Robotics in the e.deorbit Phase B1

Roberto Lampariello*, Giorgio Panin*, Wolfgang Rackl*, Bernhard Brunner*, Phillip Schmidt*, Marco De Stefano*, Jürgen Telaar**, Stéphane Estable**

*DLR, **AIRBUS

ESTEC, 25.05.2016

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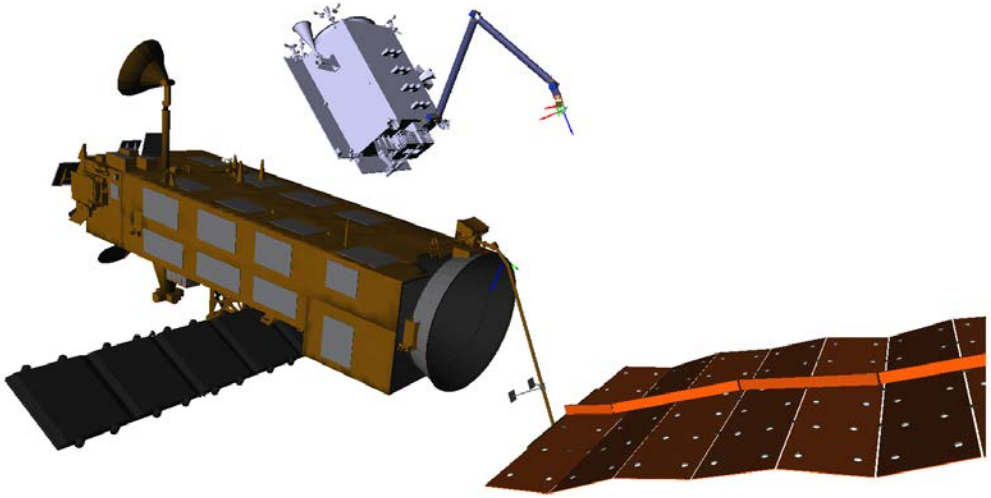
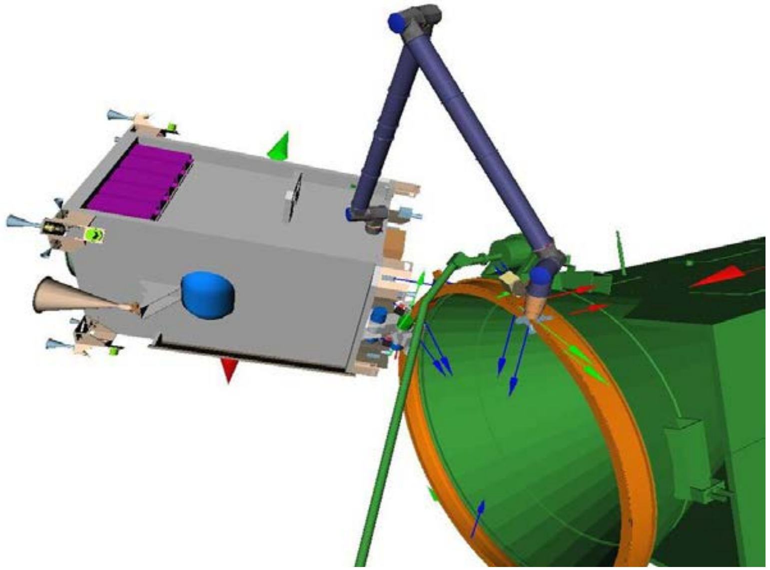
Mission goals



- grasp ENVISAT at its Adapter Ring with robot manipulator during synchronized flight

Chaser at Capture Point

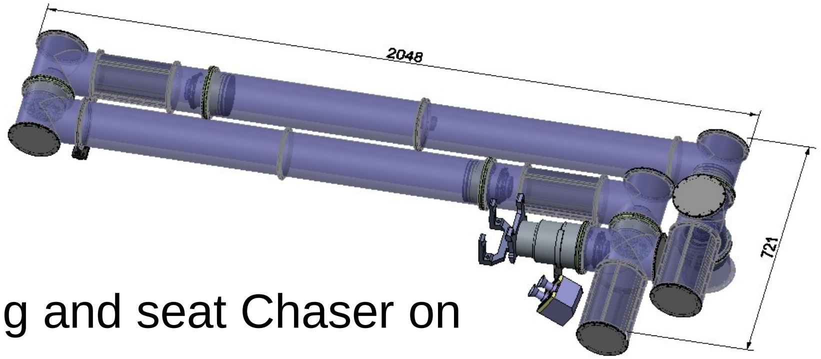
and following that



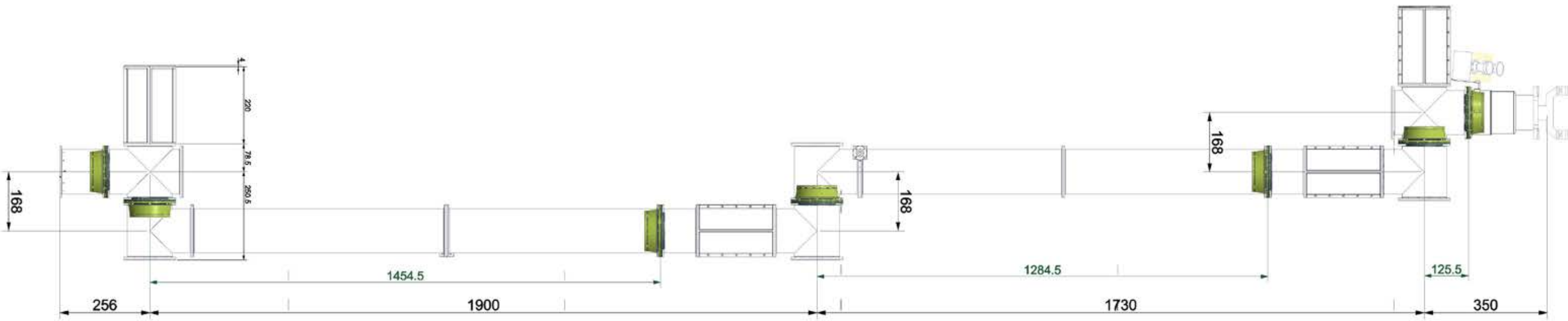
- bringing Chaser spacecraft onto Adapter Ring for fixation with a dedicated clamping mechanism, to allow for deorbiting maneuver

Chaser at Fixation Point

Robot arm configuration



- 7-DoF arm kinematics designed to grasp Adapter Ring and seat Chaser on Adapter Ring
  Link lengths [mm] = 256, 168, 1900, 168, 1730, 168, 350
  Total length [m] = 4.236
- Joints max. output torque: Repeated peak torque 176 Nm, Momentary peak torque 314 Nm; max. braking torque = 100 Nm (Phase A)
- Joints max. speed of 10°/s
- Joint design allows torque-based impedance control concept for compliant grasp maneuvers



