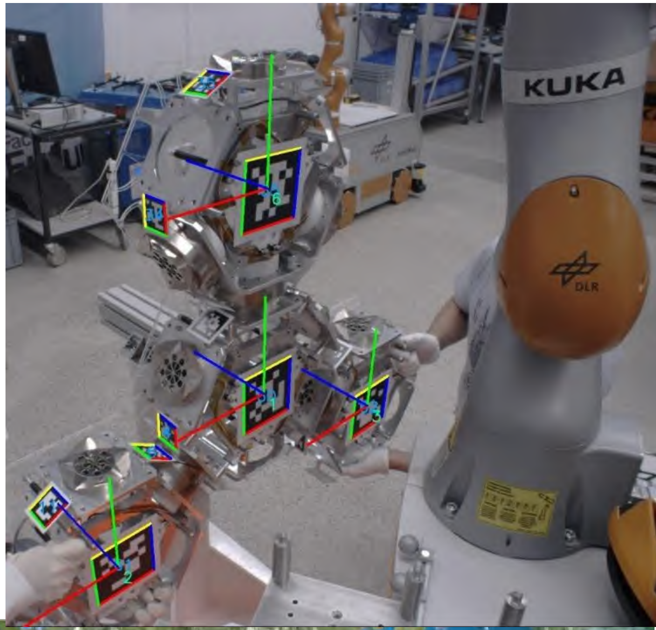
- Unique AprilTag fiducials mounted on each SMT
- Functions integrated and tested on dPAMT with on-board camera sensor:
  - Tile detection and localization
    - tile grasping
    - platform navigation
  - Assembly monitoring
  - Visual servoing
- Tests show accuracy compatible with assembly tasks, camera FoV, SI tolerance







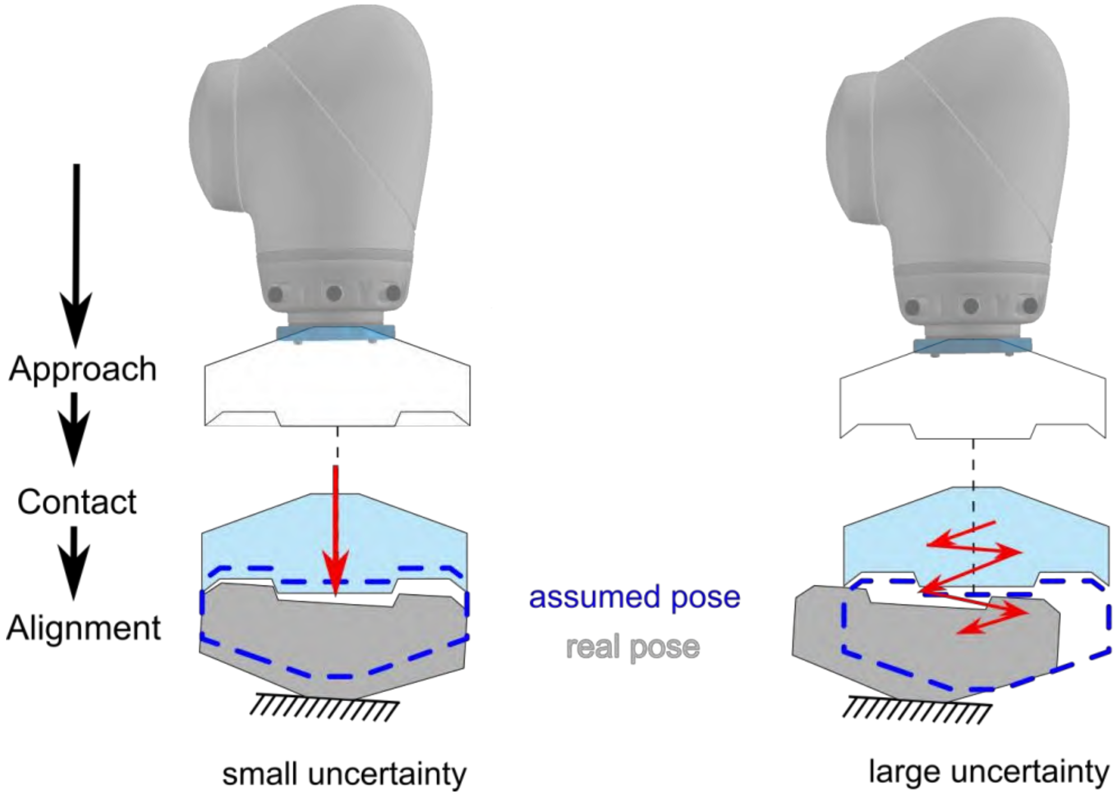




dPAMT – Control and execution

Implemented skills:
- Pick_smt
- Place_smt
- Move_collision_free
- Move_mobile_base
- latch_hotdock / *_hotdock
- localize_smt
- localize_assembly_area

