Space Robotics
** Technologies and Applications **

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Applications for Space Robotics

- Support astronauts during for their work outside and inside the module (ISS)
- Mitigation of space debris
- On orbit maintenance and repair
- Live extension of satellites in GEO
- On orbit assembly of huge structures
- Exploration and preparation of manned extraterrestrial missions
Registered objects in geo-synchronized Orbit (GEO)

Approx. 2 million kg of space-debris jeopardize manned and un-manned space-systems!
Registered objects in low Earth Orbit (LEO)
Space debris in LEO: Increase of future population

→ Cascading effect starts to increase space debris even w/o any launches

→ Only way to limit increase is to actively remove objects from LEO

(source: NASA)
Requirements / Problems

- **Environment**
  - Vacuum (Cooling)
  - Thermal cycles along the orbit
  - Temperature difference (one side hot other side cold).
  - Radiation

- **Communication**
  - High round trip time (RTT)
  - Equidistant data-packets on up- and downlink

- **Launchloads**
  - Shock and vibration
Communication paths and corresponding round trip times

- Relais satellite in GEO: 500 ms
- Spacecraft in GEO: 250 ms
- Spacecraft in LEO: 20 ms
Predictive Simulation

signal delay > 600 ms, well known environment
Telepresence Operation

short signal delay < 600 ms, unknown environment

Diagram showing the components and connections of a telepresence system, including auditory-visual channels, haptic channels, and a teleoperator.
Telepresence Operation

short signal delay, unknown environment
On Orbit Servicing Szenarios

Inspection System
On Orbit Servicing Szenarios in LEO

- Short communication time
- Target Satellite is uncooperative
- Relative motion is unknown

Dynamic Interaction
RObotic GEostationary orbit Restorer ROGER (ESA 2002)

A mesh is thrown towards the target satellite by the means of several ejected small masses.
ENVISAT
Possible Capture Methods  (Subset only)

Antenna  Structure  Adaptor
Capture the Structure Part

Servicer attitude in stabilization/berthing phase

![Graph showing servicer attitude vs time](image-url)
On Orbit Servicing Scenarios

Satellite Servicing in GEO
ROTEx - The first remotely controlled Robot in Space

IEEE Judith A. Resnik Award
1994 – JOHANNES DIETRICH
Inst. Robotics & Syst. Dynamics - Wessling, Germany

'For development of a successful high-performance, rugged, multi-sensor, miniaturized robotic gripper for use in the outer space environment.'
Telerobotic Concept

The on board control loop is closed with real sensor data in “shared control mode”

The predictive control loop on ground is closed with simulated sensor data
The control loop is closed via the ground segment, due to extensive video data processing.
MARCO 3-D Window for the Payload Operator

3D Input-Device Mode Selection

TM Mode Selection

Simulated Robot

Real Robot

3D Cursor

Quicklook Display red: real white: simulated
Shared Control

Red: Sensor controlled
Green: Position controlled
ROTEX On-Board Operation
ESS  (Experimental Servicing Satellite, 1997)

Chaser Satellite

Target Satellite TV-Sat 1

deployed Solar Generator

defective Solar Generator

Elbow Joint

Shoulder Joint

Manipulator

Endeavor
Capture-Tool

- Spogee motor nozzle
- Upper range finder group
- Crown locking mechanism
- Lower range finder group
- Planetary roller screwdrive
- Drive motor
- Force torque sensor

[Image of the capture tool]
ESS Cutter
Simulation System for Satellite Capturing

- Robot A
- Model of Apogee Motor
- Dyn. Model Target Motion
- TCP Difference
- Dyn. Model of ESS - Manipulator
- Tool Center Point
- Dyn. Model of ESS
- Capture Tool and Sensors
- Video, F/T and Distance Data
- Sensor - control
- Robot B
- AOCS Model
HIL Simulation System for Satellite Capturing
GETEX / ETS-VII 1999

- Target (0.4t)
- Chaser (2.5t)
- Launched by H-II rocket on Nov. 28, 1997
DLR’s Groundsegment for ETS VII Tsukuba, Japan

- Experiments:
  - Video-sensor controlled pick and place operations
  - Investigation of the dynamic behavior of robot and satellite
Defining the operation

Pick Operation

Place Operation
Investigating Robot and Platform Dynamics

Getex Dynamic Motion Experiment 01

- Forward motion
- Backward motion

Experimental Results and Model Updates

Prediction errors are due to uncertain moments of inertia and location of the CoM
Dynamic Motion Experiment

After in-flight identification of moments of inertia and CoM
Dynamic Motion Experiment
Preparing light weight Robots and Hands for Space Application

Requirements:

- low weight
- low energy consumption
- In size and agility comparable humans (antropomorph)
JUSTIN System:
Weight: 45 kg
DoF: 43
Control Loop: 1kHz

Head:
DLR 3D Modeller
Stereo Camera
Laser Scanner and Stripe Projector
3 DoF

2 DLR Light Weight Arms (left and right)
7 DoF each

Torso:
4 Joints / 3 actuated

2 DLR Hands in left and right configuration
12 DoF each
Dextereous Robotic Hand  DEXHAND

- Four finger hand
- Mass less than 3kg
- 12 active joints
- All components space qualifiable
Dexterous Robotic Hand  DEXHAND
ROKVISS
Roboter Komponenten Verifikation auf der ISS
ROKVISS Experiment Goals

- Adopt the light weight robot’s functional concept
- Weight and volume of the joint mechatronic should be kept as far as possible ►► COTS
- Verification of the tele-presence operational mode in a realistic mission environment
- Identification of the friction behavior over time
- Planned mission duration 1 year
Modifications (1)

- All heat emitting electronic parts need to be thermally coupled to the robot’s structure to allow for heat dissipation
- Thermo switches and heater foils keep the joint within its operational temperature range
Modifications (2)

- Electronic parts with extended temperature range (-45 C to +85 C) are used (COTS).

