Compliant control of the robotic arm during clamping operation in the e.Deorbit mission

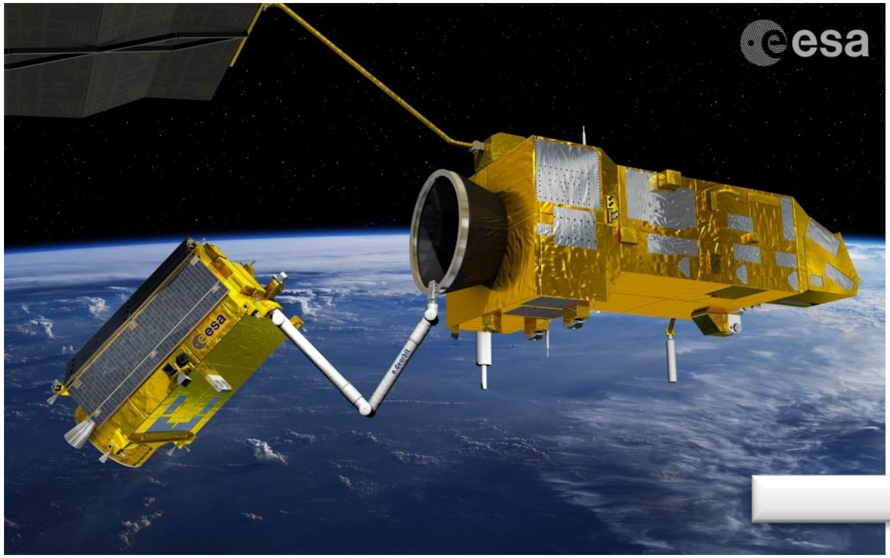
Fatina Liliana Basmadji, Tomasz Rybus, Aleksandra Biedrzycka,
Małgorzata Pawlus, Karol Seweryn

Space Research Centre of the Polish Academy of Sciences (CBK PAN)

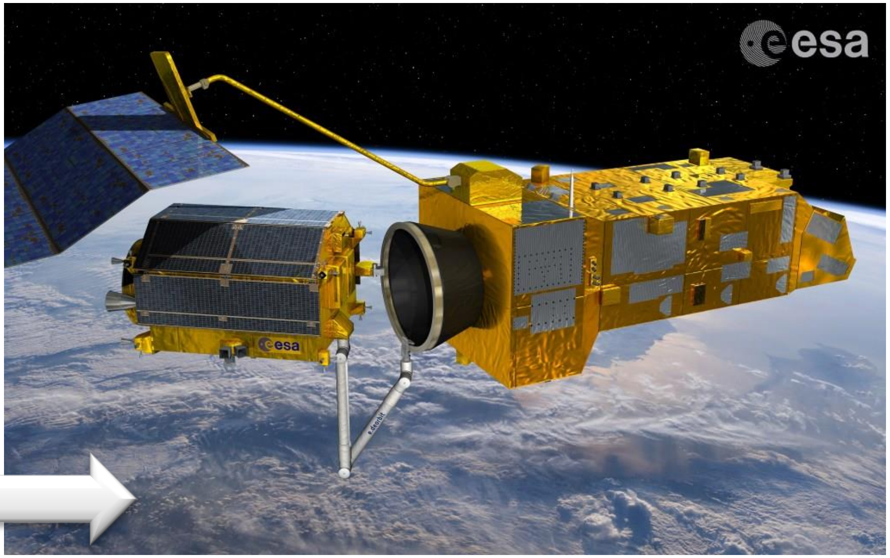
Clean Space Industrial Days
23 – 25 October 2018

CBK task in e.Deorbit consolidation phase

Task: to develop and verify by simulation a cartesian force/torque compliant control for the robotic arm during the clamping operation.

