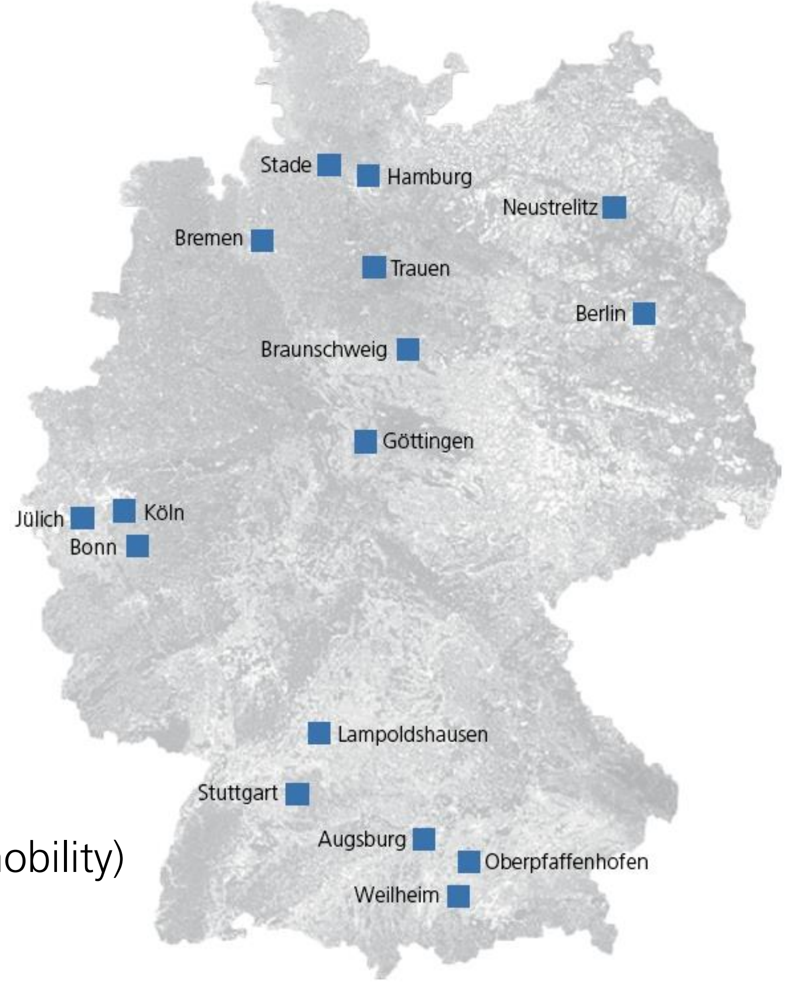
From Space to Terrestrial Application Domains of Robotics Research

Julian Klodmann
Institute of Robotics and Mechatronics
German Aerospace Center

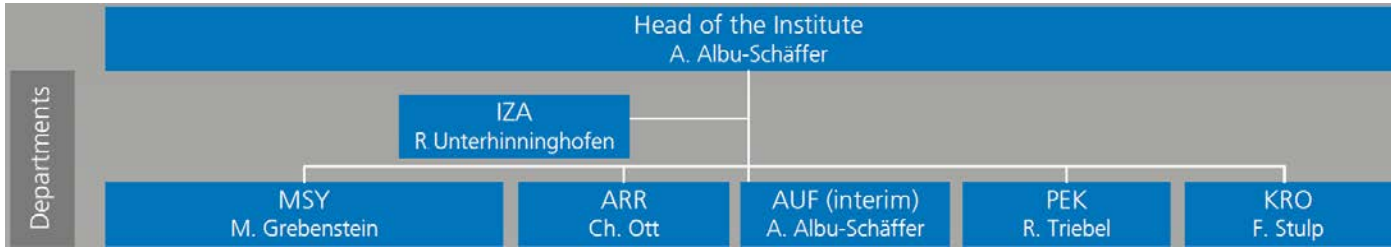
German Aerospace Center (DLR)

- Key research topics
  - Aeronautics (performance, ecologics, safety of flight systems)
  - Space (exploration, zero gravity, observation, communication, navigation, transport)
  - Energy (renewable energies and efficiency, supply reliability, energy storage)
  - Transport (mobility for humans and goods, economy, safety, environment protection)
  - Digitalization (economy, big and smart data/data science, cyber security, intelligent mobility)
  - Security (aviation, space, energy and transportation)
  - German Space Administration



- In numbers
  - ~8000 employees
  - 33 institutes and facilities
  - 20 locations in Germany

