On Validation Tools for Orbital Robotics

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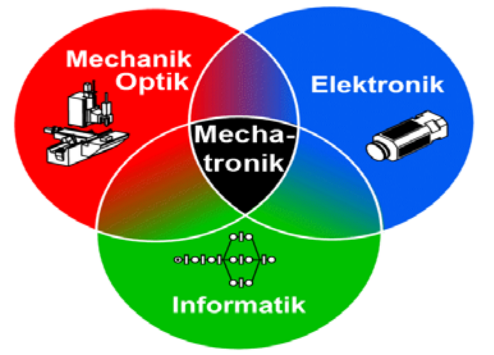
Clean Space Industrial Days

ESTEC, May 2016



Contents

- Orbital Robotic System Verification & Validation on Ground
- Two Related Mission Studies: DEOS and eDeorbit
- Verification Tools at the RM-DLR
- On-going testing of Robot Control Methods

Verification and Validation Challenges

Typical mission-related robot **system requirements**:

- End-effector positioning accuracy in open-loop
- End-effector positioning accuracy in closed-loop, i.e. visual servo accuracy
- Link flexibility – effect on controlled system performance
- Impedance matching – effect on impact dynamics
- Parameter identification (inertial parameters, flexible mode parameters)

Verification and Validation Challenges

Possible approaches for on-ground testing and validation:

- Hardware facility: scaled robot simulator, flat floor, cable-suspended robot simulator, …
- Software/Simulation: multibody dynamics, structural dynamics, computer rendering, …
- Preferably, a combination of both

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We believe that simulation alone is not enough. An Engineering Model is necessary for:

- Tuning of the robot controller, which is problematic and only possible on the hardware
- Analysis of effects such as stiction, cable harness, structural vibrations, etcetera

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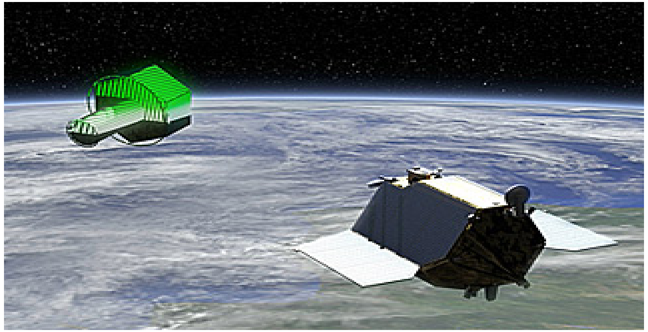
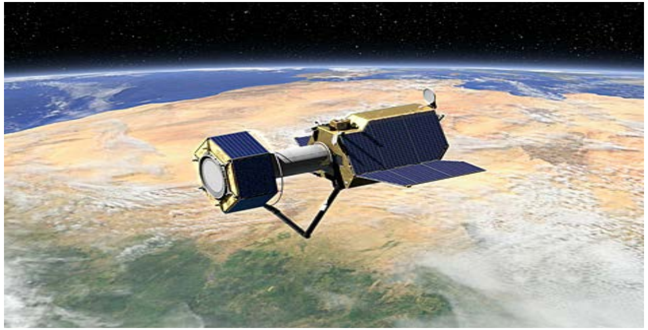
Also need more missions → support IODISPLay initiative and a DEOS follow-on!

