Autonomous Assembly for One-of-a-kind Production

Korbinian Nottensteiner

Robotic Assembly – Recent Advancements and Opportunities for Challenging R&D (Workshop, 20.08.2018)

CASE 2018, 14th IEEE International Conference on Automation Science and Engineering

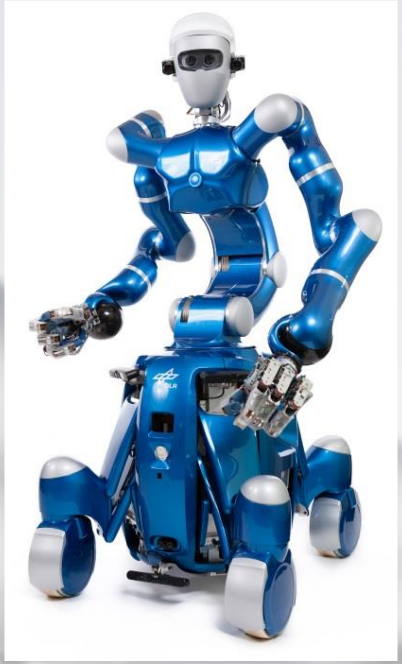
DLR

Institute of Robotics and Mechatronics (RM)

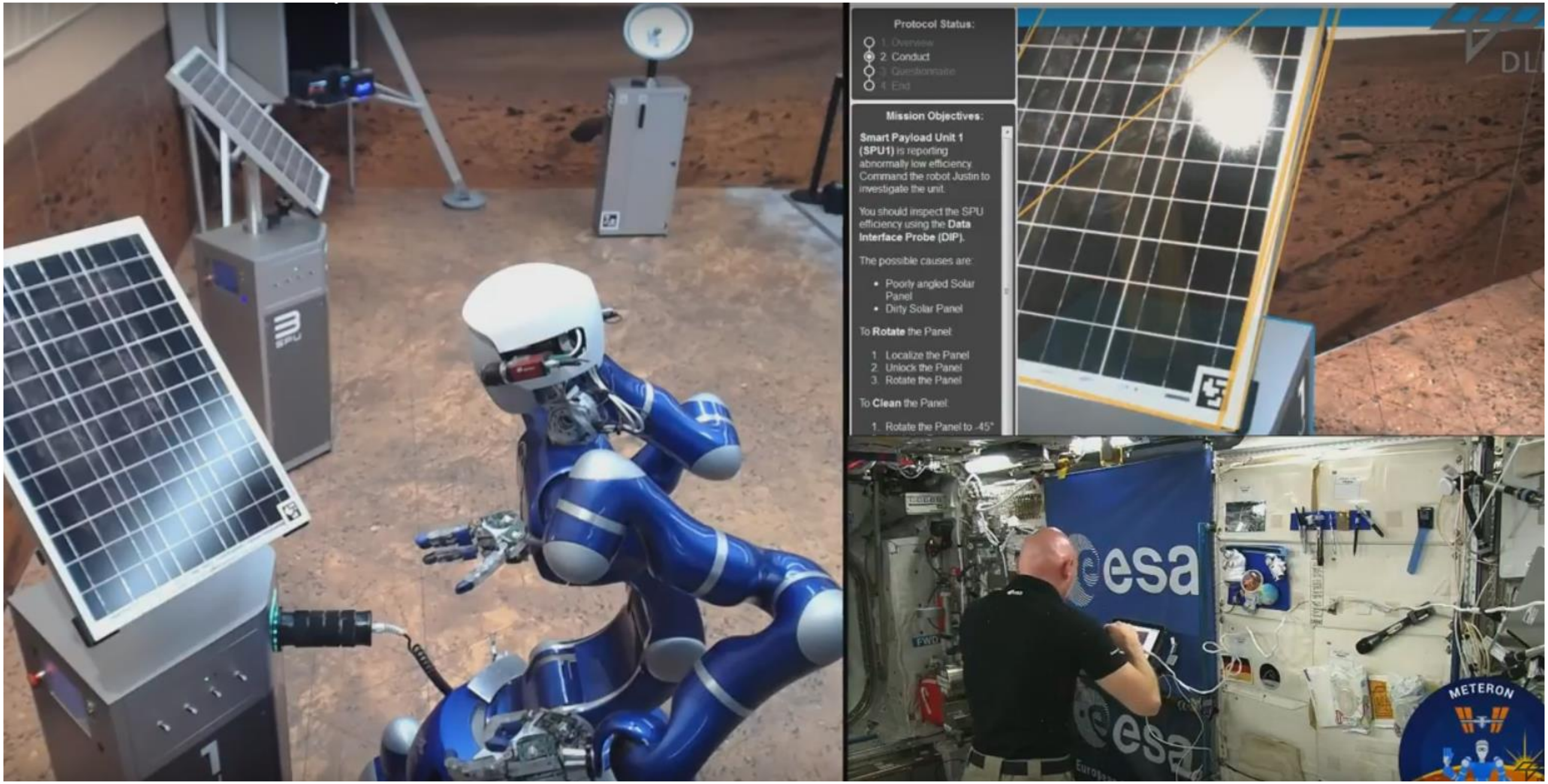
- German Aerospace Center (DLR)
  ~ 2000 employees, 35 institutes, 20 locations

  Main research areas:
  Aeronautics, Space, Energy, Transport
  Security, ***Digitalization (since 2018)***

- Institute of Robotics and Mechatronics
  ~ 200 employees in Oberpfaffenhofen (OP)



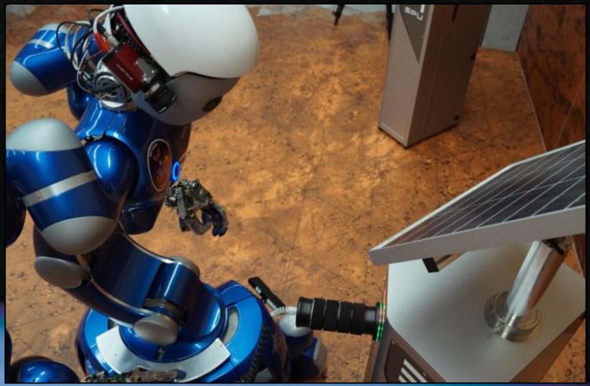
News on METERON SUPVIS Justin Experiment



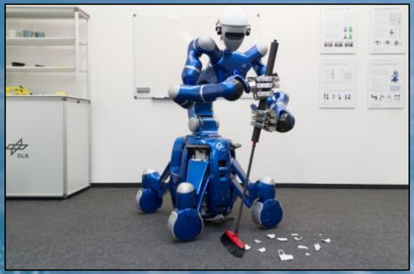
RM Application Domains

On Orbit Servicing

Space Robot Assistance



Planetary Exploration



Intelligent Service Robots

Medical, healthcare & human interfaces

Field Robotics

Future Manufacturing

Factory of the Future

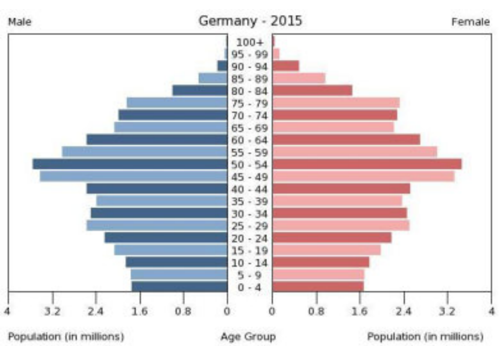
Intelligent robots for digitally-driven production

Trends and challenges

- Customization of products
- Sustainable and efficient production
- Reshoring
- Demographic change

Project goals

- Showcase the usage of intelligent robots in digitally-driven production
- Adaptable production lines through mobile and connected production robots
- Safe, highly efficient and intuitive collaboration between human and machine