Institute of Robotics and Mechatronics
Structure & Application Domains

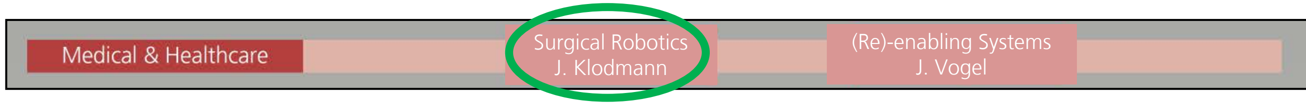


- 6 departments subdivided into expert groups
  - *Mechatronic Systems (MSY)*
  - *Analysis and Control of Advanced Robotic Systems (ARR)*
  - *Autonomy and Teleoperation (AUF)*
  - *Perception and Cognition (PEK)*
  - *Cognitive Robotics (KRO)*
  - *Institutes Development and Central Tasks (IZA)*

- 7 research domains
  - *3 space application domains*

  transferring technology bilaterally with

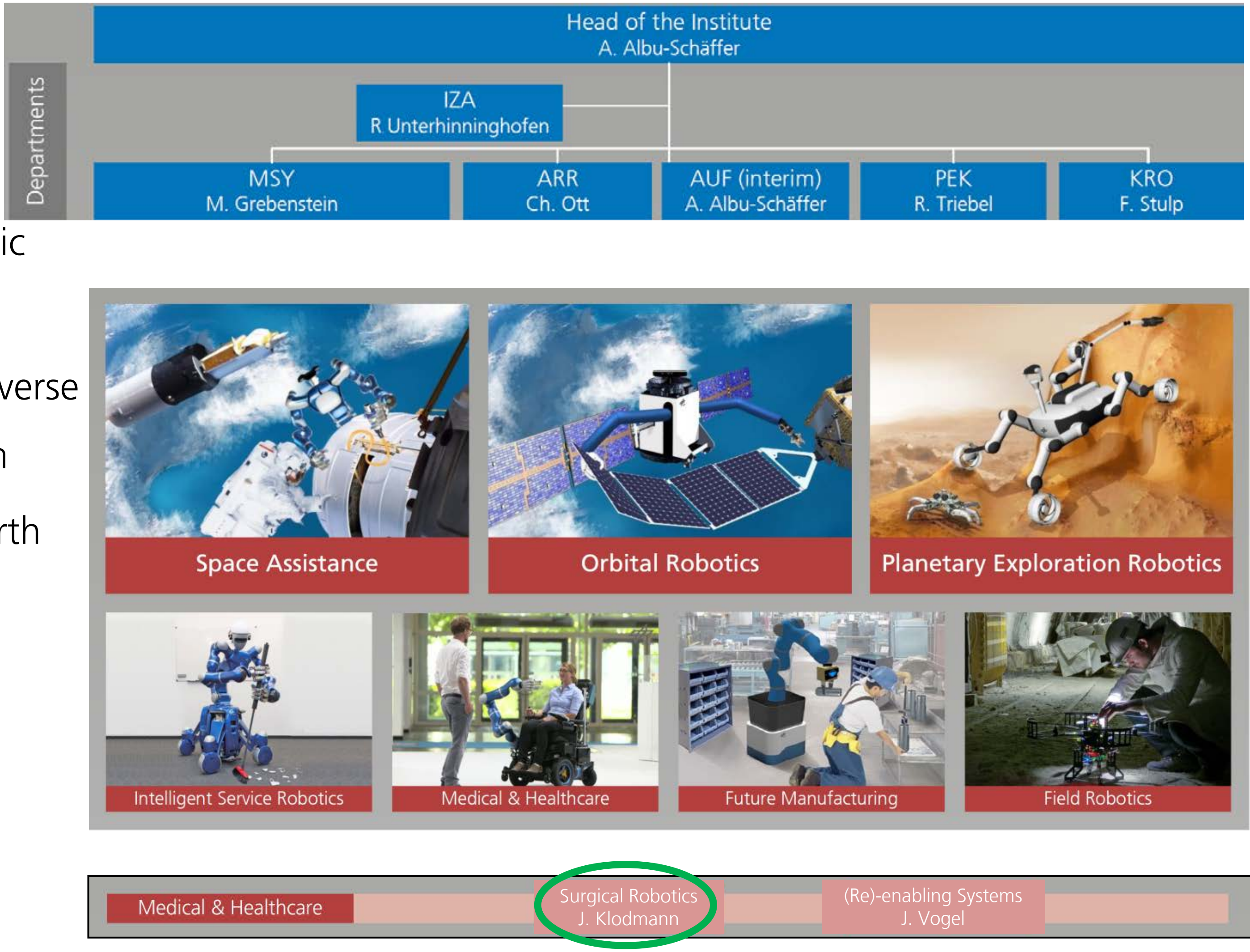
  - *4 terrestrial domains*



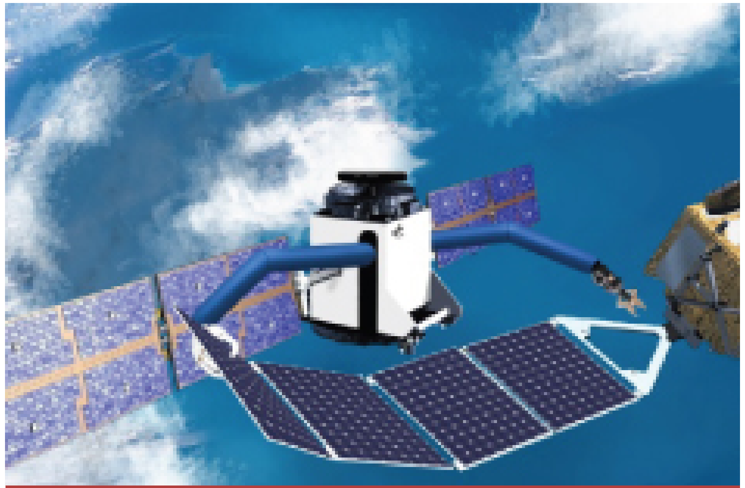
Institute of Robotics and Mechatronics
Vision and Mission

Three main fundamental aspects:

- Methodical developments in robotics and functional understanding of human skills in order to advance robotic manipulation, locomotion, and assistance
- Contributing technically to the understanding of the universe through robotic exploration of bodies in our solar system
- Assembly and maintenance of space infrastructure in Earth orbit
- Addressing major societal challenges:
    - Health-care
    - Aging society
    - Industrial competitiveness
    - Electro-mobility and unmanned flying systems