- A latch-up protected power supply circuit was developed and implemented
  - built with radiation tolerant parts, temperature range: -55 C to +125 C)

- A dedicated task scans the memory for bit-flips.
ROKVISS Joint Element Characteristics

- 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

Max. allowed torque during ROKVISS operation: 40 Nm
ROKVIISS External Unit (REU) and On Board Computer (OBC)
ROKVISS on ISS from January 2005 until November 2010

- **Launch:** with Progress M-51 on Dec. 24. 2004 from Baikonur-Cosmodrome

- **Installation:** End of January 2005 during space-walk

- **Location:** Zvezda-Module
ROKVISS Communication System

- In order to keep the round-trip communication time as low as possible, ROKVISS has an own S-band communication system, including an own antenna (Communication Unit for Payloads CUP).
- Uplink data rate: 256 kbit/s
- Downlink data rate: 4 Mbit/s, including 3.5 Mbit/s video-data.
- Uplink frequency: 2058.0 MHz
- Downlink frequency: 2234.9 MHz
- Modulation BPSK
- Round trip time: < 20 ms
ROKVISS Tele-presence

- Realtime Communication Link
- Roundtrip delay: 12 – 18 ms
- max. Jitter: \( \sim 1 \) ms
- Contact Period: up to 7 minutes

![Diagram showing tele-presence system with 3 MBit/s downlink, Stereo-Video, Haptic-Control, 128 kBit/s up- & downlink, 500 Hz Sample rate.]
ROKVISS Video
Spring Experiment

![Graph of msr torque over time](image)

![Graph of msr current over time](image)

msr current 12.05.2005

- Blue: msr 1
- Green: msr 2

DLR-RM, Klaus Landzettel, Space Robotics 52
ROKVISS operation via remote ground-station

- Uplink 256 kBit/s
- Downlink 4 MBit/s

Ground station DLR-RM

Command data: Internet or dial in connection

Ground station RTC or LRT
ROKVISS Remote Control with Laptop via DSL

Round-trip-time ~80 ms
After a very successful operation of ~6 years in free space, ROKVISS was dismounted from ISS in Nov. 2010.
ROKVISS preparation for return with Sojuz Capsule

47cm x 16cm x 16cm

210 mm
Visible Differences on Surface
(anodic treatment, LN9368 / 2101)
First Tests with the System back on Ground

- No performance degradation!
- Electronic and mechanic components survived without any difficulty!
OLEV Orbital Life Extension Vehicle
Station keeping: N/S Correction

Target ~ 2t

Chaser ~ 0.5 t

F = necessary thrust

N/S Correction

W

E

S

N

= CoG
Orbital Life Extension Vehicle (OLEV)

DLR contribution

- Capture Tool, development of a space qualified version
- Final approach from 5 m until docking
- Ground control concept for final approach phase
- Video based tracking of the nozzle-rim
CaptureTool

- Qualified version of the ESS-Capture Tool
- Radiation hard up to 100 krad.
Tracking the Apogee Motor‘s Nozzle Rim

Operator places red marker above the nozzle rim
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
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
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
Kommunikation über S-Band

Bahnhöhe: 600 km  
Bahninklination: 87°
Vorgelagerte S-Band-bodenstationen erhöhen die Gesamtkontaktzeit auf ca. 20 Minuten

Kontaktzeit ~ 7 min
Signallaufzeit < 20 ms

Kontaktzeit > 40 min
Signallaufzeit ~ 500 ms
Free floating Base with Limit Supervision

- Robot on a free floating base
- Expected base motion is new reference for AOCS
- AOCS compensates orbital disturbances only
- AOCS keeps system within operational window
Greifen des DEOS Clients

- Path-planning considering the platform dynamics is performed on ground
- Path-data are uploaded, execution is time-triggered
- Stabilization of coupled satellites
Dynamik behavior
Hardware in the Loop Simulatoren

EPOS

DEOS-Simulator
Tele-Presence Operation with Time-delay
METERON

Mars End-To-End Robotic Operations Network
Multi Purpose End-To-End Robotic Operations Network

- Validation of end-to-end operations for planetary surface robotics
- Verification in relevant environment of planetary surface robotic systems and activities operated from orbit
- Validation in realistic operational conditions of DTN-based communications.
METERON REFERENCE MISSION

- **Rover Control Center** manages the overall robotic operations
- **Mission Control Center** manages the space mission
  - Telemetry/Command via the **Ground Stations**
- **Manned Orbiter** (or **Surface Habitat**) from which crew control the robotic element
- **Relay Satellite** which interconnects:
  - the **Rovers** with the Manned Orbiter/Surface Habitat, other surface Rovers, and;
  - with the **Ground**
METERON
Communications on the ISS

Source: Presentation to ESA on CR 011812: "Integration of ESA/Columbus Ethernet LAN/PWS system into Joint Station LAN", Brett Willman, NASA ISS Avionics & Software Office

Robotics “Work-station” (incl. DTN node)
integration in Columbus
Network integration (local ISS, end-to-end)
• Final increment with 3D stereo vision for full immersion operations.
• High data rate communication link required
• ODAR channel on the US side of the ISS will be used for realtime video uplink
Direct telepresence on a board of ISS using dedicated and public network infrastructure.
THANK YOU!