DEOS

Deutsche Orbitale Servicing Mission

The In-flight Technology Demonstration of Germany's Robotics Approach to Service Satellites

B. Sommer, K. Landzettel, T. Wolf, D. Reintsema,
German Aerospace Center (DLR)

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B. Sommer

German Aerospace Center, DLR

Space Agency

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K. Landzettel

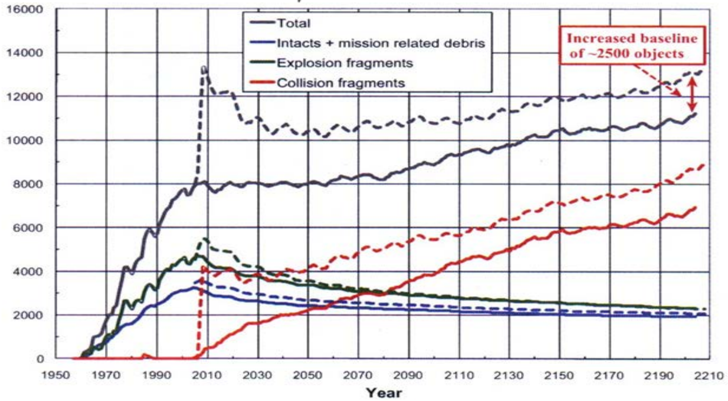
German Aerospace Center, DLR

Institut of Robotics and Mechatronics

Setting the scene - Motivation

- **Hundreds of satellites populate** the Earth **orbits from LEO to GEO** in order to respond to increasing needs of society for tele-communication and navigation, weather forecasts, transnational agriculture planning etc..
- Space flight follows **"throw away mentality" -** Existing satellites **are not prepared** for any intervention
- International agreements [IADC] call for **removal of satellites** from their orbits at EOL - **many don't**.
- **Cascading effect** increases space debris even w/o any launches – **prevention measures are not enough** maintain save access to space
- Mastering the **capabilities for OOS** are major **stepping stones** on the way to explore the Solar System.