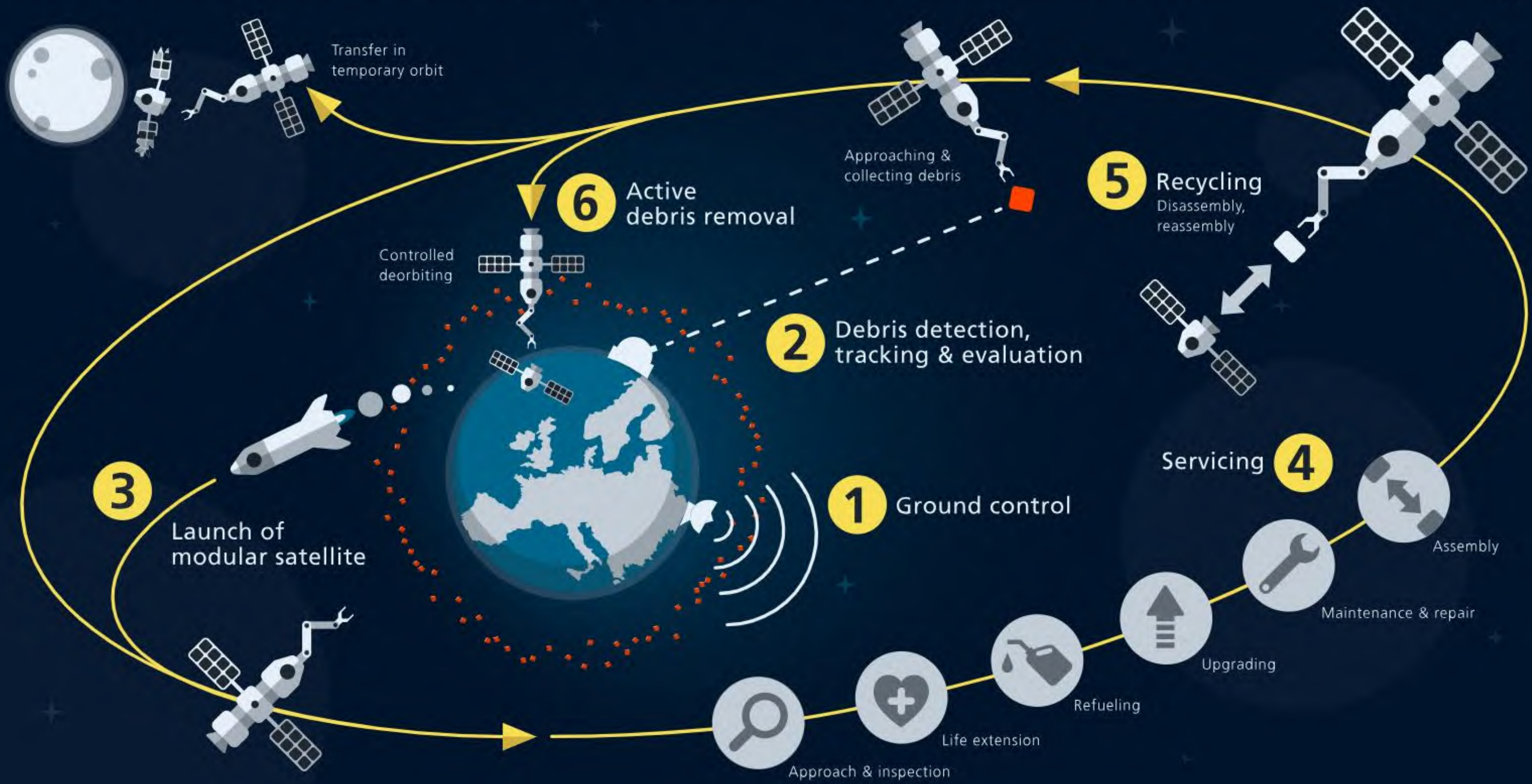
Compliant assembly strategies



PULSAR – Final demo

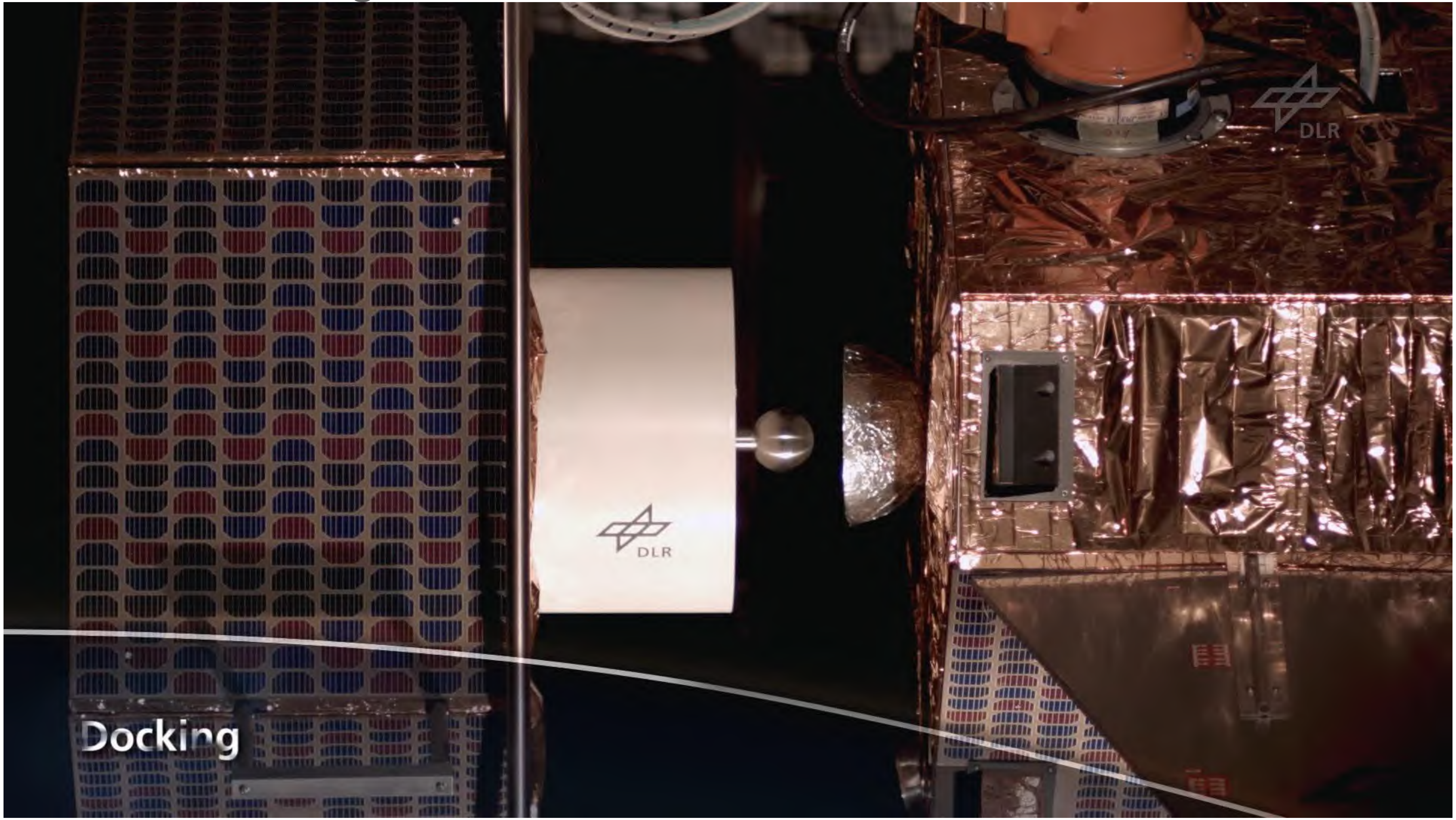
[Roa et al., ASTRA 2022]

ROBOT TECHNOLOGIES FOR SUSTAINABILITY IN EARTH ORBIT



End-to-End Simulation

OOS-SIM: On-Orbit Servicing Simulator



[Artigas et al, ICRA15]

CAESAR arm: Compliant Assistance and Exploration SpAce Robot

Manipulator	
Joint Position Sensor Resolution	82.830 inc / 320°
Motor Position Sensor Resolution after Gear	11.650.644 inc / 320°
Length of Manipulator arm	2.4m + x (7dof)
RA Mass	~ 60kg
Thickness of Aluminum Housing	2mm
Internal Databus	Deterministic, real-time EtherCAT with 100MBit/s
Range of Motion	320° for all axis
Joint output torque	80Nm for all axis
Joint velocity	Up to 10°/s
Environment	
Operational Temperature	-20°C to +60°C
Non-Operational Temperature	-50°C to +80°C
Radiation Hardness	40krad TID (with additional shielding 100krad TID)
Mission Time	Up to 15 years

