A planar air-bearing microgravity simulator for validation of robotic capture operations

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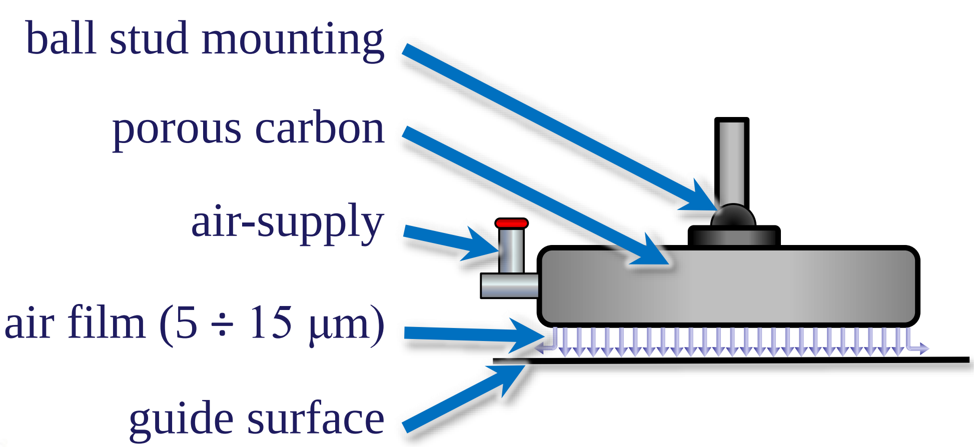
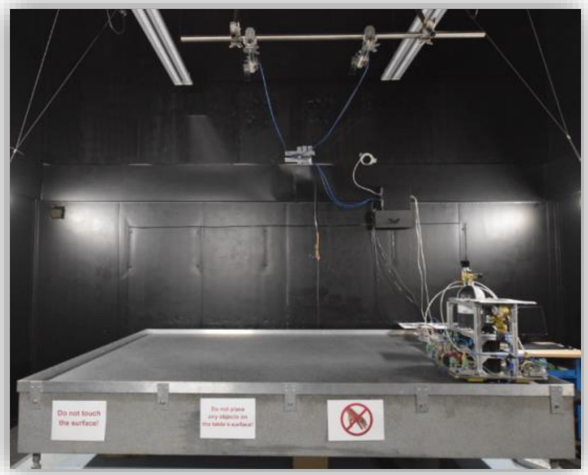
Outline

- Introduction
- Test-bed at CBK PAN
- Elements of the air-bearing simulator
- Demonstration of test-bed capabilities
- Summary

Validation of technologies for IOS and ADR missions

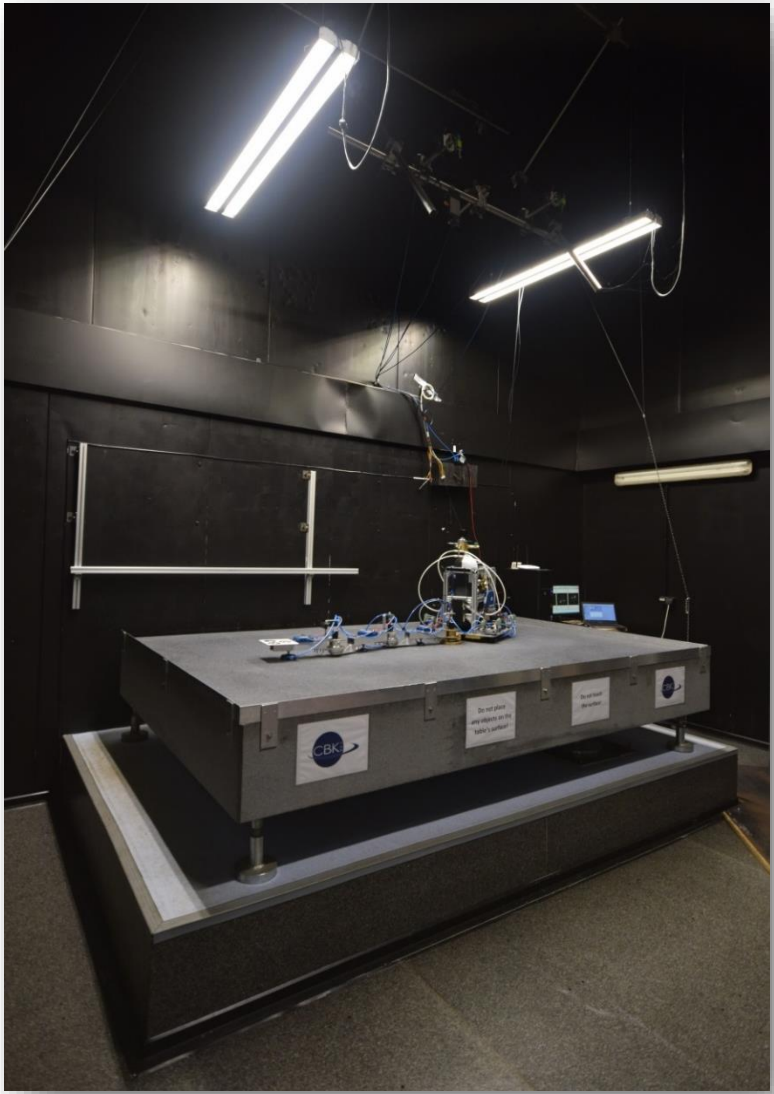
- Robotic systems developed for IOS and ADR missions should be tested in simulated microgravity conditions.
- Various approaches are used to simulate microgravity: tests based on industrial manipulators, suspension systems, parabolic flights, drop towers, and air-bearing simulators.
- Air-bearing simulators emulate the dynamic behaviour of the free-floating satellite-manipulator system, offering low disturbances and low operating costs.





