The RACOON Lab

Technologies for operating robots - in space

2017

Executive Summary

RACOON does end-to-end technology development and evaluation in space robotics for close-range proximity operations

End-to-End: We consider the complete system from the operator up to the satellites.

Development: We will develop new technology within the described reference scenarios.

Evaluation: We will evaluate existing technology within the described reference scenarios.

Space Robotics: We will focus on technology for space robotics.

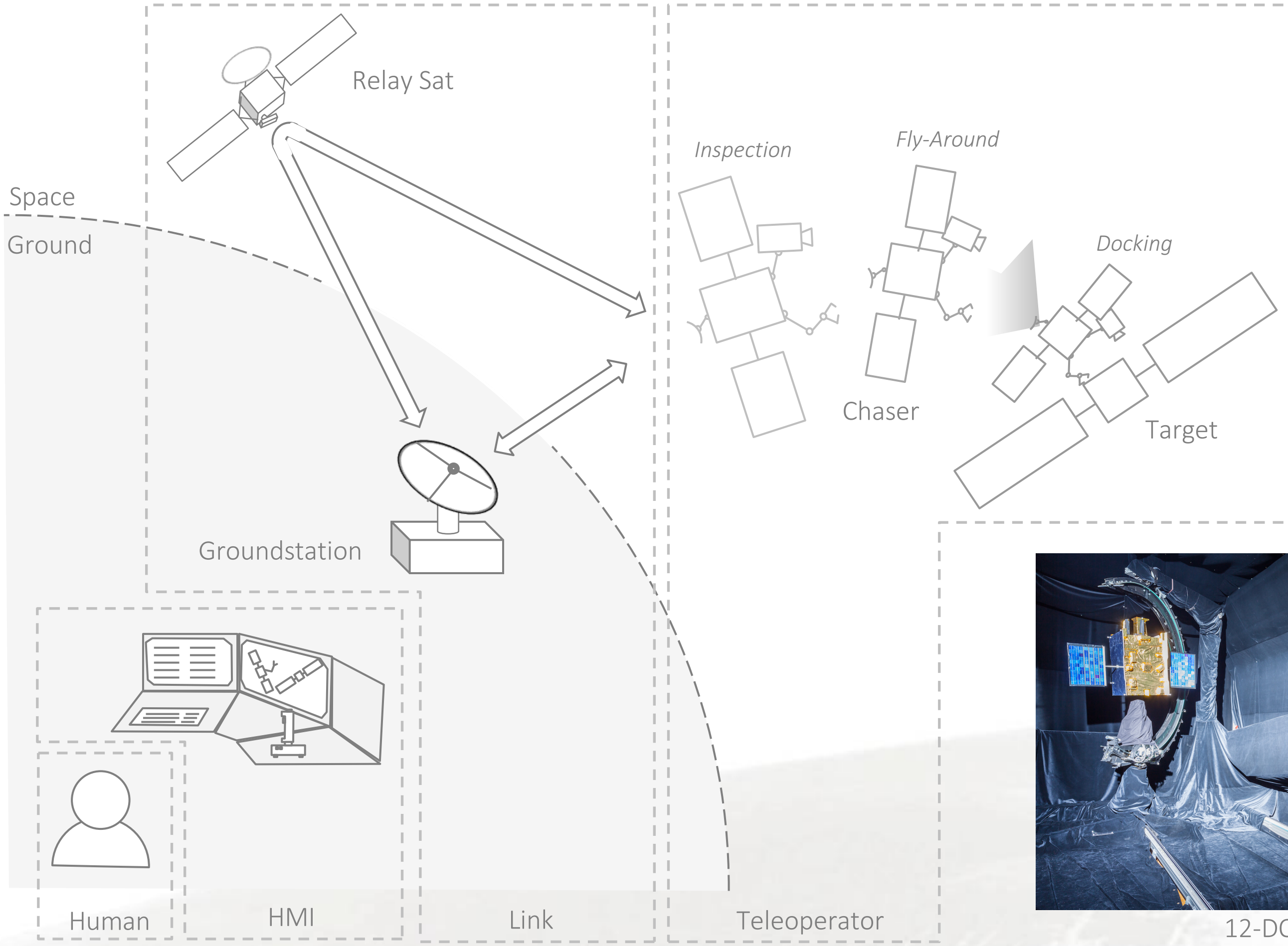
Close-range: We will focus on technology for the close-range navigation (less than 20m).