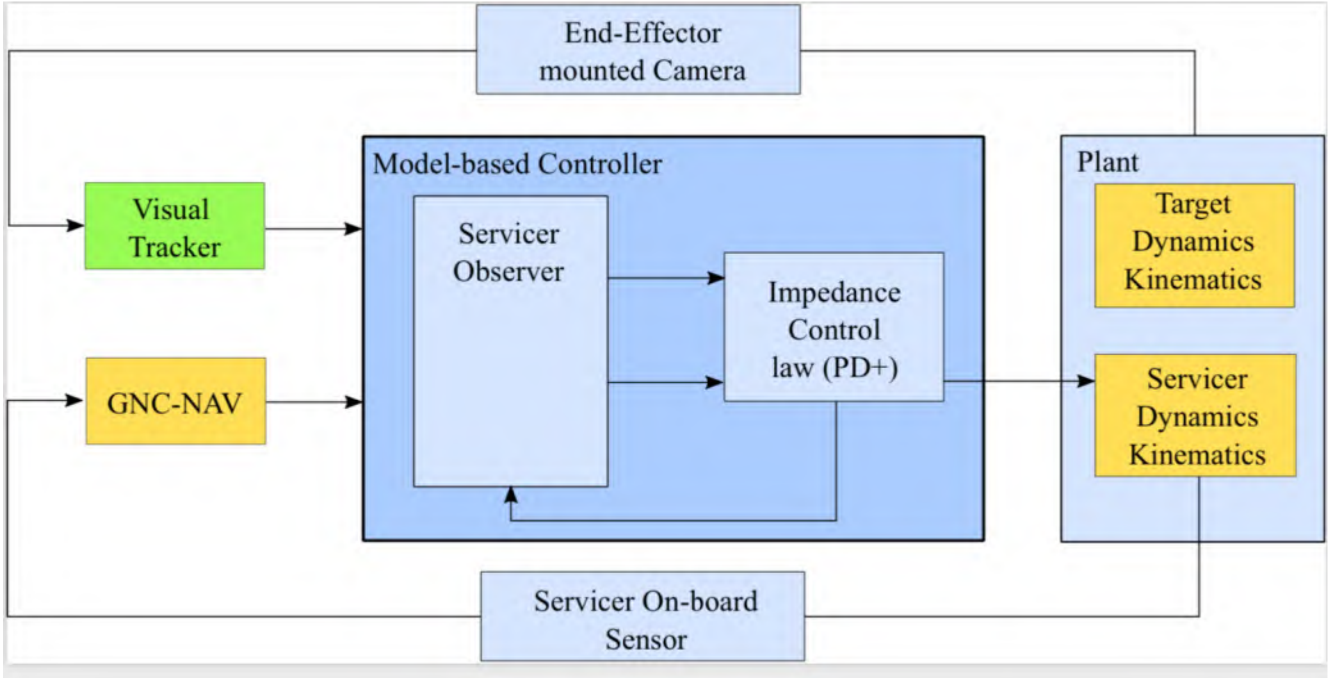
[Beyer et al., IAC18]

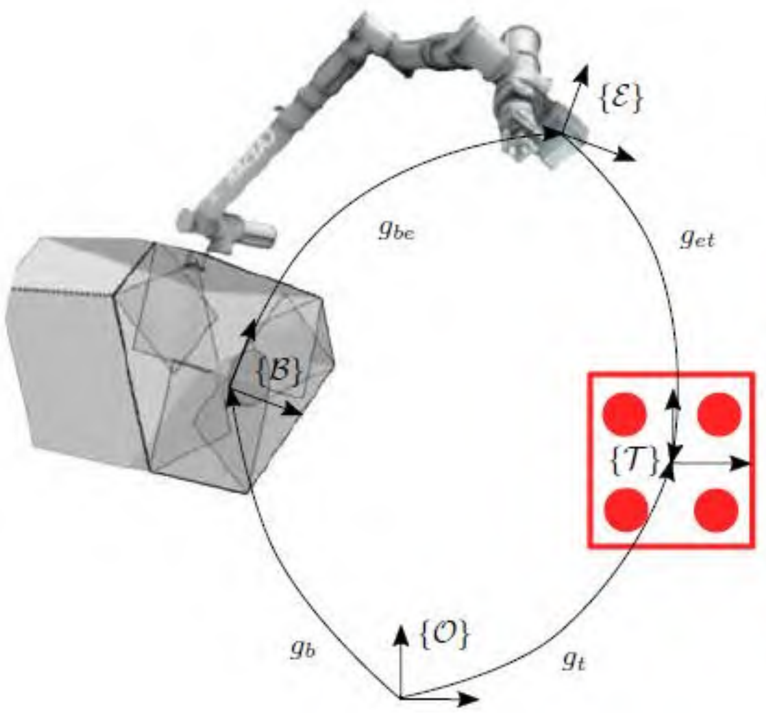
Control aspects

Model-based controller design provides:

- State information during inter-sampling periods
- High-rate impedance control useful in interaction
- Robustness against occlusion and packet lost (outlier rejection)
- Disturbance estimation for precise control

Model-based controller requires input from navigation and GNC:





- g_b: GNC-NAV spacecraft pose
- $g_{be}(q)$: CAESAR forward kinematics pose
- g_t: Target pose
- g_{et}: Camera measurement


EROSS+
EUROPEAN ROBOTIC ORBITAL SUPPORT SERVICES
DLR
KUKA
DLR

IV. TELEOPERATION

Teleoperation of a humanoid robot

[Porges et al, ICRA19]

Teleoperation of a humanoid robot

DFG Deutsche Forschungsgemeinschaft

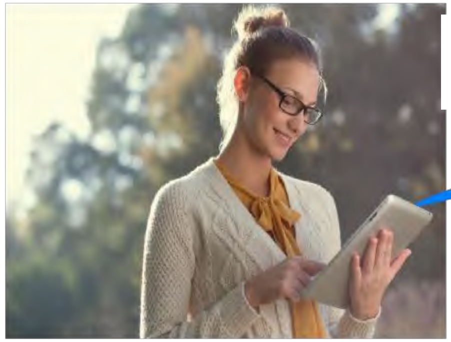
[Connan et al, SciRob20]

Closing the circle: From/To ground to/from space

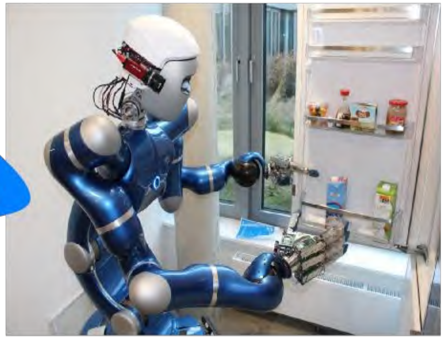
Daily living support for elderly and disabled people

gefördert von
Bayerisches Staatsministerium für
Wirtschaft und Medien, Energie und Technologie