Related Missions – DEOS


Approaching

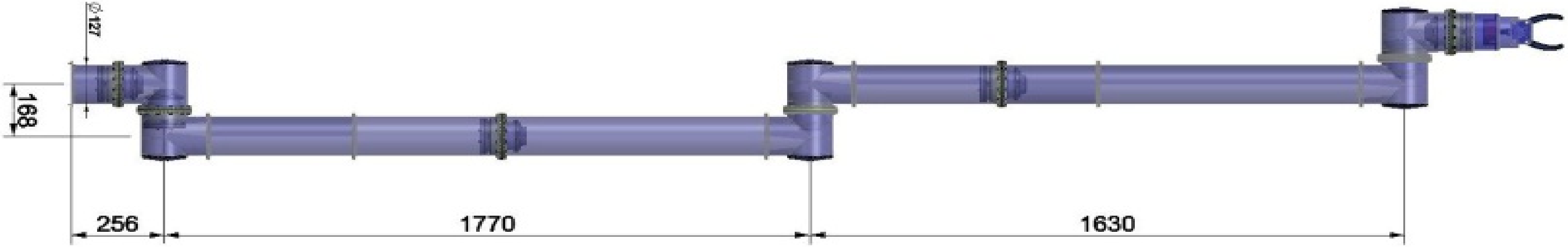

Docking & Repair


Grasping

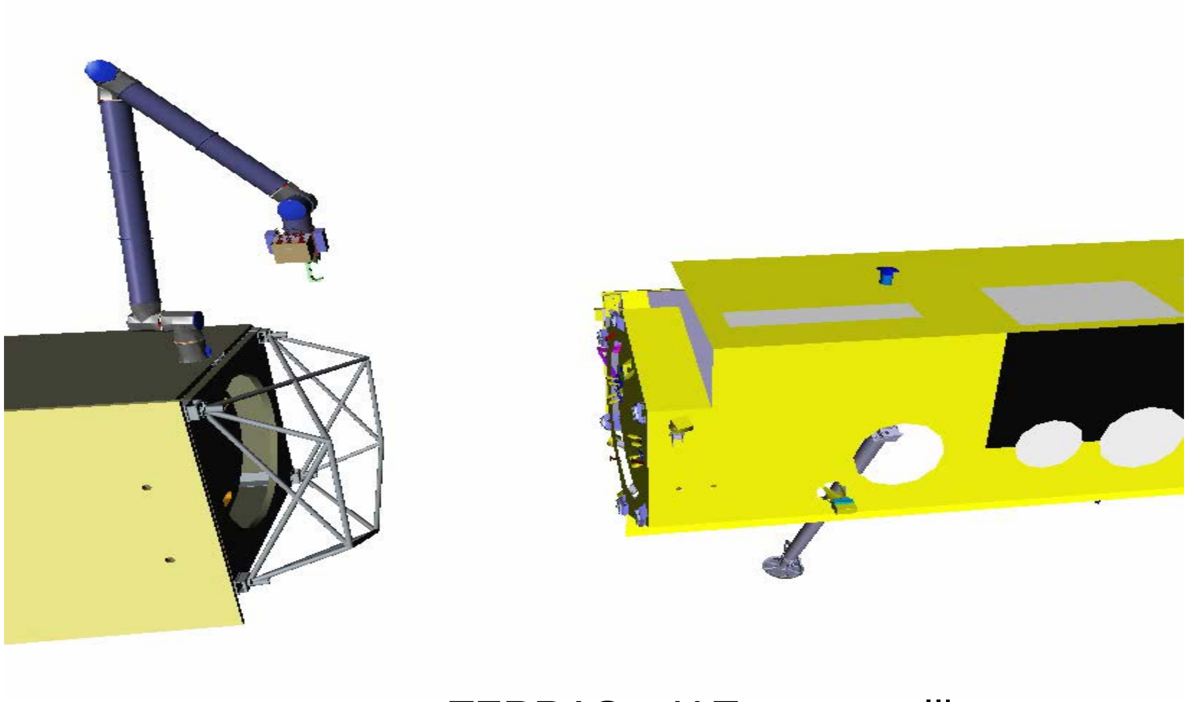

Deorbiting

DEOS Follow-on Activities

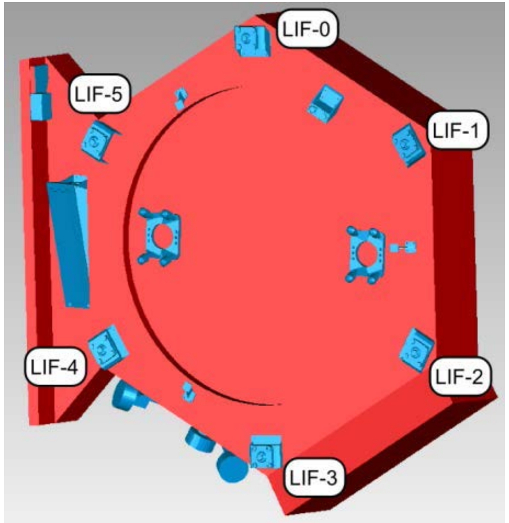
- Build a DEOS-like “space arm” to reach TRL 6
- Validate the arm on the ISS – DLR Agency call in discussion



Related Missions – DEOS Phase B2 D2C



TERRASar-X Target satellite



TERRASar-X interfacing surface

Related Missions – DEOS Phase B2 D2C

TCP Precision

joint precision

- ***Image Resolution***
- ***Frame rate***

Motion Planner

Motion Controller (impedance/ position)

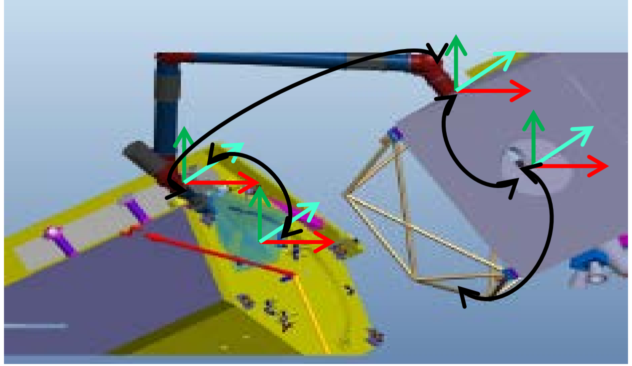
DEOS Arm

Camera

Camera Pose Estimation

Pose Estimation Precision

Kinematic Chain



Validation Tools – Computer Vision Mockup for DEOS Phase B2 D2C

Real scale satellite mockup

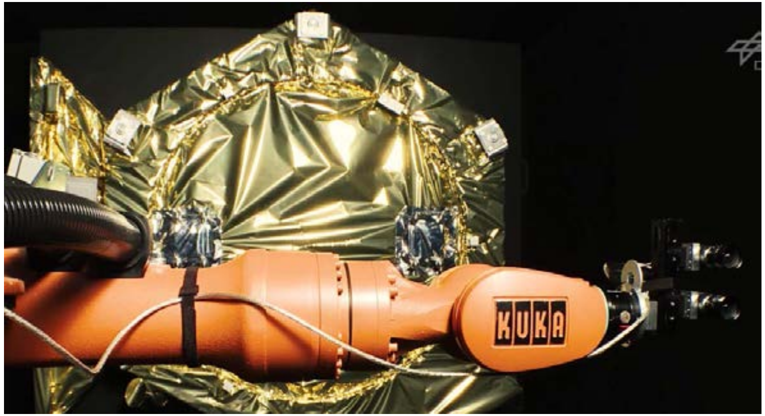
- Approx. 1.8m diameter
- 6 LIFs (Launcher Interface)
- All Attachments & MLI wrapping

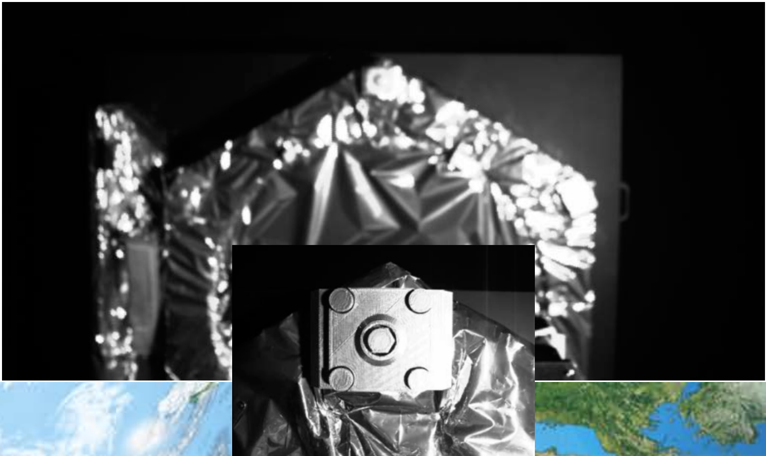
Stereo cameras

- Each 780 x 582 px
- Focus 20cm □sharp at target •FOV ≈ 56° x 44° (6mm focal length)
- 600mm base line