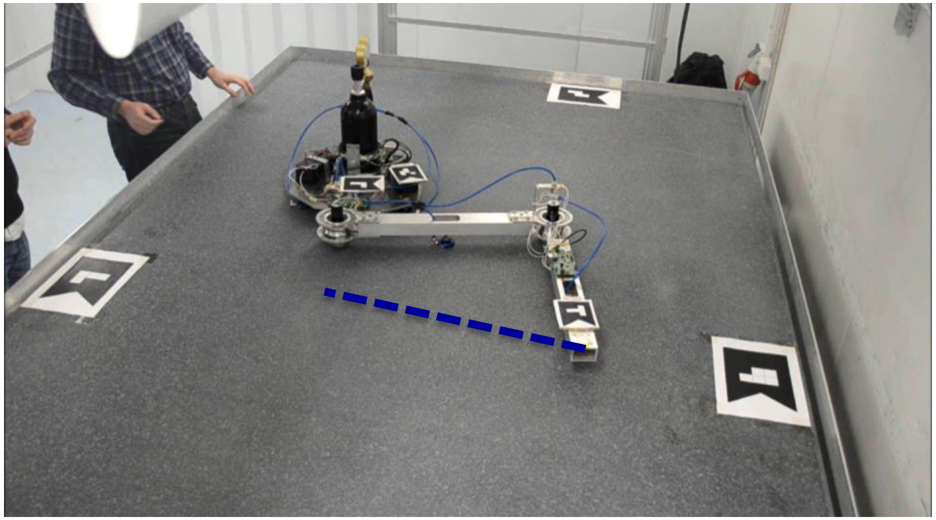
Planar air-bearing microgravity simulator at CBK PAN

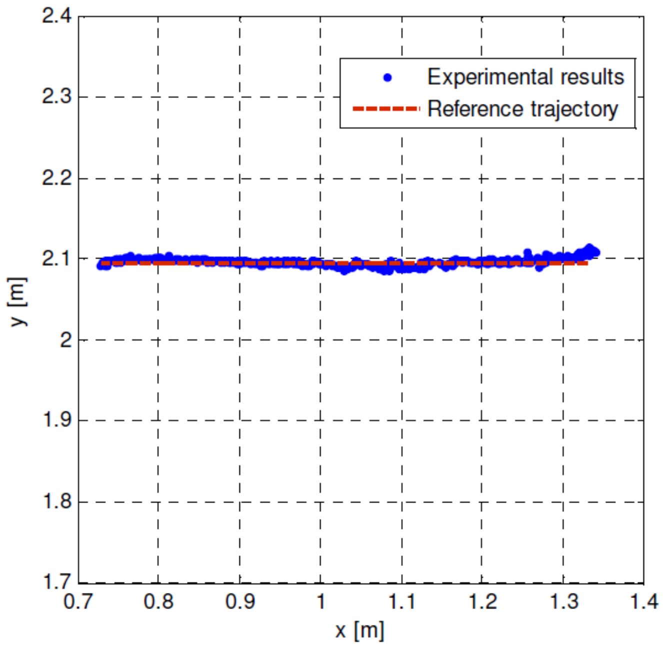
- Simulator is based on a flat and precisely levelled granite plate: 2 m x 3 m.
- The mock-up of the satellite-manipulator system is mounted on planar aerostatic air-bearings and placed on the test-bed surface.
- Microgravity conditions are simulated in two dimensions.
- Scaling laws allow to perform experiments with scaled-down systems.



The beginning…

- Planar air-bearing microgravity simulator at CBK PAN is in operation since 2012.
- First results presented at the ASTRA 2013 conference: Rybus T., et al., New Planar Air-bearing Microgravity Simulator for Verification of Space Robotics Numerical Simulations and Control Algorithms.

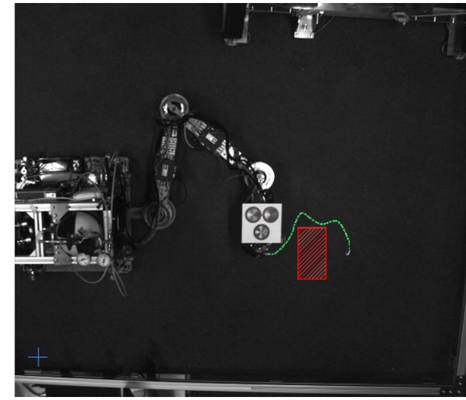


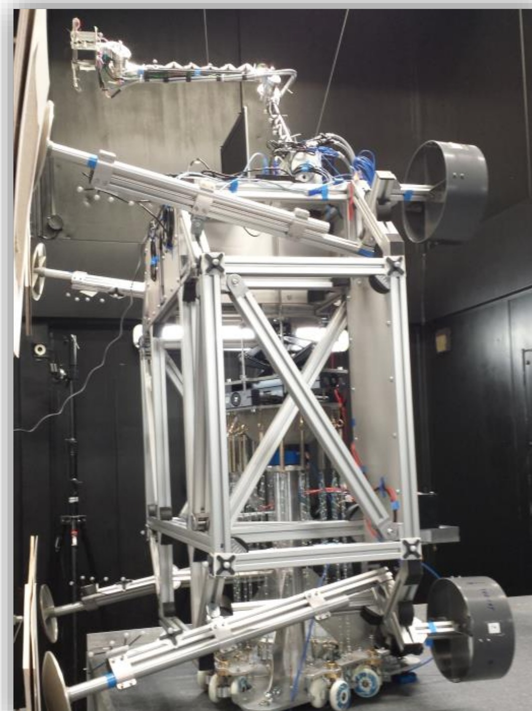


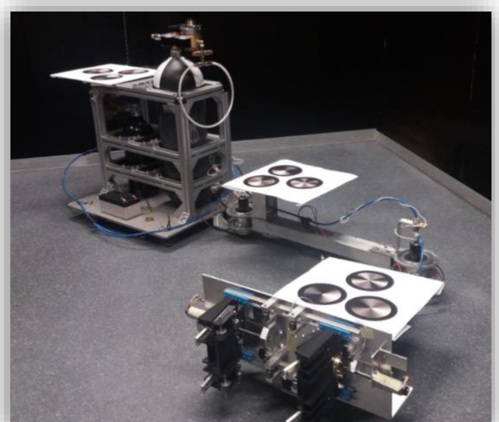
End-effector position

Applications of the test-bed

- Validation of manipulator trajectory planning and control algorithms.
- Simultaneous control of a free-flying chaser satellite and its manipulator.
- Research on flexible-joint manipulators.
- ESA Projects: „e.Deorbit Phase B1” and „Sample Acquisition Means for the Phootprint Lander: Experiments and first Realisation” (SAMPLER).

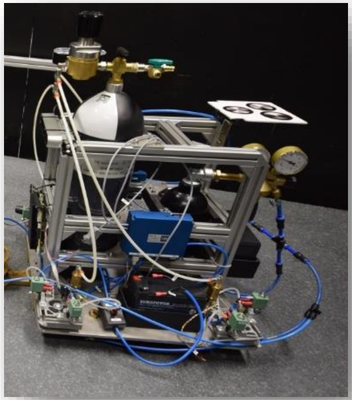




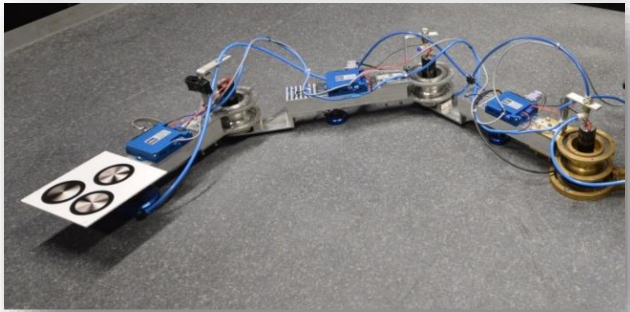


Major upgrades

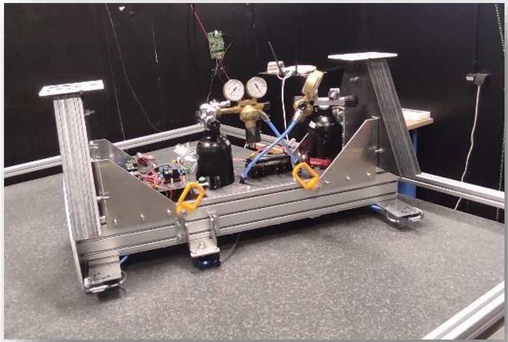
- 2015 – 2016: „Development and validation of the laboratory model of a space robot equipped with resistojet thrusters” (NCBiR).



