Technology Development for Exploration and Servicing
From Tele-operation to Autonomy in Space Robotics

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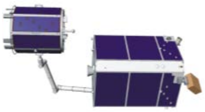
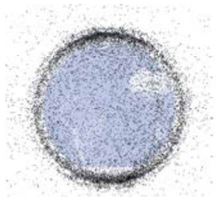
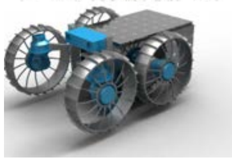
Applications and Challenges for Robotic Systems

- On-Orbit Servicing (OOS)
  "Robots are assisting the human, extended arm of human in space"
- Space Situation Awareness (SSA)
  "Many synergies with OOS technologies yet not jointly pushed forward"
- Robotic exploration of planets and asteroids (REX)
  "The most interesting places for scientists are most challenging for robots in terms of mobility, autonomy, and communication"







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On-Orbit Servicing

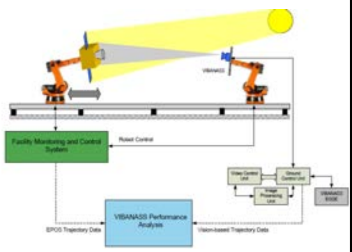
"Robots are assisting the human, extended arm of human in space"

Source: NASA

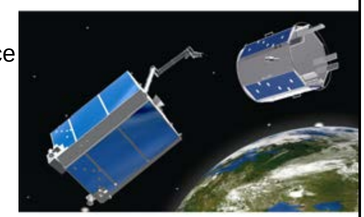
Source: NASA

Selected On-Orbit Servicing Initiatives

- Past Projects
  - Inveritas (Innovative technologies for relative navigation and capture) Astrium Bremen/DFKI Bremen
  - VIBANASS (Vision-Based Navigation Sensor System), Kayser Threde



- Current Projects
  - KARS (Controller for autonomous space vehicles), Astrium Friedrichshafen
  - DEOS (Deutsche Orbitale Servicing Mission), Astrium Bremen

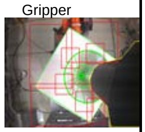


20 Years of OOS Mission Experience

- 1994: ROTEX- D2 Mission
  - Grasping of a free floating object
- 1997: ESS (Experimental Servicing Satellite)
- 1999: GETEX ETS-VII
- 2005: OLEV –Capture Tool
- 2005: ROKVISS
  - Design of a two-link robot for ISS based on LWR III Joints, equipped with stereo camera and joint torque sensors
  - Control Loop with visual and haptic feedback succssesfully demonstrated (Roundtrip-time lower than 20 msec)
- 2006: TECSAS
- 2009: Return of ROKVISS Experiment to Earth
  - Joint investigations for materials analysis, friction and lubricant analysis
- 2009-2012: DEXHAND
  - Development of a space qualifiable dextrous hand for ESA (ISS Environment), 12 active joints allow antropomorphic grasping, force torque sensors for haptic feedback


Capture Tool


ROTEX - Gripper


ESS –Model based Grasping


Cutter Tool


DEXHAND

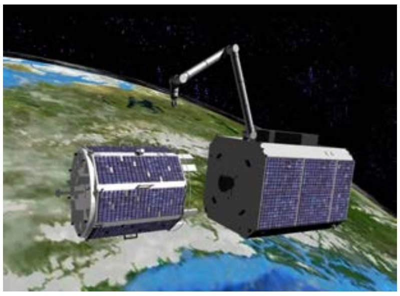

ROKVISS

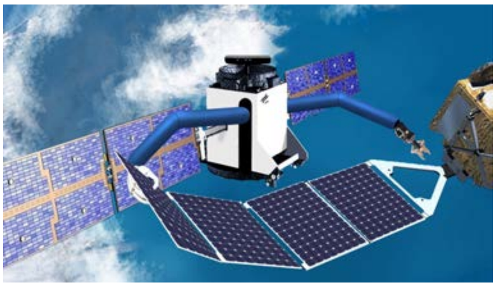

GETEX Satellite&Arm

On Orbit Servicing

Robotics provides a scalable technology:

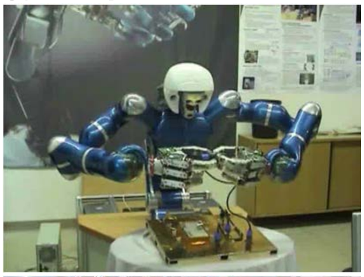
- from tasks like
  - deorbiting
  - space debris removal
- over *maintenance and repair*
- to *complex assembly* assistance functions
  - new ISS?
  - future manned Mars spacecraft

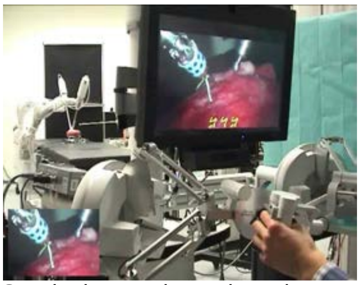




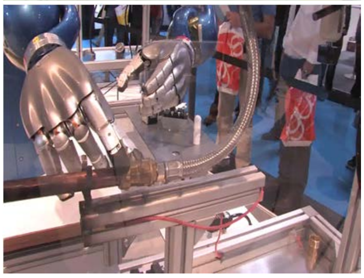
Tele-Operation – A Key Technology in Space and on Earth

- Same technology in
  - space
  - surgery (6000 operations/day with daVinci system)
  - maintenance and repair of nuclear, off-shore, chemical plants





Surgical operation - shared autonomy



industrial plant maintenance and repair

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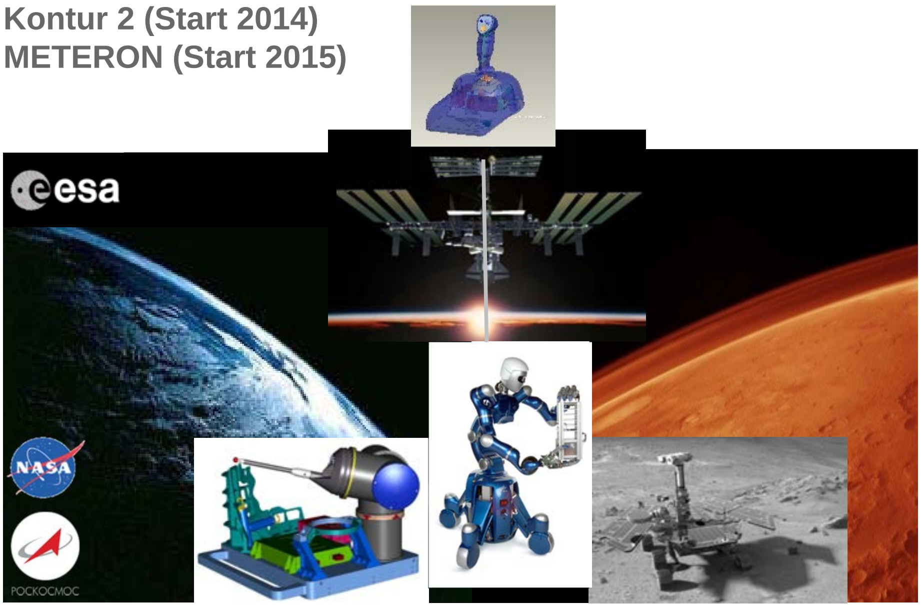
Kontur 2 (Start 2014)
METERON (Start 2015)



Mars-**E**nd-**T**o-**E**nd-**RO**botic **N**etworking METERON

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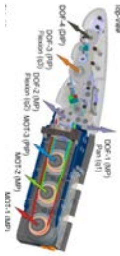
DEXHAND - Four Finger Dexterous Hand developed for ESA