Industrial robot KUKA KR16-2

- 2.5mm worst case positioning error
- 220 to 20cm distance to target





Validation Tools – Computer Vision Mockup

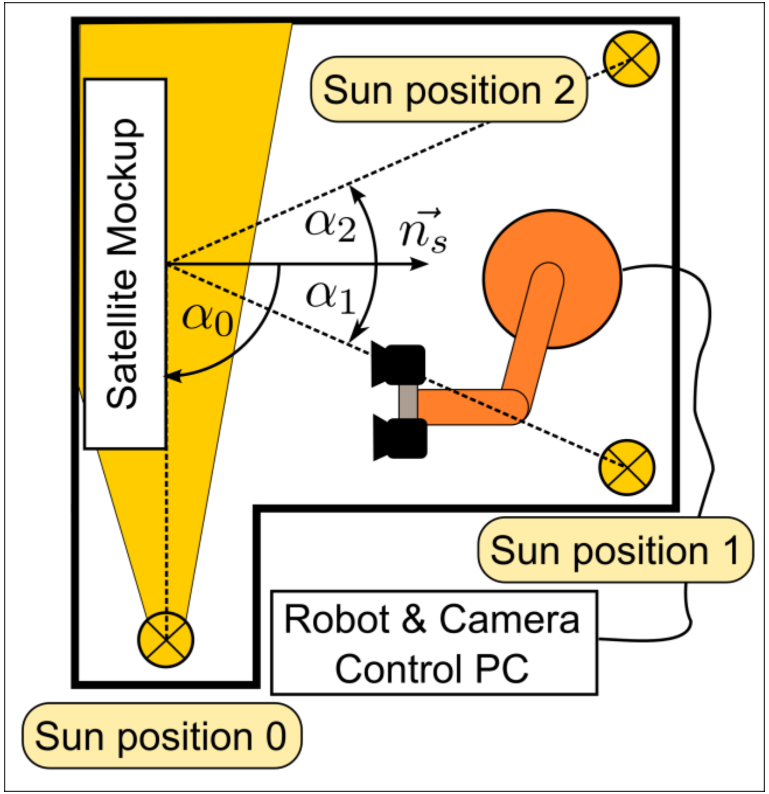
- 3 sun incidence angles wrt. front face normal:

  Sun 0: 90°, Sun 1: 31°, Sun 2: -31°
- Generated publically available data base with

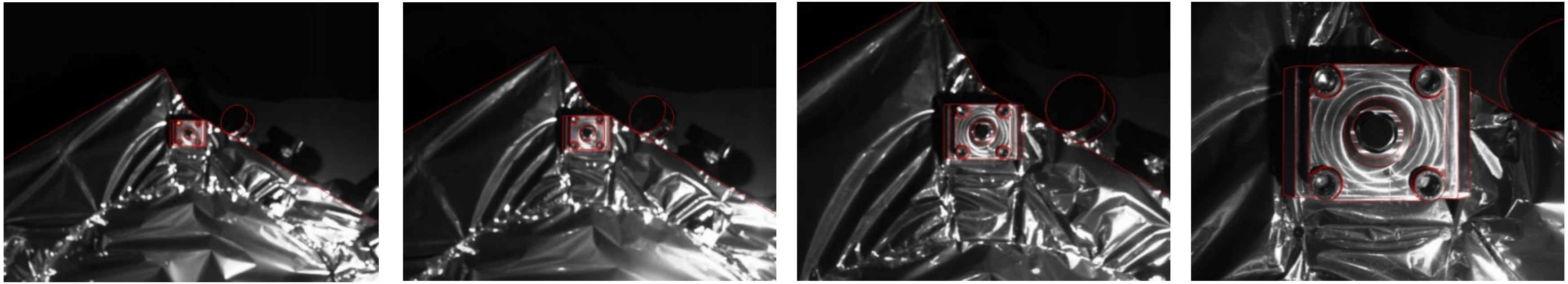
  > 800 Test trajectories, see:

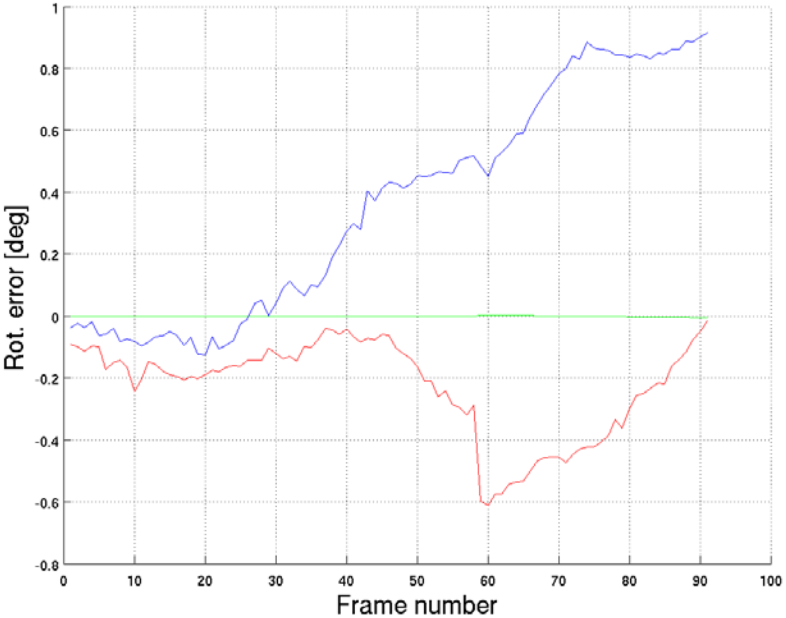
  Lingenauber, *et al*, ASTRA 2015
- Required mission end-effector positioning