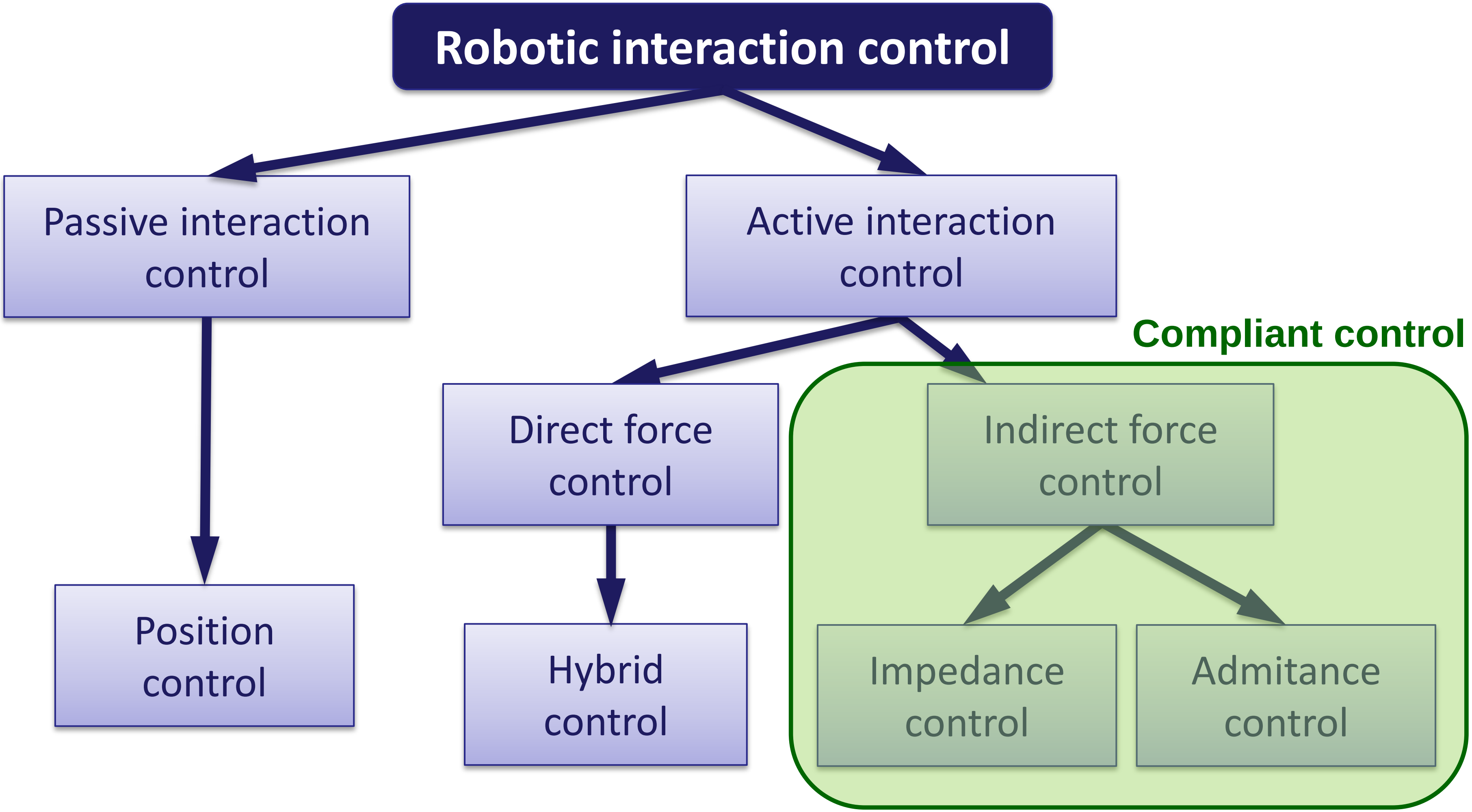


Source: ESA



Source: ESA

Interaction control

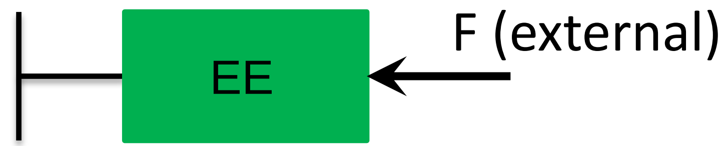


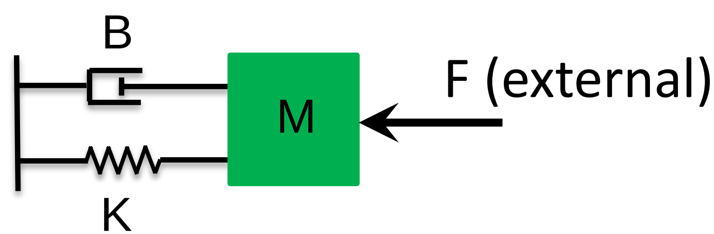
On the basis of Interaction control classification proposed in [1]

[1] L. Villani and J. De Schutter, “Force control,” in Handbook of Robotics, B. Siciliano and O. Khatib, Eds. Berlin, Germany: Springer, ch. 7, 2008.

Impedance control

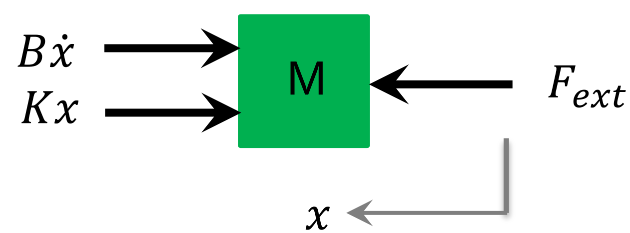
In impedance control, manipulator's end efferctor is controlled in such a way that it reacts to external forces as if it was a mechanical system with defined mass, stiffness and damping.





$$\sum F_x = F_{ext} - B\dot{x} - Kx = M\ddot{x}$$

$$M\ddot{x} + B\dot{x} + Kx = F_{ext}$$



where: M – Mass,
B – Damping coefficient,
K – Stiffness coefficient.

Impedance control

The desired behaviour of the system when subjected to external forces and moments :

$$M_d(\ddot{X}_a - \ddot{X}_d) + B_d(\dot{X}_a - \dot{X}_d) + K_d(X_a - X_d) = -F_{ext}$$

Thus, linear and angular accelerations are calculated as following:

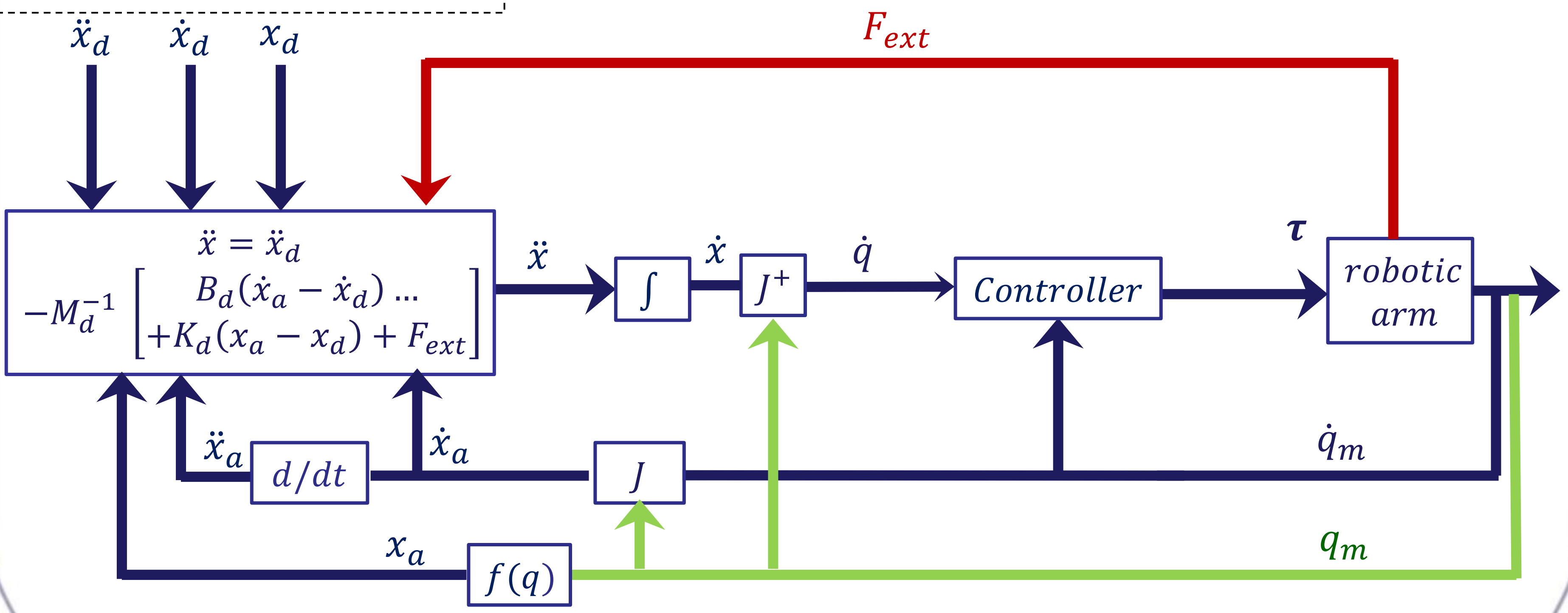
$$\ddot{X}_a = \ddot{X}_d - M_d^{-1}\ [B_d(\dot{X}_a - \dot{X}_d) + K_d(X_a - X_d) + F_{ext}]$$

where, $\dot{X} = [v\ \omega]^T$, the linear and angular velocities of the end effector.