Application Domains


Orbital Robotics


Space Assistance

Planetary Exploration


Future Manufacturing

Intelligent Service Robotics

Medical & Healthcare

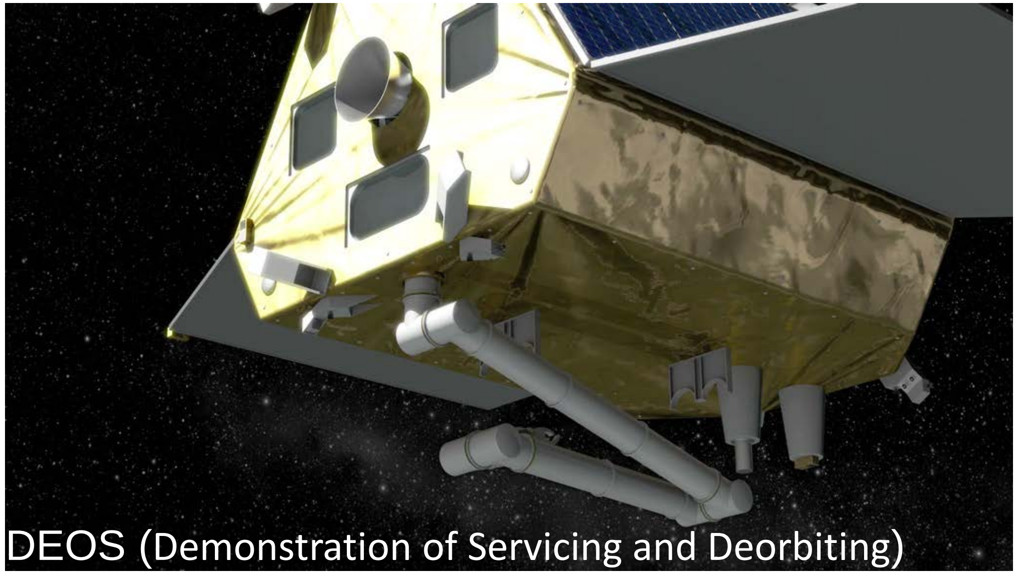

Field Robotics

Orbital Robotics

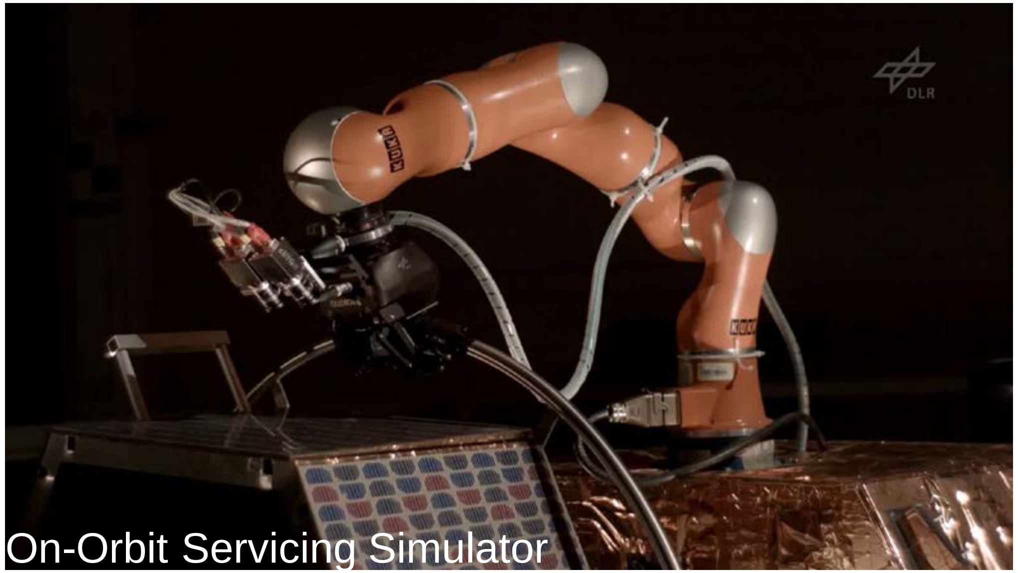
Robotics offer a scalable technology for:

- tasks on space infrastructure such as
  - orbital relocation
  - space debris removal
  - refueling, servicing, repair

- complex assembly and assistance tasks
  - modular satellites, large space structures
  - next ISS, Moon or Mars orbiters



DEOS (Demonstration of Servicing and Deorbiting)



On-Orbit Servicing Simulator

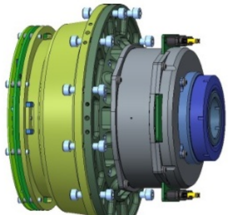
Orbital Robotics

Robotic Systems for Space Applications

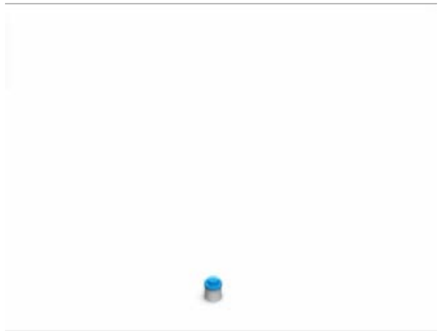
- DLR develops the robotic system CAESAR (Compliant Assistance and Exploration SpAce Robot) as core asset
- Multi-purpose design for LEO, GEO and deep space exploration

- SPACEHAND – first multi-finger hand for use in free space
- Can handle most EVA-tools used by ISS astronauts
- Baseline-component for unexpected tasks such as
  - handling of MLI foil, cables, etc.