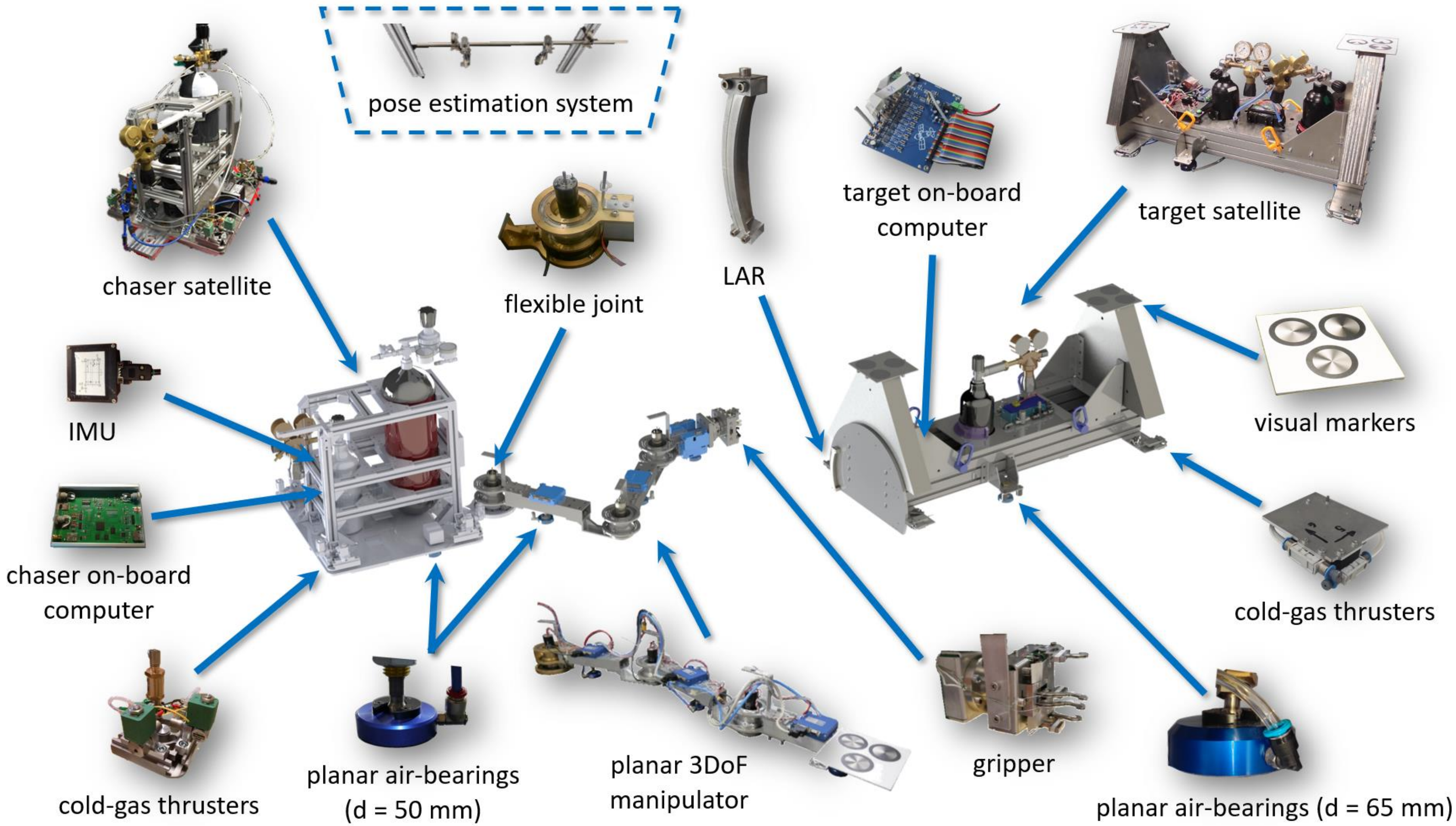
- 2017 – 2019: „Mobility of a nonholonomic space robot constrained by large movable obstacles” (NCN).