Proximity ops: We will focus on the proximity operations up to the docking/capture.

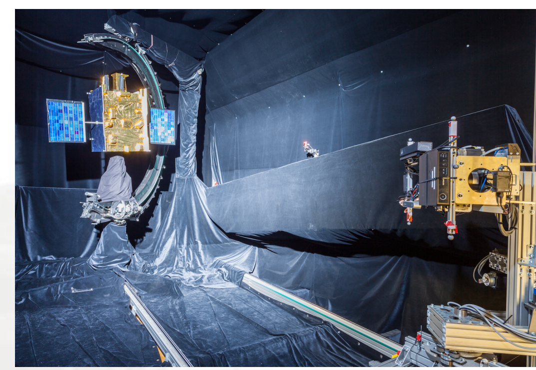
EutelSat/Astra
Space Segm. Access

LRT 4.8m Ka-Band
Groundstation

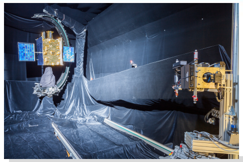
LRT Mission
Control Center



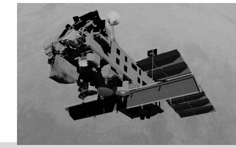
Real-Time SW
Visualization



12-DOF Hardware-in-the-loop
proximity operations simulator



Racoon Overall Spec Sheet



HIL Simulator

- 12 DOF for full orbital kinematics
- Tumbling targets up to 20 kg and 1.8 m side lengths
- Operating range 10 x 5.5 x 4.5 m
- Dynamic position-controlled sun simulator
- OptiTrack Reference System