Family member

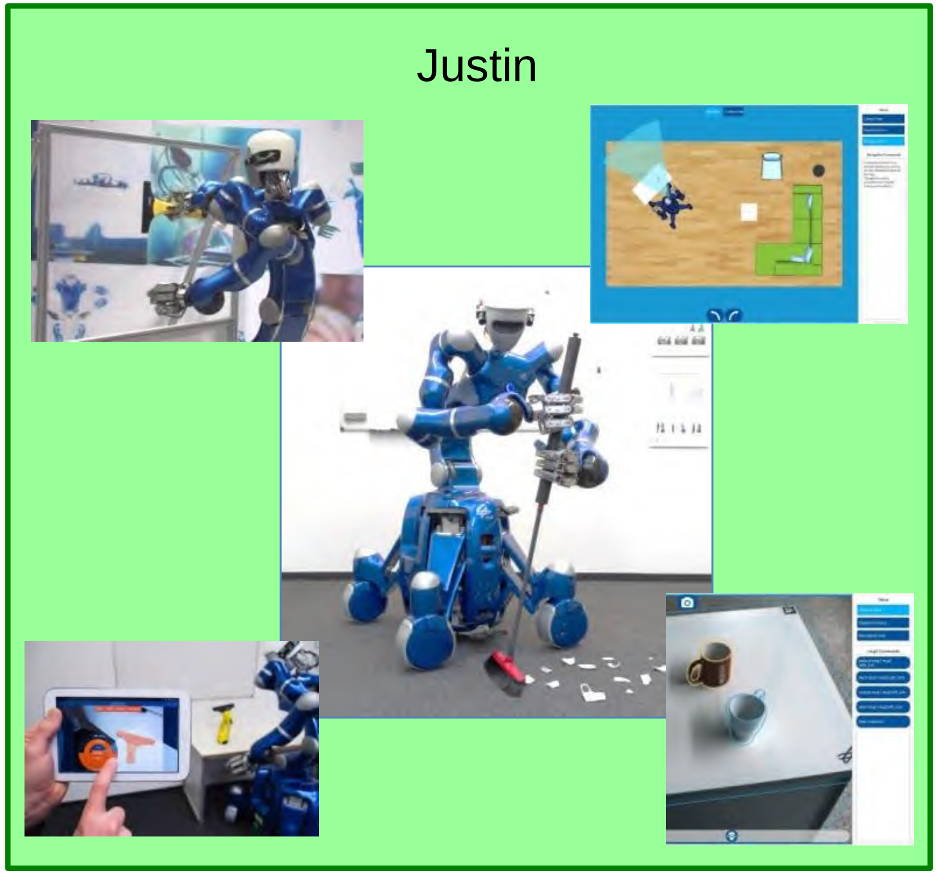


Intuitive teleoperation
by smart-phone or tablet-pc



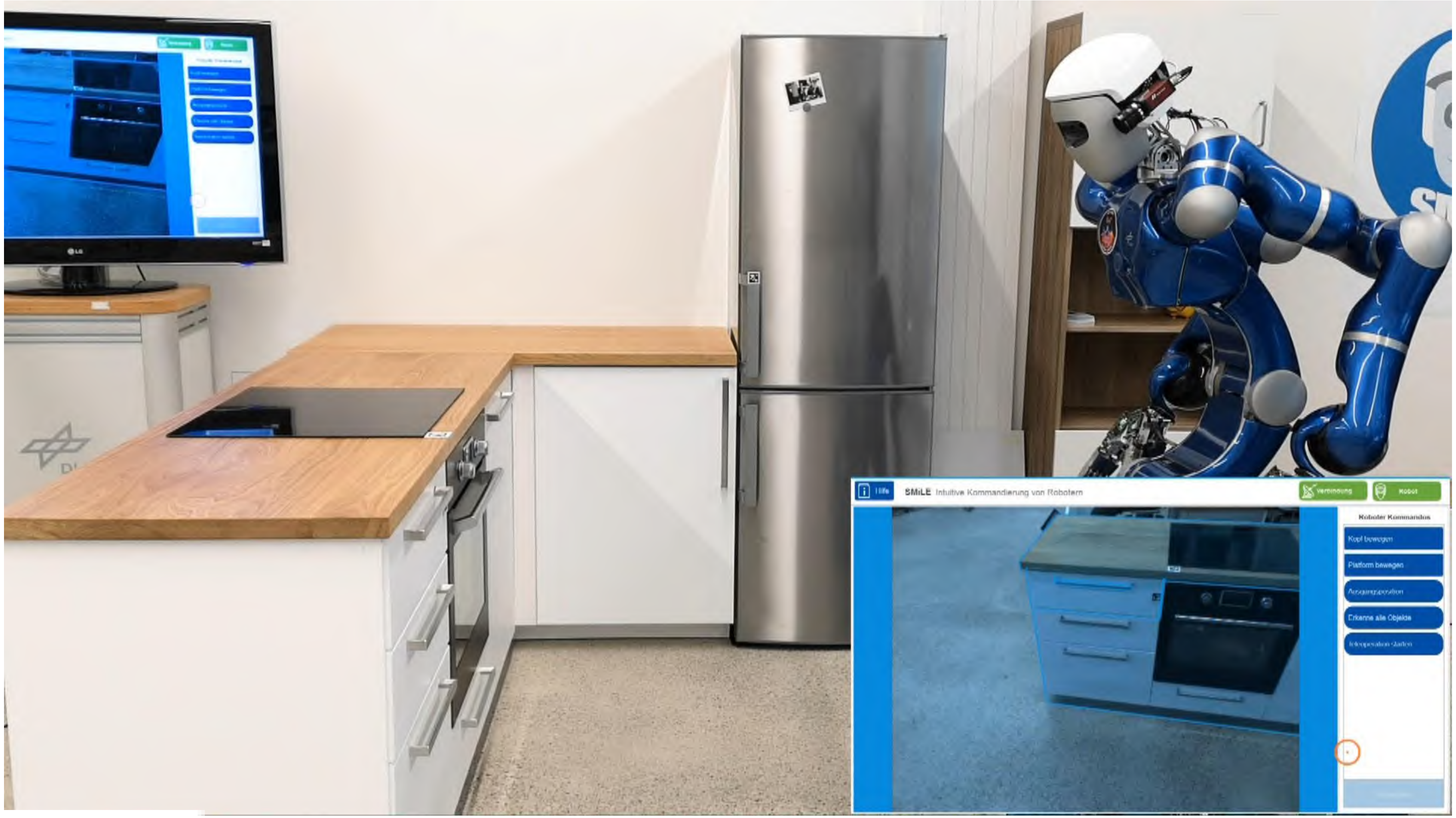
Operator

Haptic telepresence
by a remote expert



SMiLE: bring space teleoperation technology back to Earth