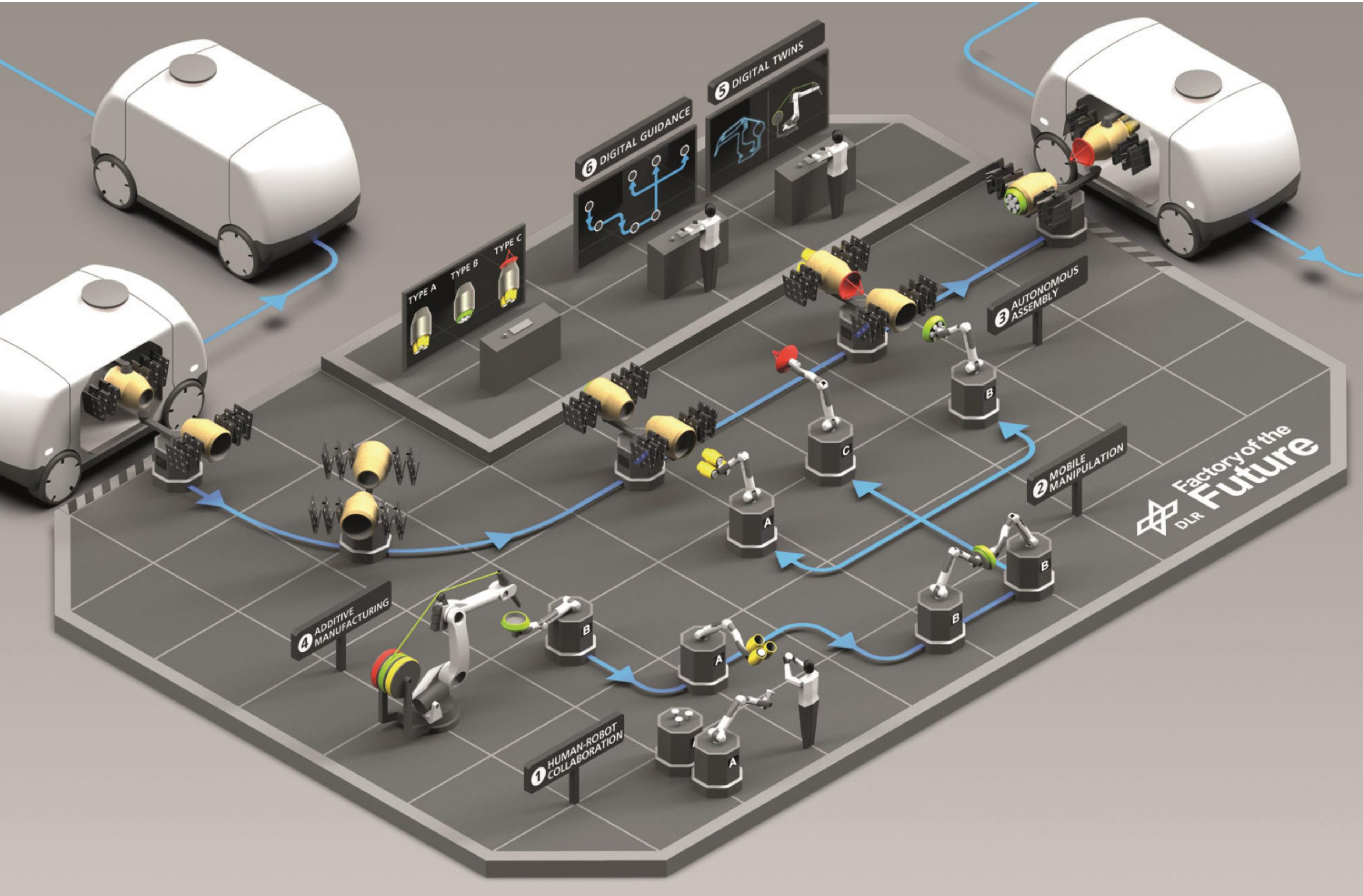


Age Structure Germany 2015

Example - Individualized sneakers: adidas SPEEDFACTORY AM4 London

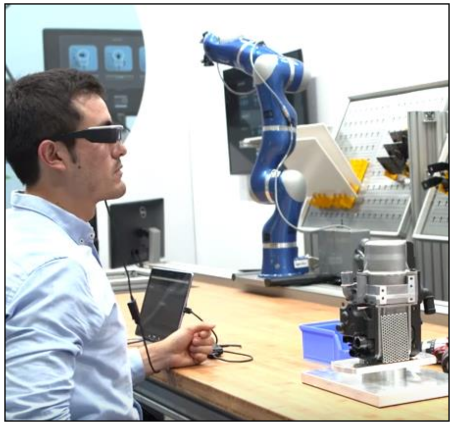
Vision – mobile and humanoid production assistant

Factory of the Future

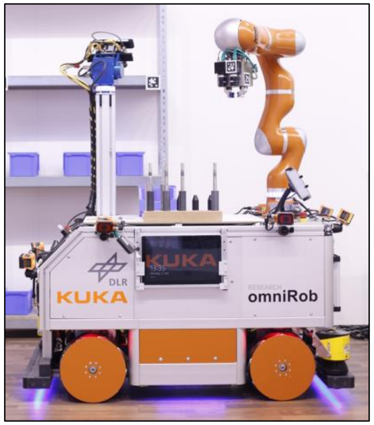


Robotic Systems of RM in Factory of the Future

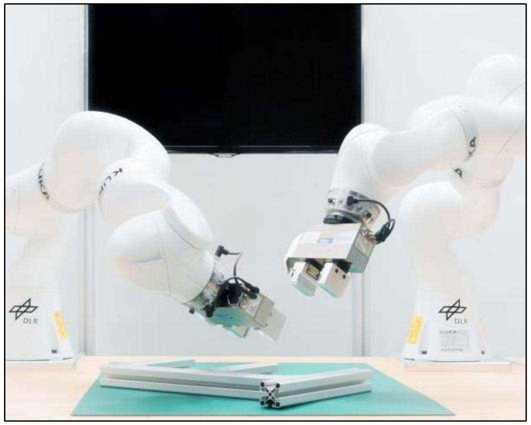
Reconfigurable Workcell



Collaborative Workbench

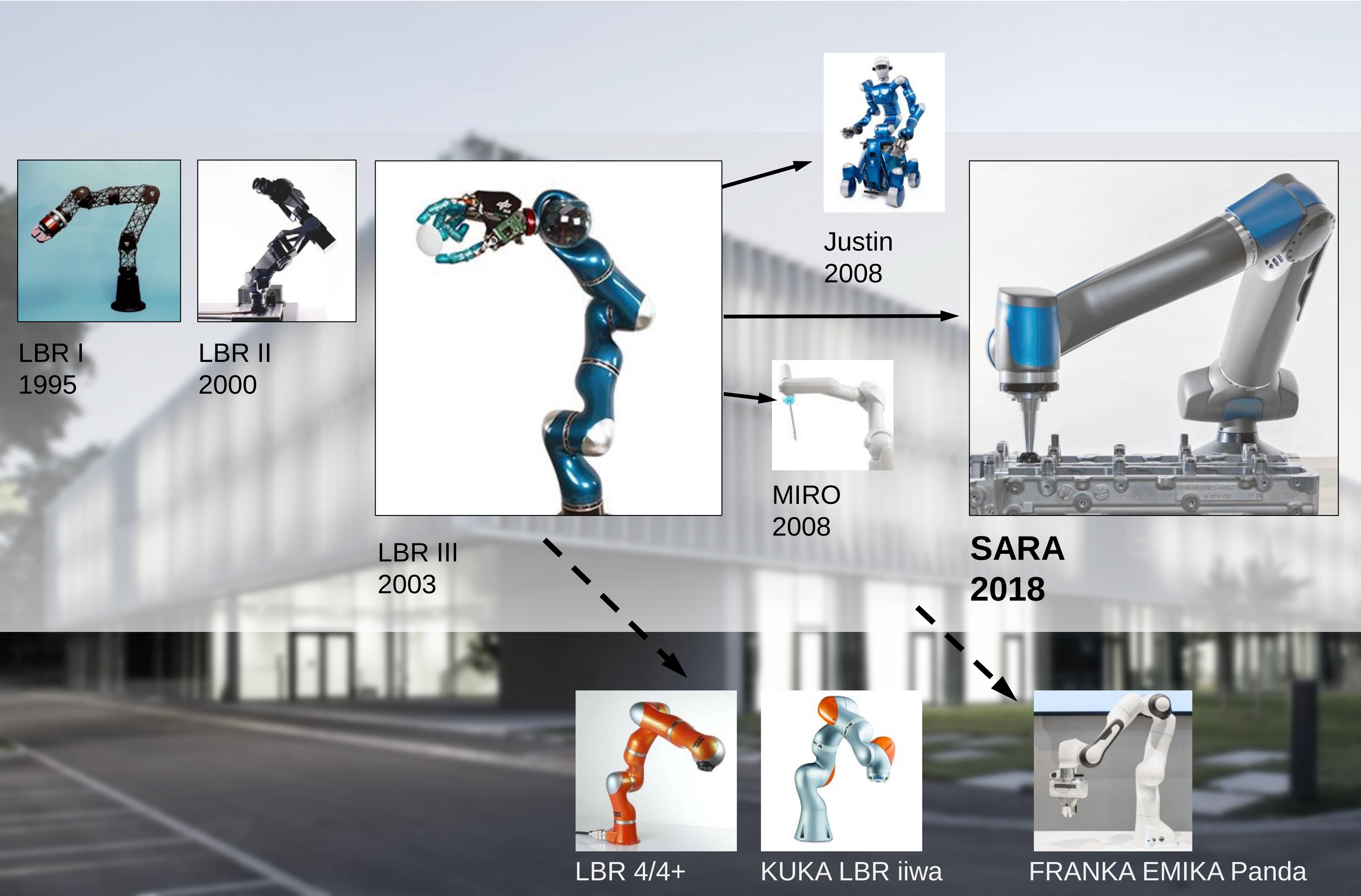


Mobile Manipulation

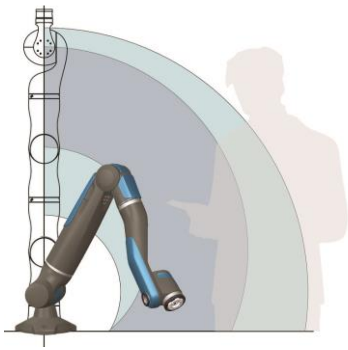


Autonomous Assembly

Development of lightweight robot arms at RM



SARA – *Safe Autonomous Robotic Assistant*



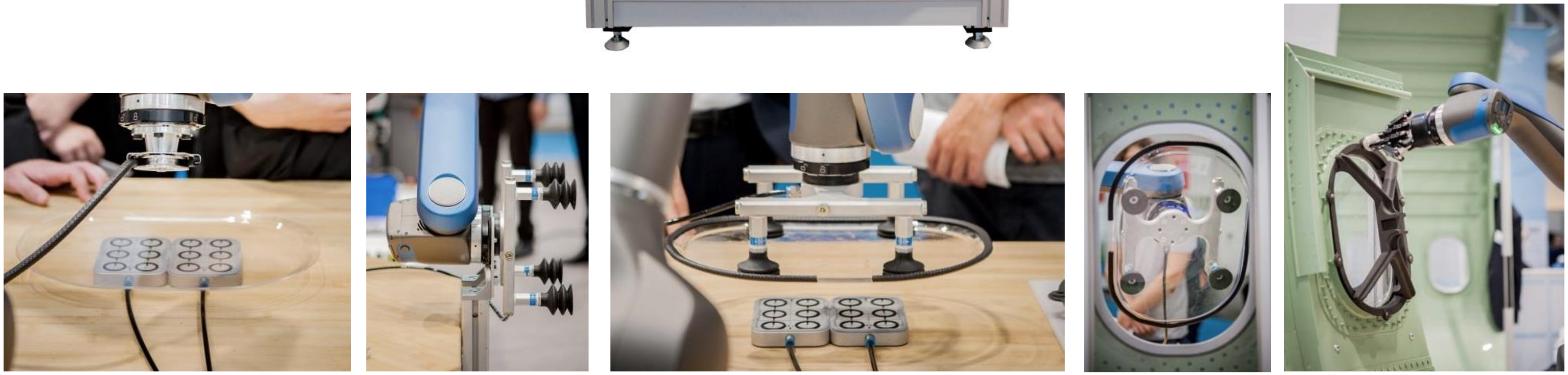
- 400 deg/s axis speed
- 12kg nominal payload
- 297 -1024 mm workspace
- 22.6kg total weight
- A7 endless

- Force-teaching in contact
- Integrated toolchanger for autonomous reconfiguration
- Integrated sensormount

Reconfigurable Workcell

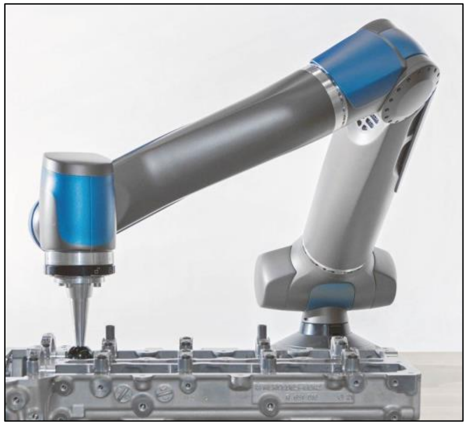
- Object fixing without extra built fixtures
- Adaptable to tasks with less human efforts

- Robot with impedance control, adequate speed, payload and workspace for assembly and object manipulation
- Exchange and share of tools, fixtures and sensors between cells

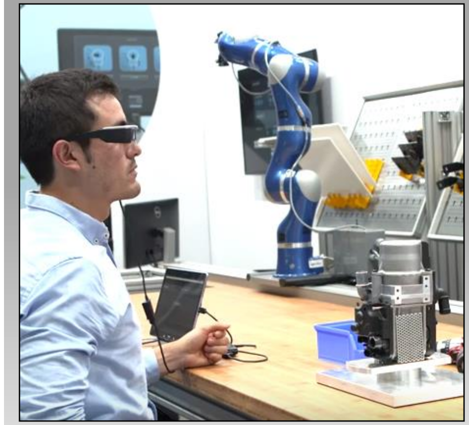


Window assembly at AUTOMATICA 2018.