CAD Model

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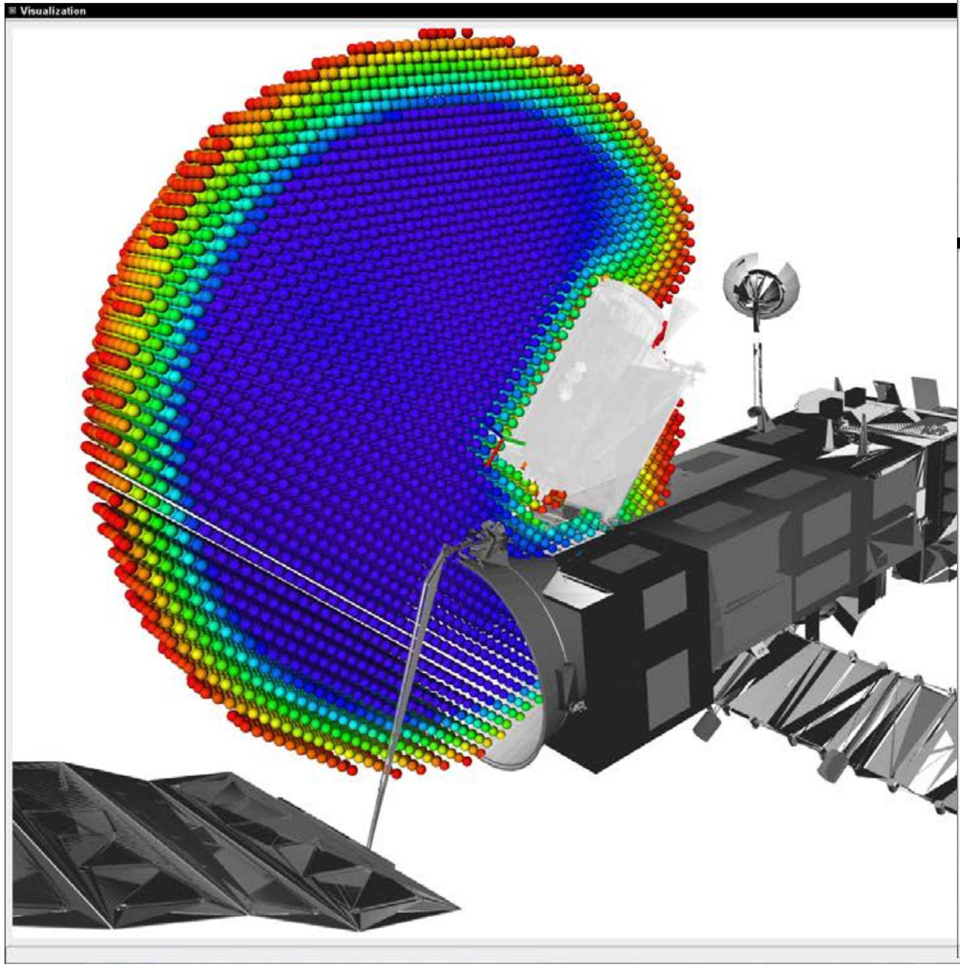
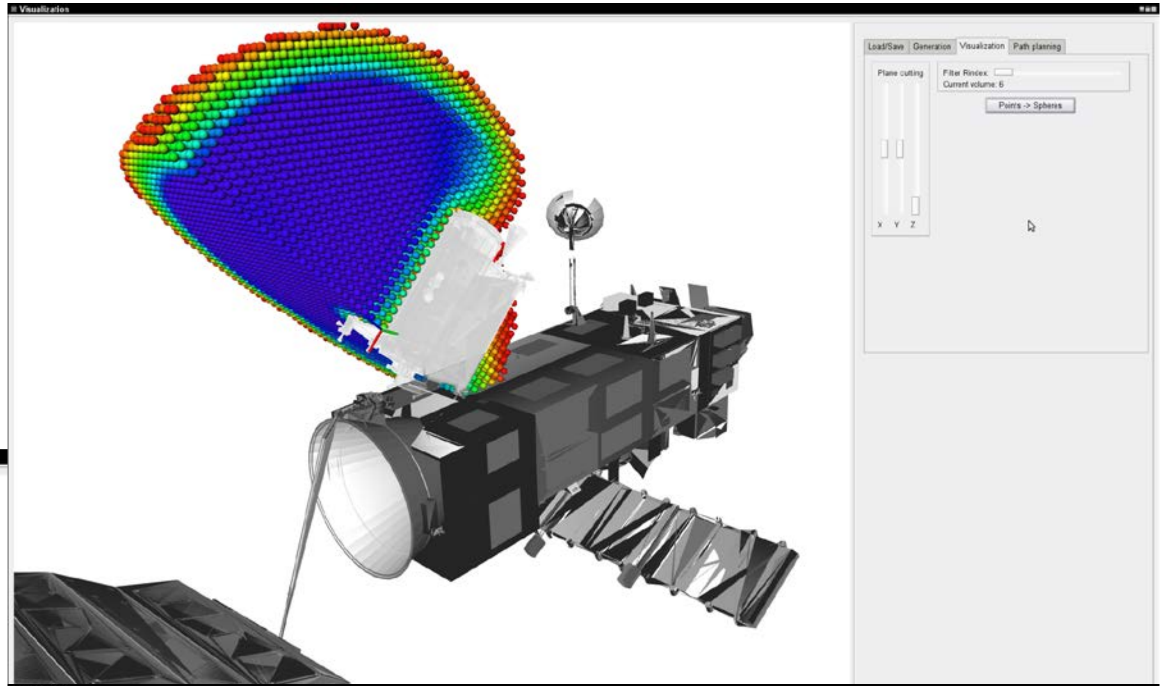
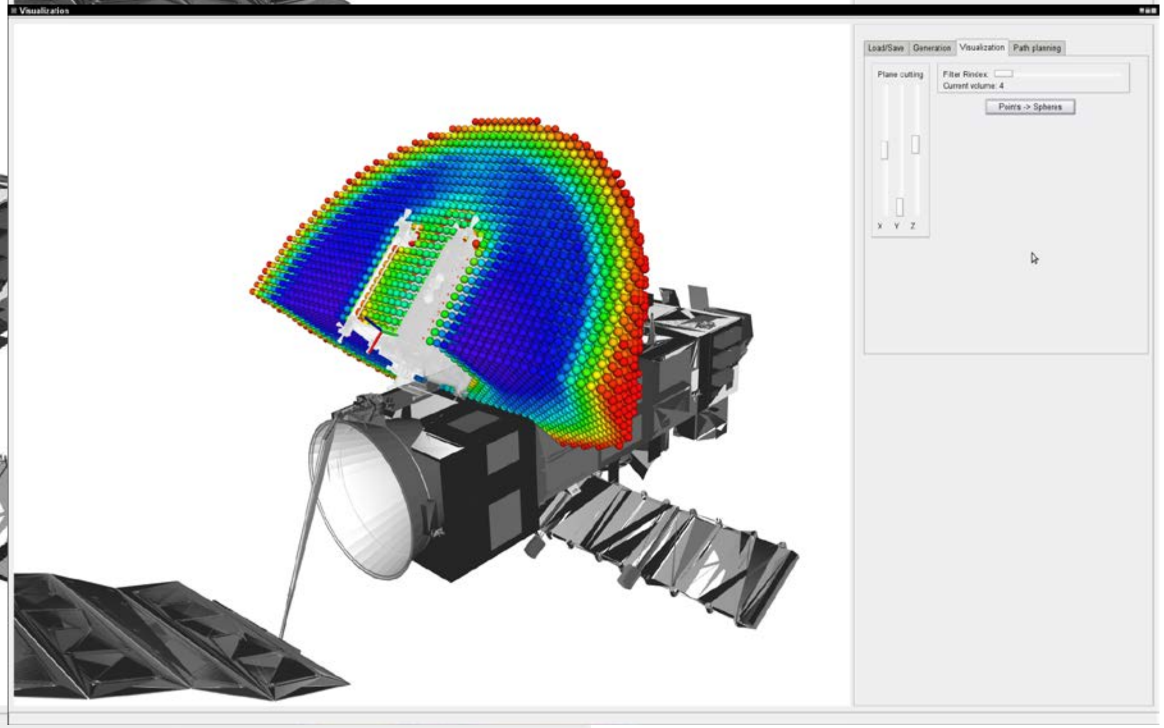
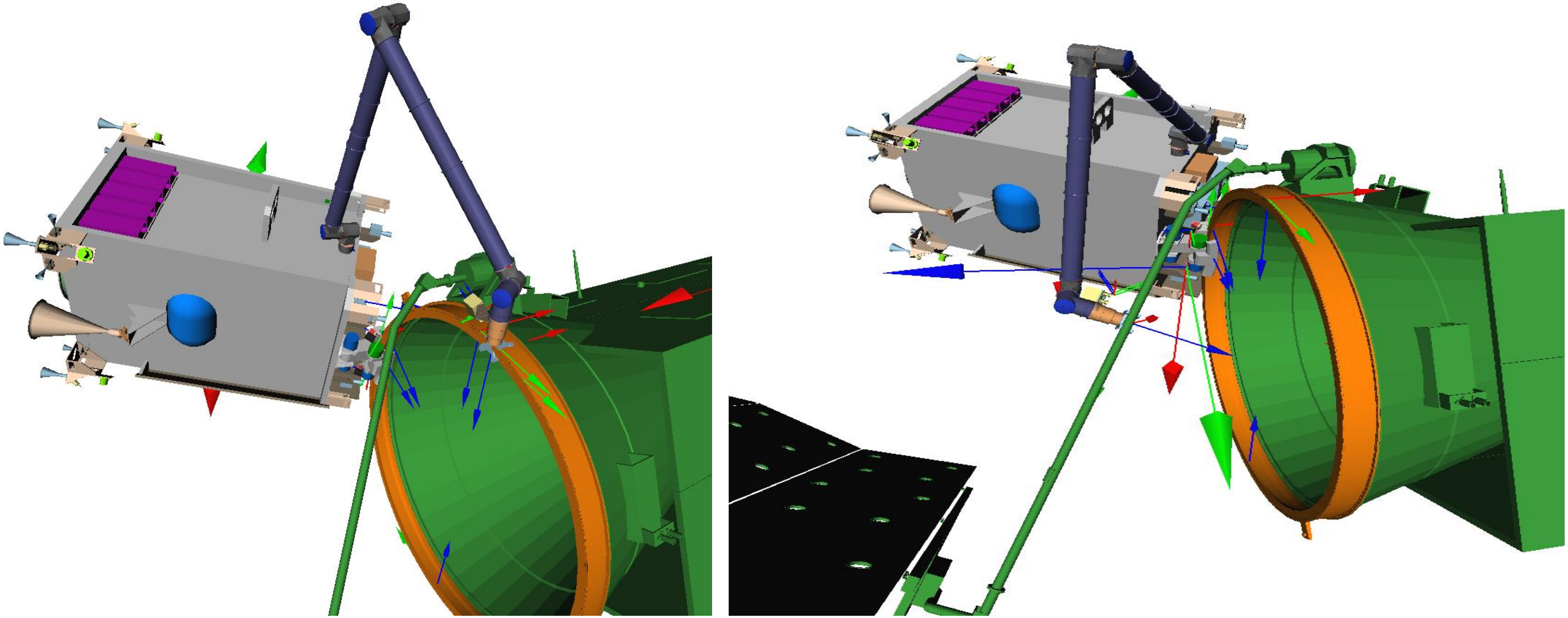
Workspace analysis at Capture Point Reachability Map