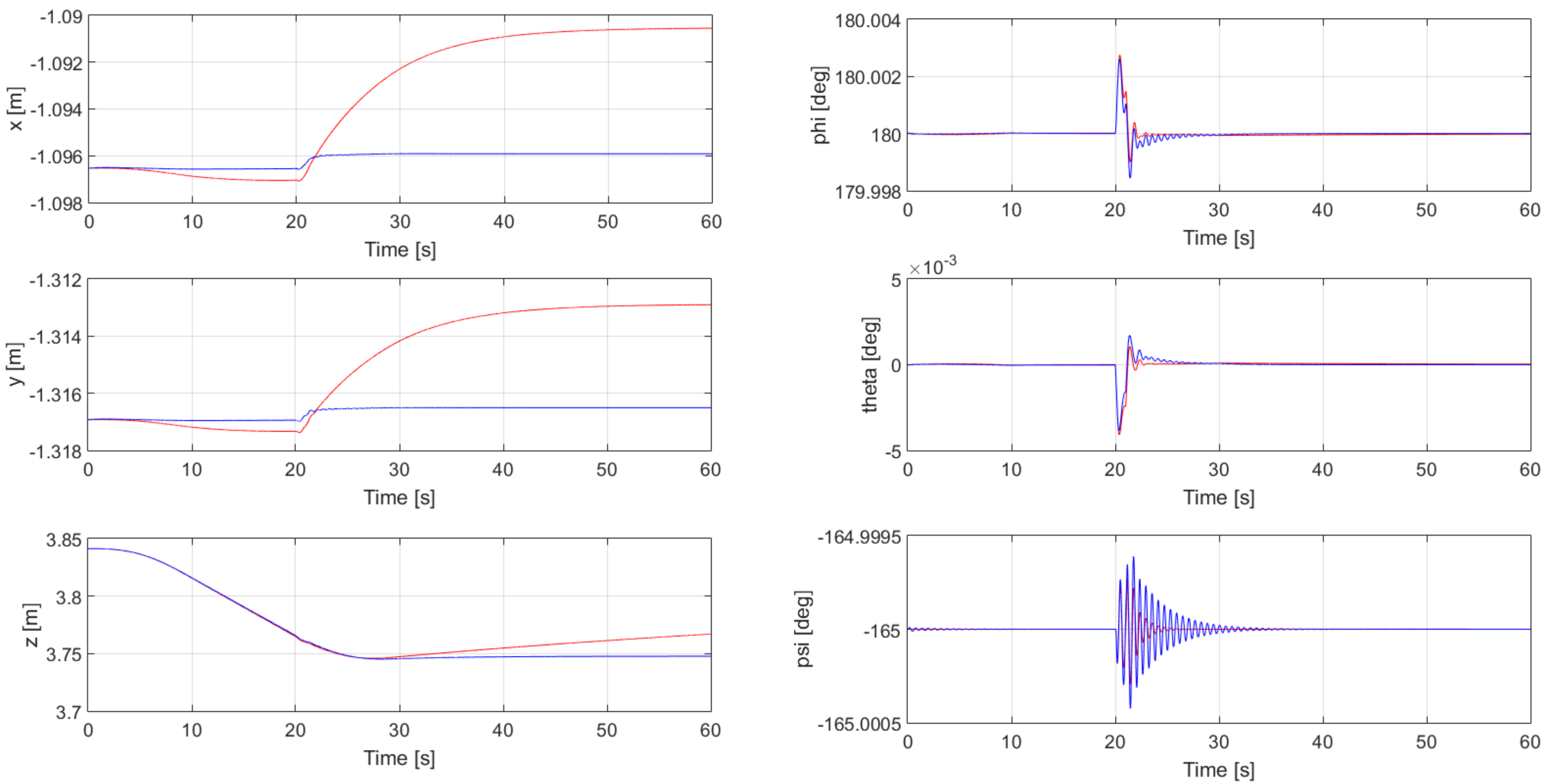
F_{ext} external forces and moments

Compliant control input/output

End-effector trajectory determined from the relative position and orientation of the clamp with respect to LAR (from Visual Servoing)