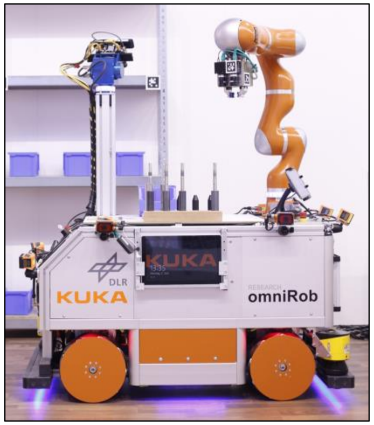
Robotic Systems of RM in Factory of the Future



Reconfigurable Workcell



Collaborative Workbench



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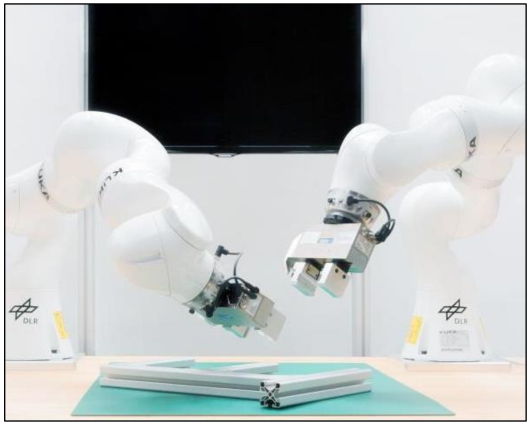
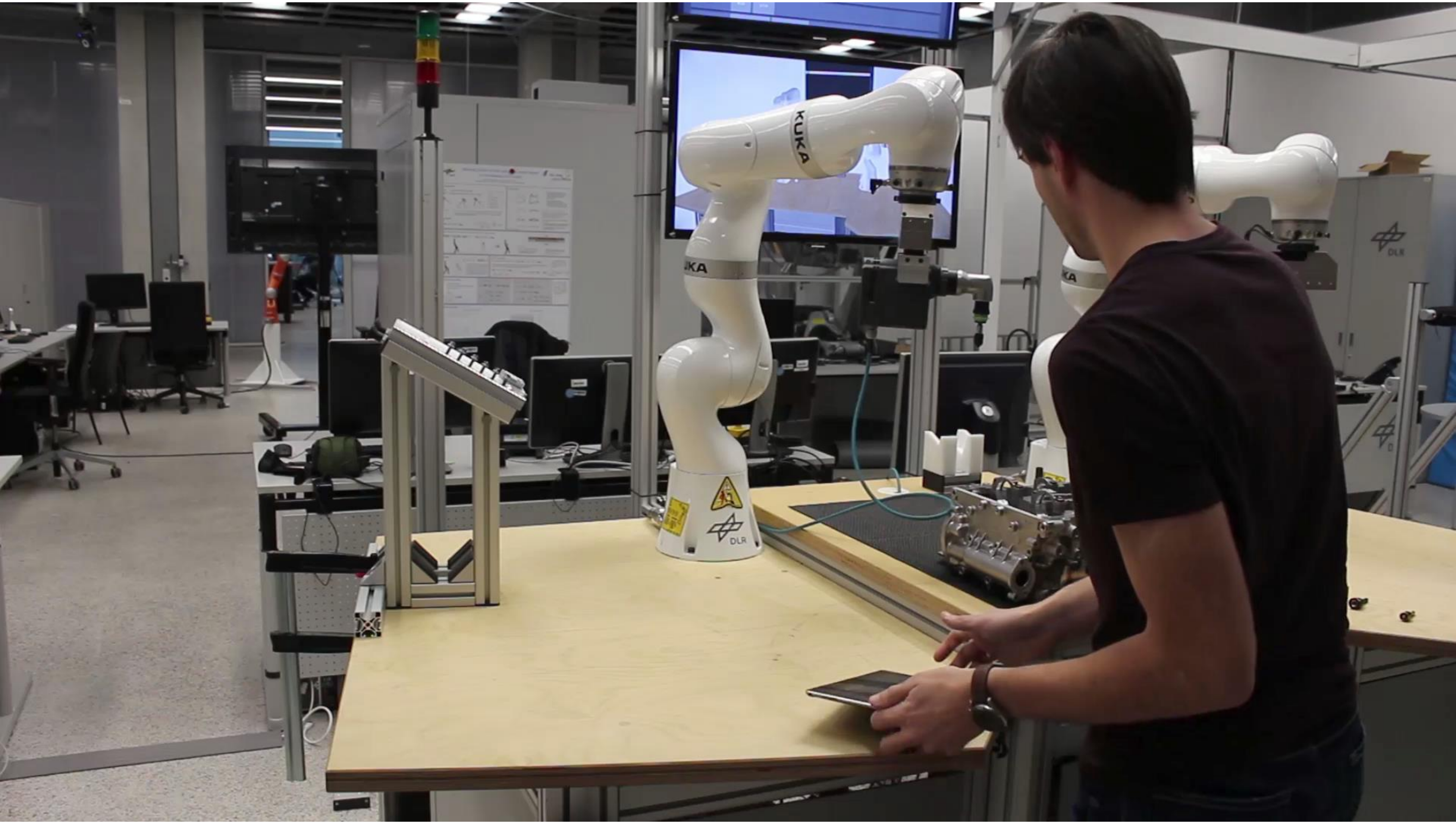


Autonomous Assembly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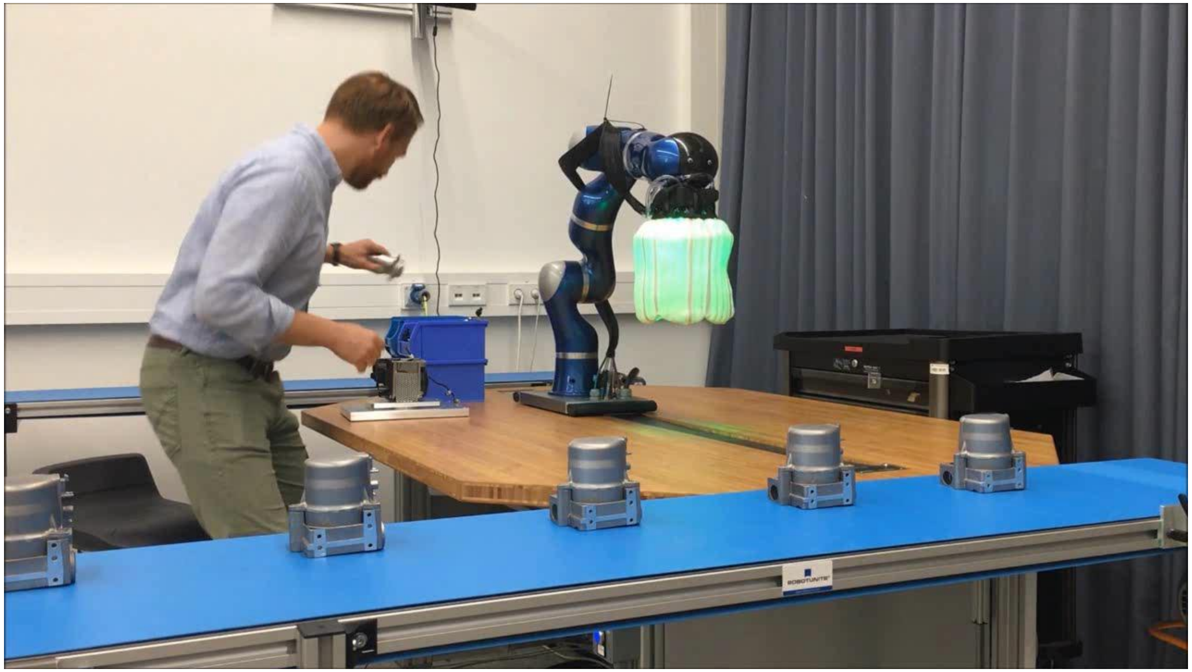
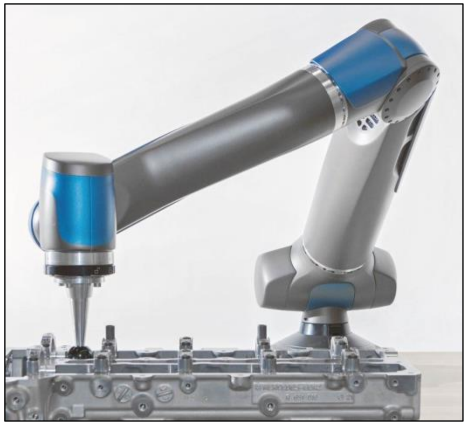
Ensure Safety and Improve Performance

Robotic Airbag System

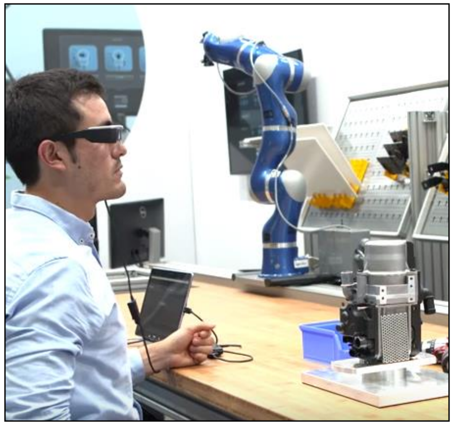
- Fenceless robot applications
- No loss of tool functionality
- Plug & produce
- Reduction of cycle-time and improvement of productivity
- Interaction and status information