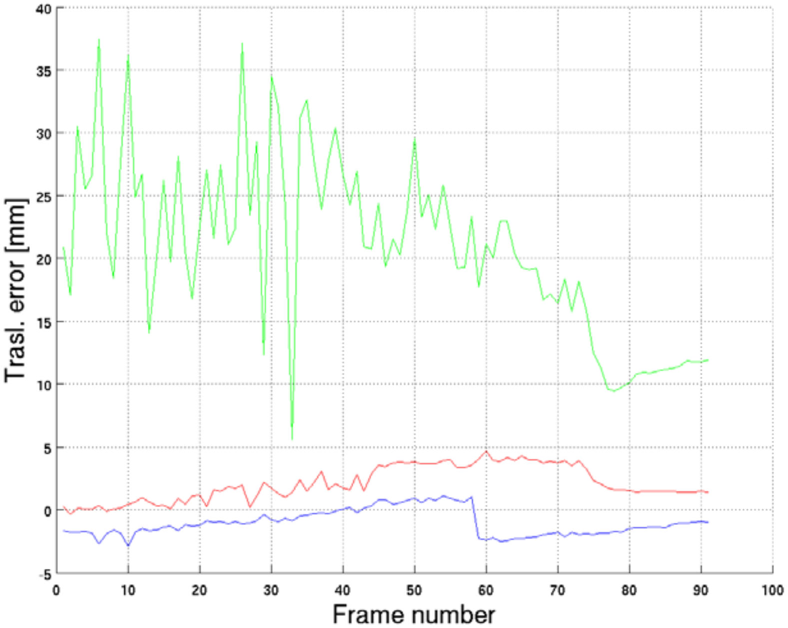
  precision of +/- 1 cm (partly) proven



Computer Vision Mockup - Visual Tracking Experiment



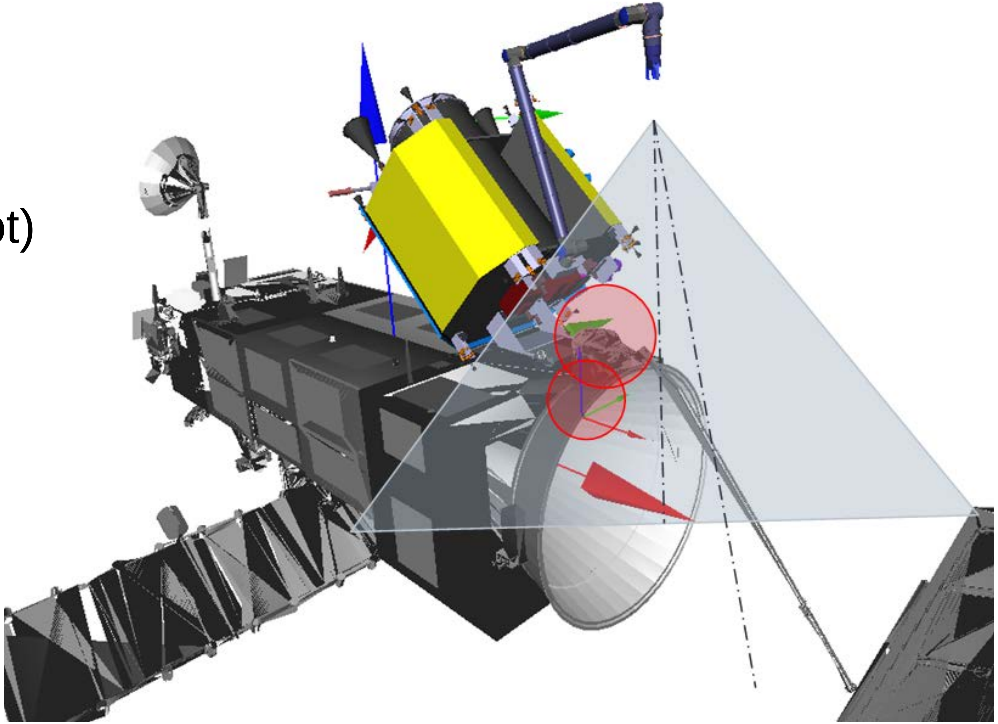




Related Missions – eDeorbit Phase A/B1

New challenges w.r.t. DEOS:

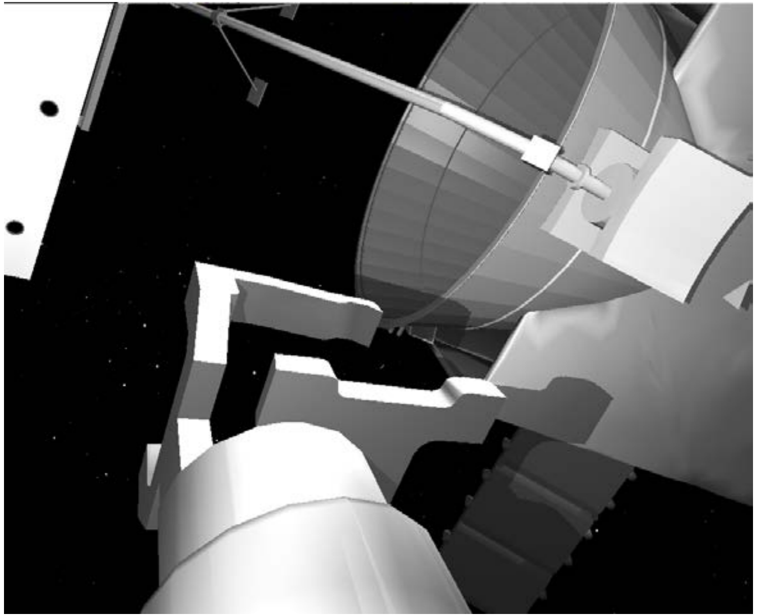
- Synchronized flight
- Coupled control (GCN/Robot) and consequent positioning precision
- Robot internal forces



Related Missions – eDeorbit Phase A/B1

Results from image processing:

- Pose estimation accuracy +/- 2,5 cm (worst case)
- Target with very little features
- More realistic orbital illumination conditions