SW Simulator

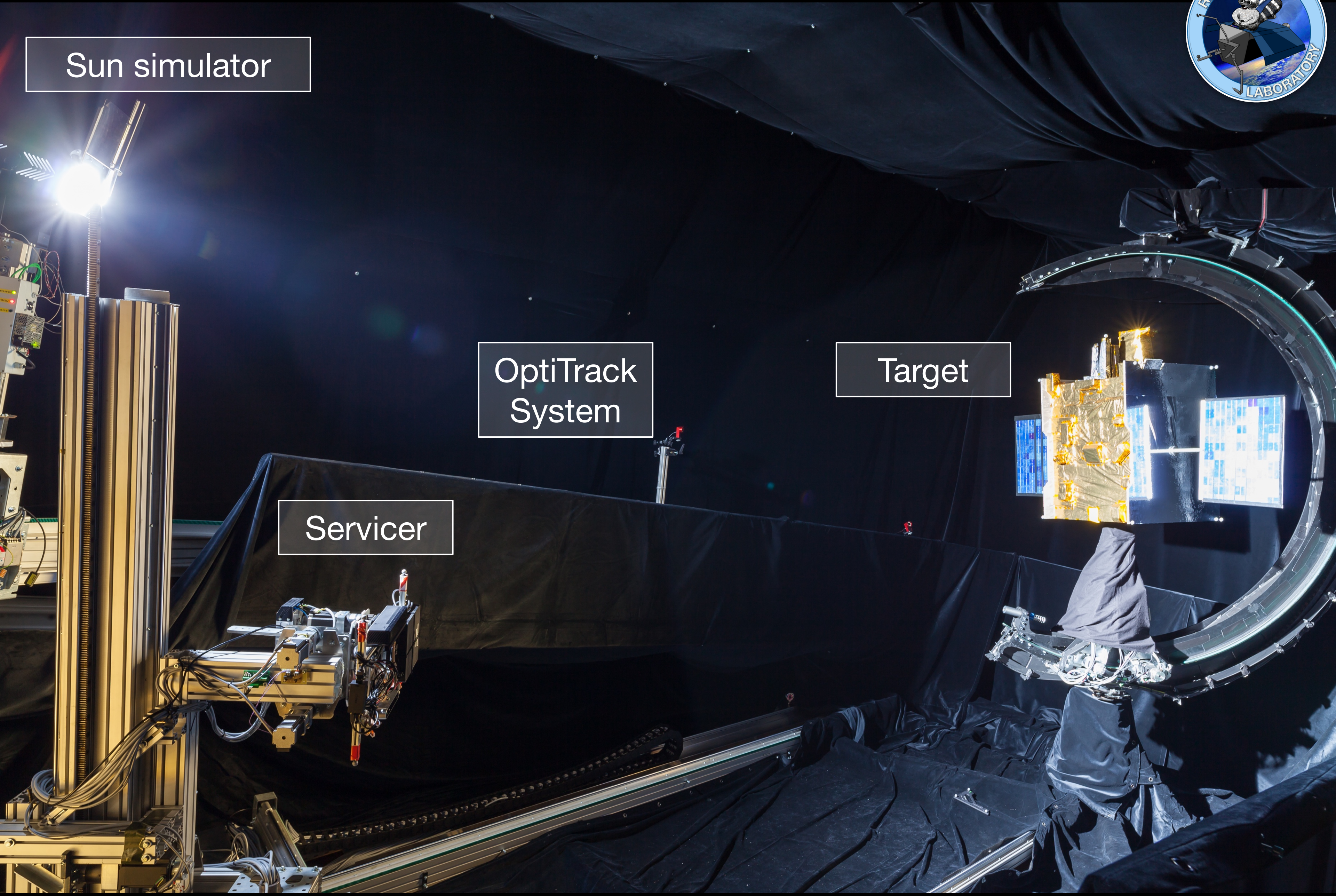
- Orbital dynamics simulation
- Rigid body dynamics
- Scenario definition
- Geometry import (e.g. CATIA V5/WRL)
- Scenario visualization
- Customizable HMI (head-up displays, acoustic feedback)