Applications ↔ Needs



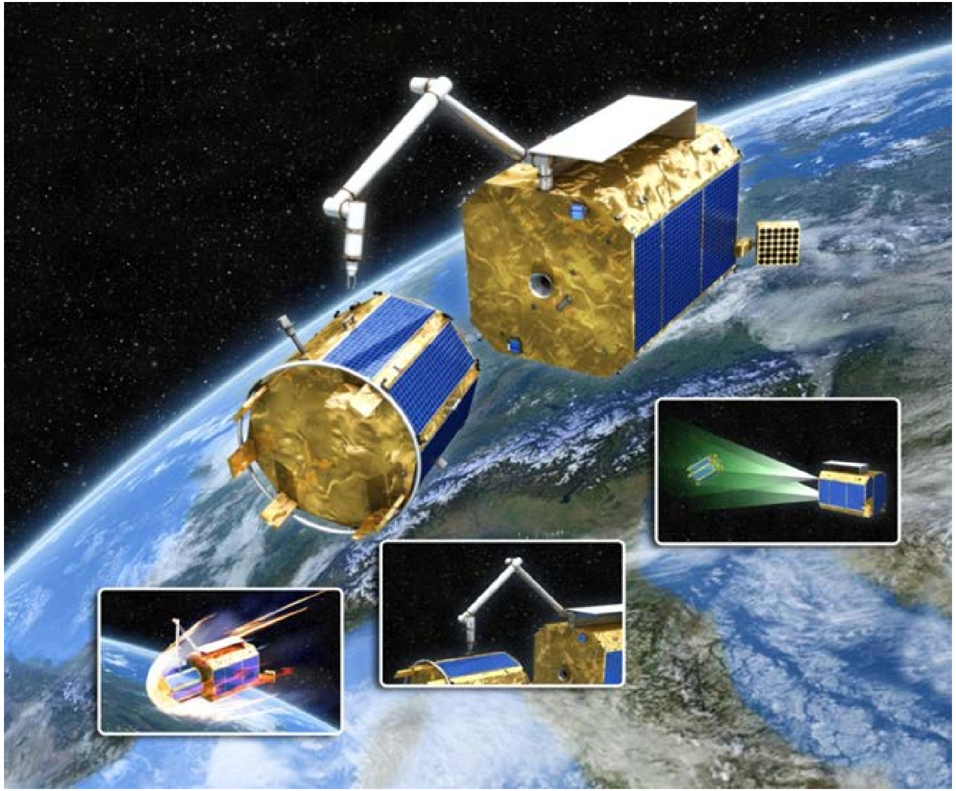
Germany's approach to OOS

- **Demonstrate the availability of technology** and verify procedures and techniques for rendezvous, capture, maintenance and removal of an uncontrollable satellite from its operational orbit through a demonstration mission -> **DEOS** (Deutsche Orbitale Servicing Mission)
- Translate the increasing needs of society and lessons learned from DEOS into **technical and technological requirements for** the extension and operation of **next generations orbital infrastructure**
- **Create serviceability/maintainability through "cooperative" satellite design**, standardization, modularity:
  - Handle lifetime of bus & P/L separately, platform lifetime much than P/L lifetime
  - Include comprehensive failure detection/diagnostics features, consider and evaluate failure propagation

The DEOS Mission

Mission statement

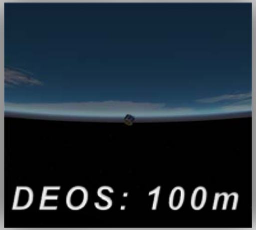
- **Locate and approach a client satellite**
- **Capture a tumbling, non-cooperative satellite using a manipulator mounted on a free flying service-satellite**
- **Demonstrate servicing tasks: refuel, module exchange etc.**
- **De-orbiting of the coupled satellites within a pre-defined re-entry corridor**

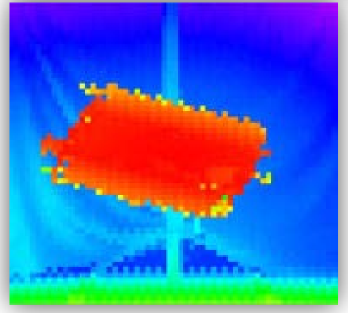


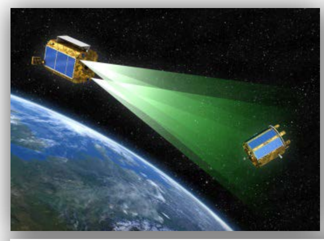
Technological Challenge

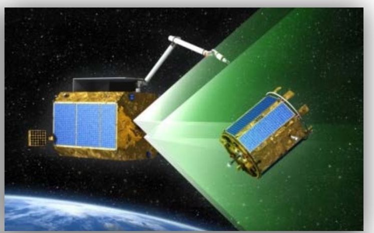
Localize, recognize and observe

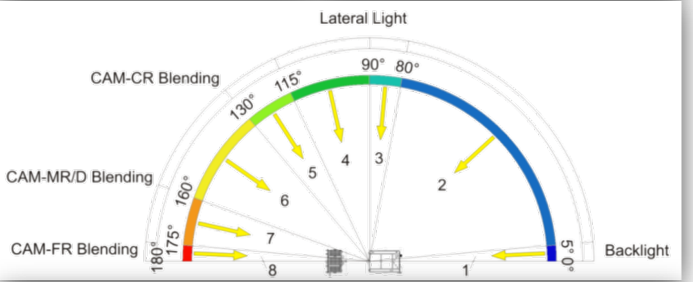
- Pivotal questions: Where is the client satellite? Is this the one we wanted to visit?
- <u>Localization</u>: Move from a coarsely know absolute position to an accurate relative distance to the client
- <u>Recognition</u>: Requires active and/or passive sensors (laser, radar, camera) depending on illumination conditions and the combination of sensor data
- <u>Challenges:</u>
  (1) Detect the satellites physical status, (damages, structure,…)
  (2) Determine relative position, orientation and motion