Compliant control

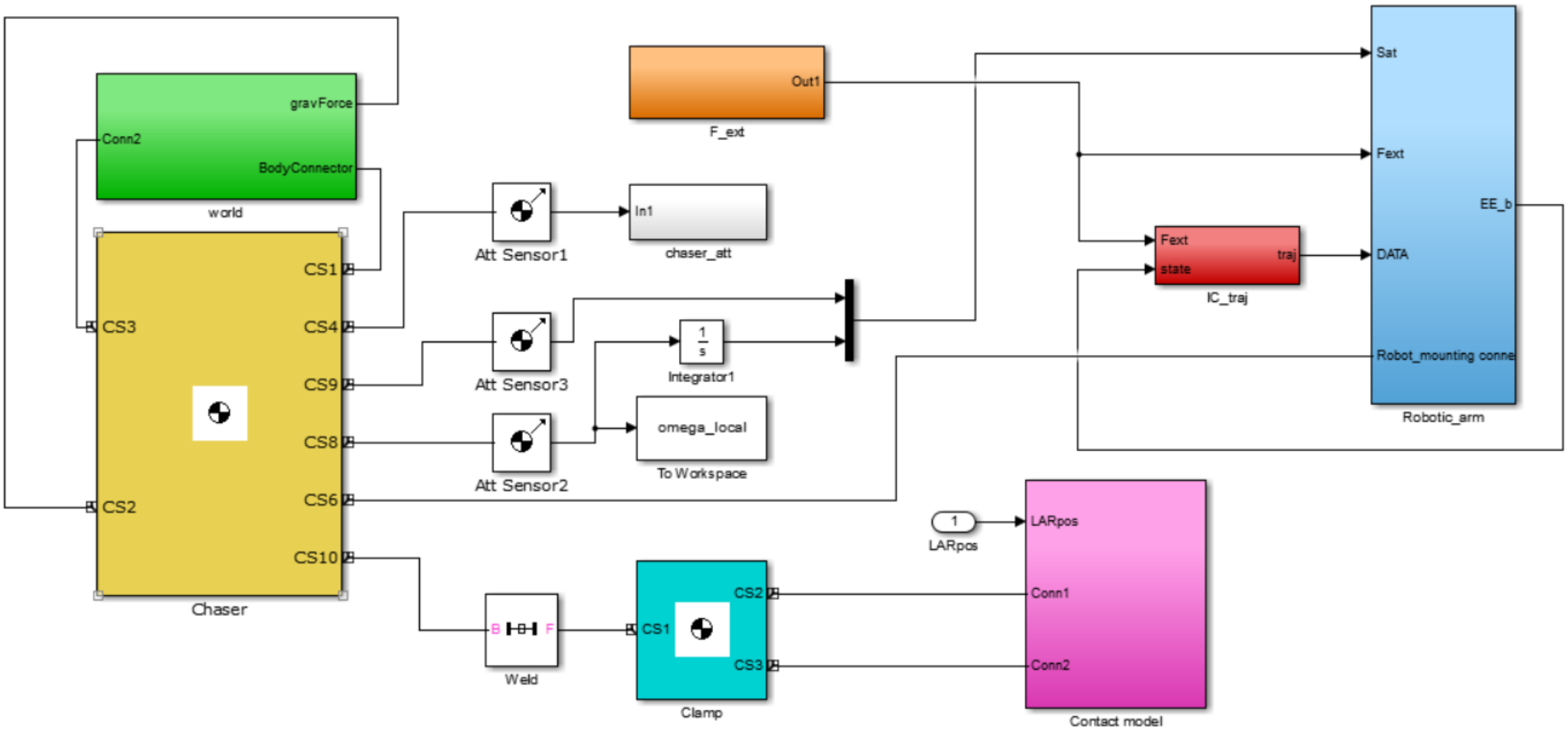


Stiffness matrix: K > K

Simulation Tool 1/2

- Compliant Control simulator (CCsim) is used to perform numerical simulations and to verify the compliant control
- CCsim is based on the "Simulation tool for space robotics". This tool is under development at CBK PAN since 2009 and was used in several projects for simulations of the final phase of orbital rendezvous manoeuvre.
- In 2016 it was cross-checked with the GMV simulator in the frame of the ESA ORCO project.
- The tool is based on SimMechanics model of a chaser satellite equipped with a manipulator (SimMechanics is software based on the Simscape, the platform product for the MATLAB Simulink).
- Dedicated Matlab functions are used for postprocessing and analysis of the simulation results.

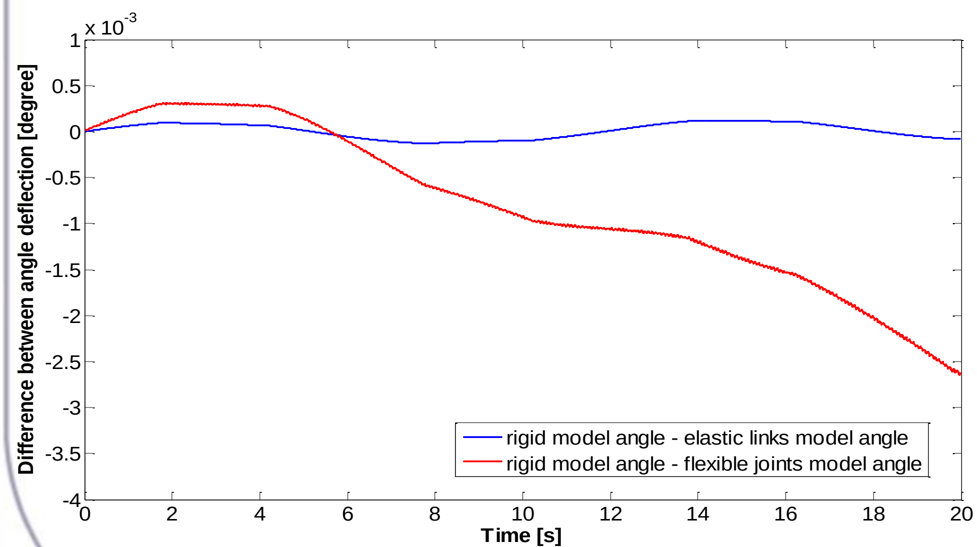
Simulation Tool 2/2



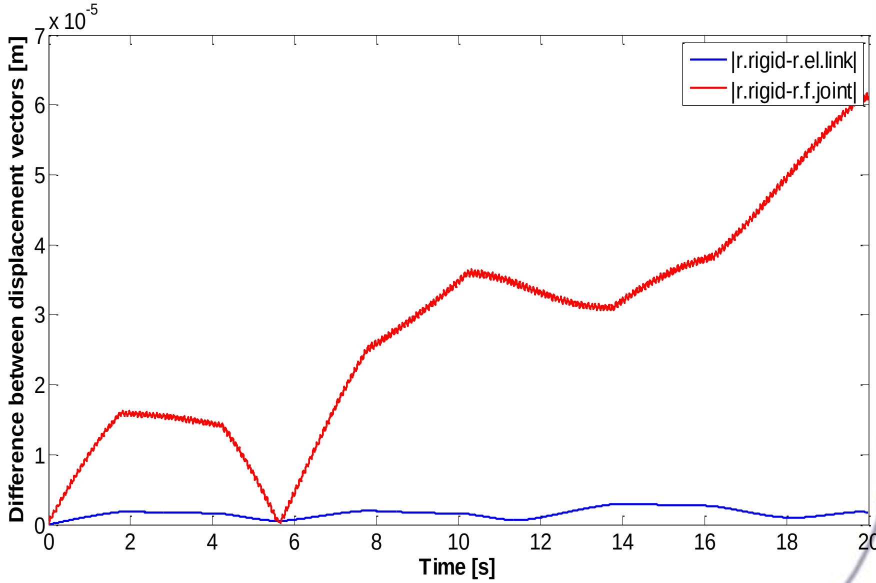
Manipulator flexibility

Results of analysis based on mathematical models performed for a simplified case:

- influence of the elasticity in joints is much more significant then influence of the elasticity in links,
- elasticity in links can be neglected.