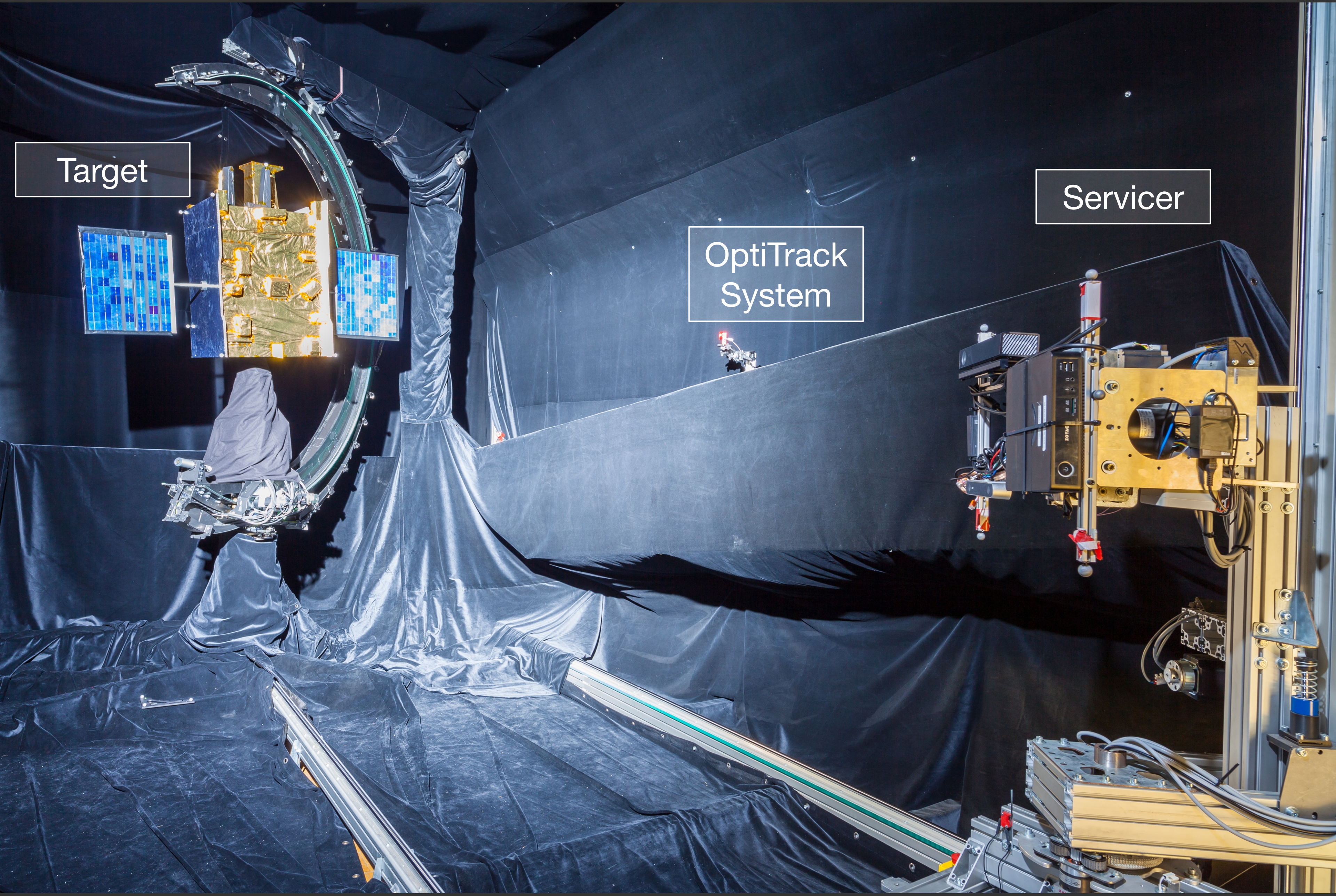
Mission Control Center

- Configurable control center
- Robotic workstation
- 2 projectors & 10+ screens
- Gigabit Ethernet

Ground Station

- Ka-Band ground station (4.8m)
- S-Band ground station
- High data rate satellite modems
- Eutelsat/Astra certified for space segment access


Sun simulator
OptiTrack System
Target
Servicer


Target
OptiTrack System
Servicer

Racoon Hardware Spec Sheet

Key Specs
- DOF: 12 (6x chaser, 5x target, 1x sun)
- Facility: length 10 m; width 5.5 m; height 4.5 m
- Default scale: 1:1 or 1:4
- 8 OptiTrack Cameras for positional ground truth logging

Mechanical Performance
- Chaser rotation rates: >10 °/s
- Chaser translation rates: > 20 cm/s in x-y direction; > 5 cm/s in z-direction
- Target rotation rates: >10°/s in major axis; > 5 °/s other axes
- Sun: > 5 °/s (on rail)

Chaser
- Only front section (sensor suite)
- Storage room: 50 cm x 50 cm x 25 cm (correlates to 2 x 2 m chaser in scaled scenario)
- Maximum weight: 10 kg
- MS Kinect V2, ZED, Structure, Bumblebee 2

Target
- Maximum size: 1.8 m sphere (correlates to 7 m satellites in scaled scenario)
- Minimum size: 50 cm center cube keep out
- Maximum weight: 20 kg

Light Sources
- Moveable light source
- Point light and ambient light (albedo)
- Point light spectrum represents sun spectrum
- Intensity (1/10 sun)