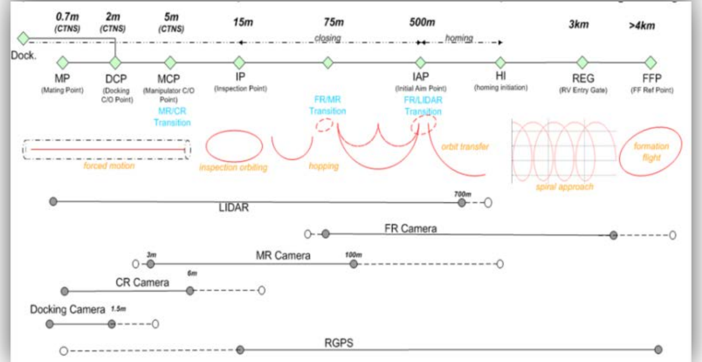












Technological Challenge

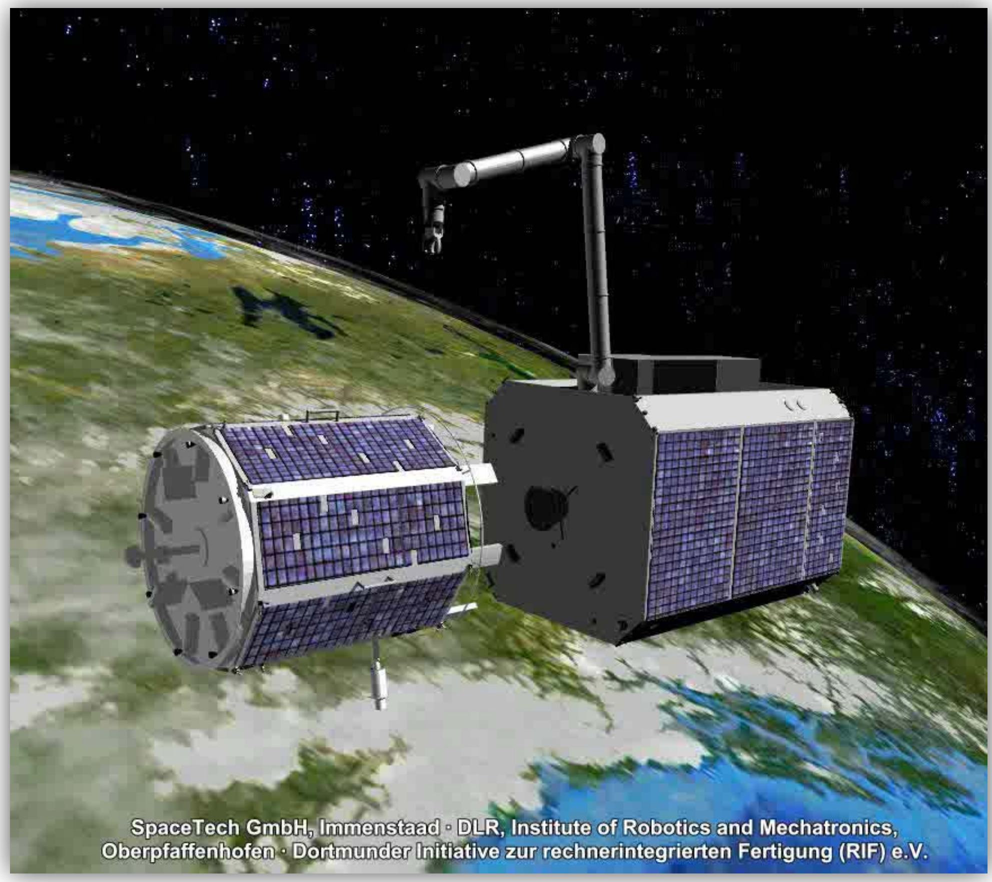
Navigation and close approach

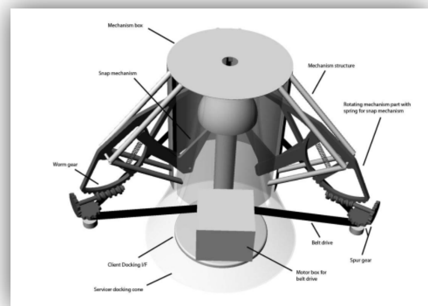
- Pivotal question: How do we safely navigate the servicer to a parking position close enough to reach the client with a manipulator?
- Challenges:
  - Determine widely autonomous absolute/ relative navigation technique for a safe approach
  - Develop autonomous collision avoidance methods
  - Select sensors and optimize sensor data fusion techniques for detection of relative position, attitude and motion estimation