Robotic Systems of RM in Factory of the Future

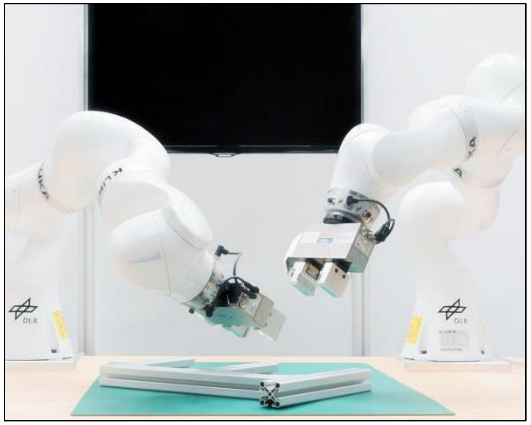


Reconfigurable Workcell



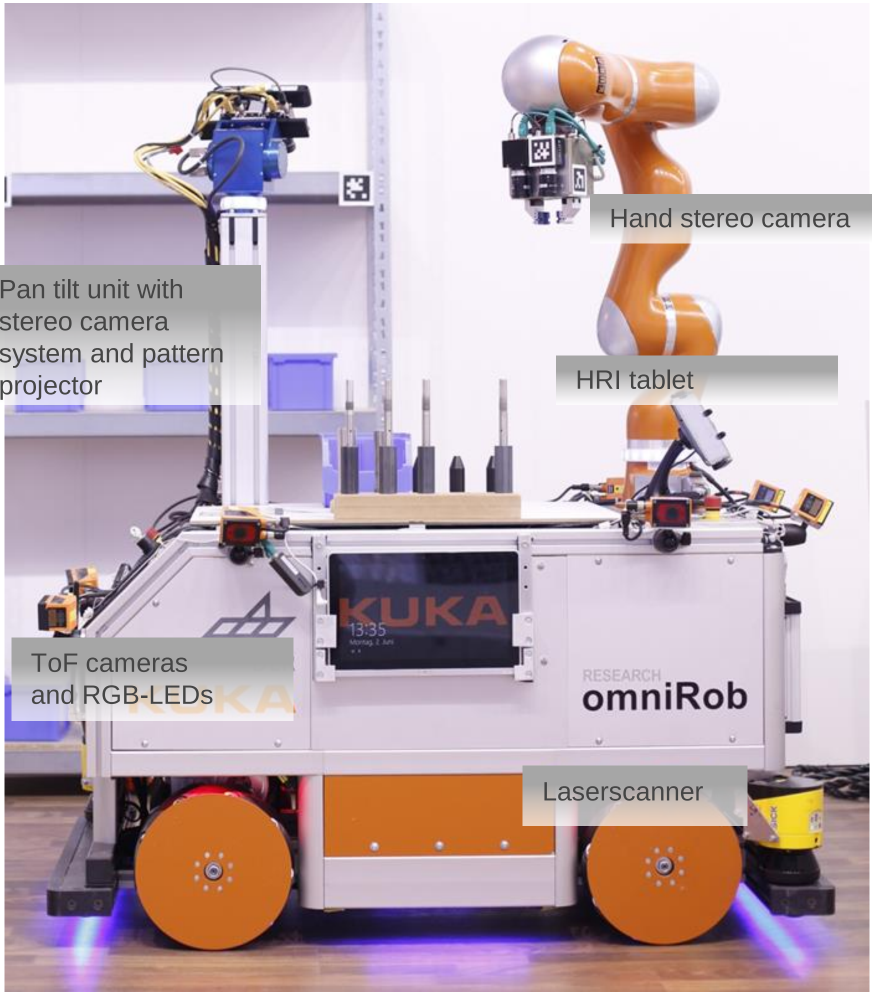
Collaborative Workbench

Mobile Manipulation



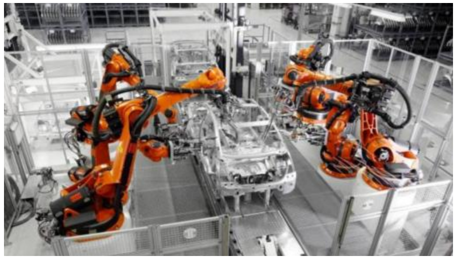
Autonomous Assembly

AIMM – *Autonomous Industrial Mobile Manipulator*



Fenced robots

↓



KUKA AG

Safe, stationary robots

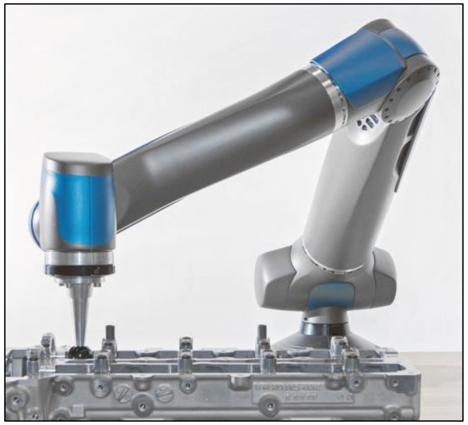
↓

KUKA AG

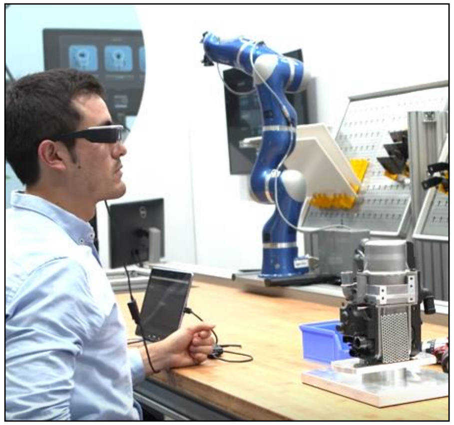
Safe and mobile robots

- Flexible
- Robust
- Autonomous
- Intuitive

Robotic Systems of RM in Factory of the Future



Reconfigurable Workcell



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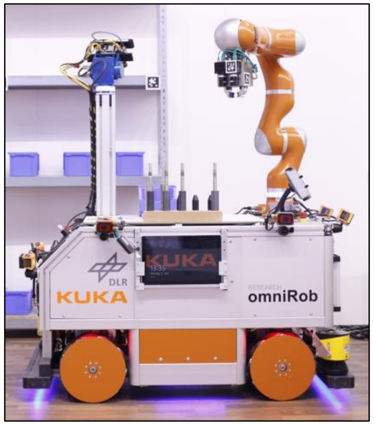
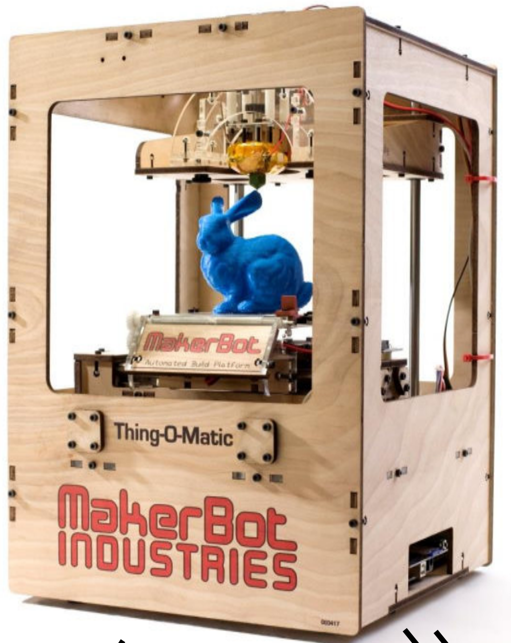
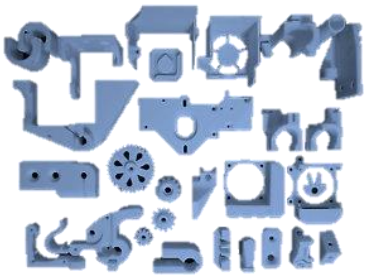