- First space qualifiable multi-fingered hand
- Handle most tools used by astronauts during standard EVAs
- Compliantly controlled and tele-operated
- Requested by the DARPA PHOENIX for on orbit assembly



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Space Situation Awareness

"Many synergies with OOS technologies yet not jointly pushed forward"

OOS System for:

- ***Satellite Live Extension***
- ***Satellite Servicing / Repair***
- ***Space Debris removal***
- ***Controlled Deorbiting***
- ***Sample Return***

Telerobotic-> Autonomous

Capture Tool / OLEV

Tecsas

DEOS

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Selected Space Situation Awareness Initiatives

- ITN Stardust (Workpackage Close-Range Navigation and Manipulation of Space Debris and Asteroids), DFKI Bremen (FP7)

- RTES-TA (Robotic technologies for the removal of space debris), DFKI Bremen (BMWi)

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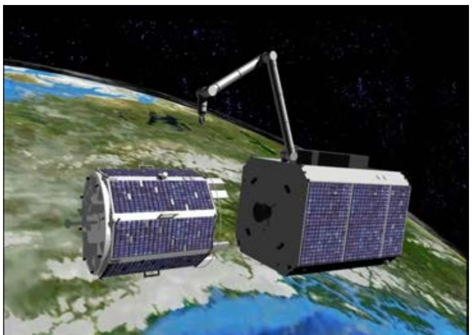
On Orbit Servicing and Space Debris

- Robot technology can handle both
  - service and repair
  - space debris mitigation

- Applied in
  - DEOS mission
  - DARPA PHOENIX Program (Requested)



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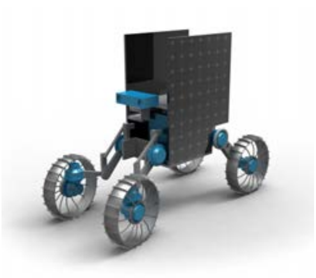
Robotic Exploration of Planets and Asteroids

“The most interesting places for scientists are most challenging for robots in terms of mobility, autonomy, and communication”



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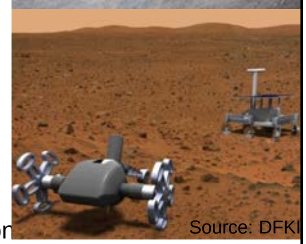
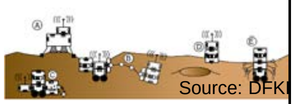
Selected Exploration Initiatives

- Finished Projects
  - Space Climber (DFKI Bremen)
  - RIMRES (DFKI Bremen)
- Running Projects
  - FASTER (Forward Acquisition of Soil and Terrain for Exploration Rover) DFKI Bremen, FP7
  - IMPERA (Integrated Mission Planning for Distributed Robot Systems), DFKI Bremen
  - LIMES (Learning Intelligent Motions for Kinematically Complex Robots for Exploration in Space), DFKI Bremen
  - MPE (Mobile Payload Element), Kayser Threde





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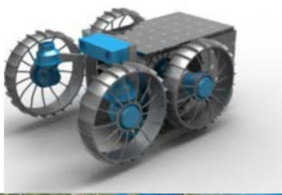
Scientific Goals

- Collecting data (e.g. images, measurements) at different places
- Collecting samples at different places
- Insitu analysis of samples e.g. volatiles
- Transportation of samples, e.g. back to landing module

- This requires
  - Mobility (e.g. driving, crawling, flying)
  - Autonomous robots
  - Teams of robots for different terrain, tasks and/or for increasing robustness

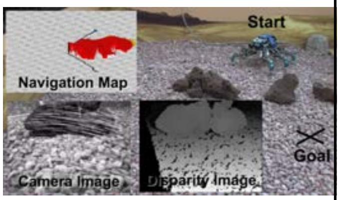


Why Robot Teams?