ROKVISS-heritage
6 years of operation on ISS



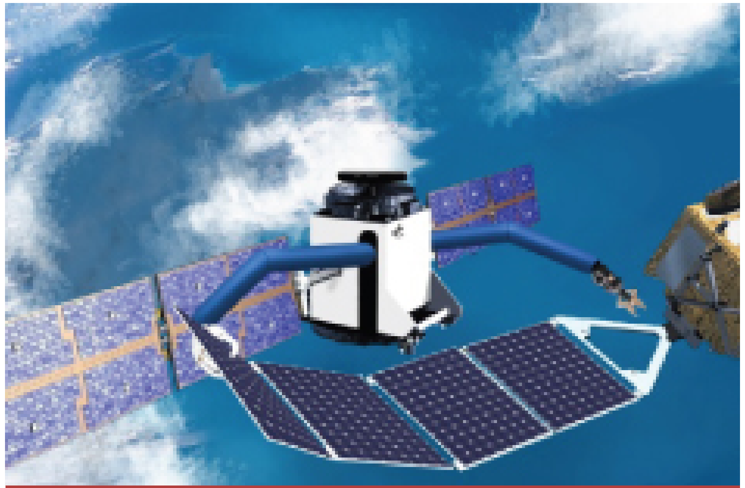
Modular joint concept



different kinematic configurations for various applications

DLR

Application Domains


Orbital Robotics


Space Assistance

Planetary Exploration


Future Manufacturing

Intelligent Service Robotics

Medical & Healthcare


Field Robotics

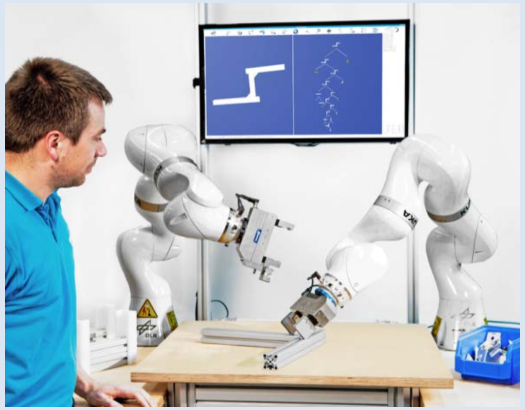
Future Manufacturing

- greater flexibility, increasing individualization, customization of products, shorter product life-cycles