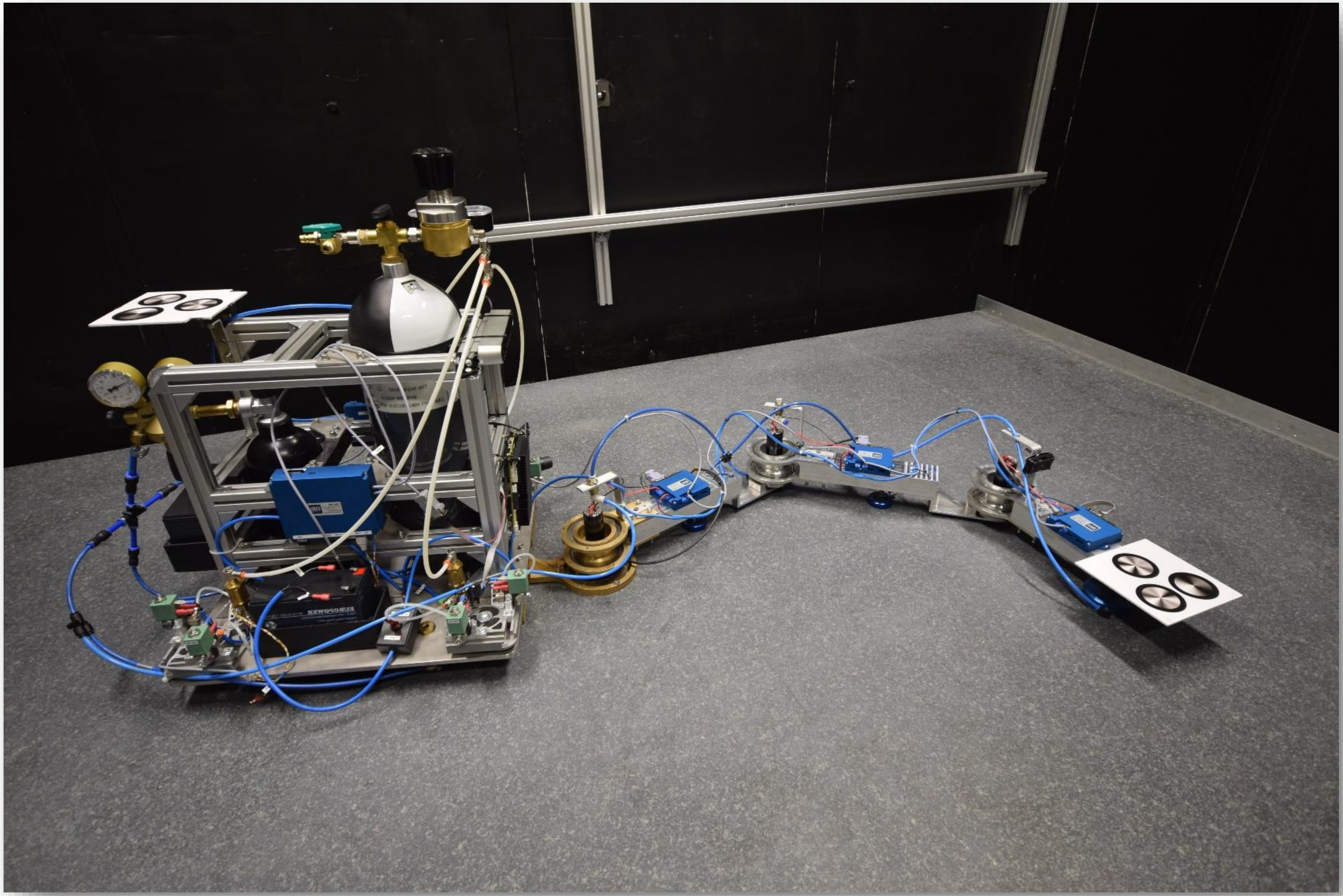

- 2020 – 2022: „Development and validation of a control system for space manipulator" (NCBiR).