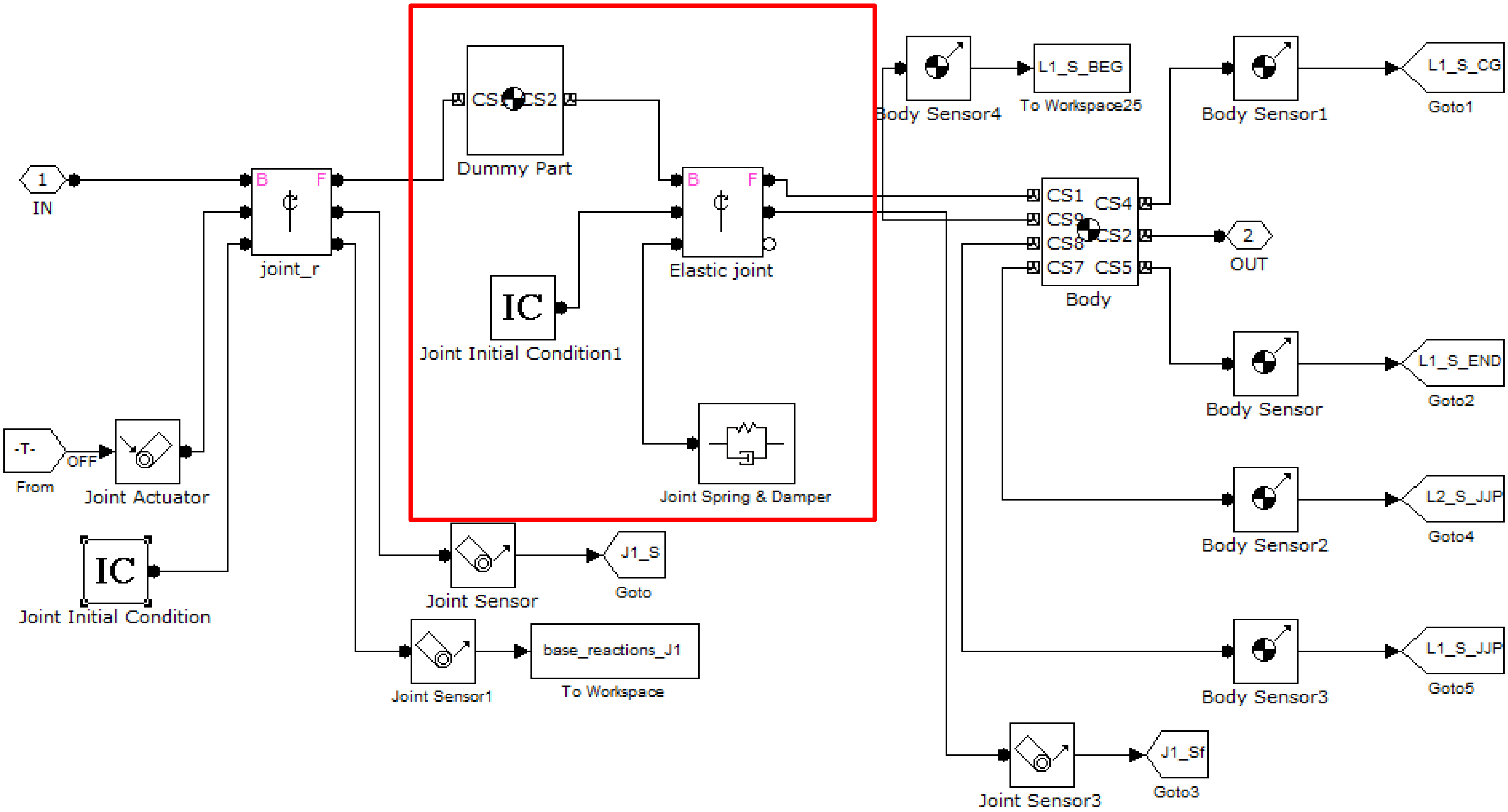


Deflection of the second link of the manipulator

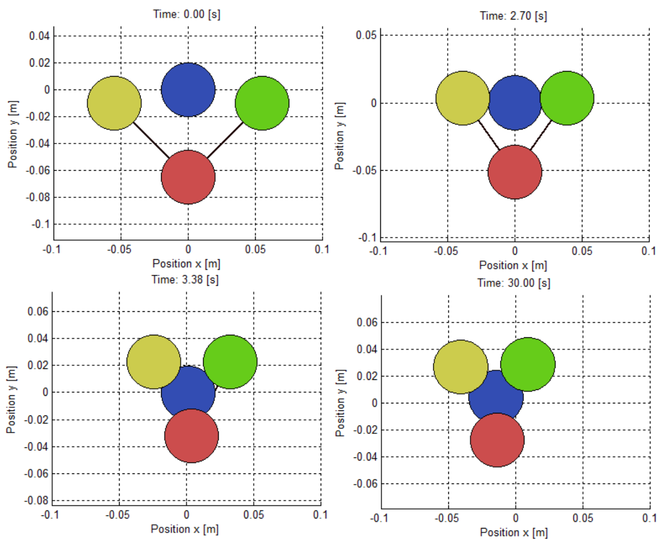


End-effector trajectory

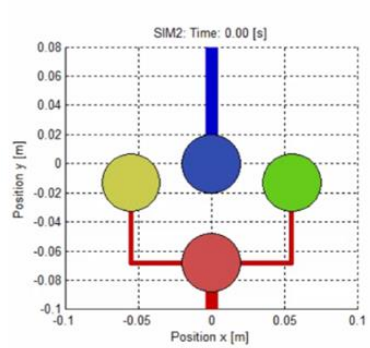
Model of flexible joint

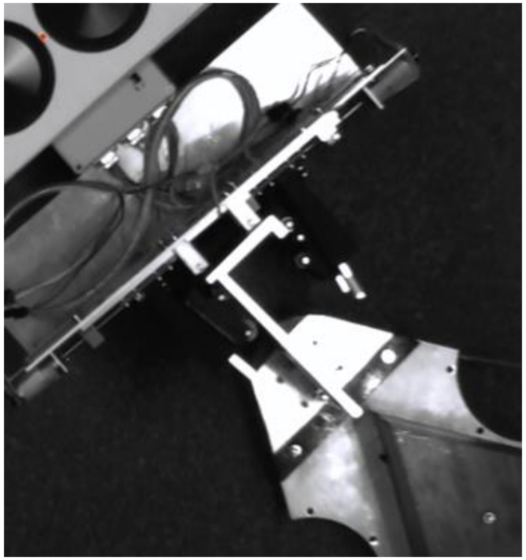


Development of a 2D contact model (e.Deorbit Phase B1)