Mobile Manipulation

Autonomous Assembly

Autonomous Assembly

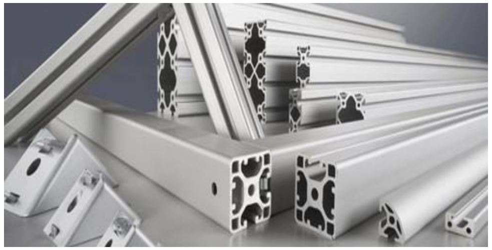




Use Case: Assembly of Aluminium Structures

Maschinenbau Kitz GmbH

FMS Montagetechnik GmbH



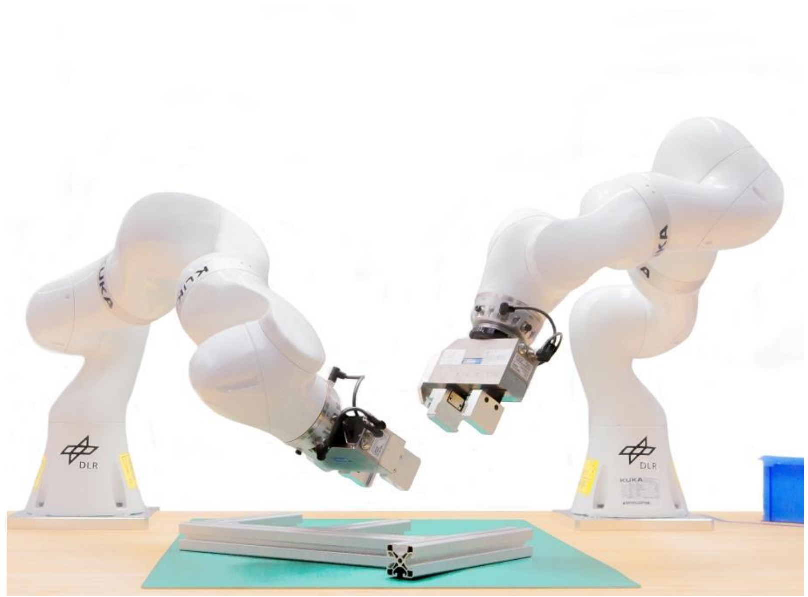
Item Industrietechnik GmbH

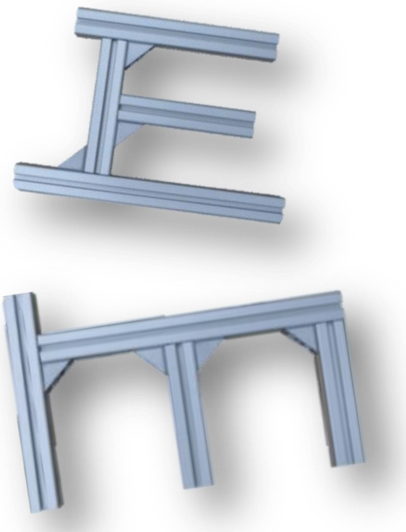
Various parts
➔Combinatorial variation

Length, configuration
➔ Continuous variation

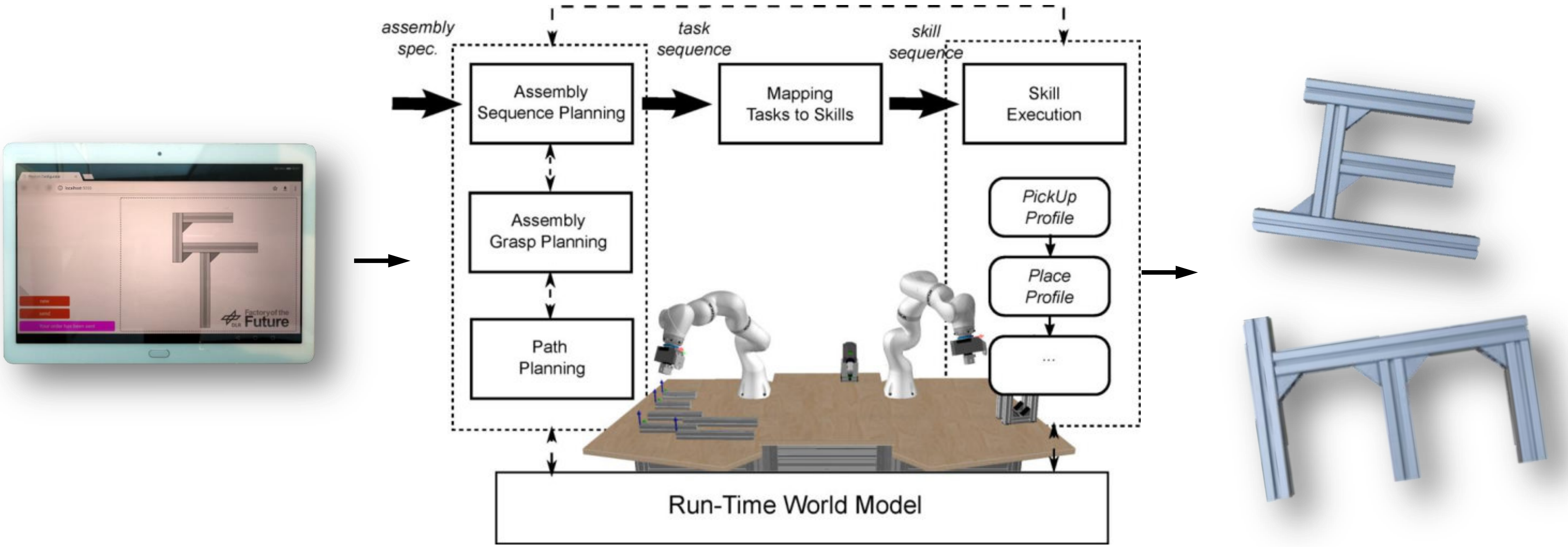
Modularity
➔reuse in different application scenarios

Workflow for one-of-a-kind production

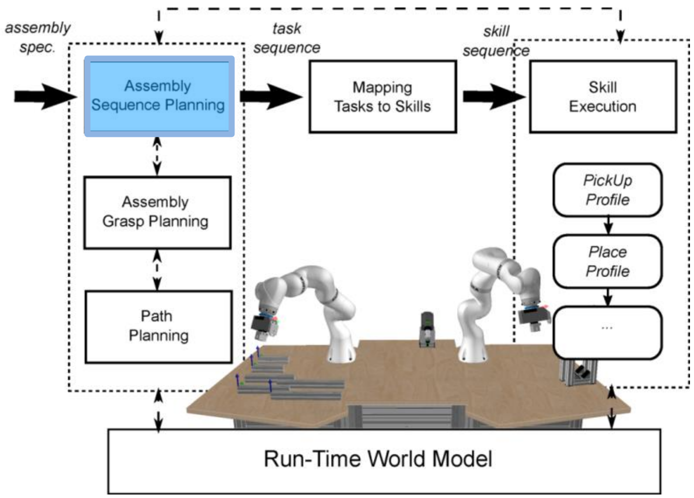


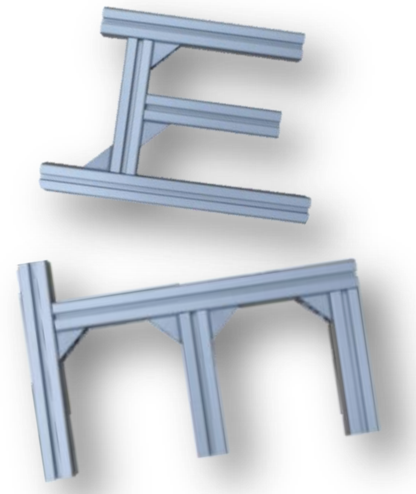


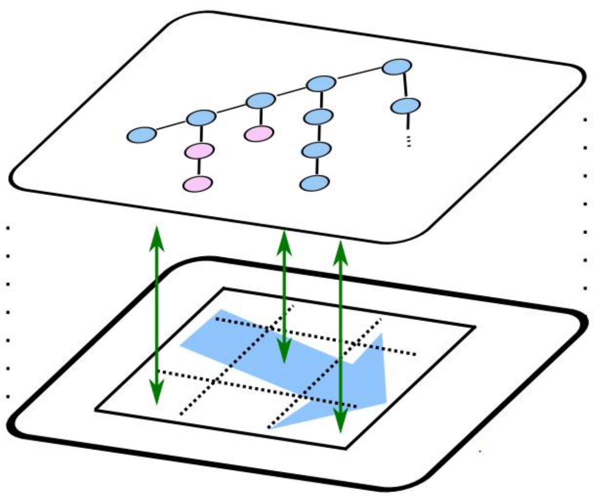
Workflow for one-of-a-kind production



K. Nottensteiner et al., "**A Complete Automated Chain for Flexible Assembly using Recognition, Planning and Sensor-Based Execution**," Proceedings of ISR 2016: 47st International Symposium on Robotics, Munich, Germany, 2016, pp. 1-8.



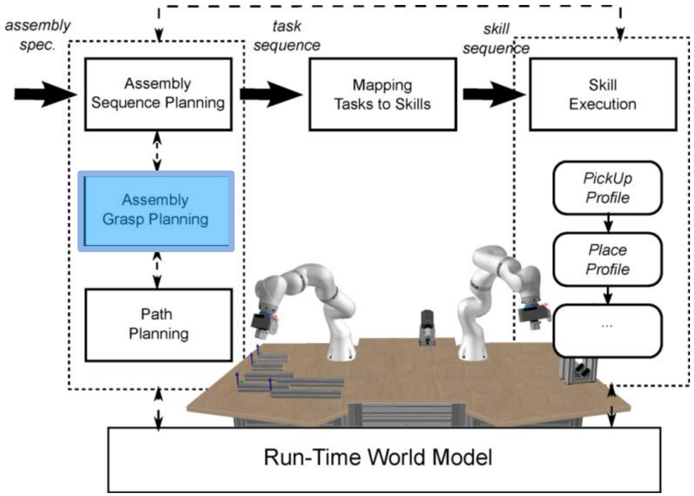


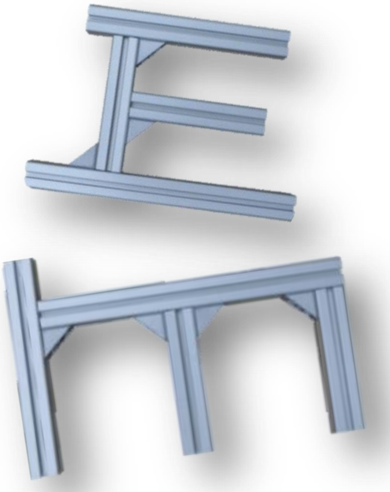


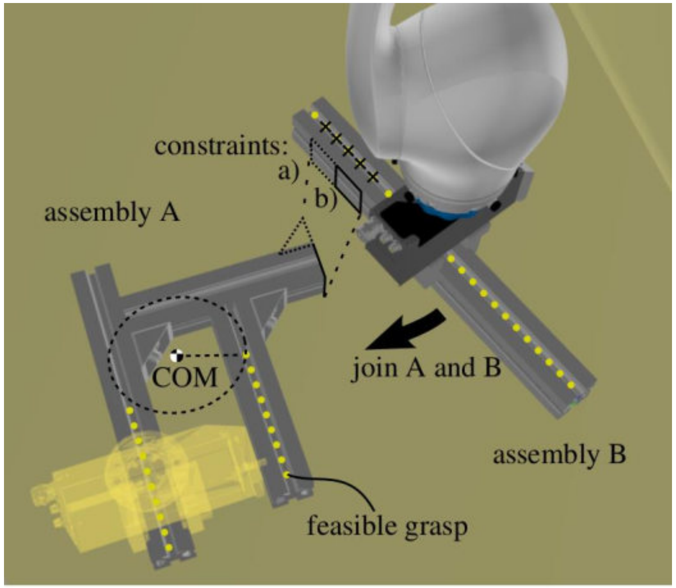
Assembly Sequence Planning

- Find a feasible execution sequence for the robot
- Hybrid planning approach
- Combination of a graph-search in a logic layer combined with a digital twin for simulation
- More details on the poster…

I. Rodriguez et. al: „**Iterative Rule Generation for Assembly Sequence Planning**“ CASE - Robotic Assembly Workshop, 2018