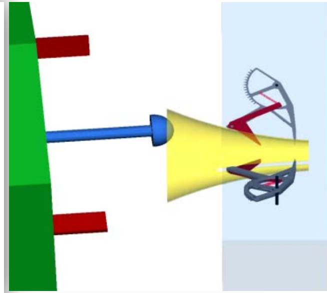
Technological Challenge

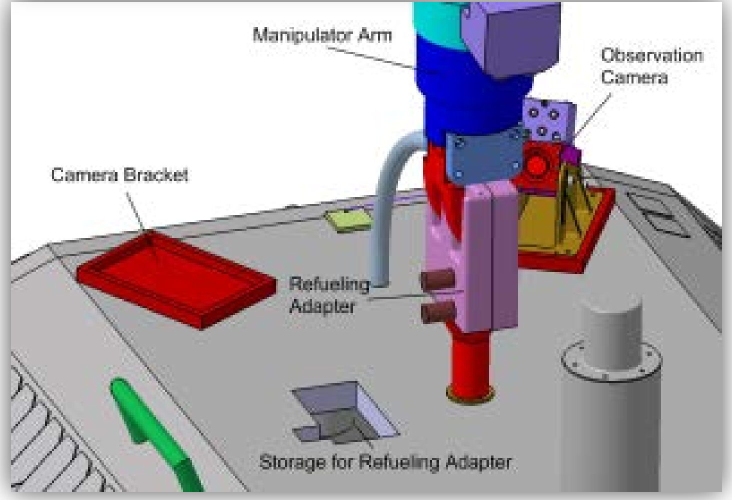
Capture and berthing

- Pivotal question: How can we capture a non-cooperative, free floating and tumbling satellite without causing any damage?
- Challenge:
  - Synchronize manipulator and client motion
  - Grasp a structural element of the client
  - Stabilize the coupled satellites by slowing down manipulator movement and thus relative motion









Technological Challenge

Maintenance and repair

- Pivotal question: What are typical tasks of a service robot?
  - Assembly/disassembly of components
  - Exchange of modules
  - Re-fuelling
  - Lock/unlock holders, clamps
  - ….
- Challenge:
  - Satellites are not prepared for any intervention
  - Provide a solid interconnection between servicer and client
  - Develop gripper and manipulator for a broad range of functions

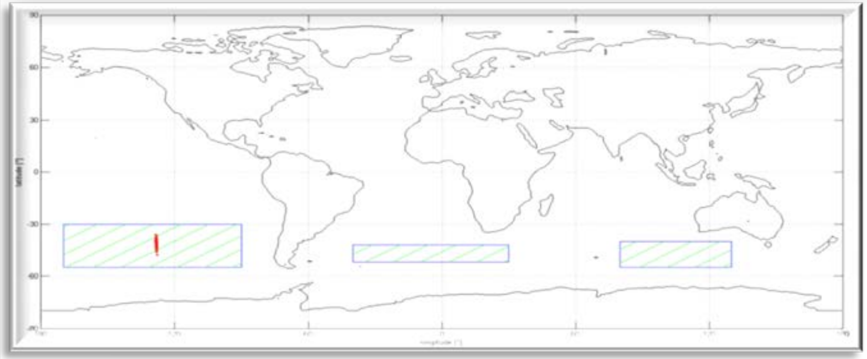
Technological Challenge

Transportation and disposal

- Pivotal question: How can we remove a non-cooperative satellite from it's position and orbit?

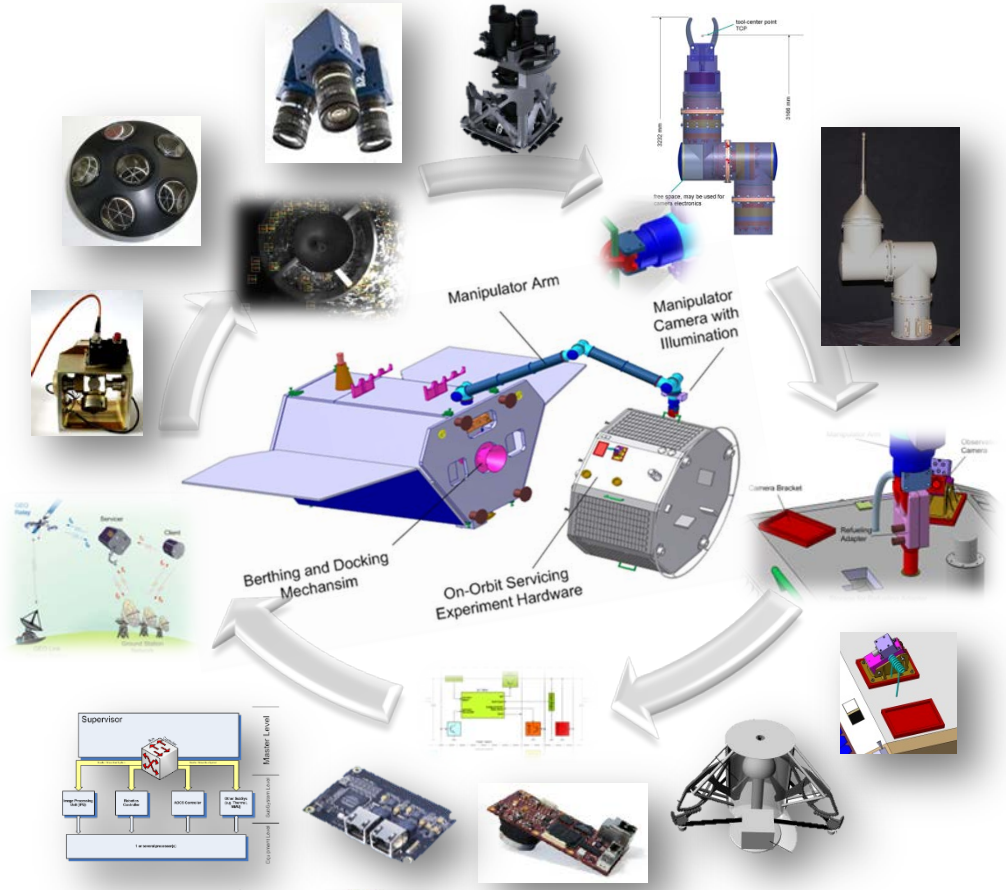
- Challenge:
  - From GEO: Transport to a grave-yard orbit
  - From LEO: Initiate controlled de-orbiting using a predefined reentry trajectory