Artificial Space Background
- Full black room covers (all 6 sides)
- Curtain reflections: < 1% of incoming light
- Cover of mechanical suspensions: > 90% (planned; nearly 100% possible)

Racoon SW Simulation & Control Center Spec Sheet

Software Simulation

- Scenario definition
  - Internal racoon scenario & model format
  - General scenario definition (initial states)
  - Surfaces, material, cameras, reference points
  - Mechanical properties (CoG, inertia)
  - CATIA V5 model import
  - WRL geometry import
- Software physics simulation
  - Orbit dynamics & rigid body dyanmics
- Software Visualization
  - 3D Visualization of orbital scenario
  - Custom data augmentation
  - Virtual camera simulation
  - Near-real-time raytracing engine

Mission Control Center

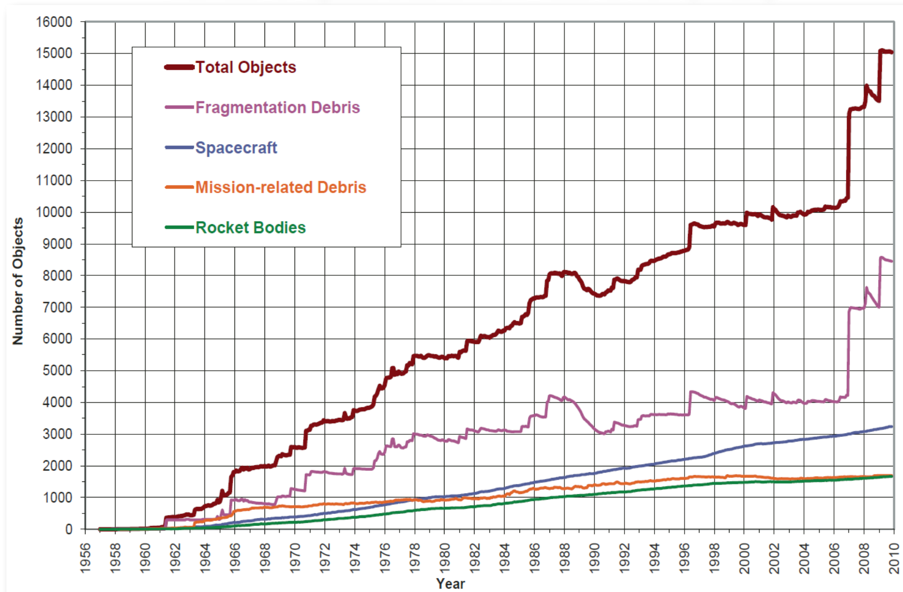
- Up to 4 workstations for mission simulation
- 3 High End workstations
  - CUDA 4 compatible GPU's
  - Stereo projection capabilities
  - PTP IEEE 1588 time synchronoization (in-house stratum 1 time server)
  - Customizable user input devices (joystick, space mouse)

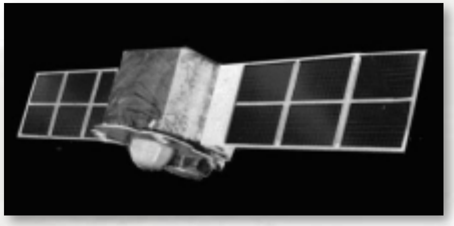
Background Information

Motivation - Space Debris Removal

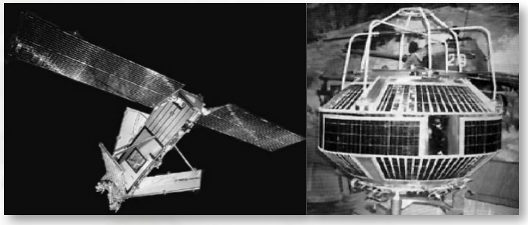
- Rising Threat
  - Possible chain reaction (Kessler Syndrome)
- Large objects are most problematic
  (Because of fragmentation)
- Solution
  - Reduce production of new debris
  - Removal of large objects from highly populated orbits
  - ➔ Very Complex Missions
  - ➔ Not Possible at the moment
  - ➔ More Research Required