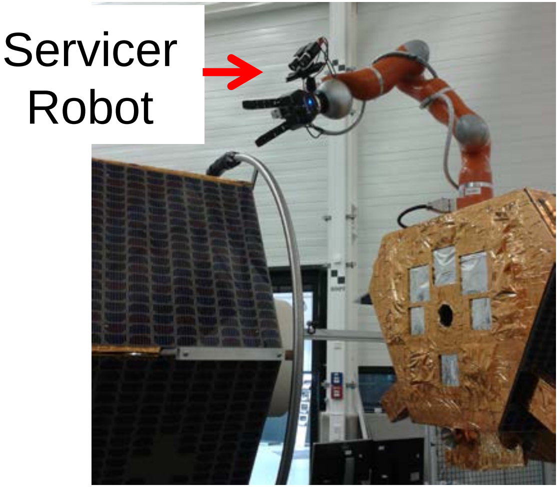


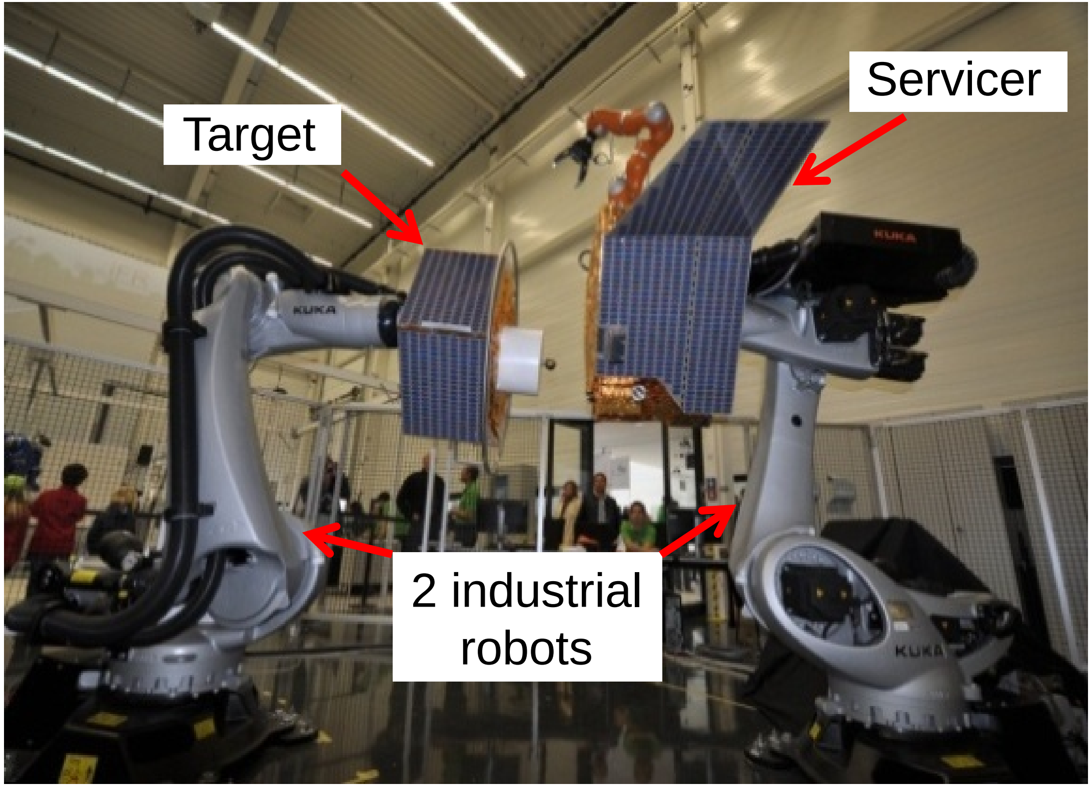
ENVISAT scenario
End-effector camera view

Validation Tools – OOS-facility

Scope of facility:

- Emulate orbital robot & free-body dynamics
- Validate robot control methods





Validation Tools – OOS-facility

General goals:

- Guarantee **stability** of facility controller in view of intrinsic time delay
  - Use of time-domain passivity

  De Stefano, *et al*, **Passivity of Virtual Free-Floating Dynamics Rendered on Robotic Facilities**, ICRA 2015

  De Stefano, M., Artigas,. J. and Secchi, C., **An optimized passivity based method for simulating satellite dynamics on a position controlled robot in presence of latencies,** *submitted* to IROS16

- Analyze **simulation truthfulness** of facility w.r.t.
  - Intrinsic time delay
  - Effect of sensor noise
  - Closed-loop behavior
  - Validation with ESTEC’s flat floor ORBIT

Flexible-link testbed

- Sensors:
  - 5 sets of strain gauges for bending reconstruction
  - High speed camera for tip deflection
  - Motor encoder

- DLR flexible joint technology

- Objectives:

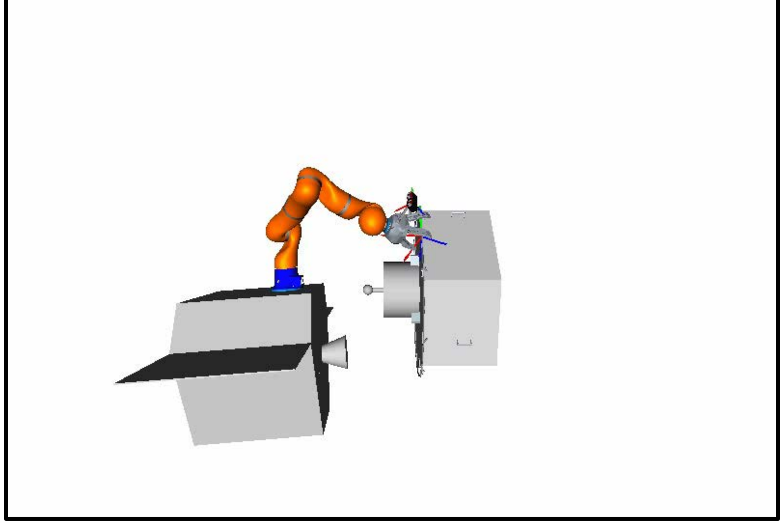
  - Study the optimal sensors set for flexible state reconstruction in the frequency range of typical space scenarios
  - Validate flexible-links control algorithms with DLR joint technology
  - Identify critical parameters for multi-link design

Validation of control methods – Semi-autonomy

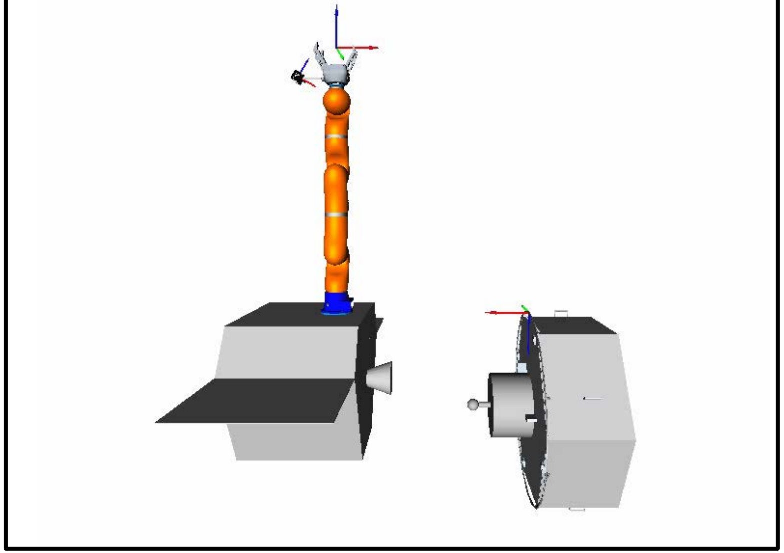
Development and Validation Steps :

- Motion planning – see Lampariello, Hirzinger, IROS 2013
- Validate Visual Servo robot control on OOS-SIM

Without reference trajectory



With reference trajectory



Validation of control methods - Telerobotics

DLR has currently two ongoing missions related to space telemanipulation:

KONTUR-2:

Goal: To develop new technologies for future space exploration missions.