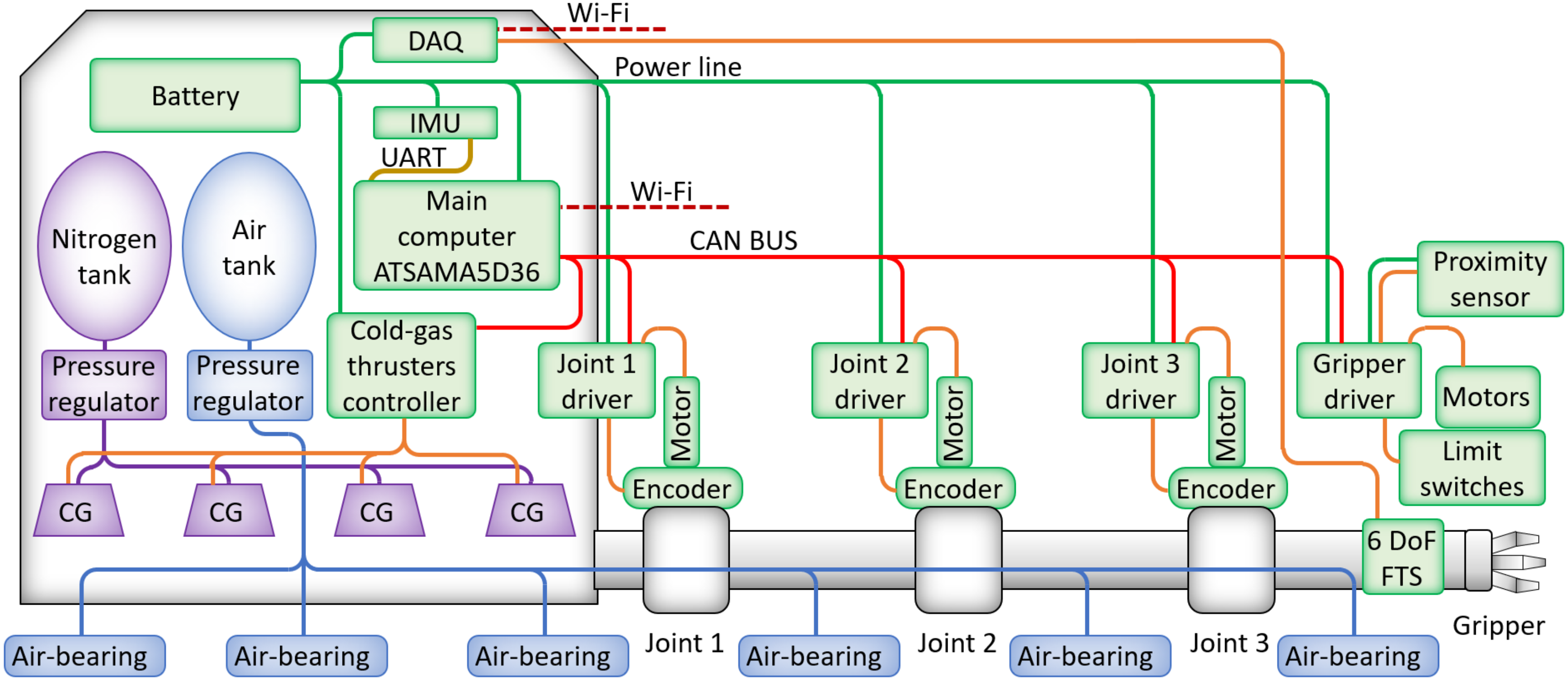

Elements of the air-bearing microgravity simulator



Chaser satellite mock-up

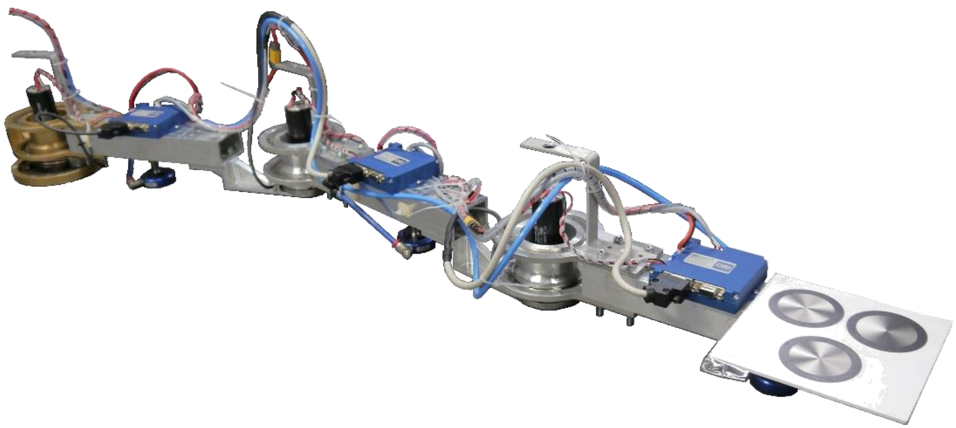


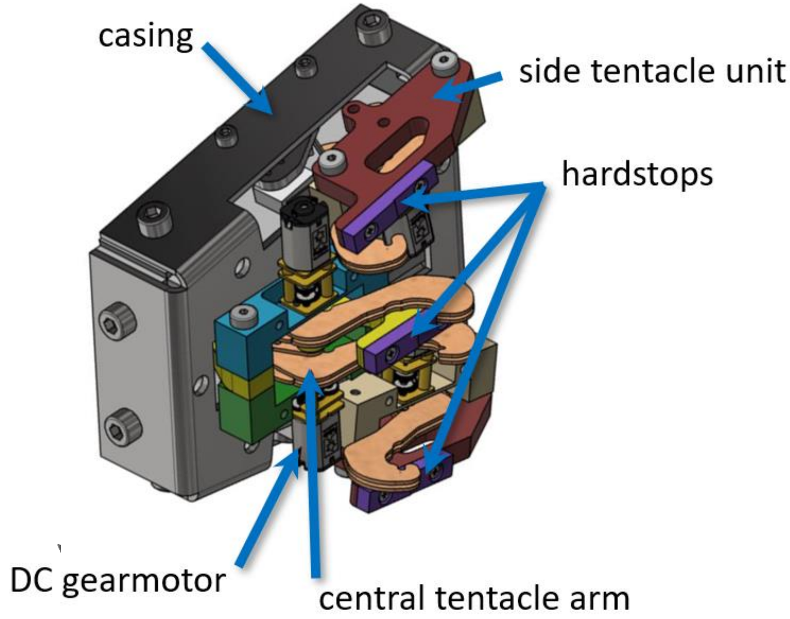
Chaser satellite mock-up



Parameter	Value
Mass	$58.69\ \mathrm{kg}$
Mass moment of inertia	$2.417\ \mathrm{kg \cdot m^2}$
Size of the base plate	$0.5\ \mathrm{m}\ \times 0.5\ \mathrm{m}$

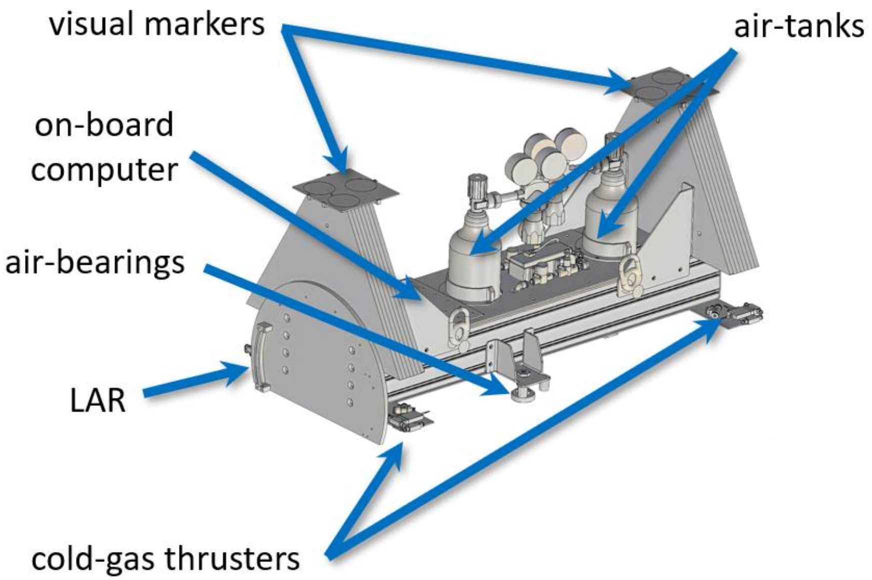
Manipulator with Modular Gripper

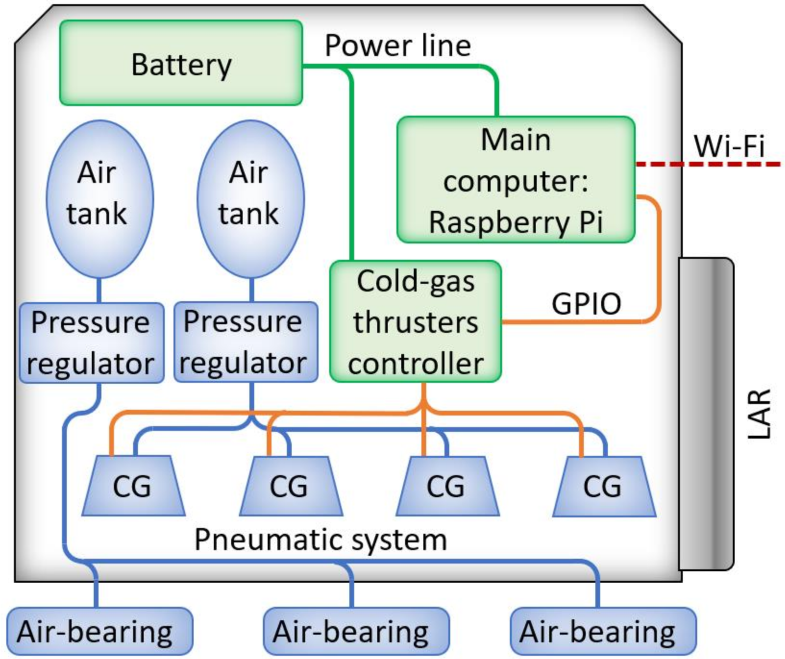




Parameter	Link 1	Link 2	Link 3 + gripper
Mass	2.81 kg	2.82 kg	4.64 kg
Mass moment of inertia	$0.0637\ \mathrm{kg}\cdot\mathrm{m}^2$	$0.0635\ \mathrm{kg}\cdot\mathrm{m}^2$	$0.0515\ \mathrm{kg}\cdot\mathrm{m}^2$
Length	0.449 m	0.449 m	0.310 m
Position of CoM wrt joint i	$[0.136\ \mathrm{m} \quad -0.002\ \mathrm{m}]^T$	$[0.134\ \mathrm{m} \quad 0]^T$	$[0.151\ \mathrm{m} \quad 0]^T$