- DEOS concept:
  - Manipulator stabilizes satellite composite
  - Satellite composite burns up in the atmosphere
  - Potential remainders hit non-populated areas



Conclusion and Outlook

- The DEOS mission shall demonstrate and verify techniques to maintain, refuel and repair malfunctioning (non-cooperative, even tumbling) satellites
- DEOS approach shall explore the mandatory techniques to remove inoperable satellites and space debris
- DEOS shall provide the prerequisites for the establishment and operation of future OOS logistics infrastructures with different lifetime of bus & P/L with
  - Remarkably increased reliability
  - Mitigation of mission risk per user and unit
  - High flexibility and fast reaction to customer wishes and needs
  - Fast deployment of technological innovations
  - No high, long term/upfront investments for customers
  - Costs per user and unit will be reduced
  - Mitigation of business risk
- DEOS robotic technologies shall stimulate and boost unmanned space exploration

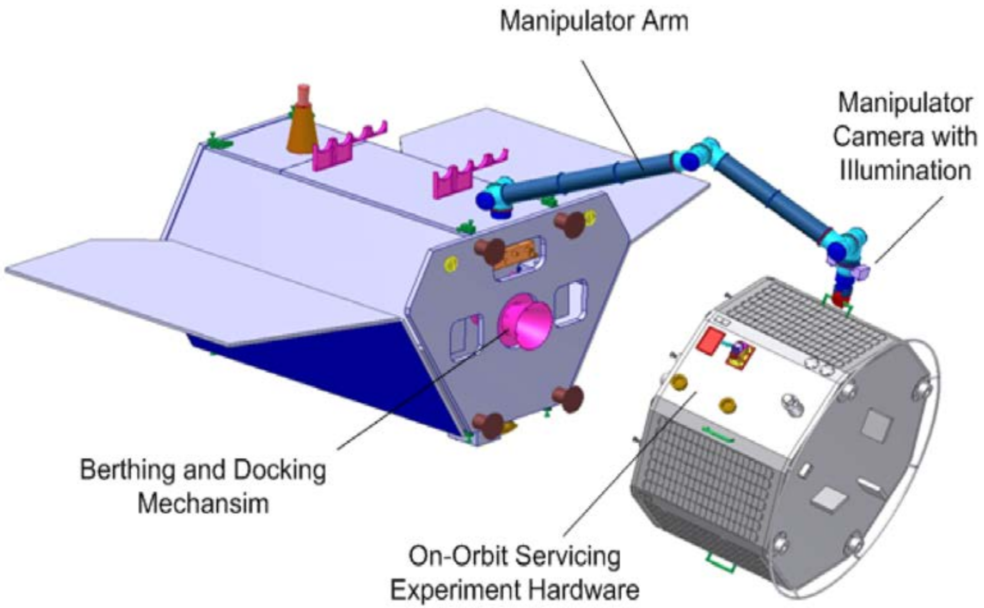


DEOS Technology Program

Key Technologies developed within the German Space Robotics Program

Robotik Sub-System

- Observation of client motion
- Identification of dynamic parameters
- Motion estimation
- Path-planning
- Path-control including visual-servoing
- Decay the motion between servicer and client