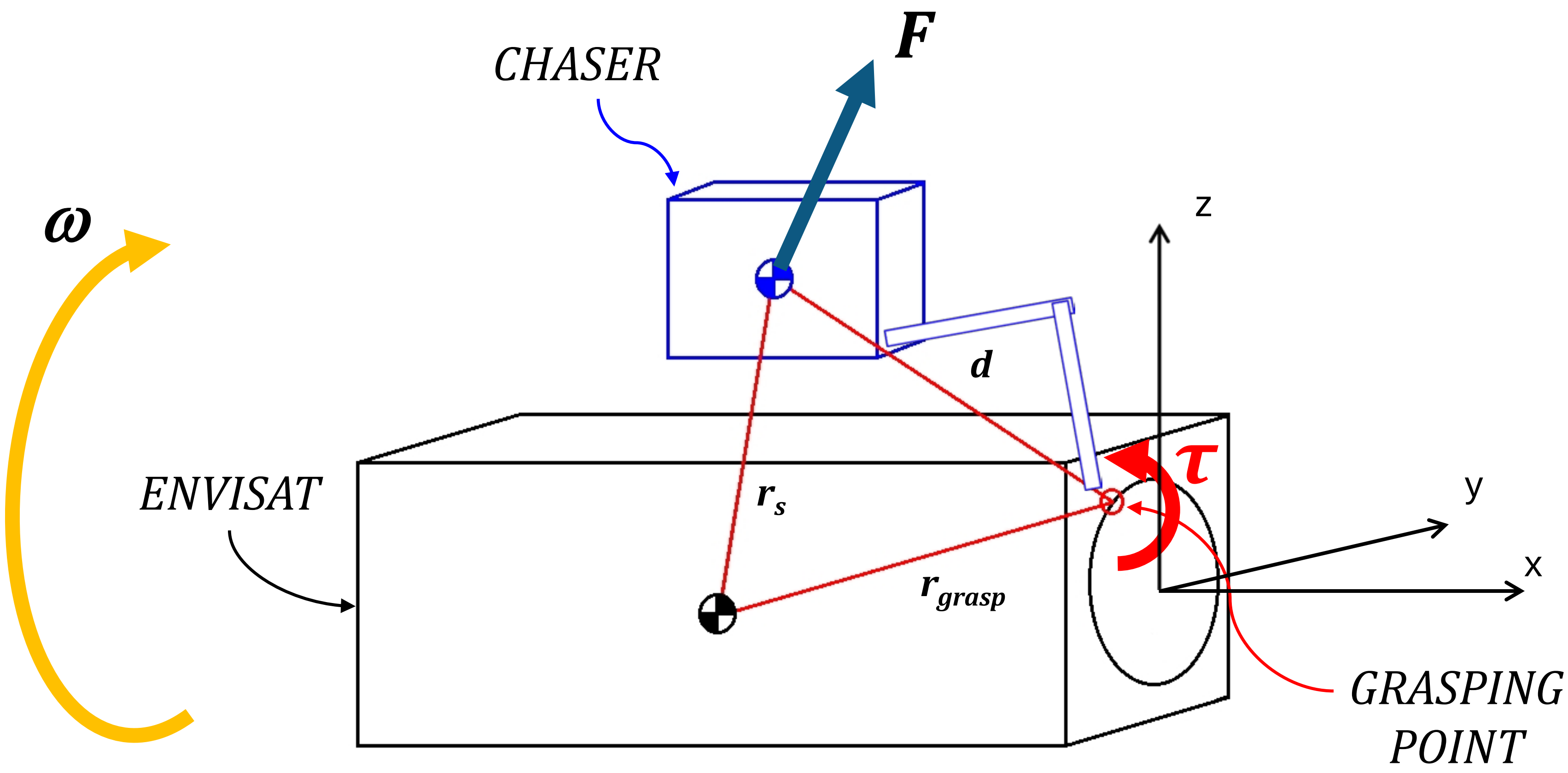
Robot configuration at Fixation Point



Configuration at Fixation Point on Adapter Ring:
Robot grasping point at “13:00 o’clock”, Fixation Point at “11:00 o’clock”;
Configuration at Fixation Point on Adapter Ring while holding Solar Panel Boom

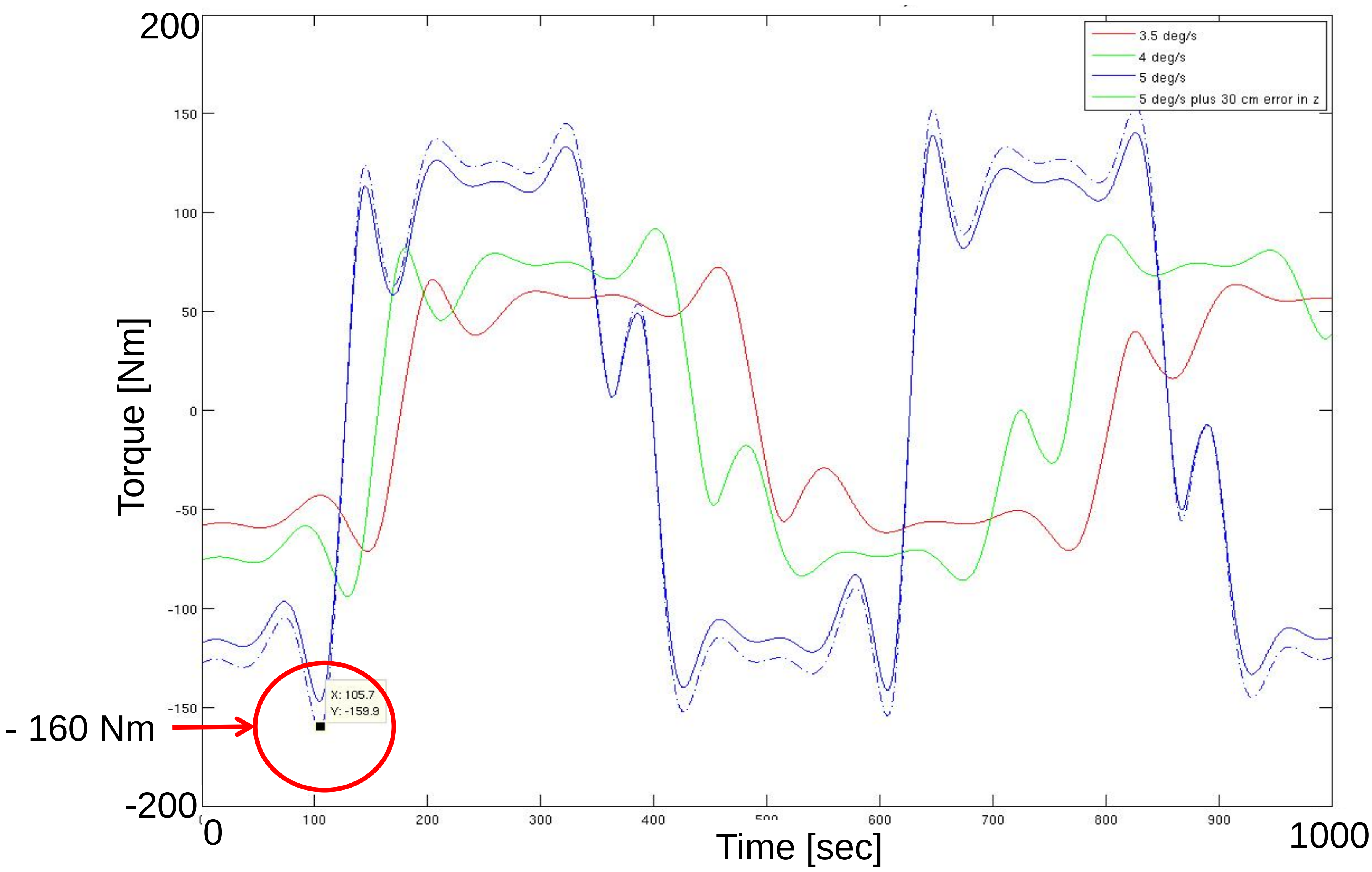
Robot dynamics

Forces/moments at the end-effector after grasping & during tumbling



Goal: determine maximum end-effector torque τ for given tumbling rates ω

Robot dynamics



End-effector torque during tumbling motion for omega_ENV(*t*=0) = [0 5 0] deg/sec

Robot dynamics

Joint torque operational limits

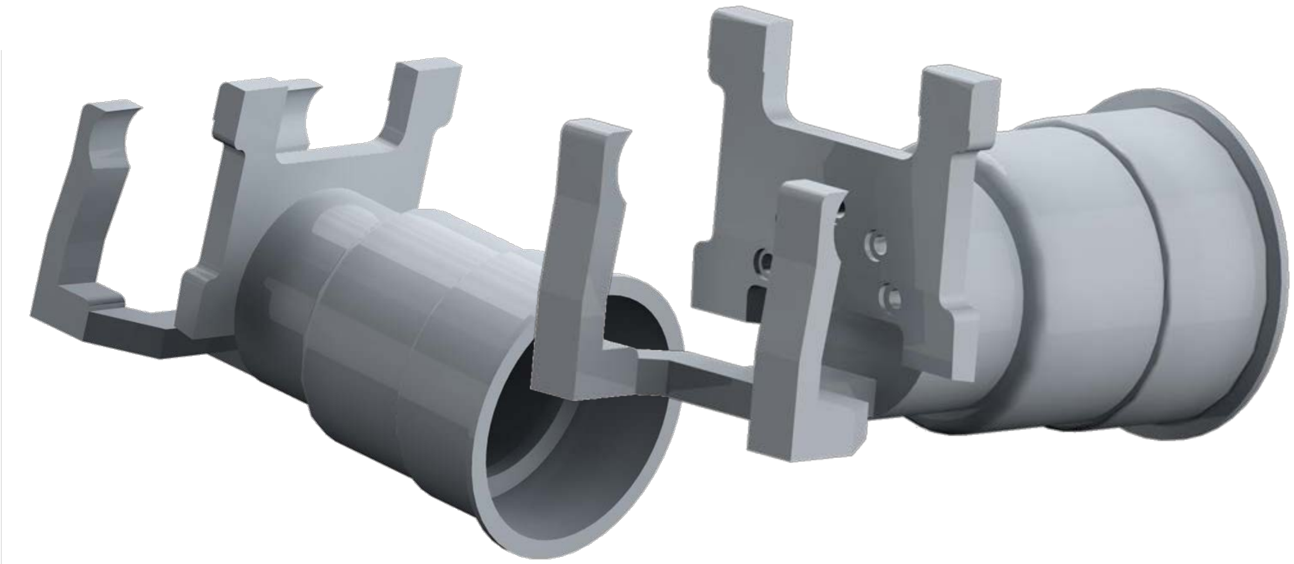
- The design specifications for the joints maximum output torque define a **repeated peak torque** and a **momentary peak torque** of 176 Nm and 314 Nm respectively

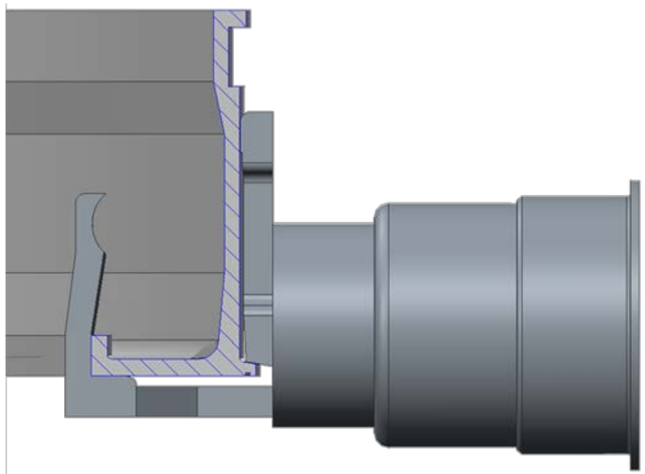
- We can foresee the following options:

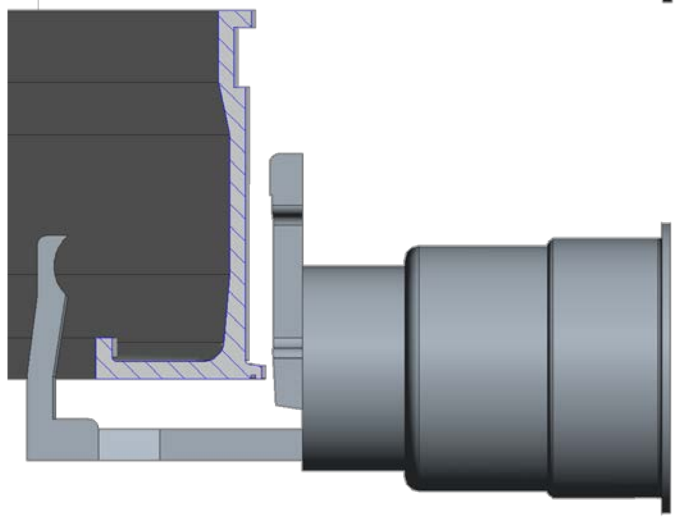
  - We accept a worst case safety margin of 1.2, given that this is fully predictable and could only increase for higher initial angular rates
  - We develop a control strategy which includes the intervention of the GNC to reduce the load in the robotic arm during this phase
  - We apply stronger robotic joints, which provide **repeated peak torque** and a **momentary peak torque** of 372 Nm and 686 Nm respectively

Robot Gripper Design

- Grasp from outside: classic hinge approach not possible due to form of adapter ring
- Solution: Linear spindle mechanism
- Five axes hold by form closure along curve of the ring
- One axis (rotation around center of ring) hold by friction

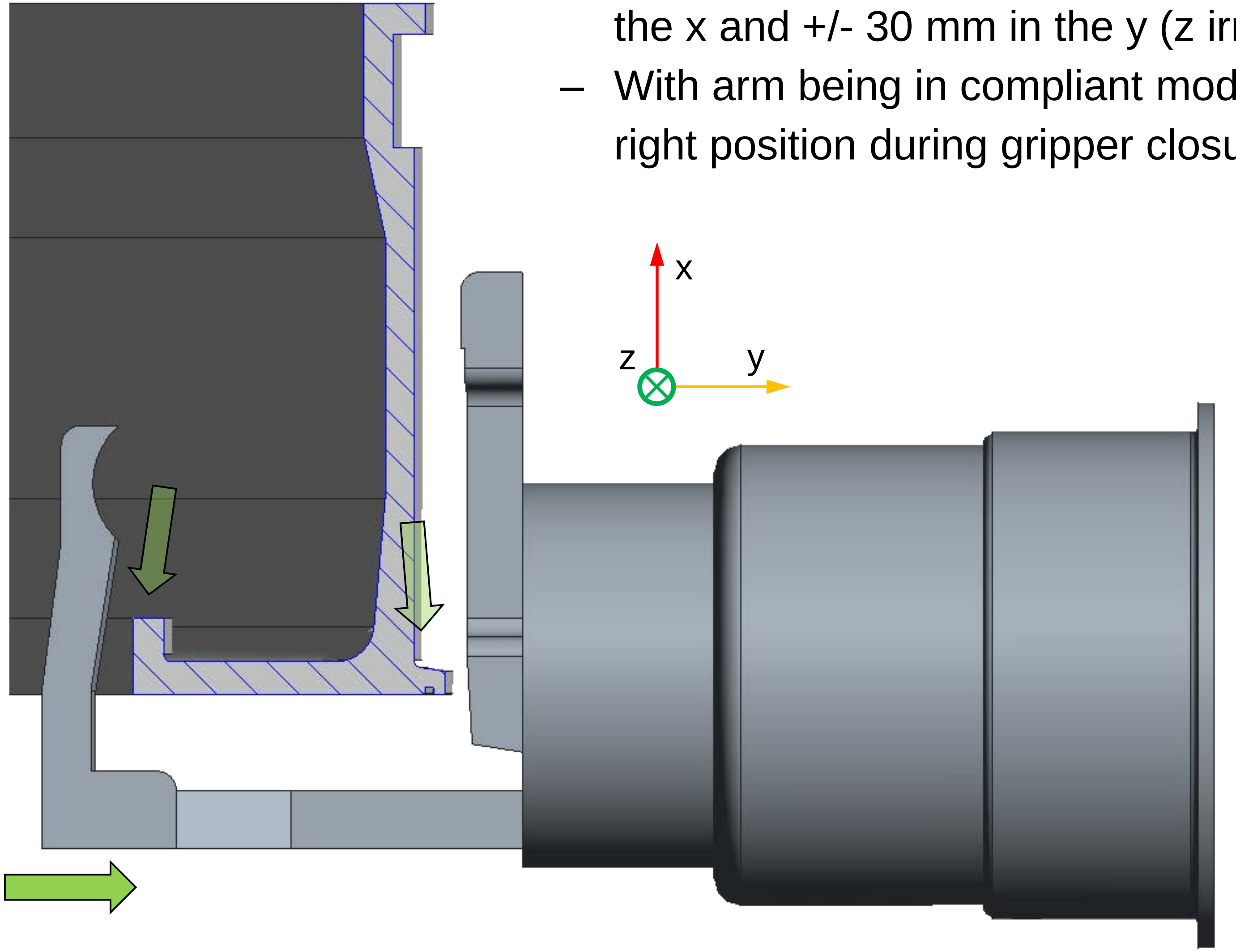






Robot Gripper Design

- Gripper design robust to positioning error up to +40 mm in the x and +/- 30 mm in the y (z irrelevant through radial form)
- With arm being in compliant mode, arm is pushed towards right position during gripper closure



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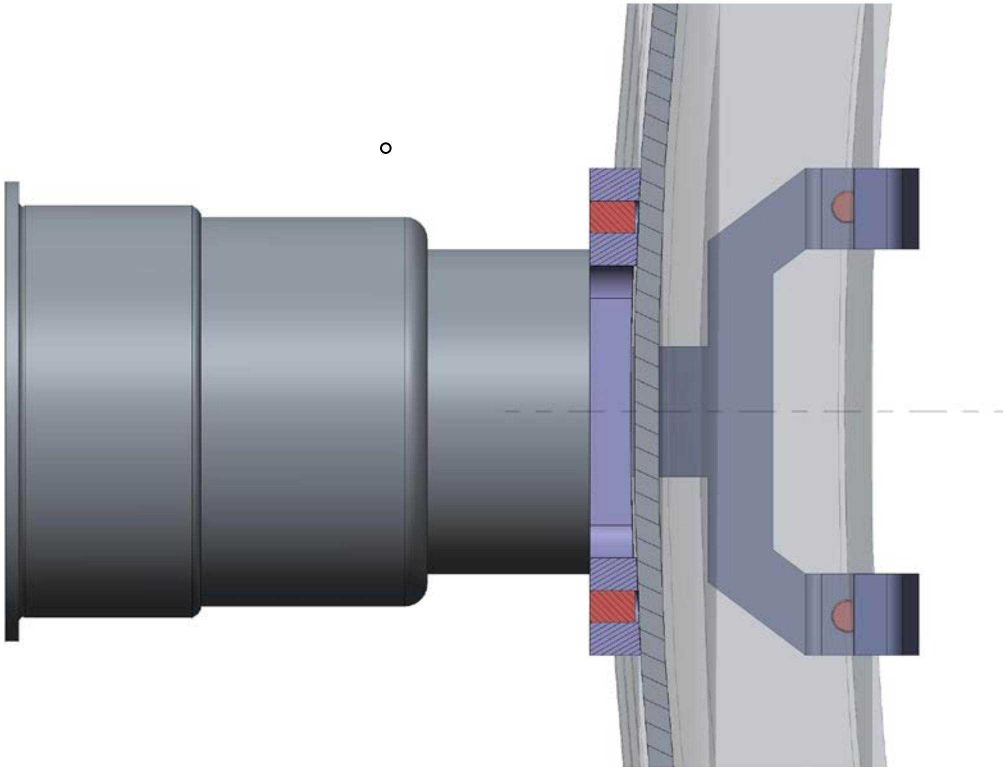
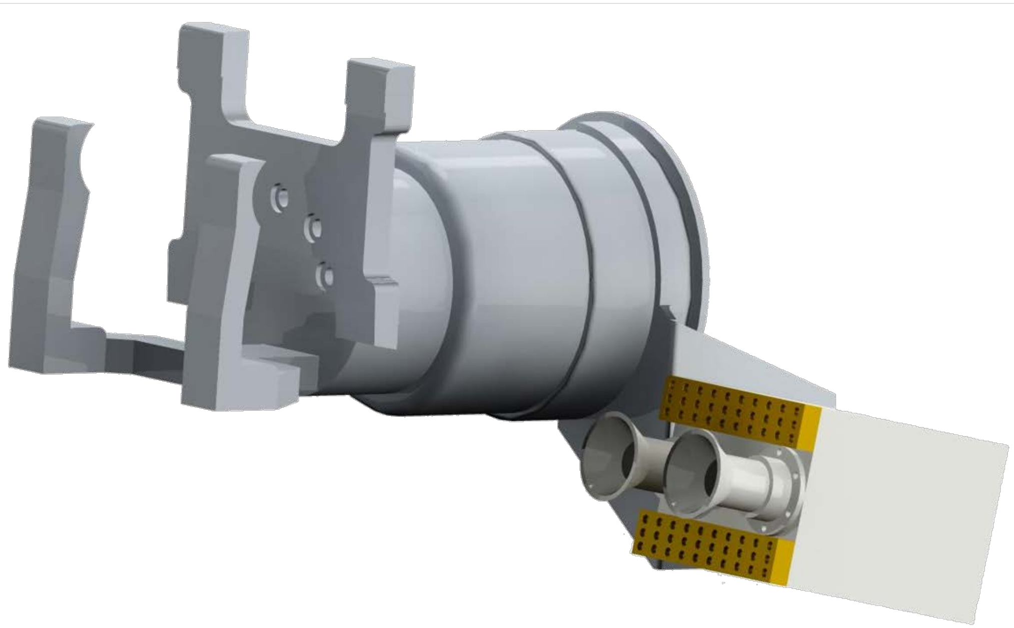
Robot Gripper Sensor Design

- Introduced **inductive sensors** for confirmation of successful grip
- Successful grip confirmation enhanced by camera signal and finger force signal



Inductive sensors (in red)