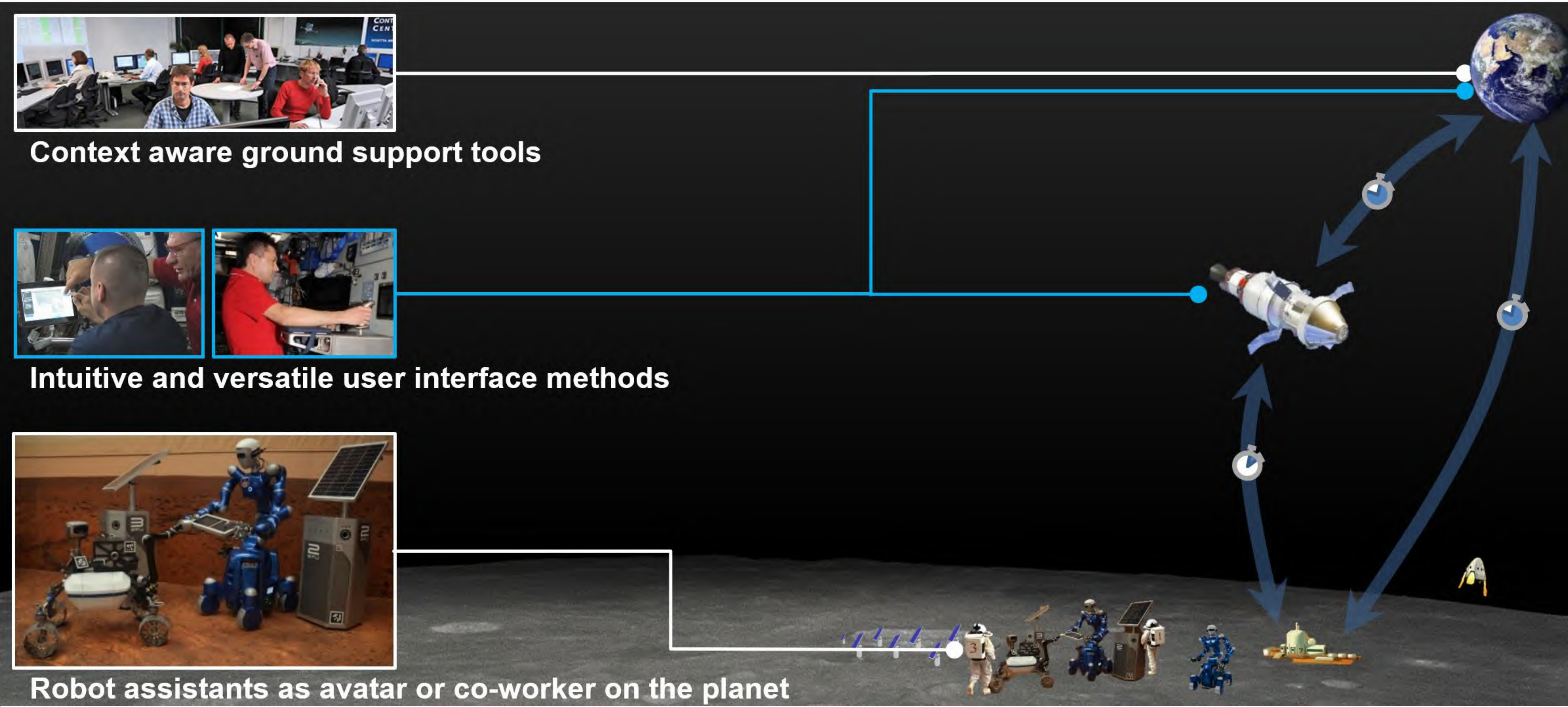
Space technology for home and service assistance



METERON SUPVIS: teleoperating a humanoid robot from Space

[Schmaus et al, RAL18]

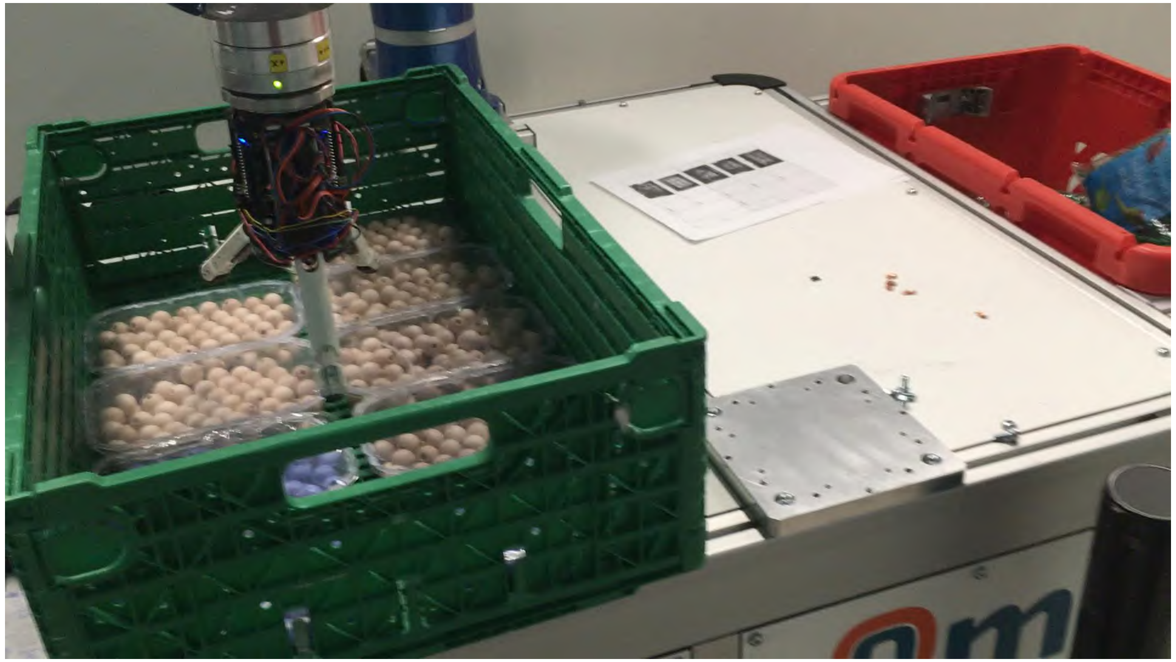
Astronauts’ partner on planetary surfaces