Target satellite mock-up

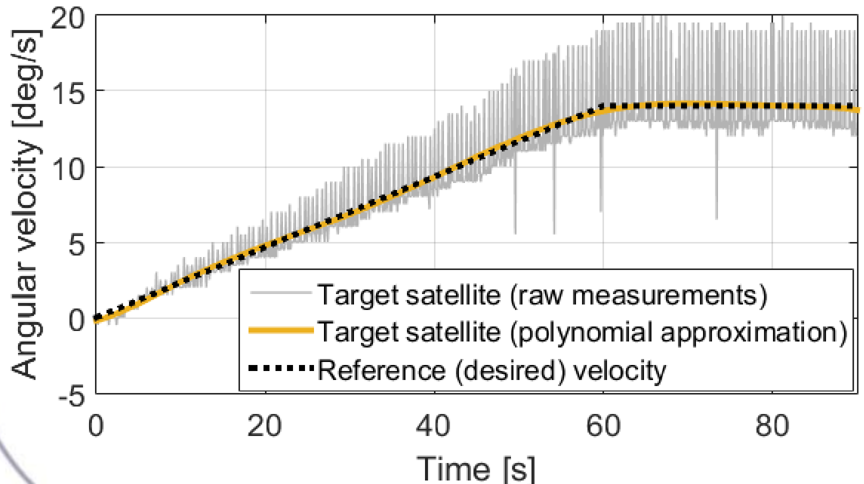


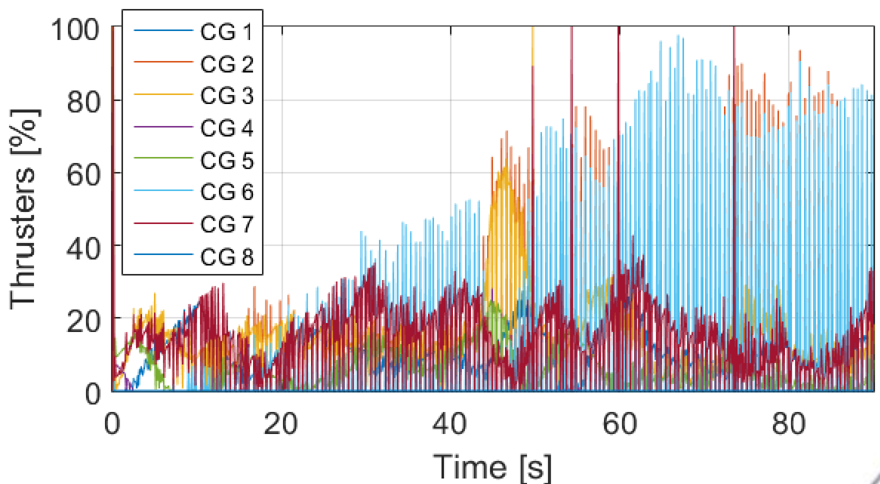


Parameter	Value
Mass	$153.5\ \mathrm{kg}$
Mass moment of inertia	$29.87\ \mathrm{kg} \cdot \mathrm{m}^2$
Position of the LAR grasping point	$[0.534\ \mathrm{m} \quad -0.166\ \mathrm{m}]^T$
Size of the base plate	$1.037\ \mathrm{m} \times 0.526\ \mathrm{m}$

Validation of new elements of the test-bed

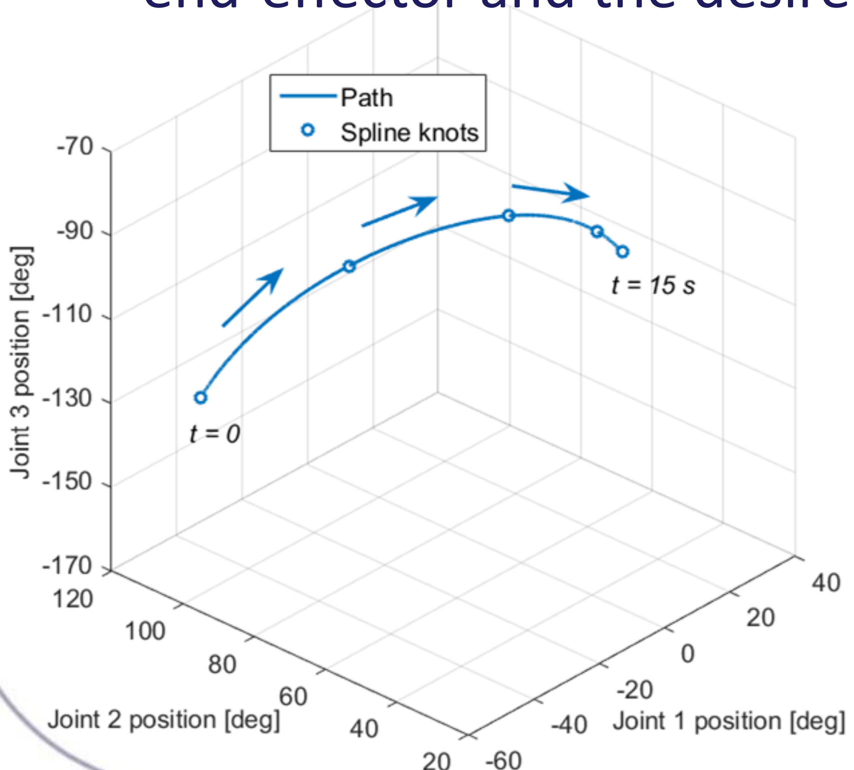
- New elements of the test-bed have been thoroughly tested to confirm that they meet all design requirements.
- The control system uses cold-gas thrusters to accelerate the mock-up to the desired angular velocity and keep constant position of the mock-up’s Centre of Mass (CoM).
- Gains of controllers responsible for the control of the target satellite mock-up's cold-gas thrusters were tuned.