Gripper stereo camera

Robotics – motion planning

Point-to-Point to Grasping Point

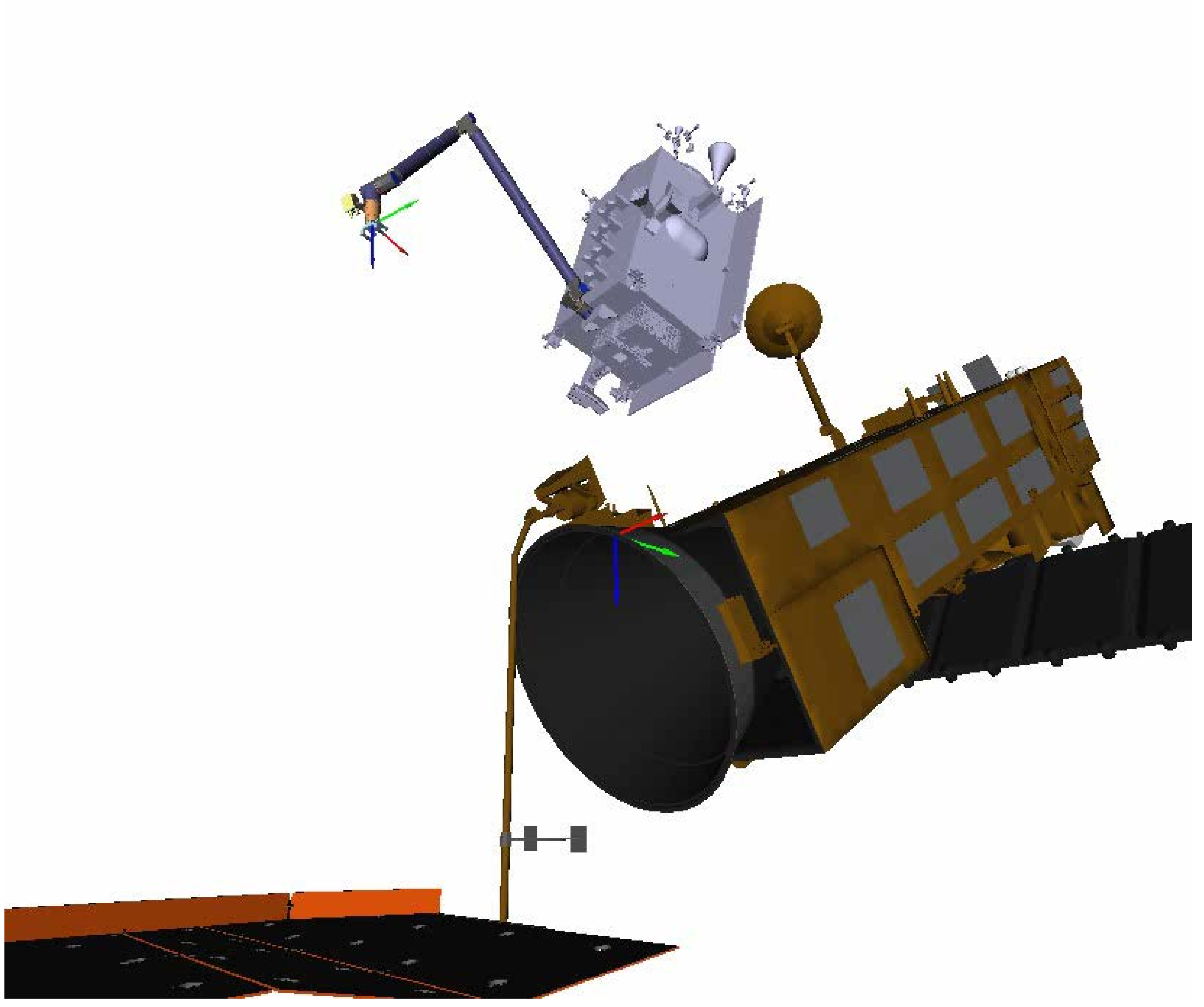
- Accounted for motion constraints:
  - Camera field of view
  - Collision avoidance
  - Robot velocity

Point-to-Point to vicinity of Fixation Point

- Accounted for motion constraints:
  - LIDAR field of view
  - Collision avoidance

Generally

- demonstrates feasibility of manoeuver
- provides a reference trajectory for visual servo or monitoring through telemetry data



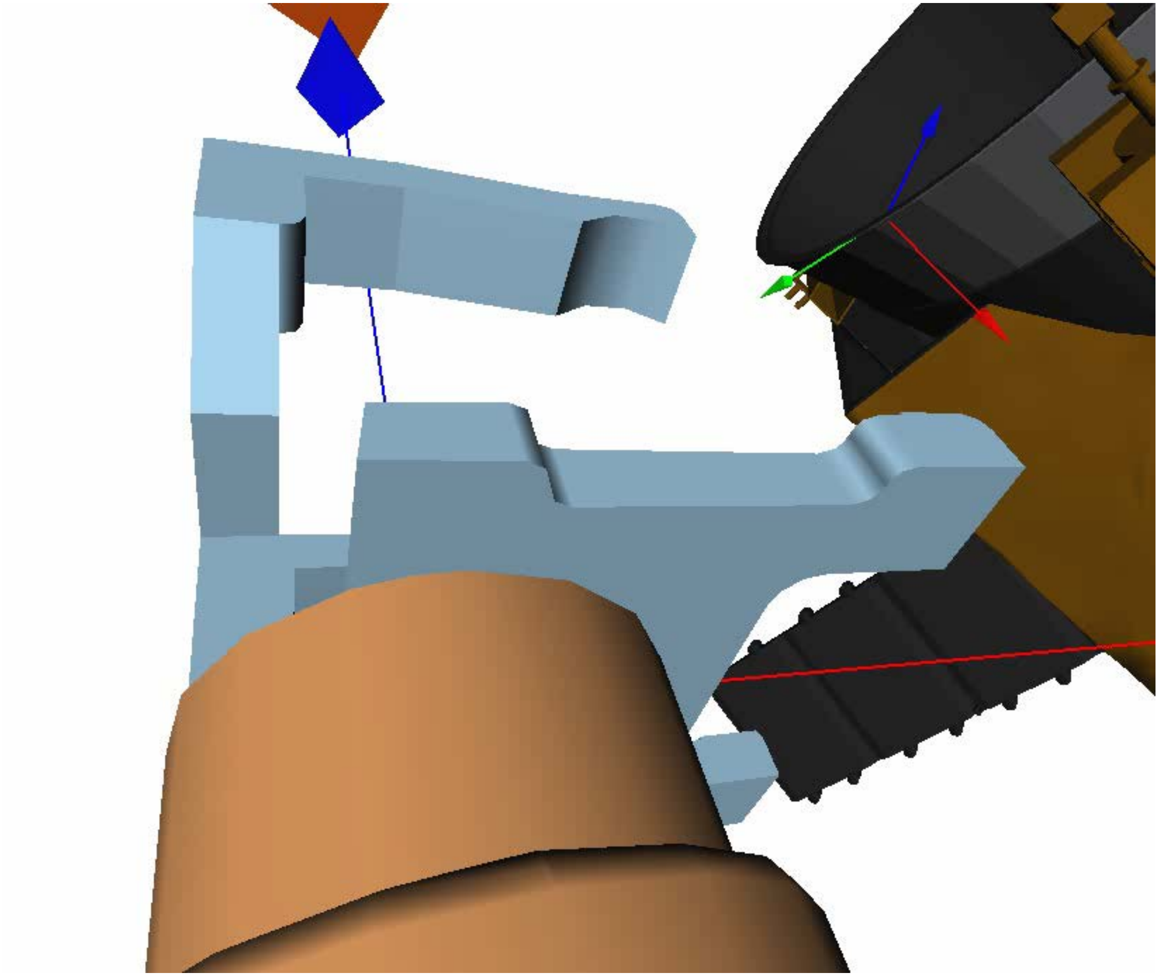
Robotics – motion planning

Point-to-Point to Grasping Point – end-effector camera view

- This trajectory is used to evaluate the computer vision algorithm with ASTOS

Point-to-Point to Fixation Point

- Trivial straight line motion onto the Adapter Ring



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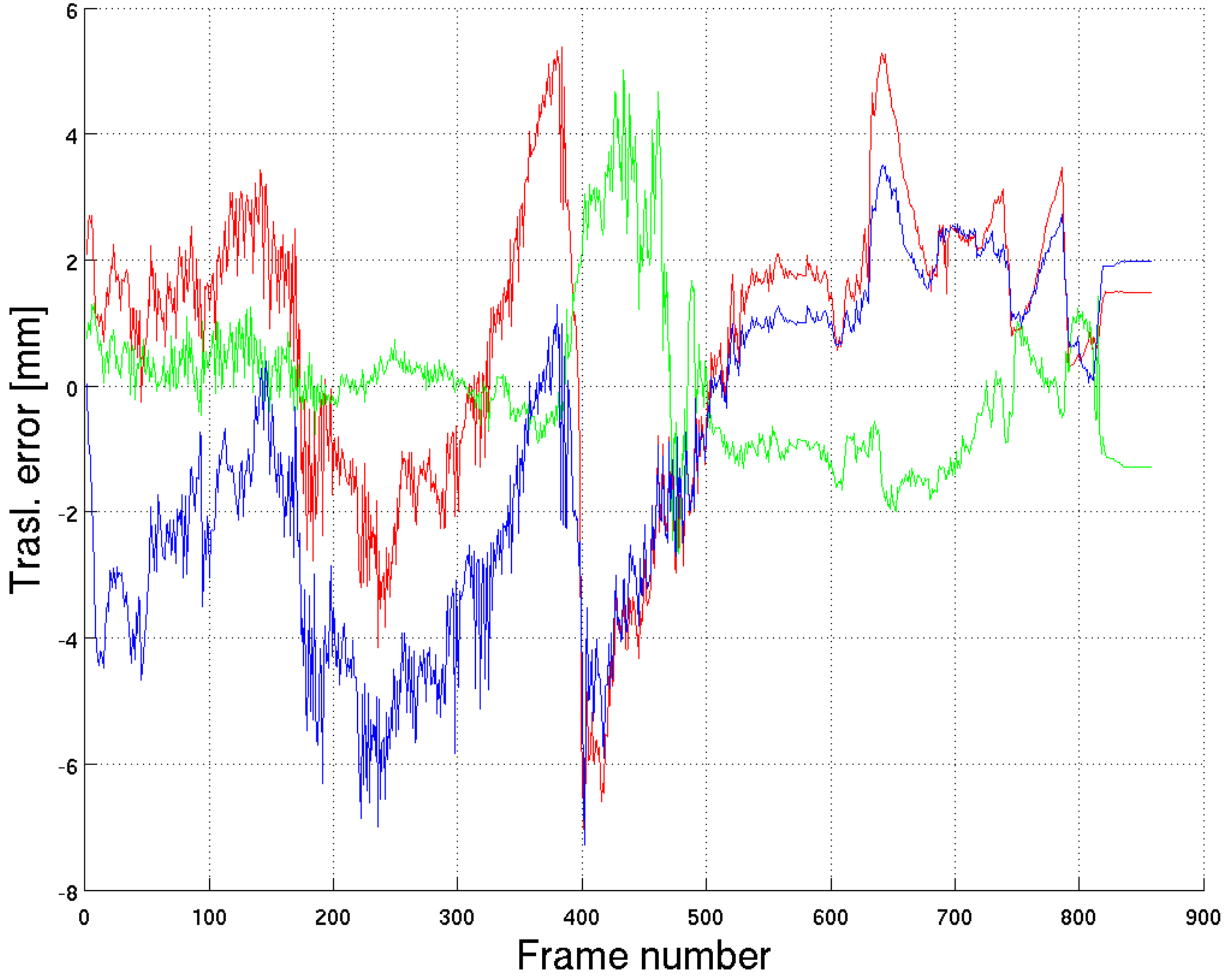
Robotics – Image Processing