V. FINAL THOUGHTS…

Next challenges….

Error recovery



Grasping in clutter

- Evolution of a hybrid gripper for industrial/logistic applications
- Analysis of human stiffness and mapping to robot impedance for bimanual manipulation
- Robot health estimation (operational capability), and planning/operation considering potential failures

Toward an autonomous robotic assistant

Autonomy

Acknowledgments

soma

http://soma-project.eu/

INTELLIMAN

AI-powered manipulation system for advanced robotic service, manufacturing and prosthetics

https://intelliman-project.eu/

SoftEnable

https://softenable.eu/

pulsar

https://www.h2020-pulsar.eu/

EROSS IOD

https://www.eross-iod.com/

Contact: maximo.roa@dlr.de

www.robotic.dlr.de/maximo.roa

European Commission

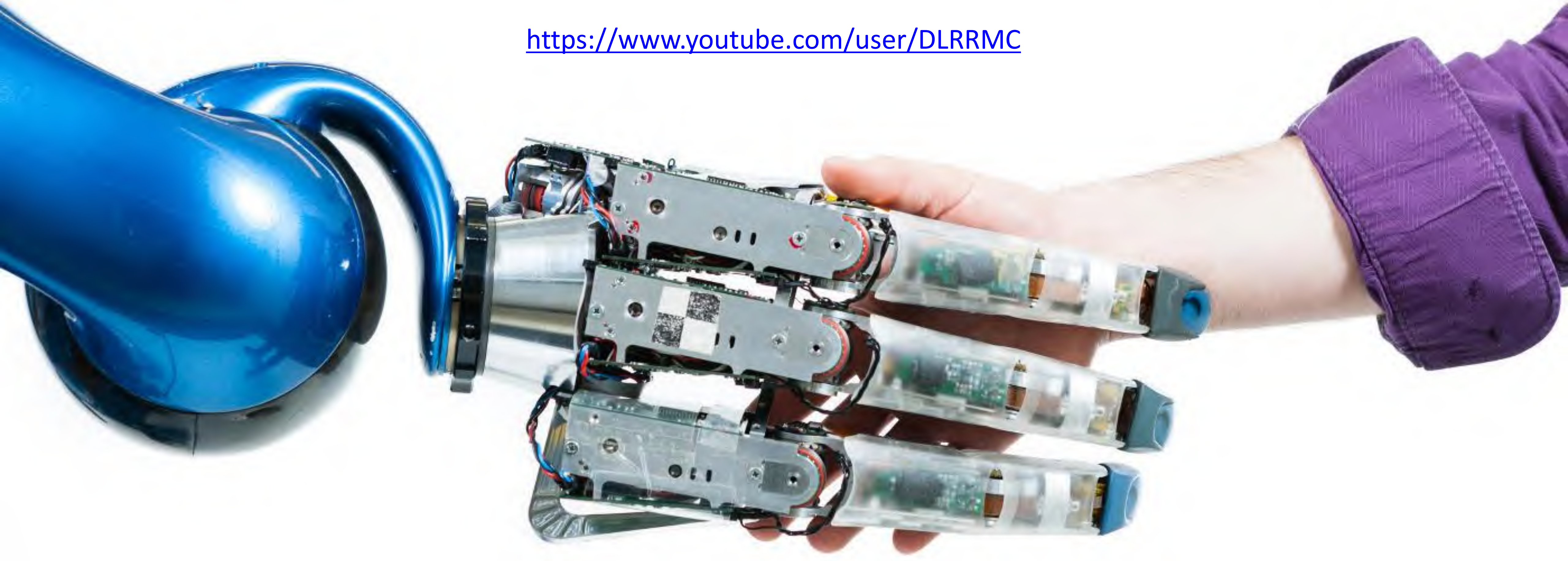
HORIZON 2020

DLR

Q&A

https://www.dlr.de/rm/en

https://www.youtube.com/user/DLRRMC



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www.robotic.dlr.de/maximo.roa

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