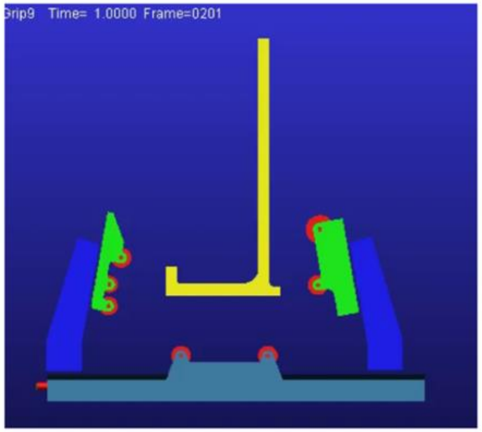


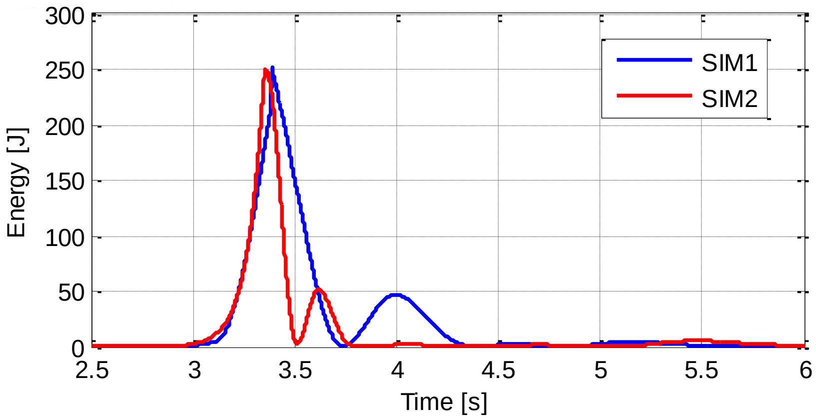
SIM2 2D simulation tool model



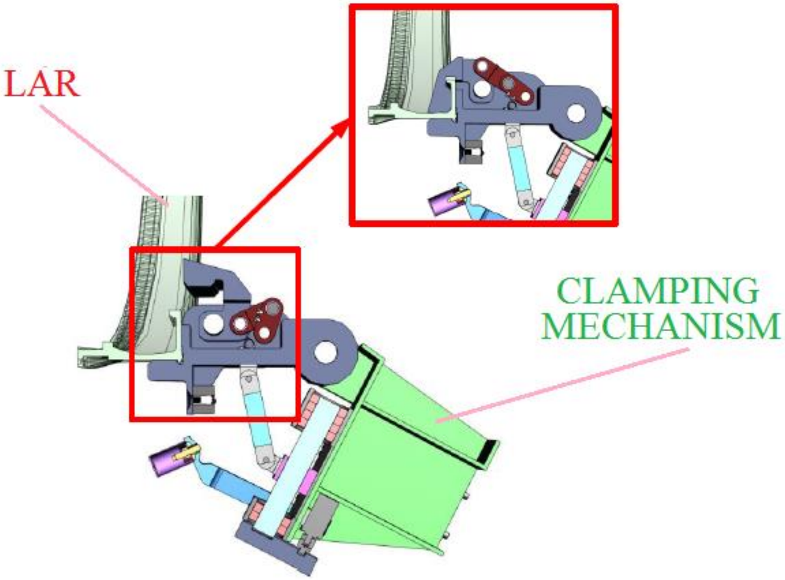


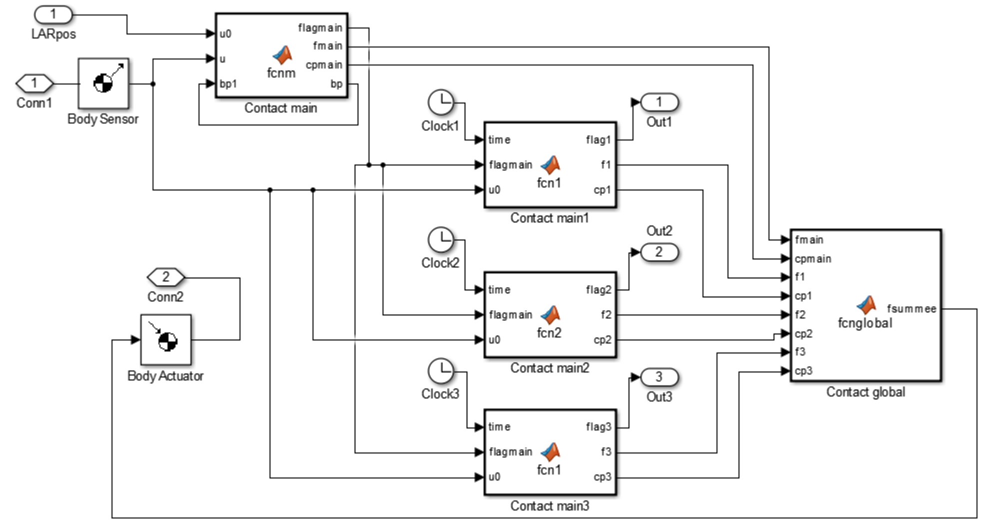
SIM1 2D Adams model

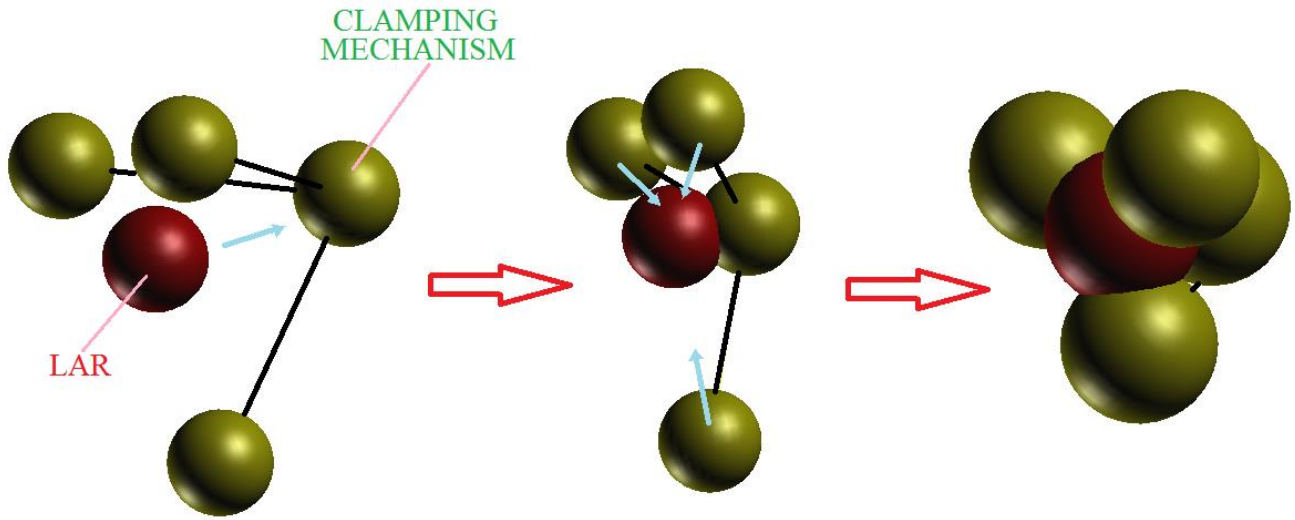




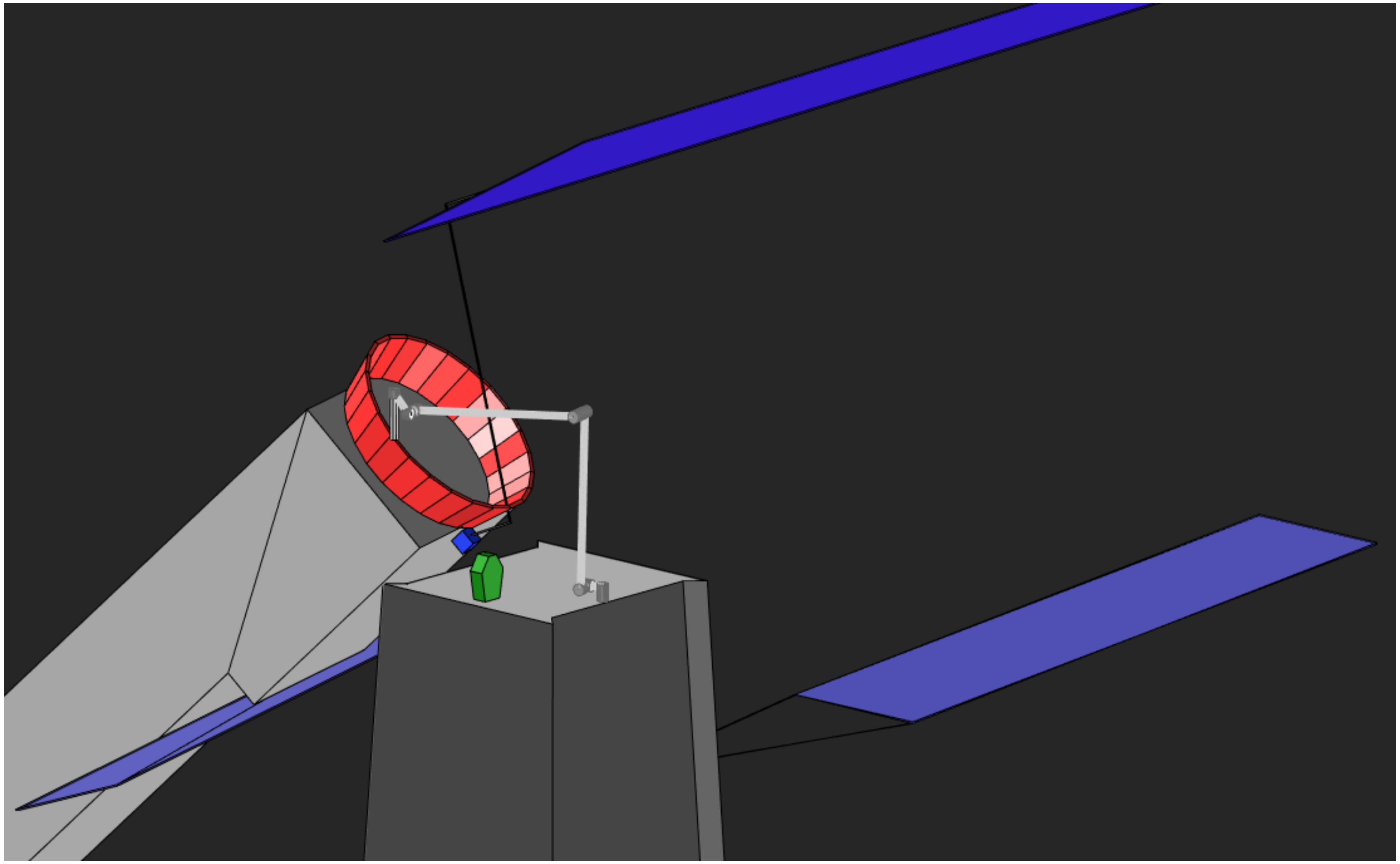
3D contact model







Animation module

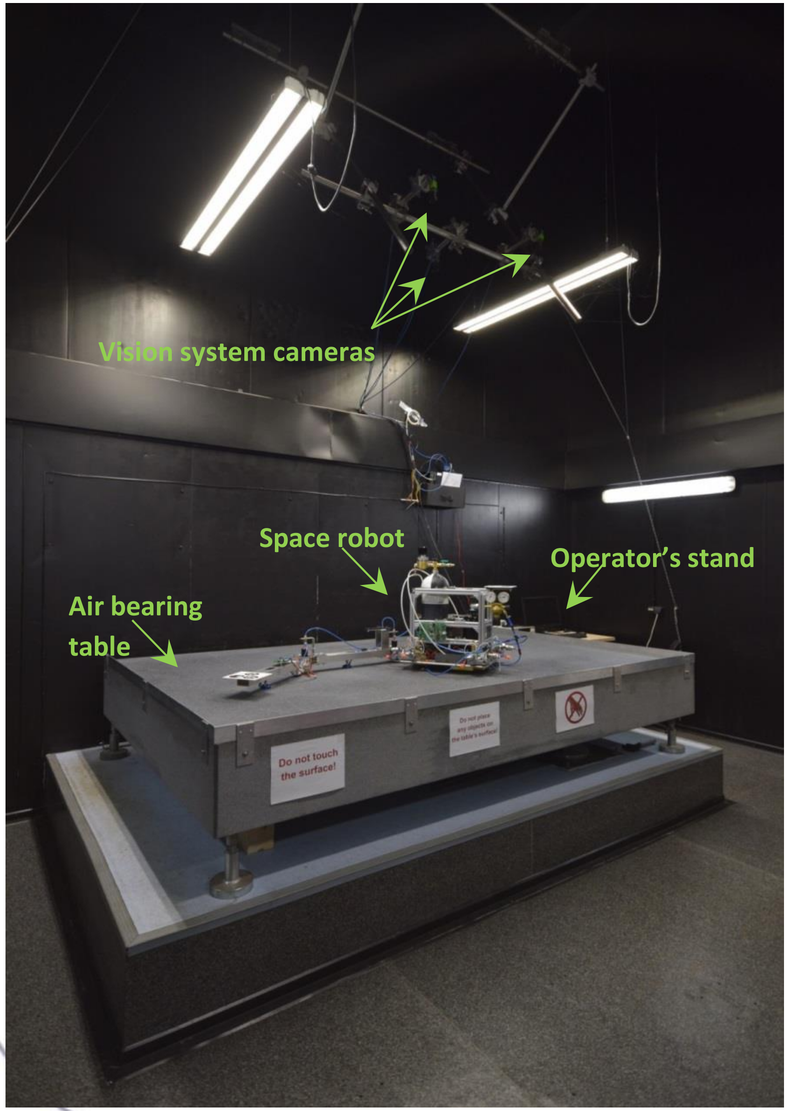


Monte Carlo

Numerical simulations are being performed with the modified and upgraded „Simulation tool for space robotics" to verify the proposed cartesian 6DOF comliant control.

- To test the proposed compliant control for a wide range of parameters and initial conditions,
- to estimate forces and torques induced by the motion of the robotic arm when the gripper is attached to LAR,
- to identify parameters that have the most significant influence on the overall performance of the compliant control,
- to find a set of initial conditions and parameters for which the maneuver can be performed with a defined safety margin.