Tracking Gripper Camera



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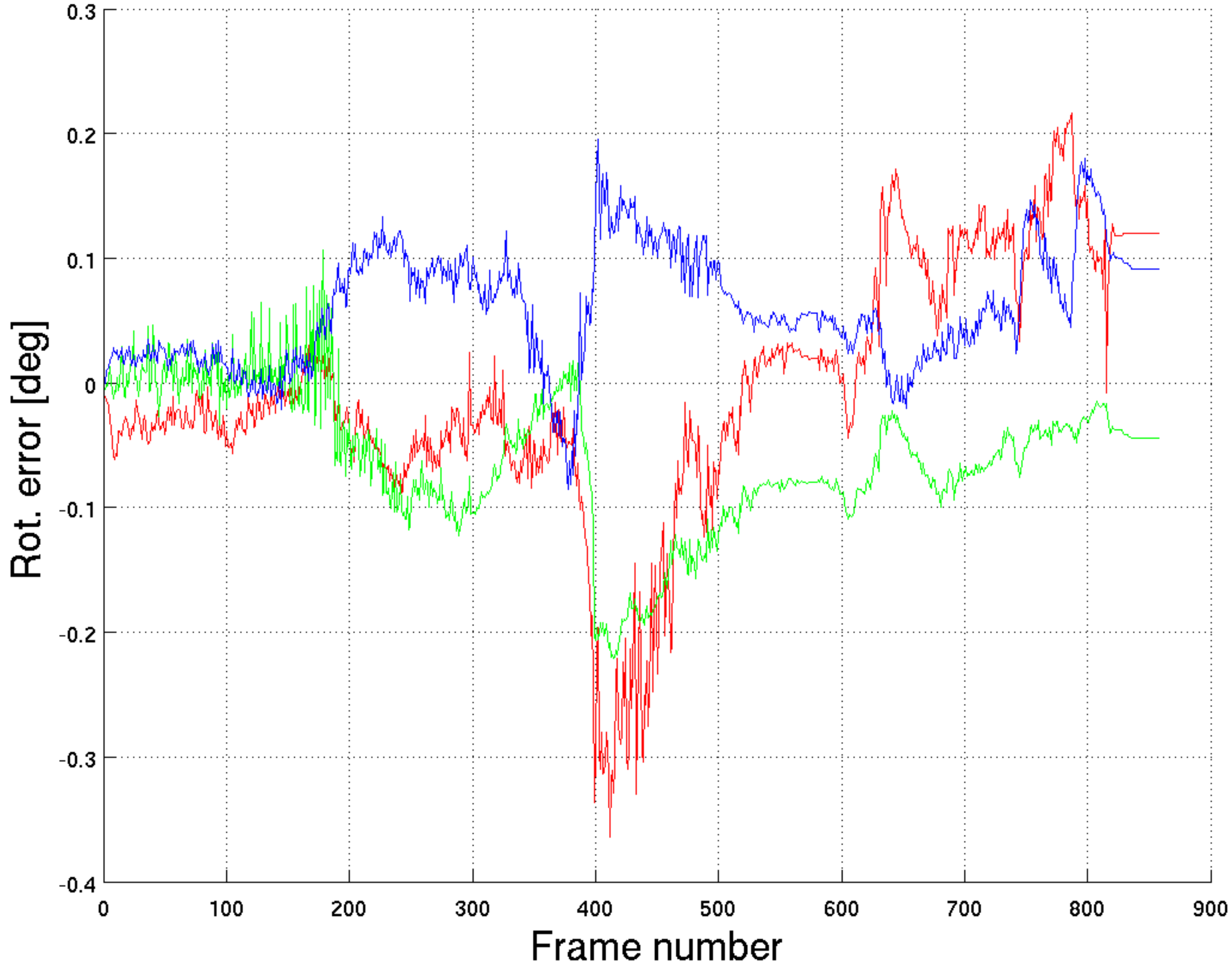
Robotics – Image Processing

Tracking Gripper Camera



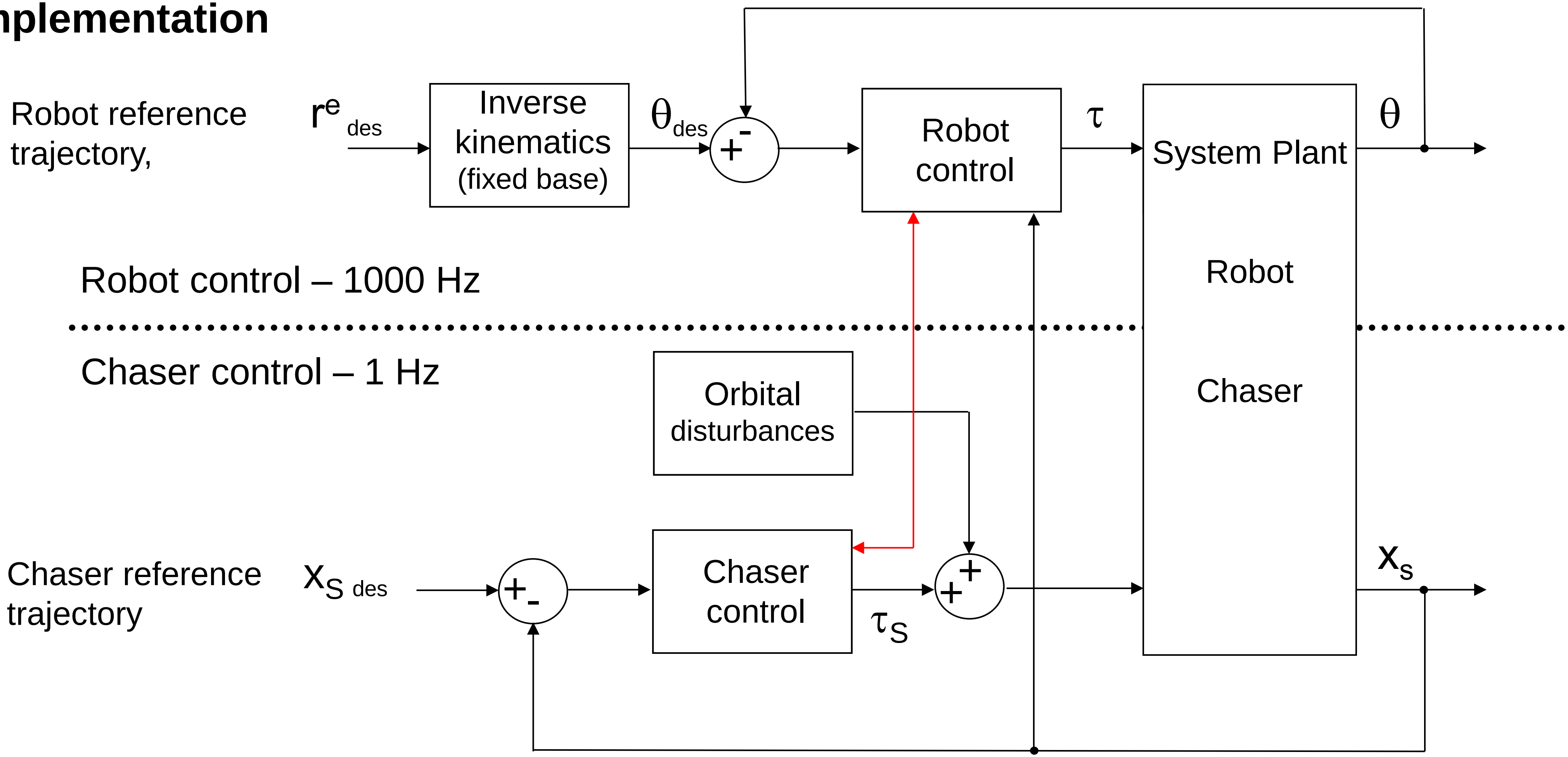
Robotics – Image Processing

General remarks

- With a sampling time of 10 Hz the approach to the Grasping Point must last approx. 60 seconds in order to guarantee tracking stability of pose estimation
- The illumination unit on the gripper was implemented with a range of 6 m
- A Monte-Carlo analysis reveals that errors of up to 2.5 cm in translation can occur at any time. There is no apparent correlation with the Sun direction.
- This calls for one or more of the following:
  - Further improvements of the image processing method
  - Inclusion of a third camera, e.g. on the Chaser
  - A larger gripper