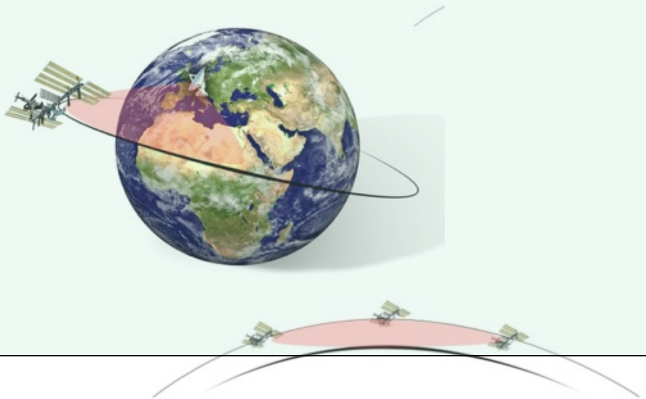
Setup: A cosmonaut located on the ISS controls a robot manipulator located at the DLR through a real-time space link.

ASTRA-Experiment

Goal: To develop and test a force-feedback teleoperation test facility for on-orbit servicing using a geostationary satellite link.

Setup: A free-floating robot manipulator (OOS-SIM facility) controlled with a haptic interface through the geostationary satellite ASTRA.

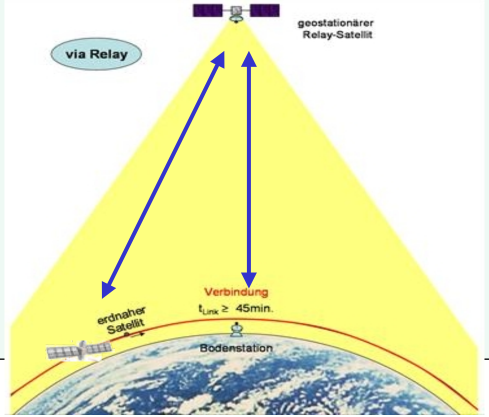
Overflight



- Point-to-point communication
- Low time delays (20ms to 100ms)
- Low package loss <0.01% - 0.5%
- Non-critical jitter
- But, short communication window 5-10min

Validation through KONTUR-2

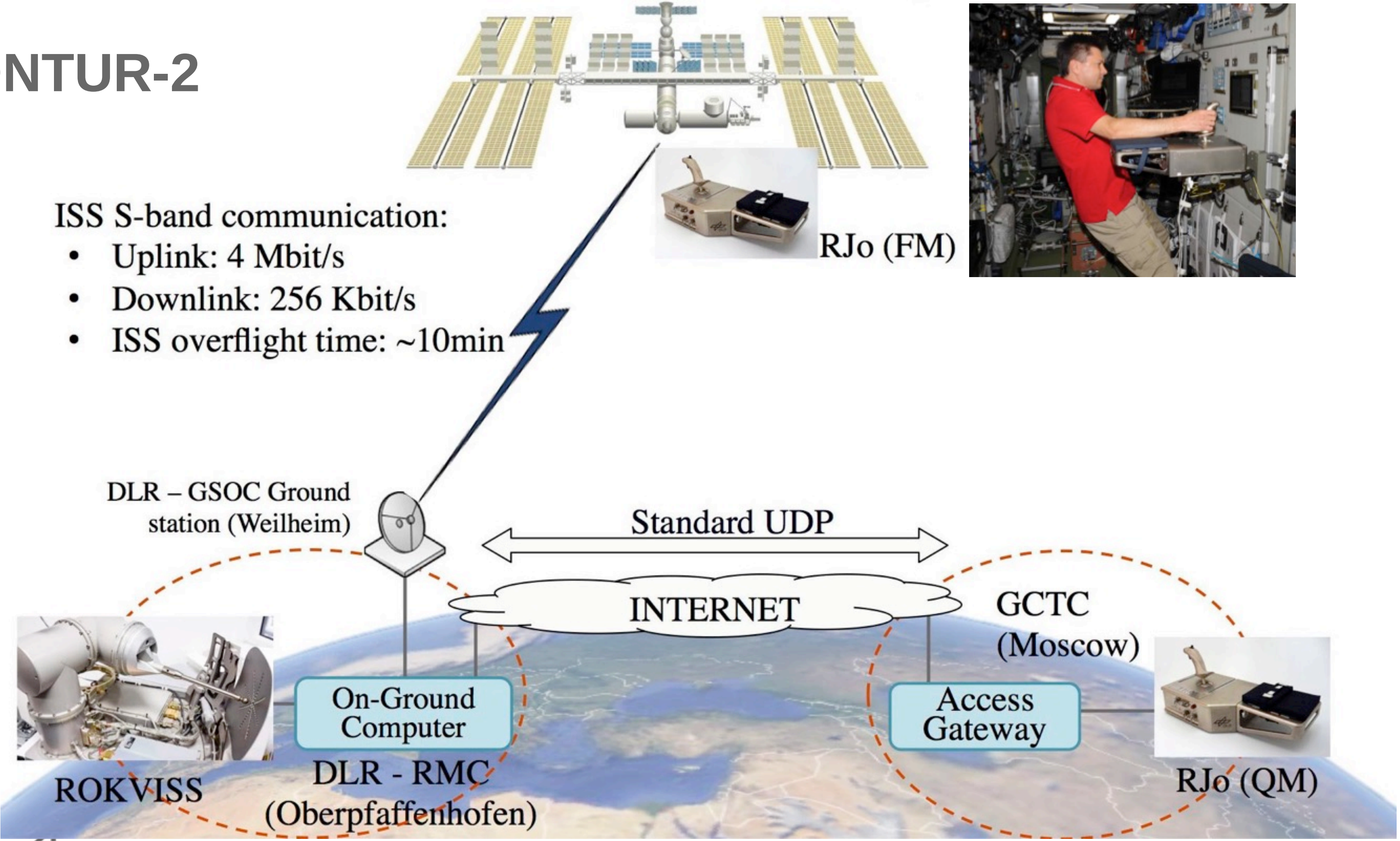
GEO Relay



- Use of a GEO satellite as a relay
- Large time delays (>500ms)
- Medium to high package loss > 1%
- Critical Jitter
- But, long communication window ≈ 1 hr