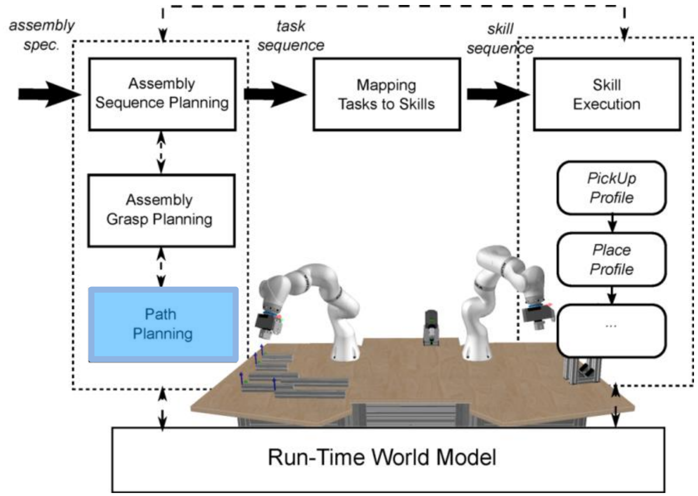


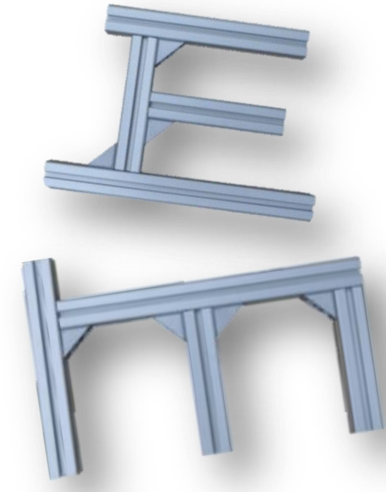
Assembly Grasp Planning

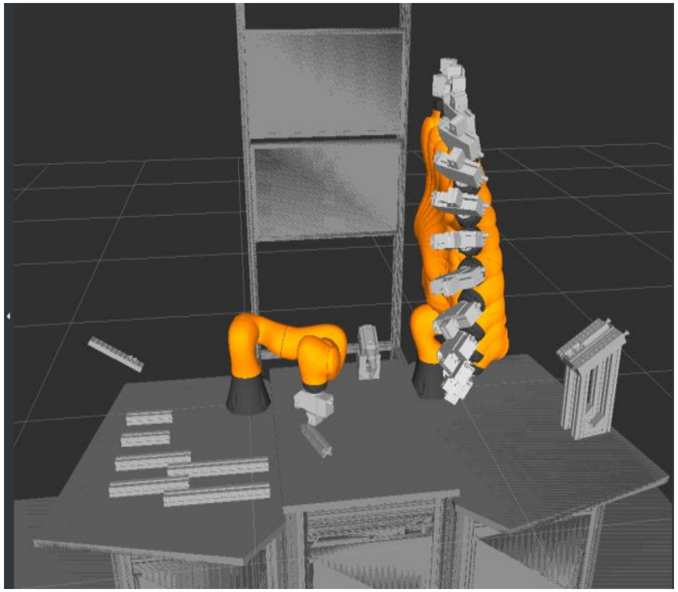
Considered constraints:

- Subassembly
- Joining action

U. Thomas, T. Stouraitis and M. A. Roa, "**Flexible assembly through integrated assembly sequence planning and grasp planning**," 2015 IEEE International Conference on Automation Science and Engineering (CASE), Gothenburg, 2015, pp. 586-592.





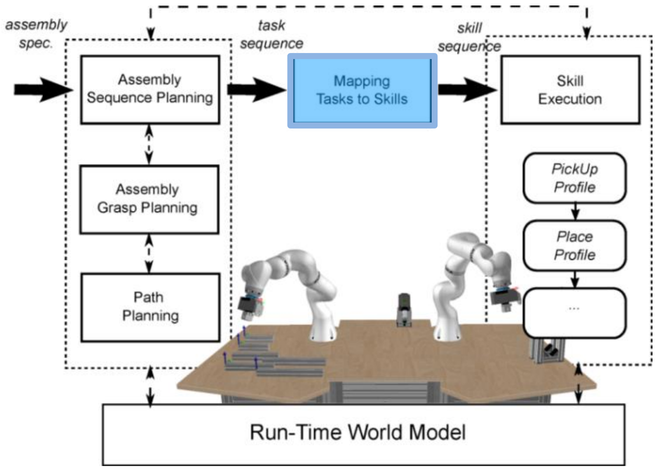


Motion Planner

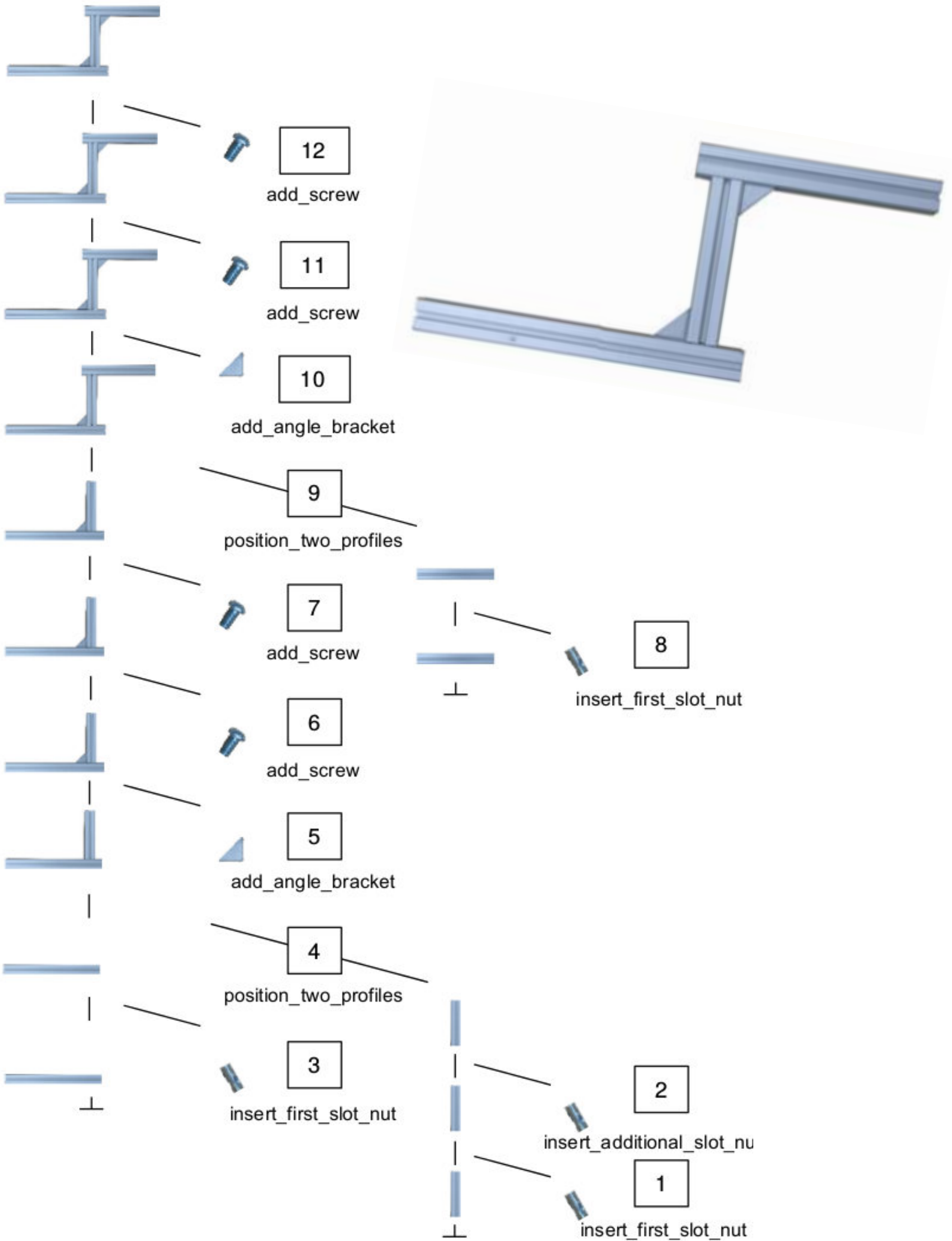
- Syncing with a run-time world model for keeping track of changes in the workcell
- RRT-based implementation

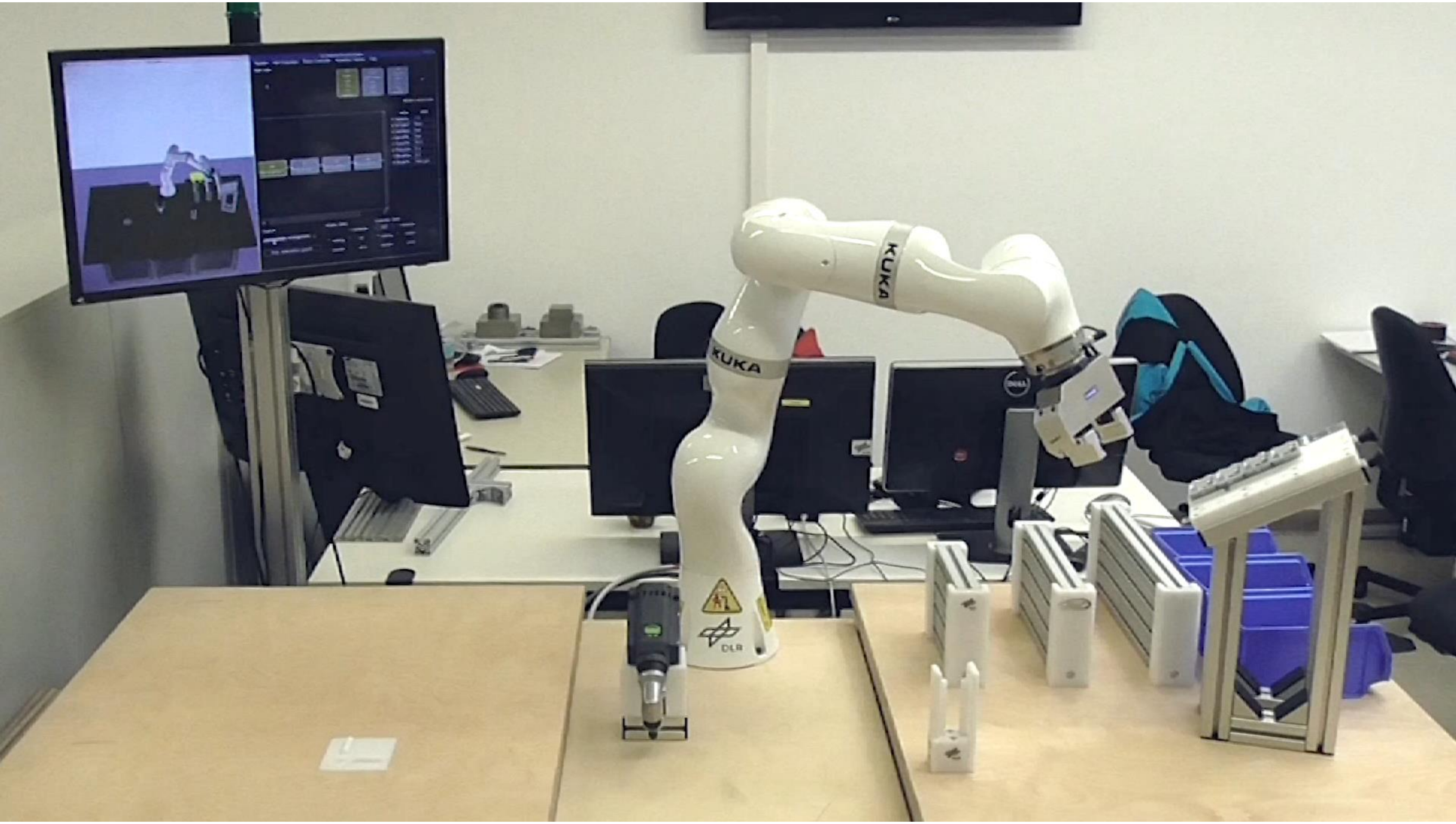
P. Lehner and A. Albu-Schäffer, "**Repetition sampling for efficiently planning similar constrained manipulation tasks**," 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, 2017, pp. 2851-2856