Robotics – Coupled Control

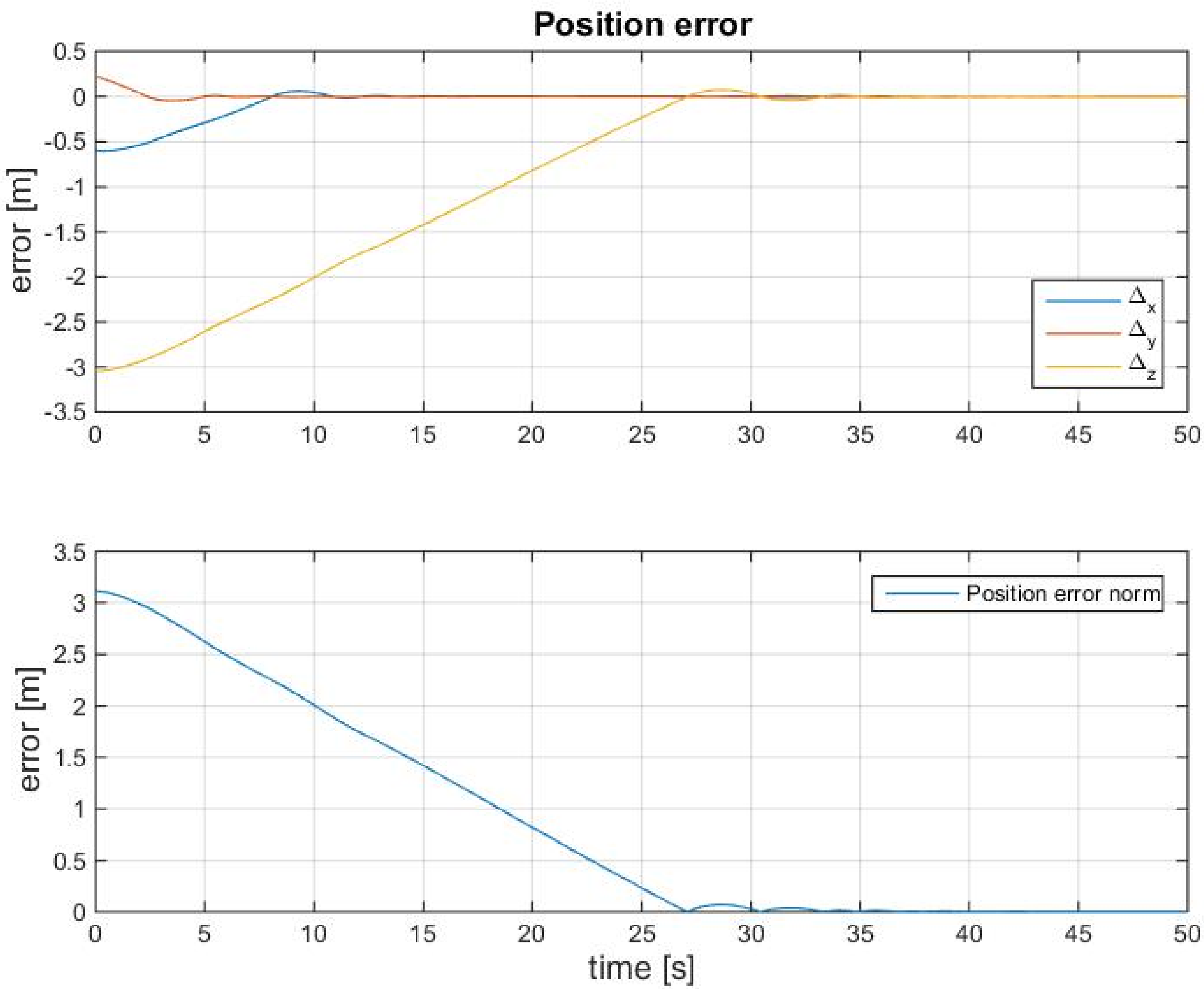
Implementation



Controllers interface consists of robot base internal forces to GNC

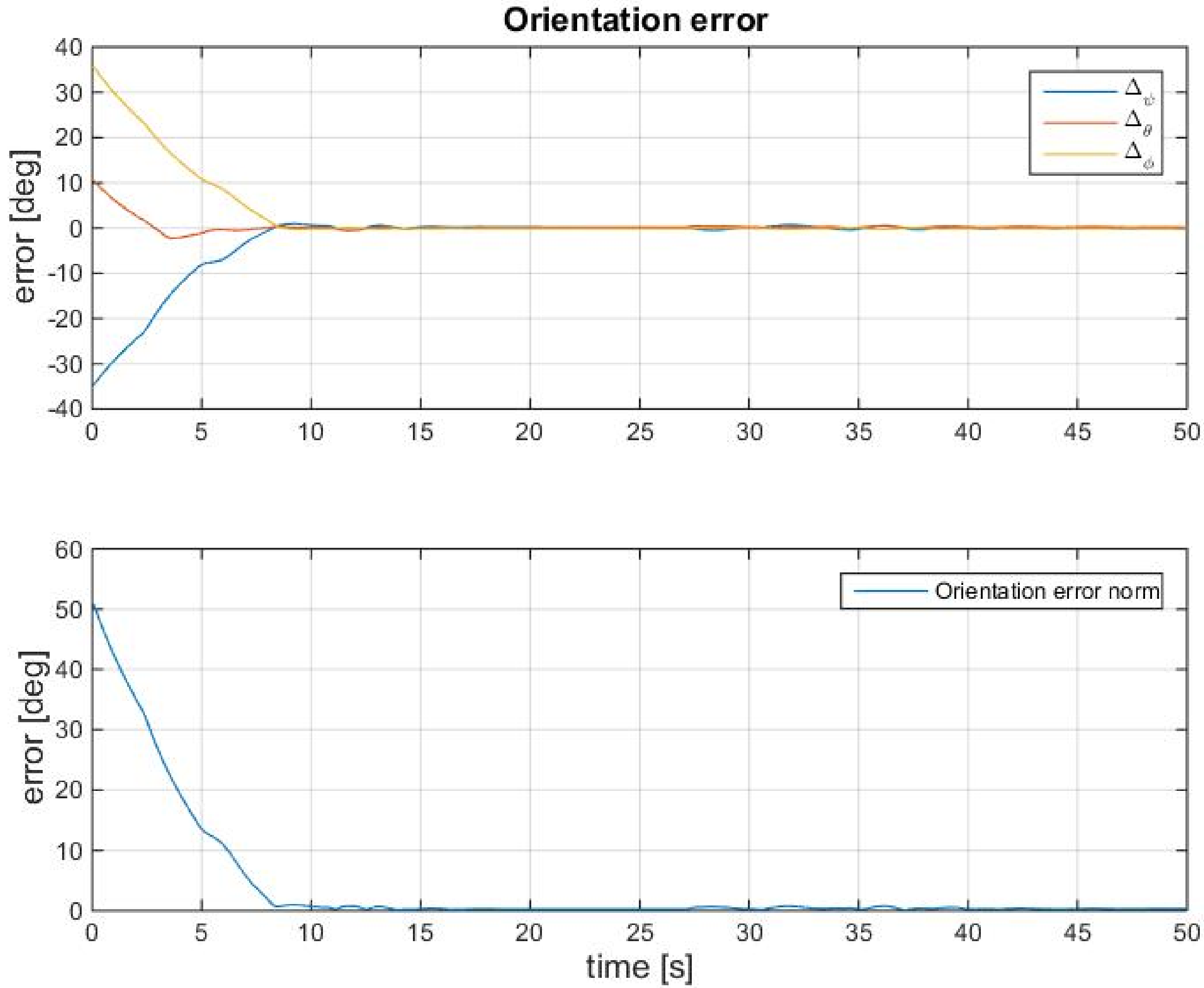
Robotics – Coupled Control

Results: ω_ENV = [0 0 5] deg/sec



Robotics – Coupled Control

Results: ω_ENV = [0 0 5] deg/sec



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Robotics – Coupled Control

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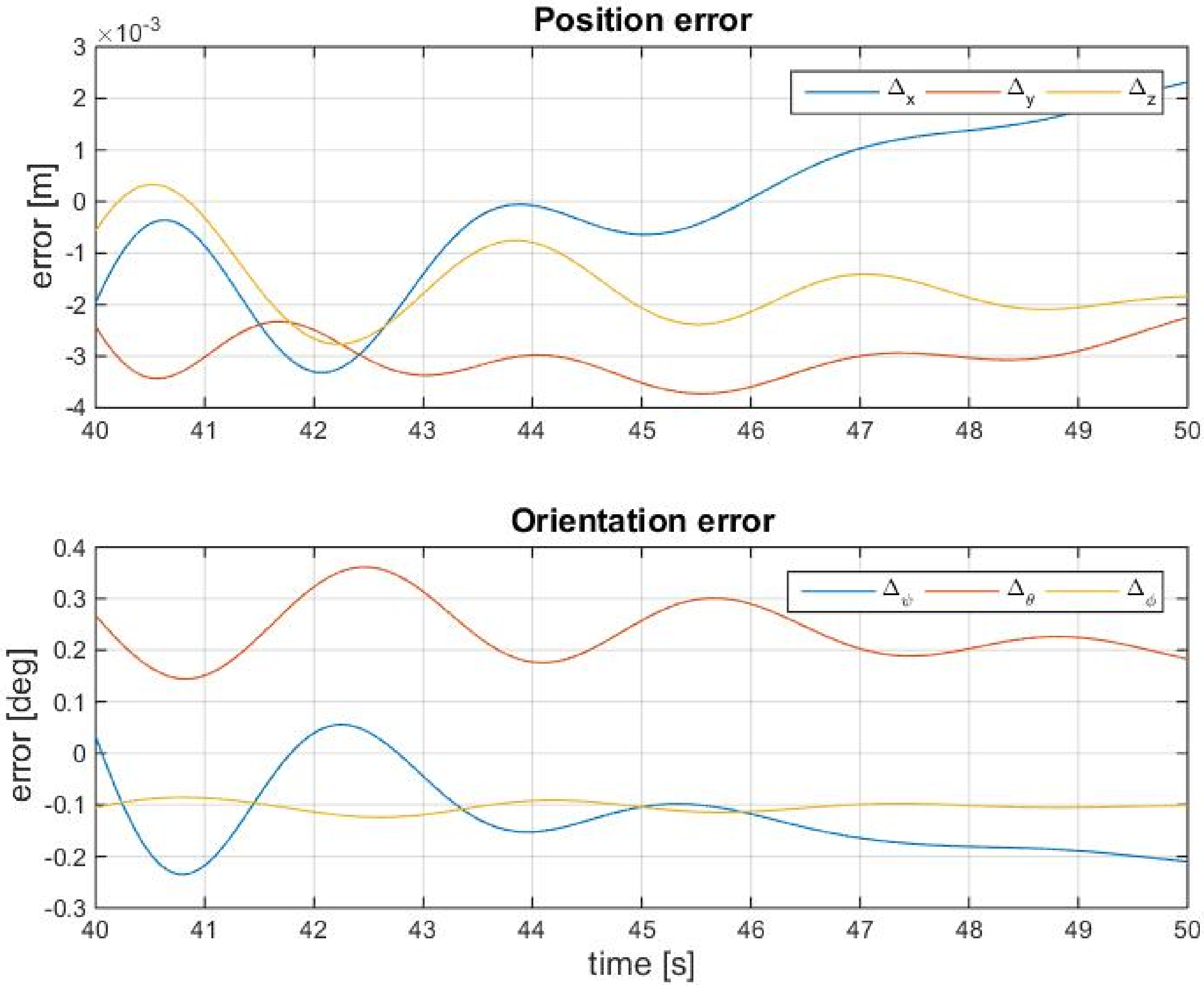