Reconfigurable Work Cell

Collaborative Workbench

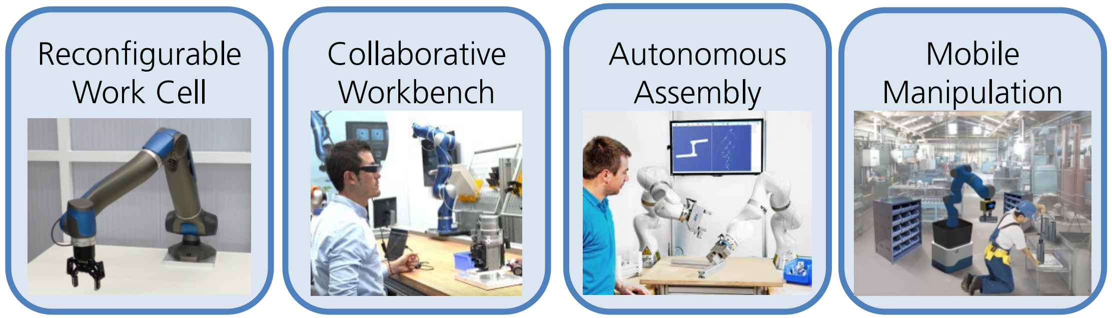
Flexible Autonomous Assembly



Autonomous Mobile Manipulation

Future Manufacturing

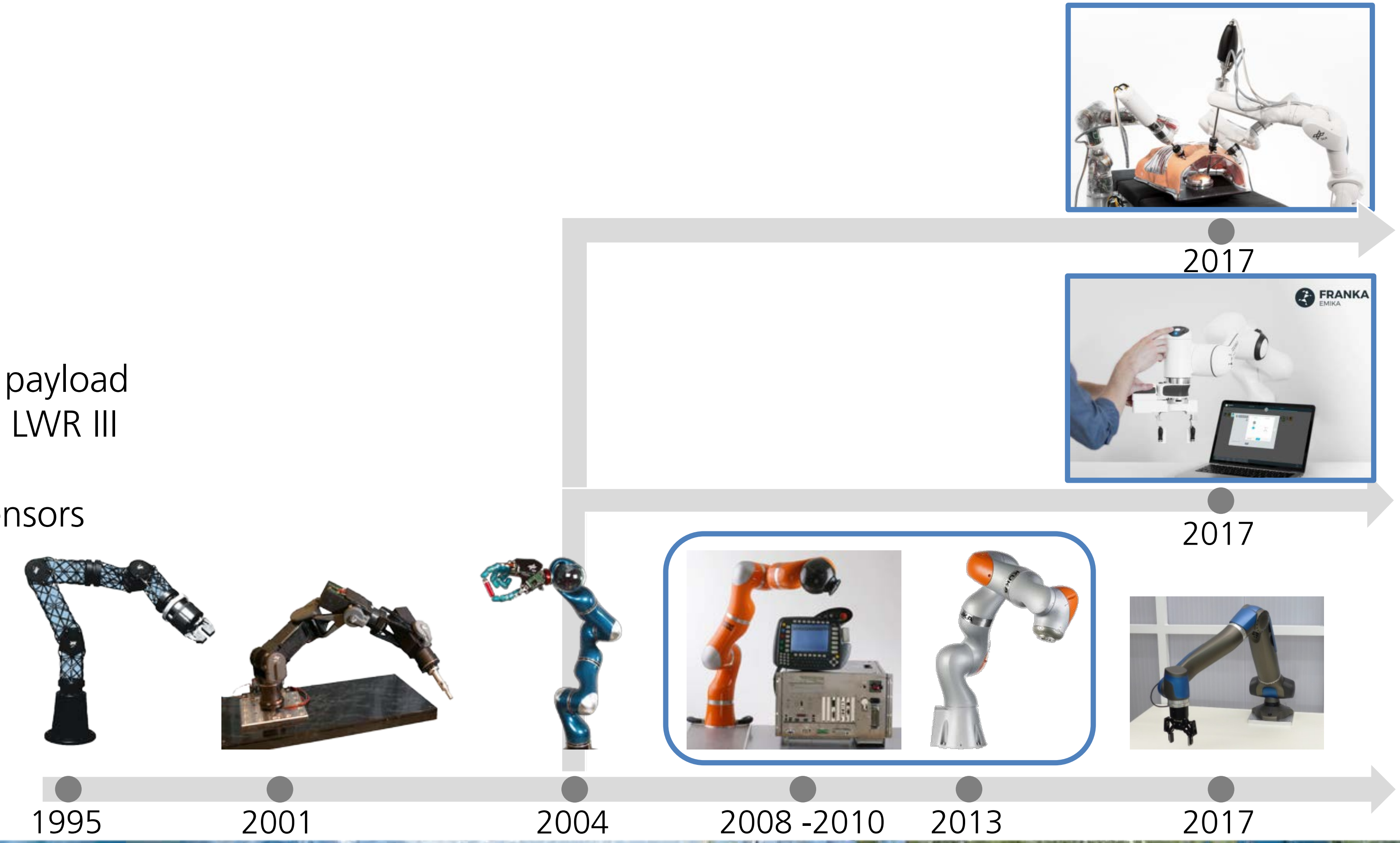
Robotic Technology



- technological driver – development of the new DLR lightweight robot SARA (Safe, Autonomous Robotic Assistant)

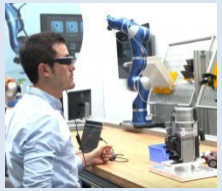
- some key features:
  - 2x max. velocity of LWR III with 12 kg payload
  - >> Cartesian workspace volume w.r.t. LWR III
  - force & trajectory teaching
  - self-configurable tools and (optical) sensors