Sequence Example



- Four major task types:
    - *insert_slot_nut*
    - *add_angle_bracket*
    - *add_screw*
    - *position_profiles*
- Every task is mapped to a sequence of robotic skills provided by a skill library

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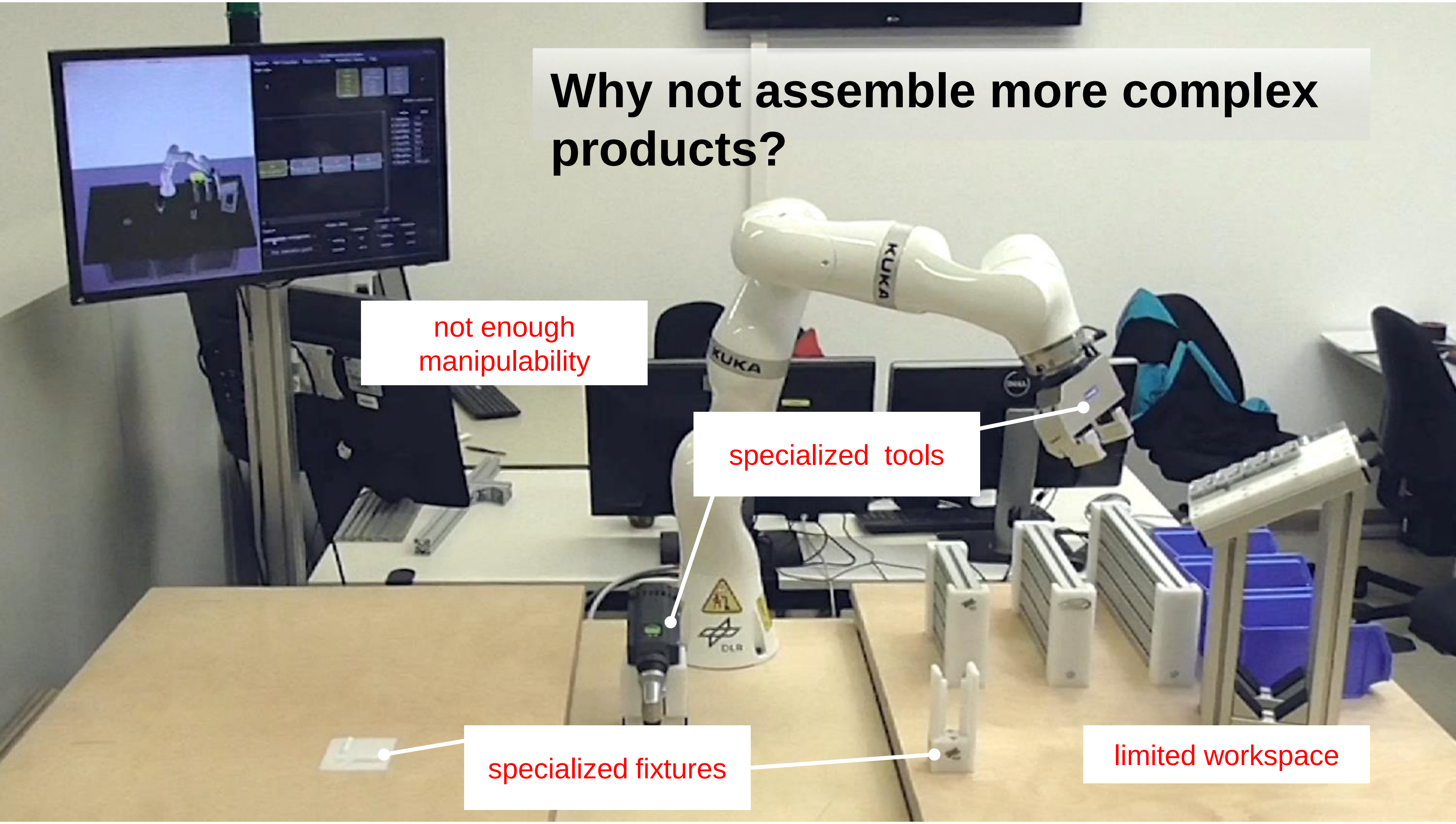
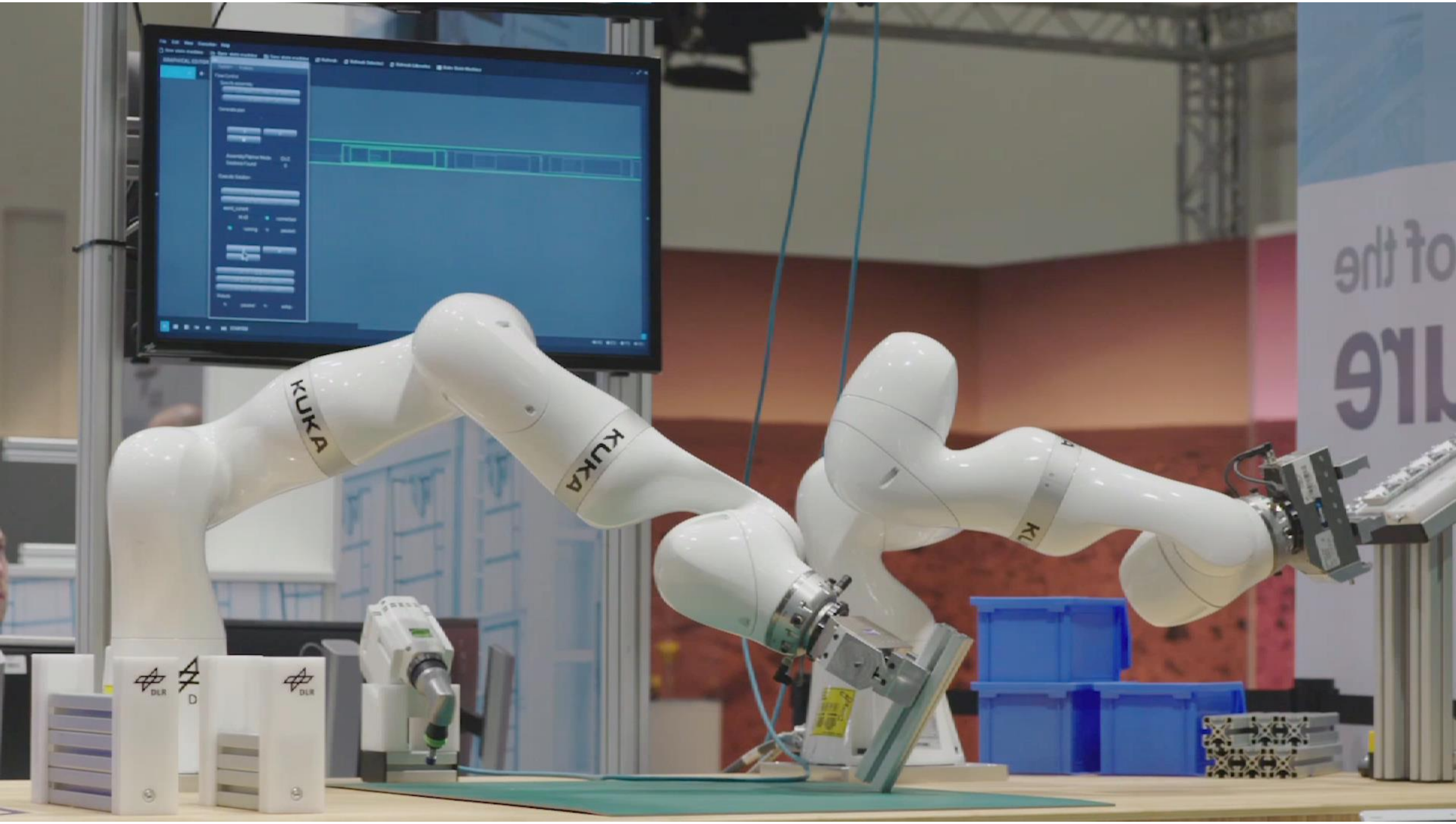
Why not assemble more complex products?