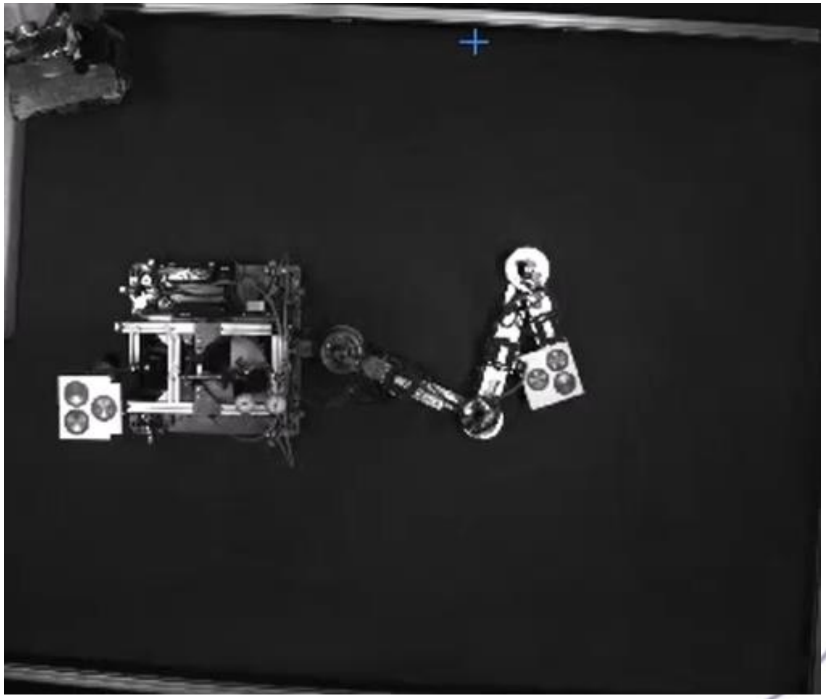




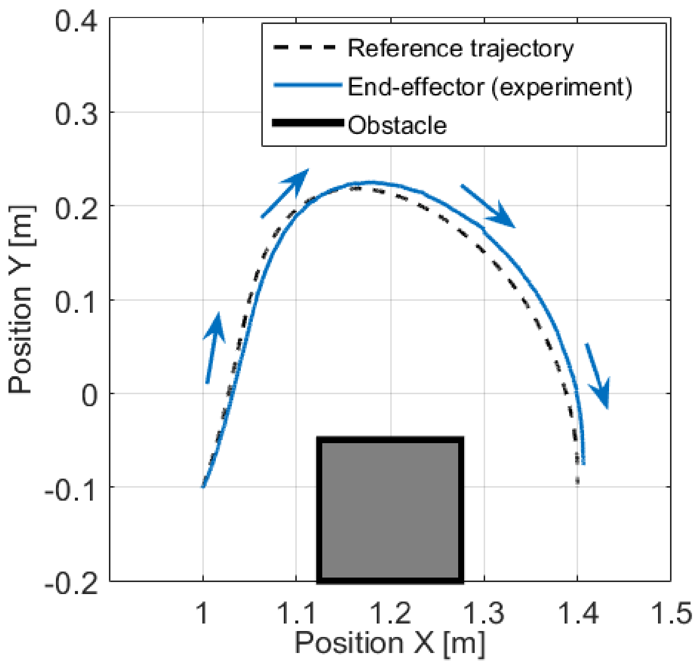
Tracking optimal collision-free trajectories

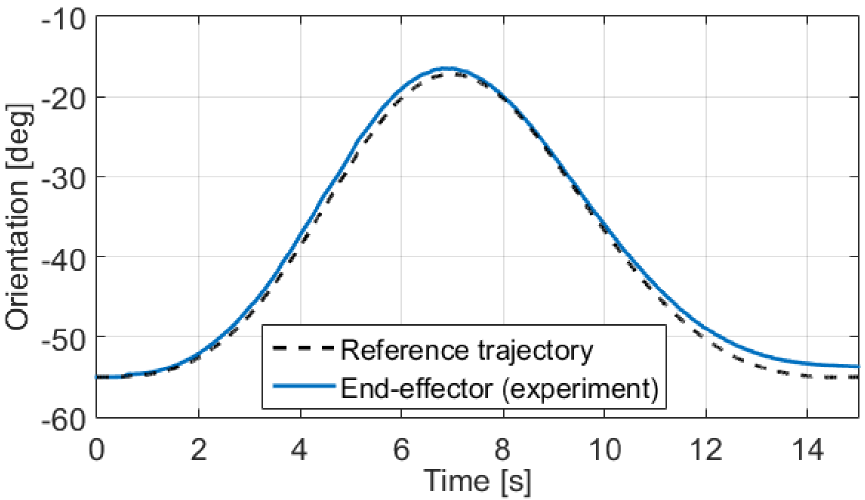
- Demonstration of optimal collision-free manipulator trajectory planning using spline-based trajectories.
- Chaser is in a free-floating mode.
- Trajectory results in the desired position and orientation of the end-effector and the desired orientation of the chaser.