- Terrain requirements can be very different, e.g.
  - Flat terrain > driving systems (due to low energy consumption)
  - Narrow gaps and caves > crawling systems
  - Canyons > flying systems (atmosphere permitting)
- Systems can have different scientific tasks
  - collecting images
  - collecting samples
  - analysing samples
- Large areas can be covered in parallel by several robots
- Redundancy reduces risk, i.e. every system can complete the mission

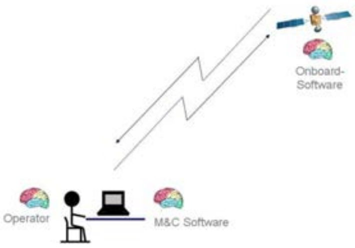
Why Autonomy for Planetary Missions?

- Long signal round trip times reduce the speed of tele-operated driving, e.g.
  - Moon: 3 s physically, 10-15 s due to processing chain of ESA/NASA
  - Mars: 8 - 42 minutes
- On-board autonomous navigation can react much faster
- Thus, larger areas can be covered
- On-board autonomy additionally provides safety functions
  - Hazard avoidance
  - Slip detection
  - Automatic homing to lander in case of signal loss
  - ...

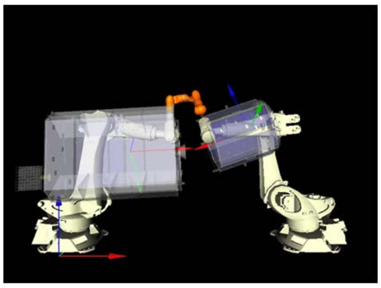


Selected Technology Development Initiatives

- Virtual Crater (finished), DFKI, RWTH Aachen
- CoHoN (Communication in Heterogeneous Networks), DFKI Bremen
- MiKKRo (Mission Control Concepts for interactive Robotic Platforms), VHS, GSOC, DLR-RM



Labs for Testing Systems and Components
OOS and SSA



- Vision based approaching
- Robot design and operation
- Dynamics and control
- Ground control
- Teleoperation and Shared Autonomy

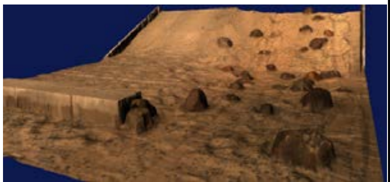
Test bed for approaching and docking

Test bed for grasping and manipulation

Labs for Testing Systems and Components
Exploration

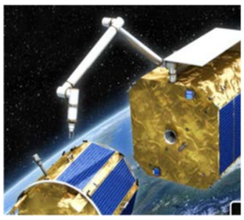
- EXOMARS indoor test facility
    - Image processing and digital modeling
    - Terra-mechanics experiments
    - ExoMars Breadboard

- Outdoor test facility
    - Cooperative, heterogeneous teams of mobile robots
    - Verification of localization, planning,
    - Experimentation for autonomous operation and communication
    - Outdoor validation



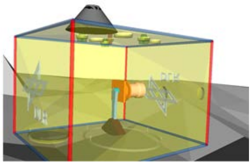
Common Technologies and Robotics Building Blocks: Actuators and Sensors


ROKVISS


DEOS


ROVER


DEXHAND (ESA)


MASCOT


ROBOSAT

Summary & Mission

- The main purpose of space robotics is
  - to *increase mission success* by automated processes
  - to enhance space missions by *reducing risks and costs*
- Missions
  - ***„Enable robots to go where scientists want to go by moving instruments, labs, and tools similar to geologists do on earth!"***
  - ***„Extend the Human arm in space to clean orbits and enable near earth missions„***
- Technology transfer to terrestrial applications to add value to society
  - Medical Robotics
  - Human-Robot Cooperation
  - Search and Rescue Robotics

Future Challenges

- Computing Plattform
- Tools and mechatronic components for OOS
- Payload/Instrument interface
- Autonomy of systems
- Robot teams
- Mobility for difficult terrain