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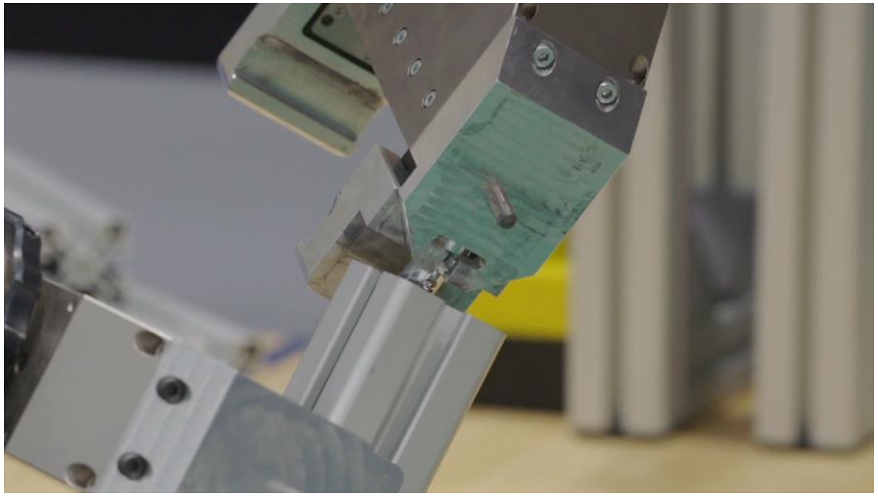
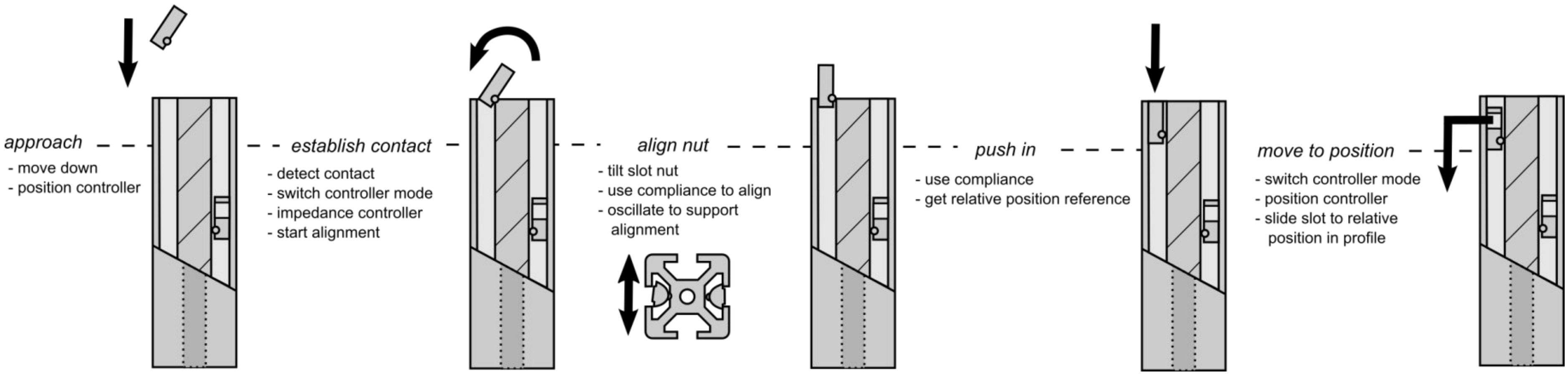
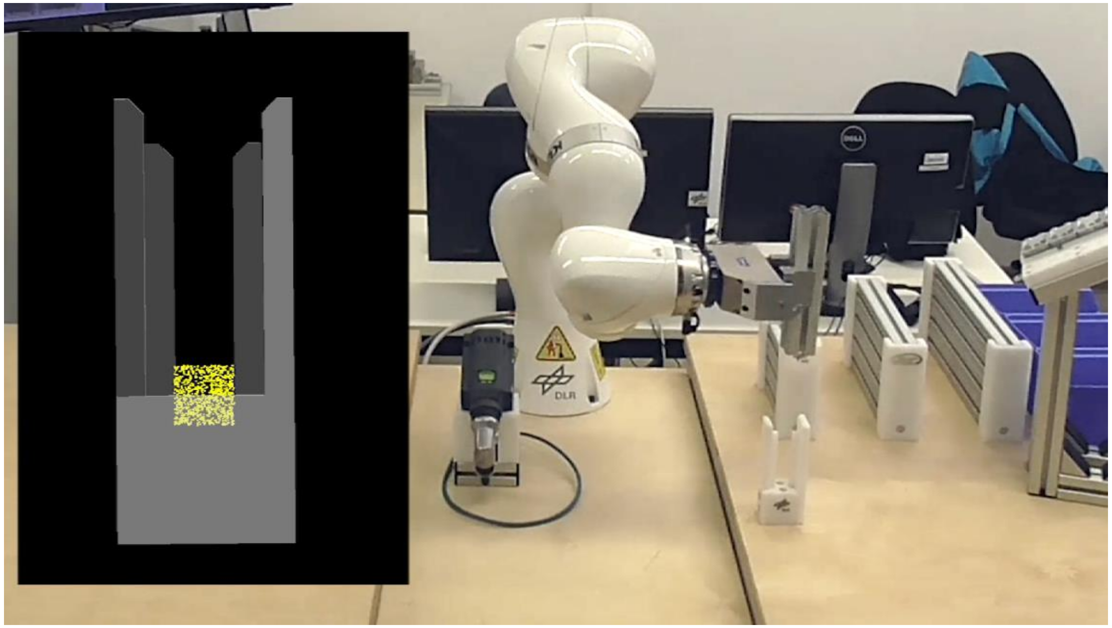
Need for relative motion coordination

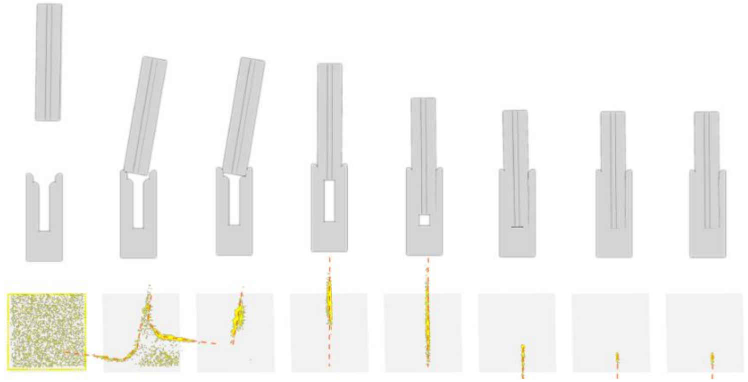




Roa, M. A., Nottensteiner, K., Wedler, A., & Grunwald, G., **Robotic Technologies for In-Space Assembly Operations**. ASTRA 2017

Skill observation based on intrinsic tactile sensing





- Use external torque sensors to estimate parts positions
- Generate representations of the relative configuration space

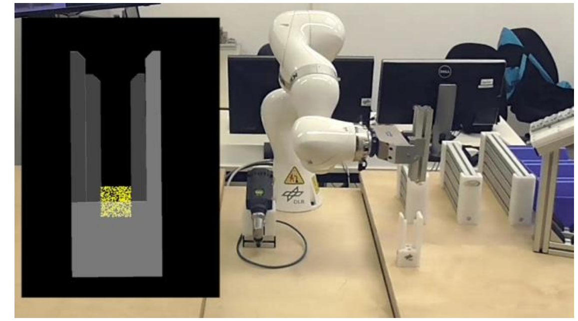
➔ Allow for adaption of the execution on the current assembly and contact state

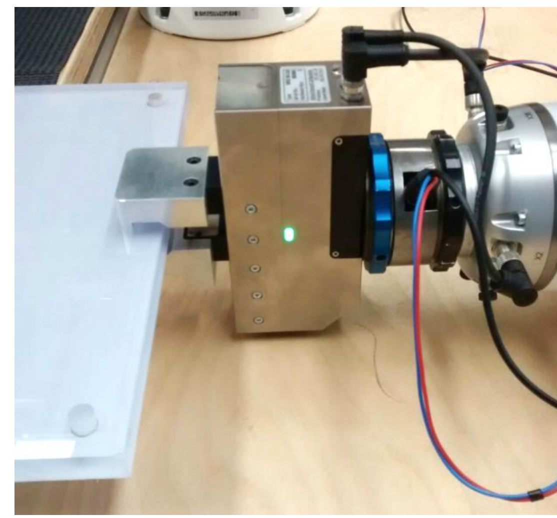
K. Nottensteiner, M. Sagardia, A. Stemmer and C. Borst, "**Narrow passage sampling in the observation of robotic assembly tasks**," 2016 IEEE International Conference on Robotics and Automation (ICRA), Stockholm, 2016, pp. 130-137.

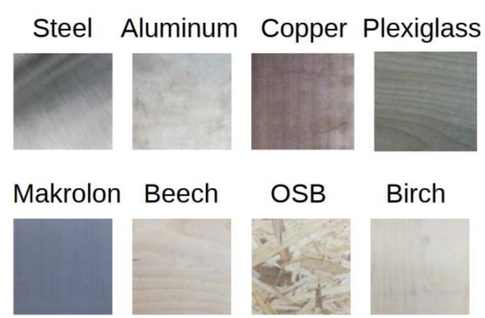
K. Nottensteiner and K. Hertkorn, "**Constraint-based sample propagation for improved state estimation in robotic assembly**," 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, pp. 549-556.

Multiple sensory inputs

- Intrinsic tactile sensing
- Structure borne sound classification
- Vision feedback for assembly state tracking







Goal: Apply machine learning to incorporate multiple sensory inputs as feedback for the execution of robotic assembly tasks

Conclusions

- Planner driven robotic assembly system that creates individual assemblies with no expert required.

- In a one-of-a-kind production scenario:
  More complex products require assembly systems with more degrees of freedoms and high manipulability.

- In workcell layouts without calibrated fixtures:
  Need for feature-based relative motions during the assembly process.

- **Multi-sensory skill observation is required to reduce uncertainty and monitor the world state.**

- **Machine learning will help to adapt and react on the current situtation.**

K. Nottensteiner et al., "**A Complete Automated Chain for Flexible Assembly using Recognition, Planning and Sensor-Based Execution**," Proceedings of ISR 2016: 47st International Symposium on Robotics, Munich, Germany, 2016, pp. 1-8.

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F. Steinmetz, A. Wollschläger and R. Weitschat, "**RAZER—A HRI for Visual Task-Level Programming and Intuitive Skill Parameterization**," in IEEE Robotics and Automation Letters, vol. 3, no. 3, pp. 1362-1369, July 2018.

R. Weitschat, J. Vogel, S. Lantermann and H. Höppner, "**End-effector airbags to accelerate human-robot collaboration**," 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 2017, pp. 2279-2284.

A. Dömel, S. Kriegel, M. Brucker and M. Suppa, **"Autonomous pick and place operations in industrial production**," 2015 12th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), Goyang, 2015, pp. 356-356.

U. Thomas, T. Stouraitis and M. A. Roa, "**Flexible assembly through integrated assembly sequence planning and grasp planning**," 2015 IEEE International Conference on Automation Science and Engineering (CASE), Gothenburg, 2015, pp. 586-592.

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