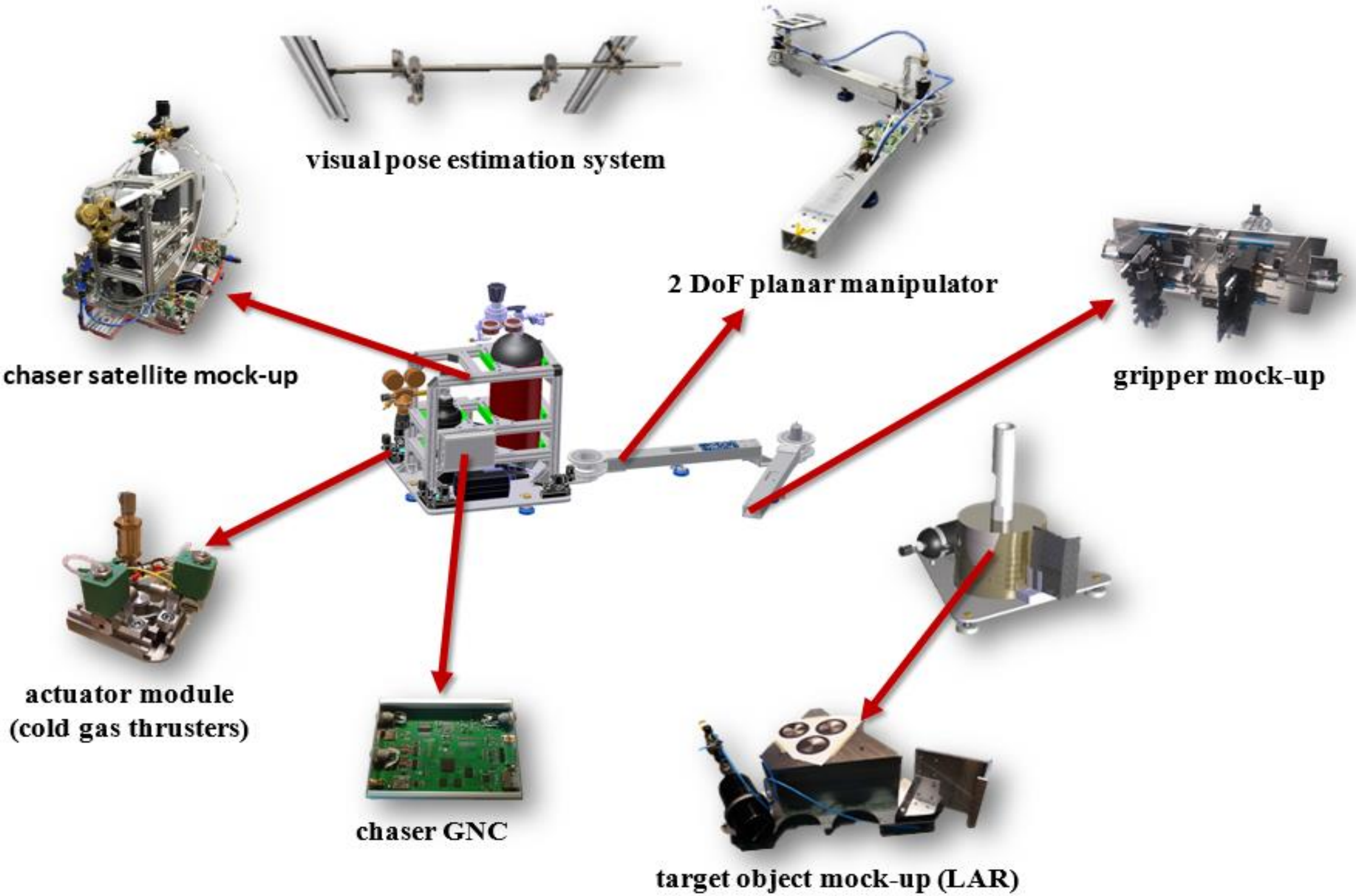
Air-bearing microgravity simulator at CBK PAN



	Parameter	Link 1	Link 2
1	Mass [kg]	4.5	1.5
2	Moment of inertia [kg·m^2]	0.32	0.049
3	Length [m]	0.619	0.6
4	Joint type	rotational	rotational

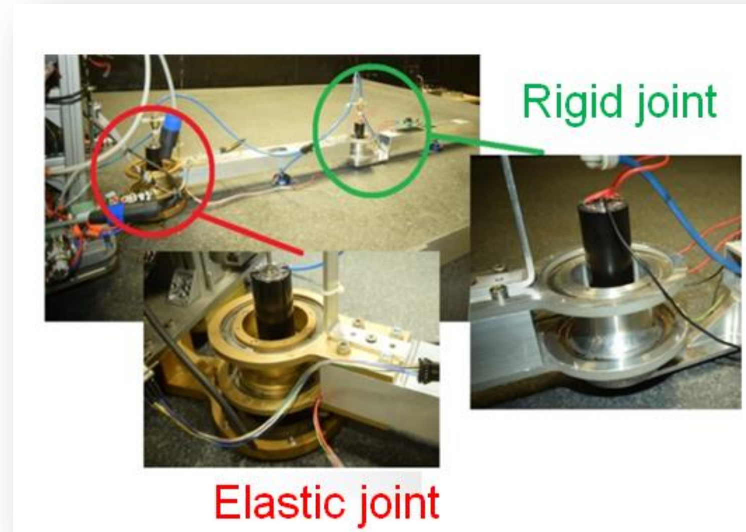
	Parameter	Value
1	Number of thrusters	4 modules x 2 thrusters
2	Thrust [N]	0.846
3	Working medium	Nitrogen
4	Nominal chamber pressure [bar]	10
	Mass flow rate [g/s]	1.575

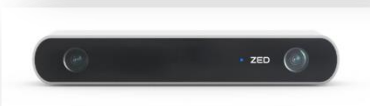
Air-bearing microgravity simulator at CBK PAN



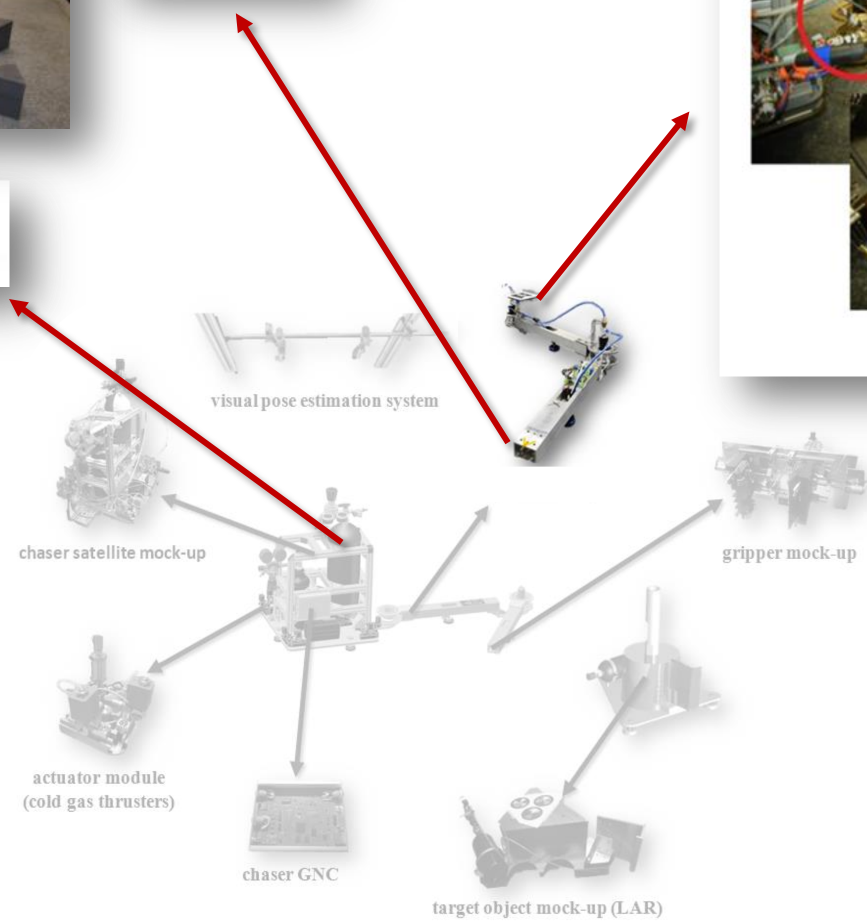
Air-bearing microgravity simulator at CBK PAN

Source: duo3d.com





Source: stereolabs.com



Thank you for your attention!