  - reusability, modularity and safety as guidelines through development



Reconfigurable Work Cell

Collaborative Workbench



Autonomous Assembly

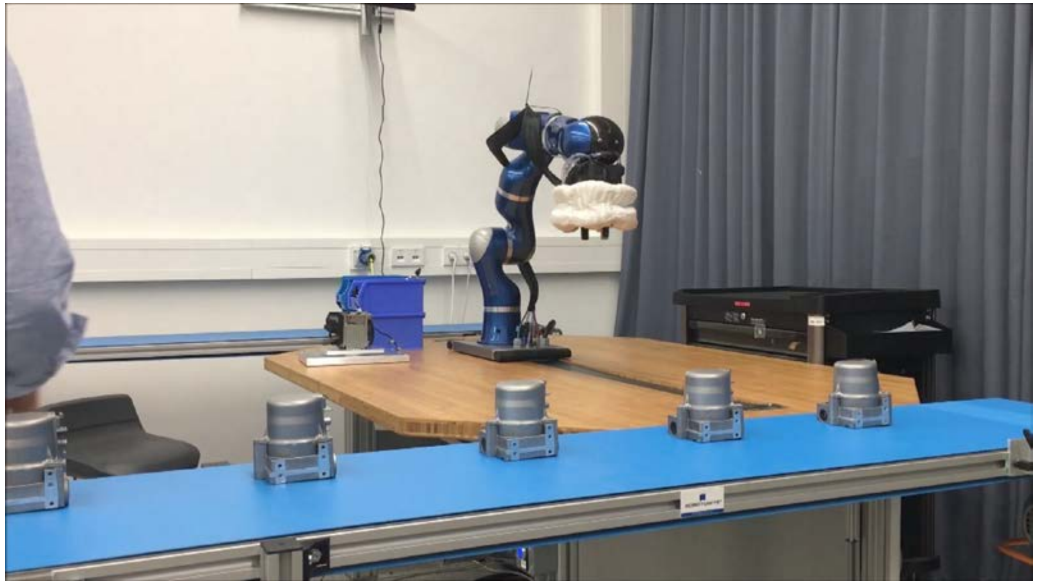
Mobile Manipulation

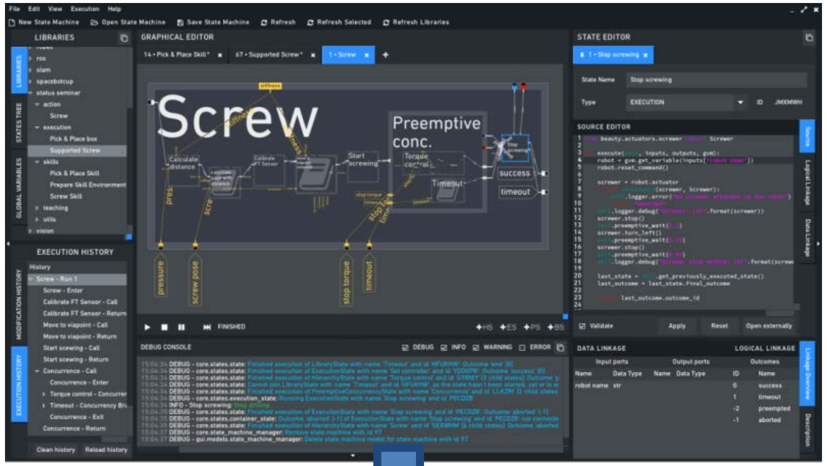
Future Manufacturing

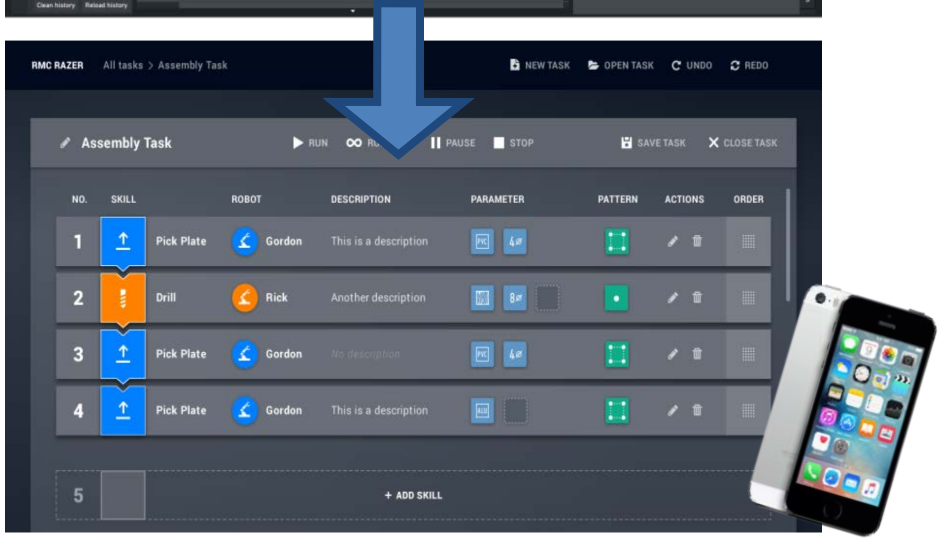
Collaborative Workbench & Intuitive Programming

- Software-Framework for flexible, hands-on programming of skills