Number of Space Debris from 1960 to now (NASA)





Fengyun-1C satellite (Jan. 2007)



Collision between LM700 Bus (Iridium) and KAUR-1 Bus (Cosmos 2251) (Feb. 2009)

Teleoperated Proximity Operations

cooperative

uncooperative

- stable attitude
- capture interface
- sensor targets

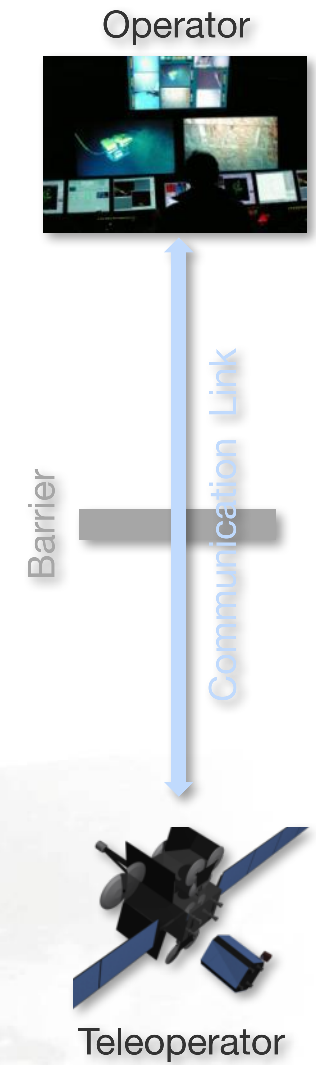
- tumbling
- no dedicated interfaces
- no dedicated sensor targets

- Automated docking & proximity operations only successfully demonstrated for cooperative targets (Progress, ATV, HTV, ETS-VII, Orbital Express)
- Uncooperative targets only successfully captured by Space Shuttle using human guidance and astronaut intervention

→ **Robotic OOS missions to include human control / supervision**

Teleoperation Basics

- Definition: Control of a machine across a barrier
- Typical barriers:
  - Distance & Time: Space, Deep Sea
  - Matter: Nuclear Power Plants
  - Scale: Medicine
- Motivation:
  - Environment not accessible / difficult to access for humans
  - Environment and tasks too dangerous
  - Required precision and / or endurance too high for humans

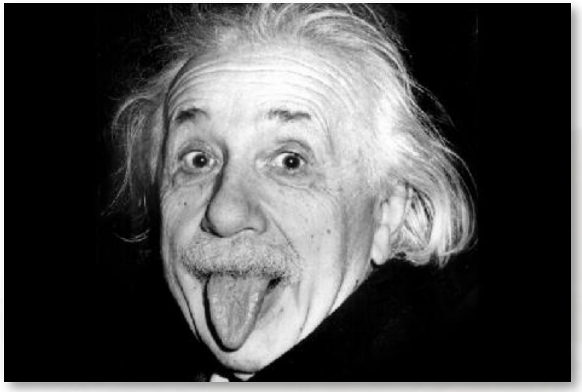


Teleoperation Advantages

Teleoperated Robotics combine human and machine capabilities

Human

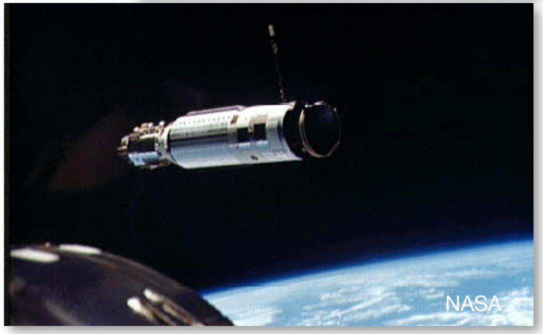
- Haptic and visual sensory system
- Spatial modeling
- Anticipation
- Flexibility
- Ingenuity