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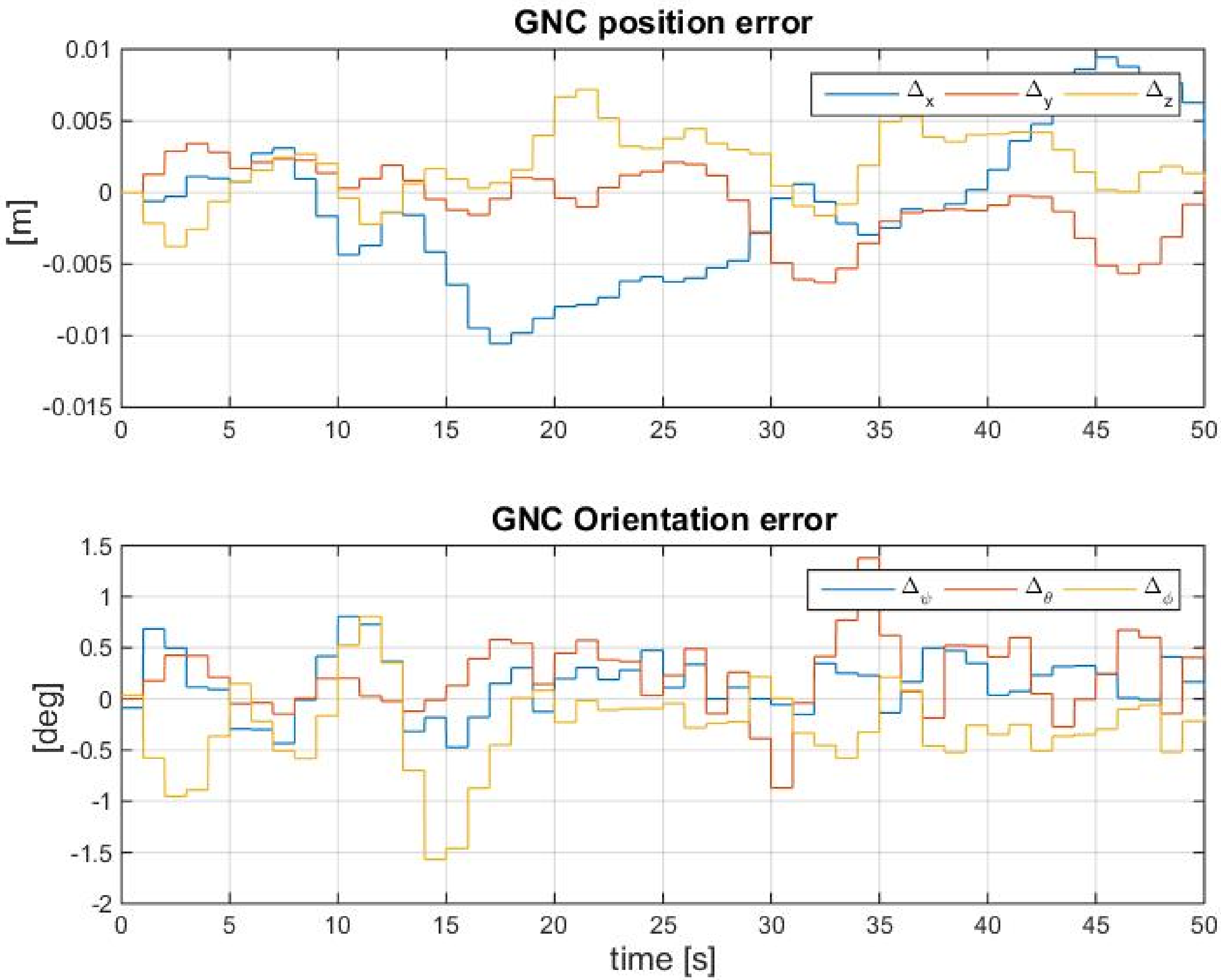
Robotics – Coupled Control

Results: ω_ENV = [0 0 5] deg/sec



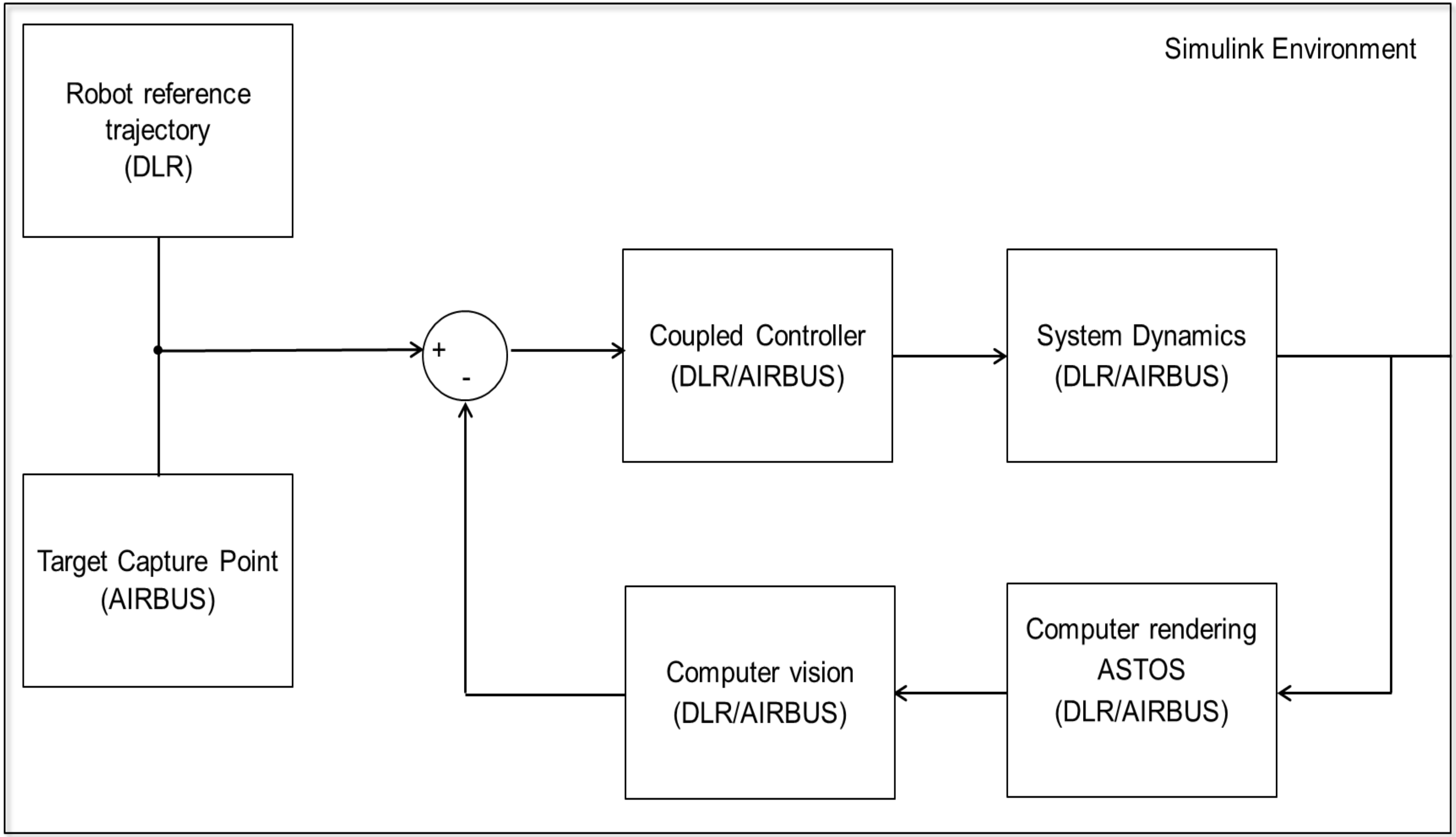
Robotics – Coupled Control

General remarks

- The two controllers converge and are stable for the cases analyzed
- The final positioning accuracy is < +/- 5 mm
- The control method can be extended to include the reference trajectory from the motion planner, for improved performance and guarantee of collision free motions
- Next steps will also include modelling of the robot visual servo and the Chaser navigation

Robotics – Visual Servo

Implementation



Robotics – Visual Servo

Implementation first steps

- computer vision sampling time and the time delays deriving from the ASTOS rendering process and from the computer vision, play a decisive role in the performance of the system.
- the controller gains are therefore limited - the settling time of the controller needs to remain large, in order that the controller does not go unstable. A large steady-state error results.
- The time delay in the simulated control system was compared with respect to the intrinsic time delay, to that implemented on the OOS-SIM facility of the RM-DLR: the simulation environment is 2x slower.
- Next steps will involve implementation of a Kalman filter and of a reference trajectory, for expected improved performance.

Robotics – Conclusion

- The robotic system for a eDeorbit mission was presented
- The considered operational conditions of ENVISAT included extreme tumbling states. The resulting robot dynamics might require a new joint design to allow for a sufficient safety factor to account for operational contingencies
- First steps in the design of a coupled controller were very promising
- The Monte-Carlo analysis of the image processing with the use of the advanced rendering ASTOS tool show the necessity to improve the system on software and/or hardware level
- First steps in the design of a robot visual servo and its performance evaluation in a simulation environment show the necessity for higher methodological complexity, to account for intrinsic time delays and sampling times.

Thank you for your attention!

roberto.lampariello@dlr.de
www.robotic.dlr.de/Roberto.Lampariello