DEOS Manipulator and Gripper

DEOS-Arm based on modified ROKVISS modules

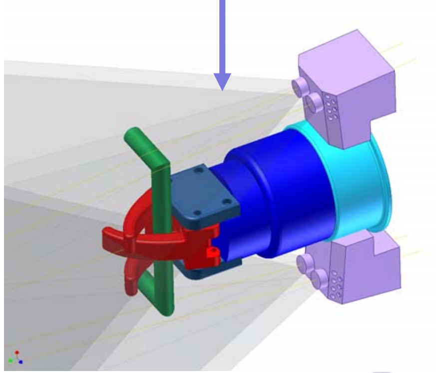
- **Length: 3 m**
- **Weight: ~ 36 kg**

Gripper based on drive similar to joint module

- **3 Fingers**
- **Weight: ~ 4 kg**

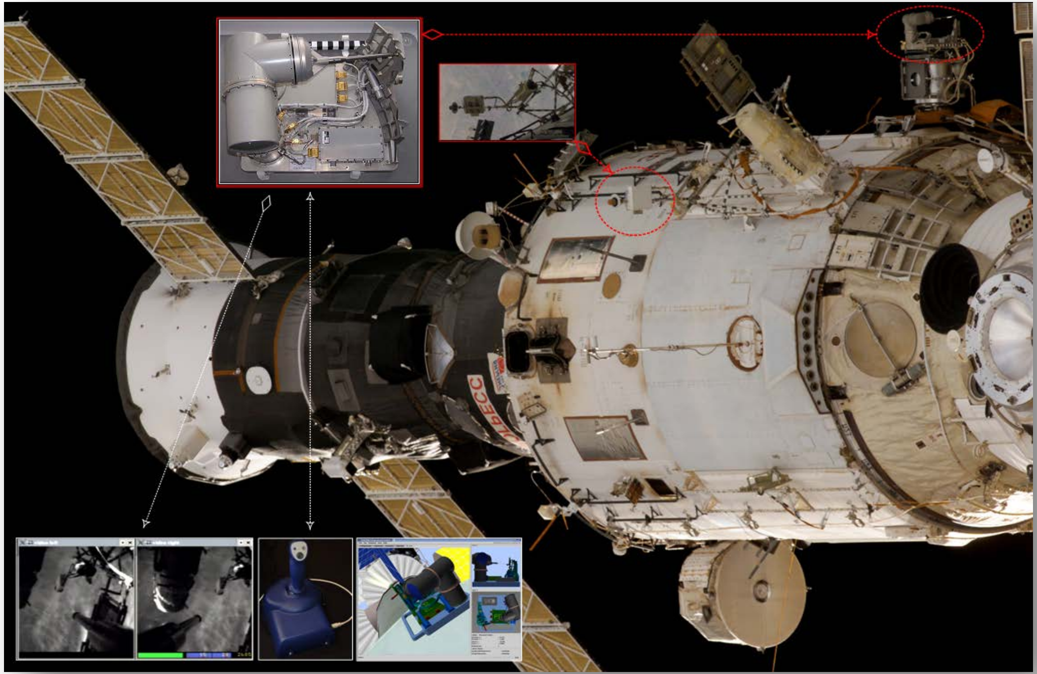
Joint Element

- **Mass:** 2480 g
- **Size**: D 142 mm, L 108.5 mm
- **Hollow axle diameter:** 25 mm
- **Gear ratio:** 160/1 (Harmonic-Drive)
- **Output torque:** 120 Nm (nominal)
- **Max speed:** 15 rpm



Slide 15.

DEOS Manipulator derived from ROKVISS

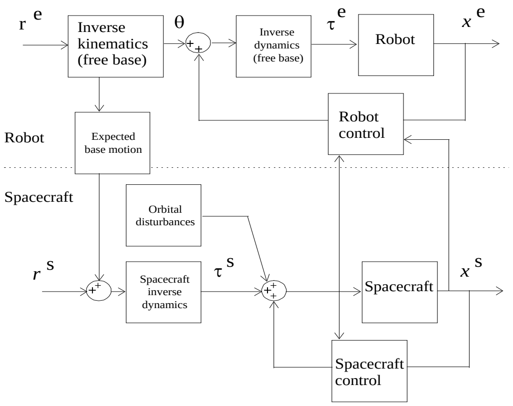


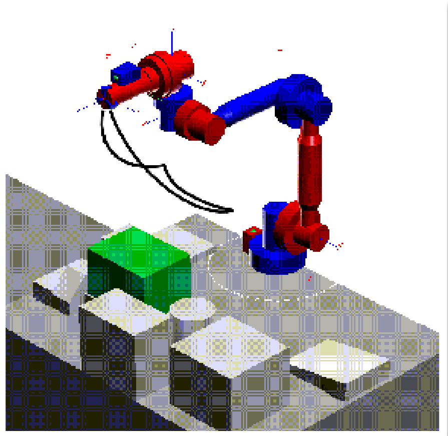
S-Band Communication
- Signal round trip : 12-30 ms
- Contact to ground: 5-8 min/orbit
- Limited bandwidth