Robot

- Endurance
- Precision
- Robustness
- Patience

Space Teleoperation Challenges

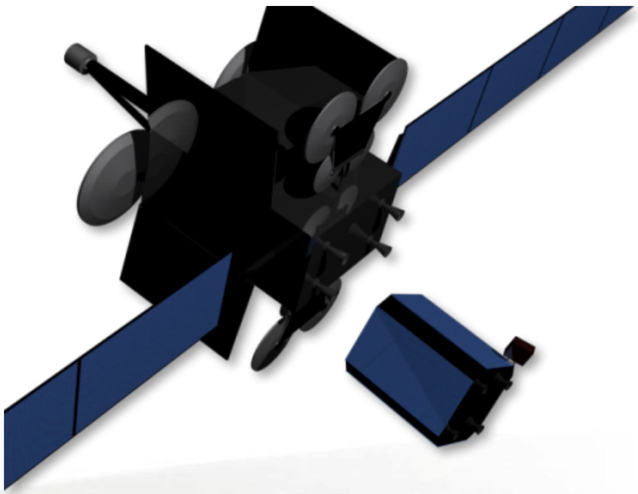


- Communication time delays
- „looking through a straw“
  - Limited number of sensors
  - Limited bandwidth
  - Limited computing capacity
- Unfamiliar environment
  - Full 6 DOF motion dominated by inertia
  - Lighting conditions
  - Target surface properties
  - No usable natural attitude and position references
- Unfamiliar vehicle behavior
  - No linear relative trajectories
  - Difficult targeting and maneuver planning

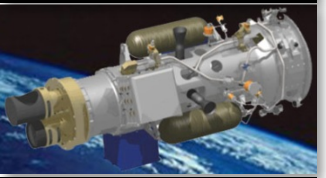
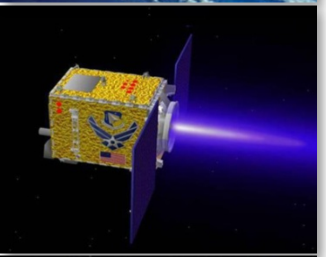
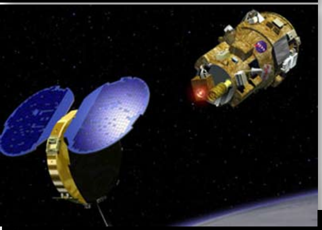
→ **Decreased Situation Awareness**

Problem: Operator Situation Awareness

- Definition (Endsley):
  - perception of elements in the environment within a volume of space and time
  - comprehension of their meaning
  - projection of their status in the near future
- For orbital maneuvering:
  - **Knowledge of ownship** position, attitude and motion
  - **Knowledge of other objects**' relative position, attitude and motion
  - **Prediction of situation elements' states** into the near future (for maneuver planning and time delay compensation)



Robotic Demonstrator Missions

- Experiments
  - ETS-VII (JAXA, 1997): teleoperated OOS, success
  - XSS-10 / XSS-11 (AFRL, 2003 / 2005): automated proximity operations, success
  - DART (NASA, 2005): autonomous proximity operations, collision
  - Orbital Express (DARPA, 2007): autonomous OOS, success
  - Prisma (SSC, 2010): autonomous proximity operations
- Planned
  - Phoenix (DARPA, ~2015): teleoperated OOS in GEO
  - DEOS (DLR, ~2018): teleoperated OOS in LEO
- Cancelled
  - Ranger (NASA): teleoperated OOS
  - SUMO (NRL): teleoperated maneuvering
  - Smart OLEV (DLR): teleoperated refueling
  - Space Infrastructure Servicer (MDA): teleoperated refueling
- Operational
  - MiTEx (DARPA): inspection in GEO
  - X-37 (USAF): unknown