Validation through ASTRA-Experiment

KONTUR-2



ISS S-band communication:

- Uplink: 4 Mbit/s
- Downlink: 256 Kbit/s
- ISS overflight time: ~10min

RJo (FM)

DLR – GSOC Ground station (Weilheim)

Standard UDP

INTERNET

GCTC (Moscow)

On-Ground Computer

DLR - RMC (Oberpfaffenhofen)

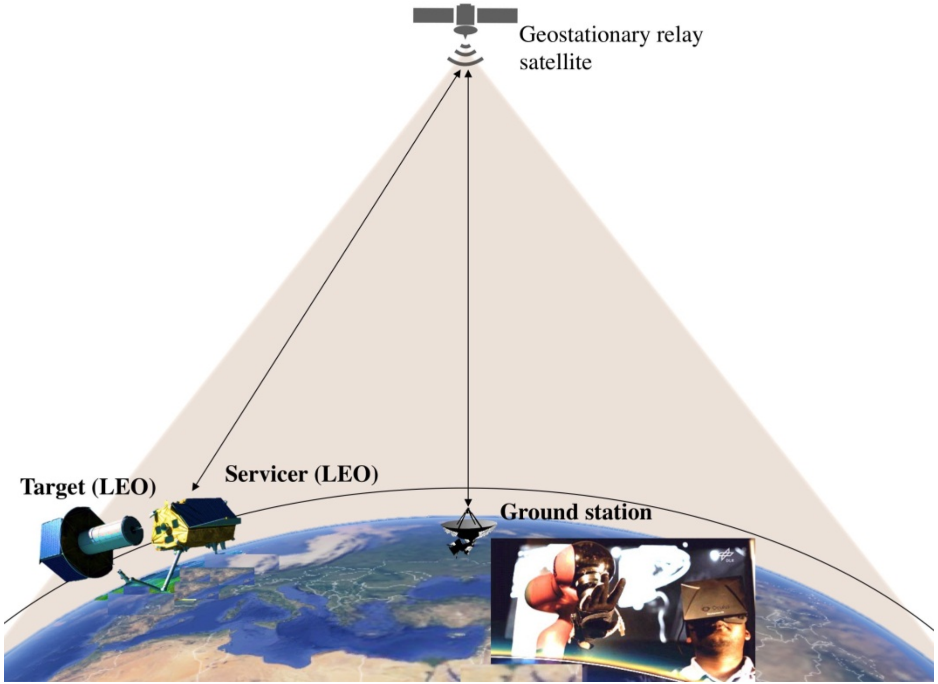
ROKVISS

Access Gateway

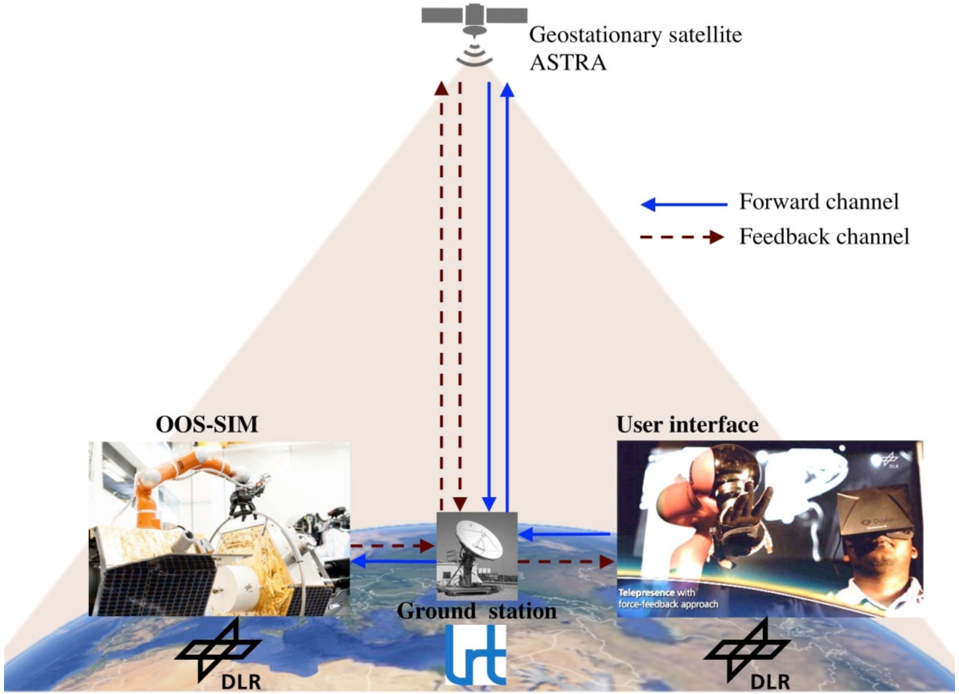
RJo (QM)

ASTRA-Experiment

To connect a master – slave system located on Earth through a real GEO relay infrastructure