  - RAFCON – flexible, modular and hierarchical flow control for experts
    Specification and Development of libraries with robotic skills
  - RAZER – simple, intuitive programming by user

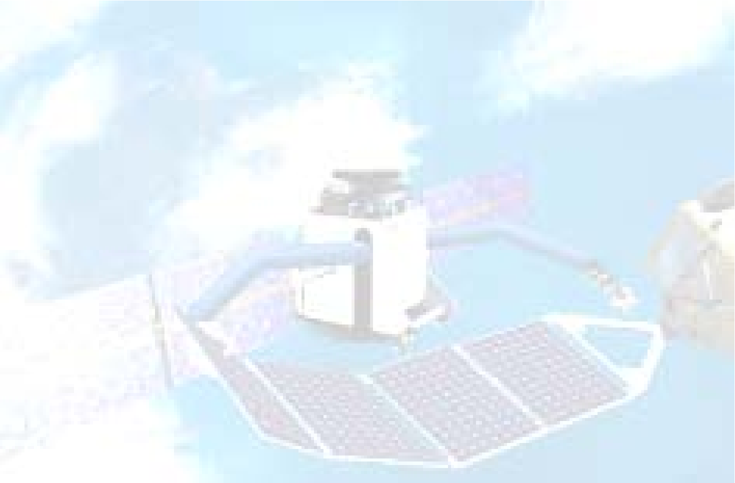
- Central Contribution to Human Robot Collaboration
  - new ISO-TS 15066 for robotic safety
  - development of safety mechanisms, e.g. robotic airbag
  - concepts for safety certification of robotic workcells