Video downlink

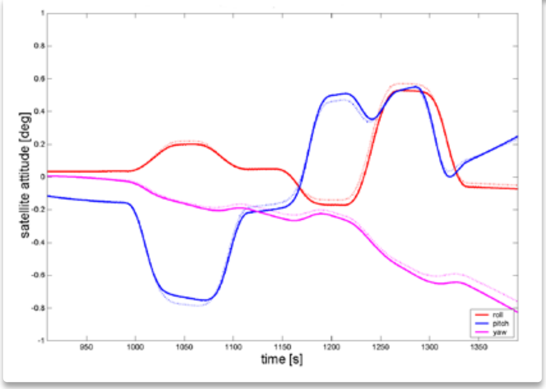
ROKVISS Manipulator since 2005 for 6 years in operation in free space on Svezda Module of ISS

Dynamic Interaction between Manipulator and Platform

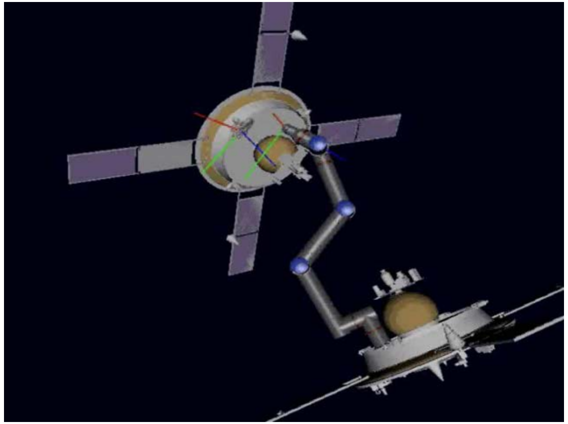




- Expected base motion is new reference for AOCS
- AOCS compensates orbital disturbances only
- AOCS keeps system within operational window

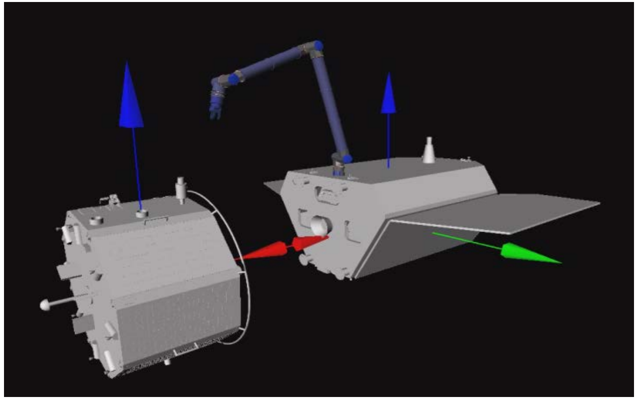


Dynamic model tested and verified during GETEX/ETS-VII Mission (1999)



Capture Sequence

- Path-planning considering the platform dynamics is performed on ground
- Path-data are uploaded, execution is time-triggered
- Stabilization of coupled satellites