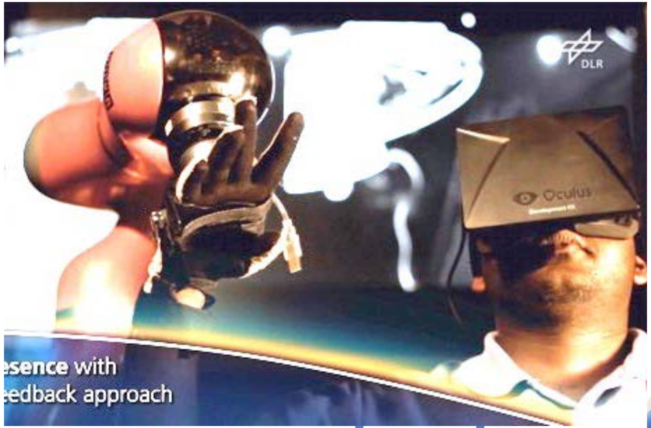
Targeted scenario

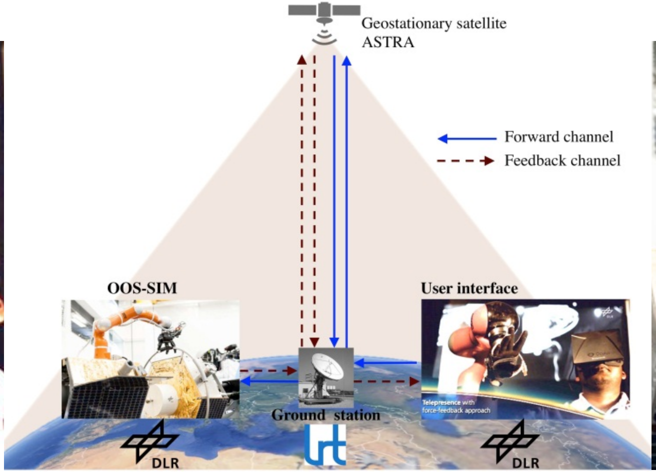


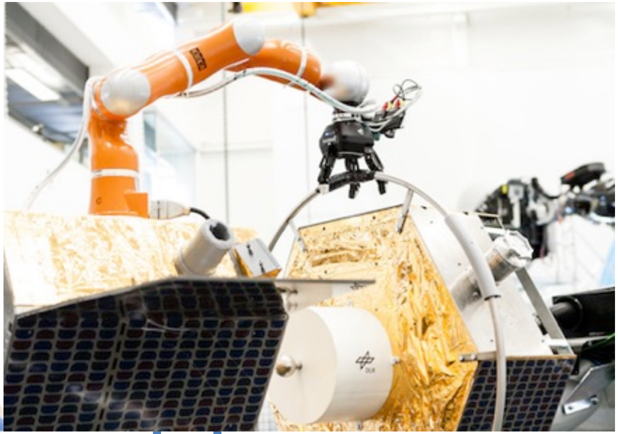
Experimental setup

ASTRA-Experiment

The goal is to prove the feasibility of grasping a non-cooperative tumbling target in telepresence through a real GEO-link.



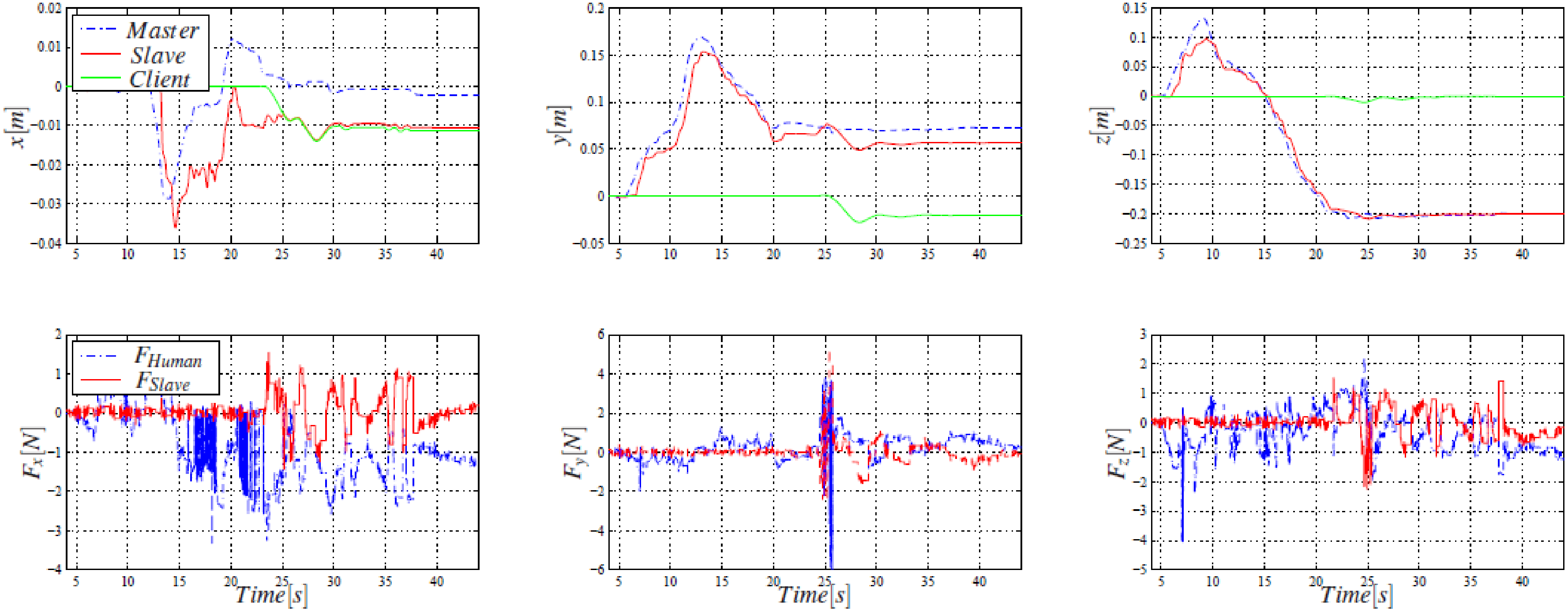




Communication length 120,000Km

Physical distance 10 m

ASTRA Experiments - Results



The user can grasp, stabilize residual momentum and even actively bring the satellite to some desired position. For details, see Artigas, *et al*, IEEE Aerospace Conference 2016

Conclusion

- In order to perform Verification & Validation of orbital robotic tasks on ground, the development of a combination of methods is being pursued. Typical system requirements are strongly task specific.
- Adequate on-ground methods can be finalized but need to be validated.
- These include experimental facilities, computer rendering and finally an Engineering Model.
- Development and validation activities in the controls domain on our experimental OOS-SIM facility already involve testing with hardware-in-the-loop, close to a ‘real world’ testing environment.

Thank you for your attention!

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See also **IEEE Aerospace Conference 2017**:

- Session on Orbital Robotics
- Panel on Robot-Astronaut Interaction