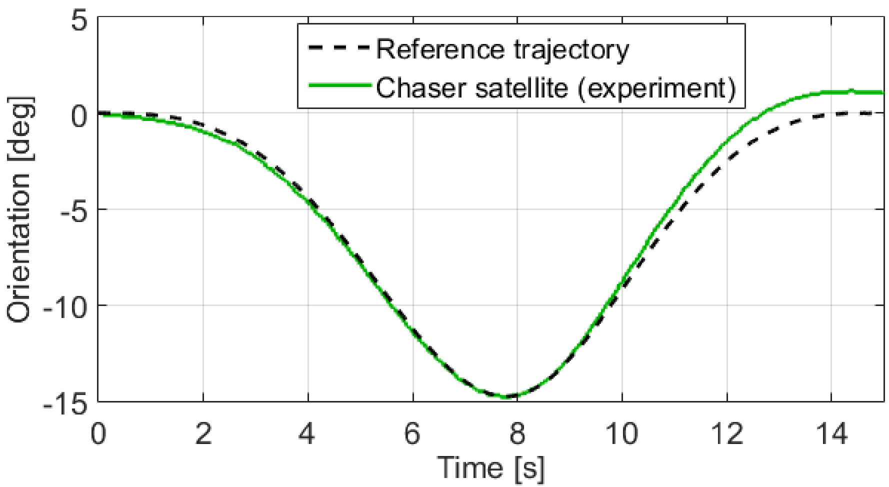




Tracking optimal collision-free trajectories

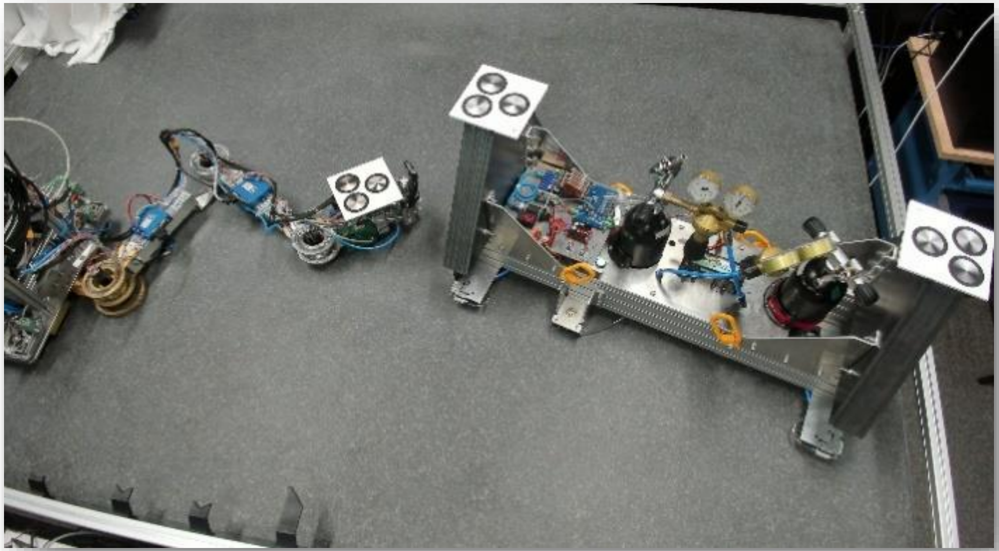


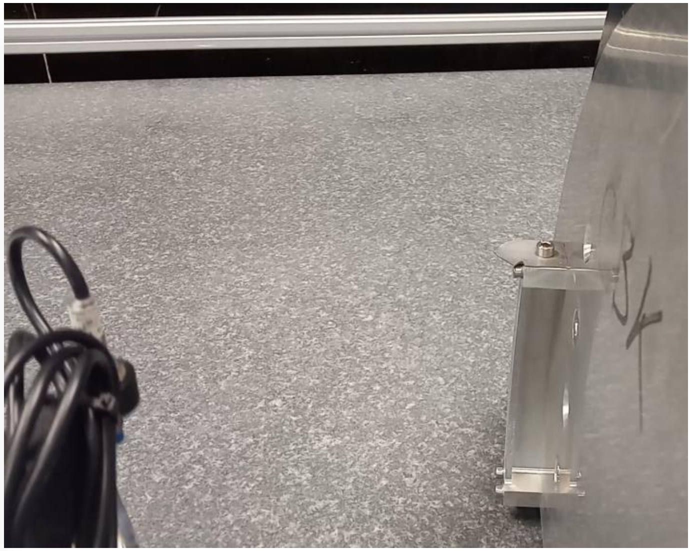




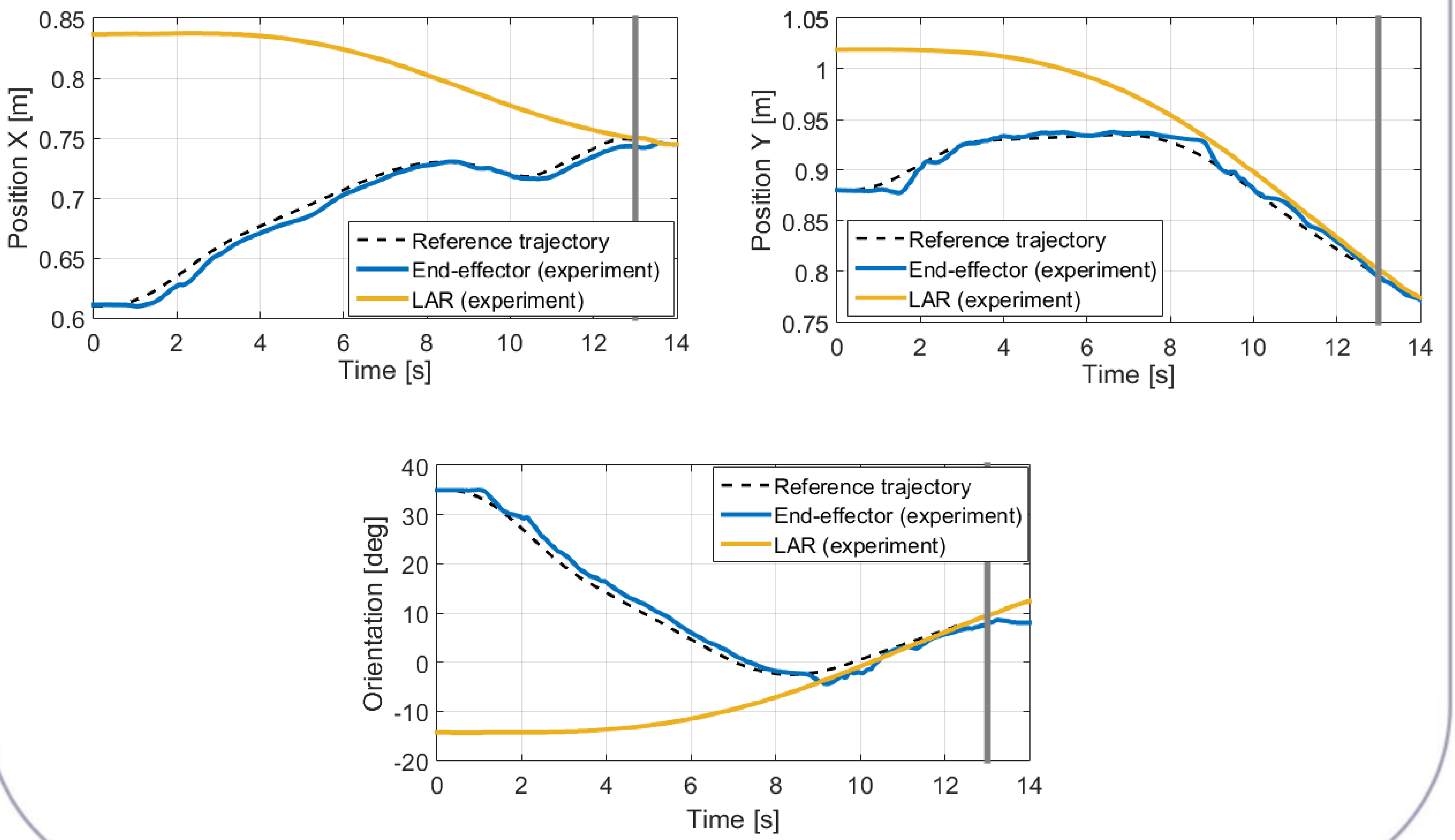
Capture operation

- The target satellite is rotating with the angular velocity of 3 deg/s at the moment of grasping.
- The end-effector follows a pre-planned trajectory and approached the LAR in a straight line with respect to the target.
- Control system based on the Dynamic Jacobian is used to ensure accurate end-effector trajectory tracking.





Capture operation



Summary

- Testing facilities that allow the simulation of microgravity conditions play a crucial role in validation of technologies developed for IOS and ADR missions.
- Over twelve years of continuous operation, the planar air-bearing microgravity simulator at CBK PAN has proven its reliability, versatility, and potential to obtain high-quality results.
- Several major upgrades of the test-bed expanded its capabilities and opened up new fields of research.
- Two new elements were recently added: the Modular Gripper and the mock-up of the target satellite.
- It is possible to simulate the entire operation of capturing a rotating target object. This allows to perform experimental verification of trajectory planning and control algorithms dedicated for the in-orbit capture operation.

Thank you for your attention!

Acknowledgments

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