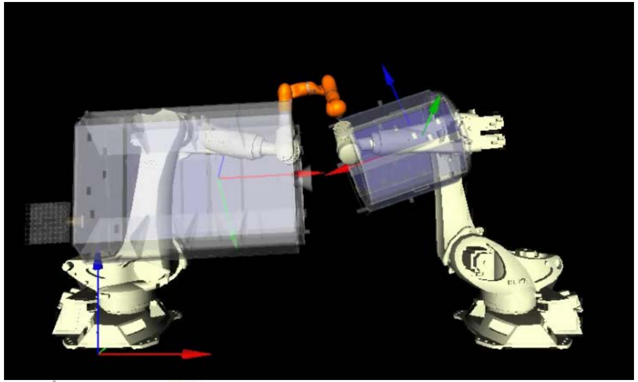
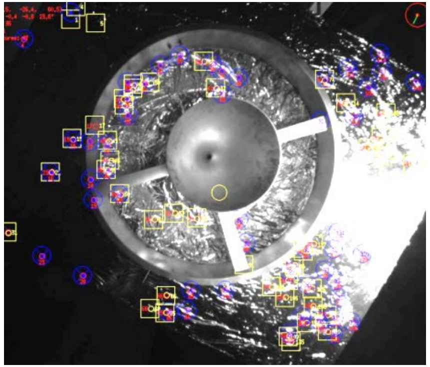
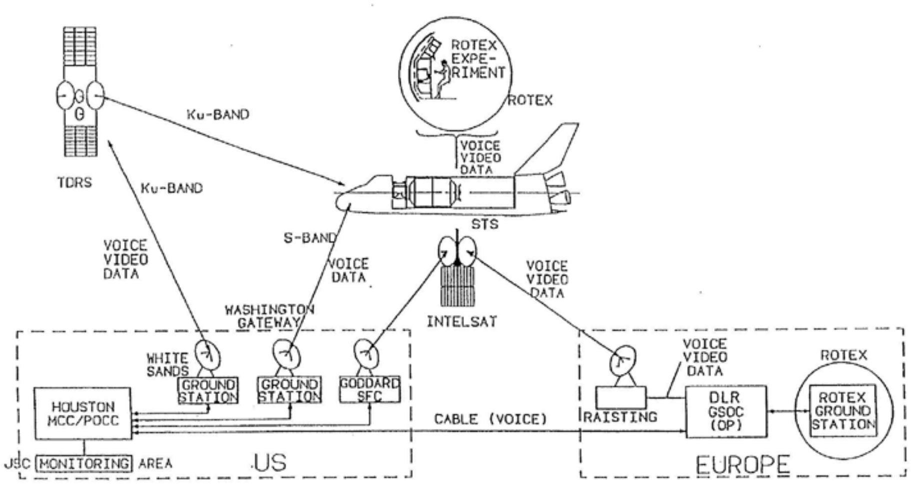


Image processing performed on Ground

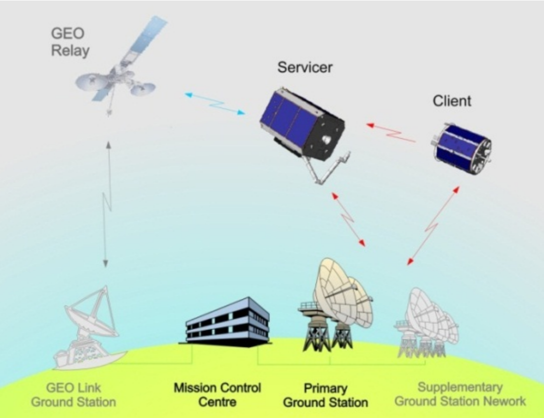
- Observation of client motion
- Visual-servoing for path refinement
- Video-images are transferred to ground

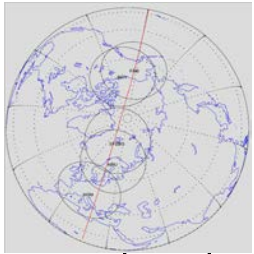




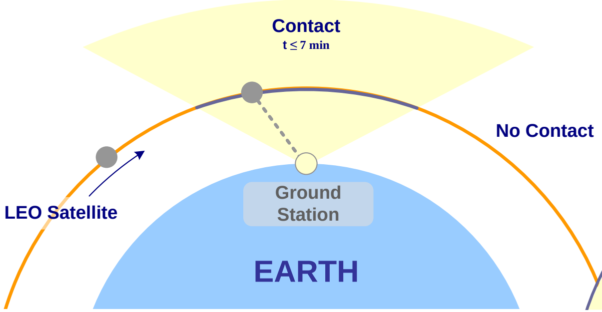
Same principle as for ROTEX
during Spacelab D2 Mission in 1993

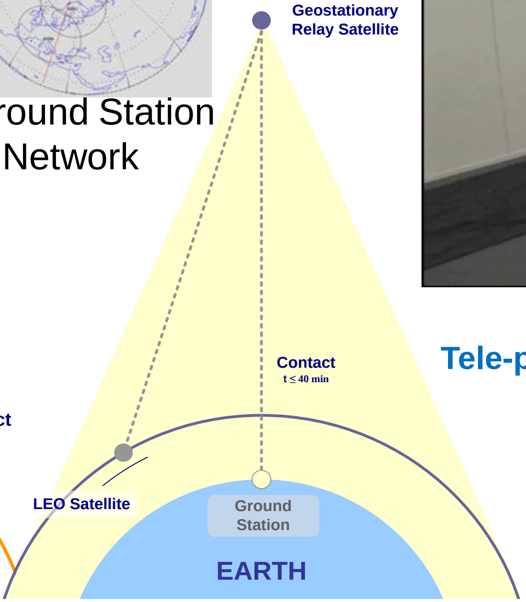
DEOS Communication





Ground Station
Network





Tele-presence Operation with 0.5 s Signal-Delay

Thank You!

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