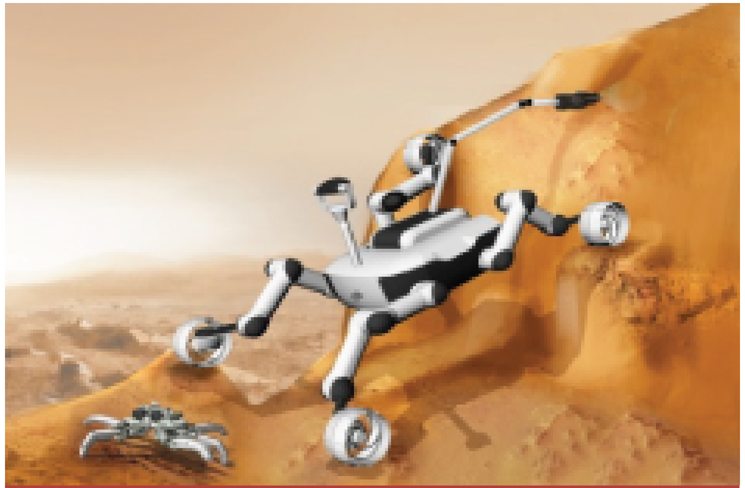


Application Domains



Orbital Robotics

Space Assistance



Planetary Exploration

Future Manufacturing

Intelligent Service Robotics

Medical & Healthcare

Field Robotics

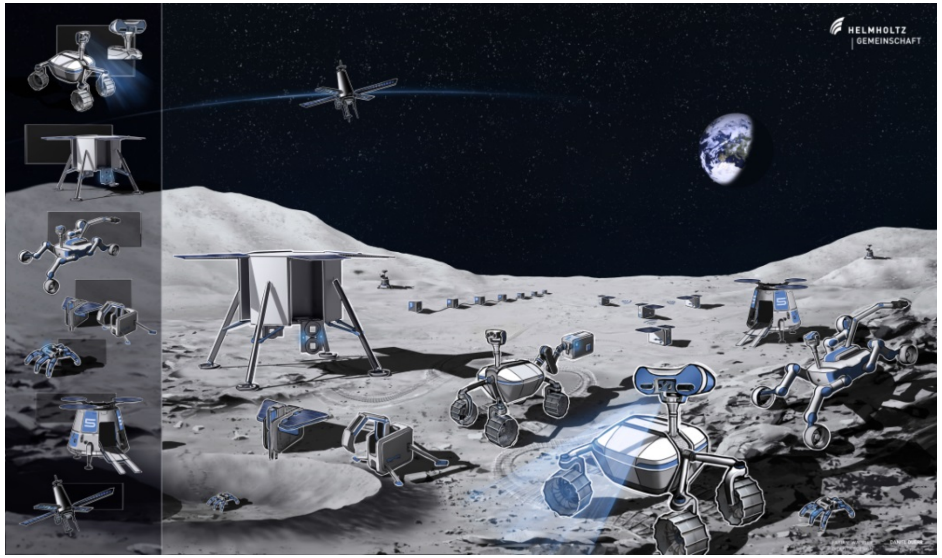
Planetary Exploration

- development and deployment of mobile system, e.g. rovers and legged robots

- hardware designs for mobility in unstructured/unknown extraterrestrial terrain
  - mass and sizes
  - sensors and actuators suitable for extraterrestrial conditions
  - different scientific tools

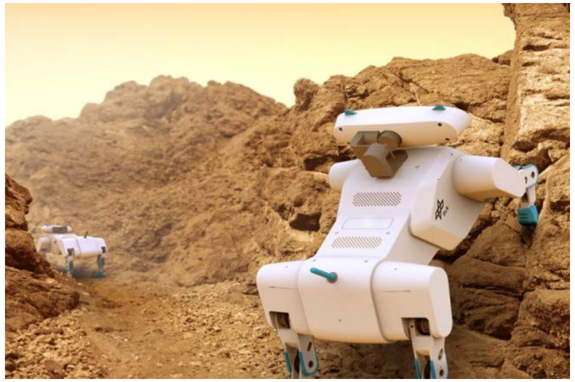
- complex scenarios, where multiple robotic systems collaborate demands a high level of autonomy, due to significant communication delays

- key scientific domains
  - perception
  - navigation
  - localization
  - object manipulation



Mobile manipulator

TransRoPorter

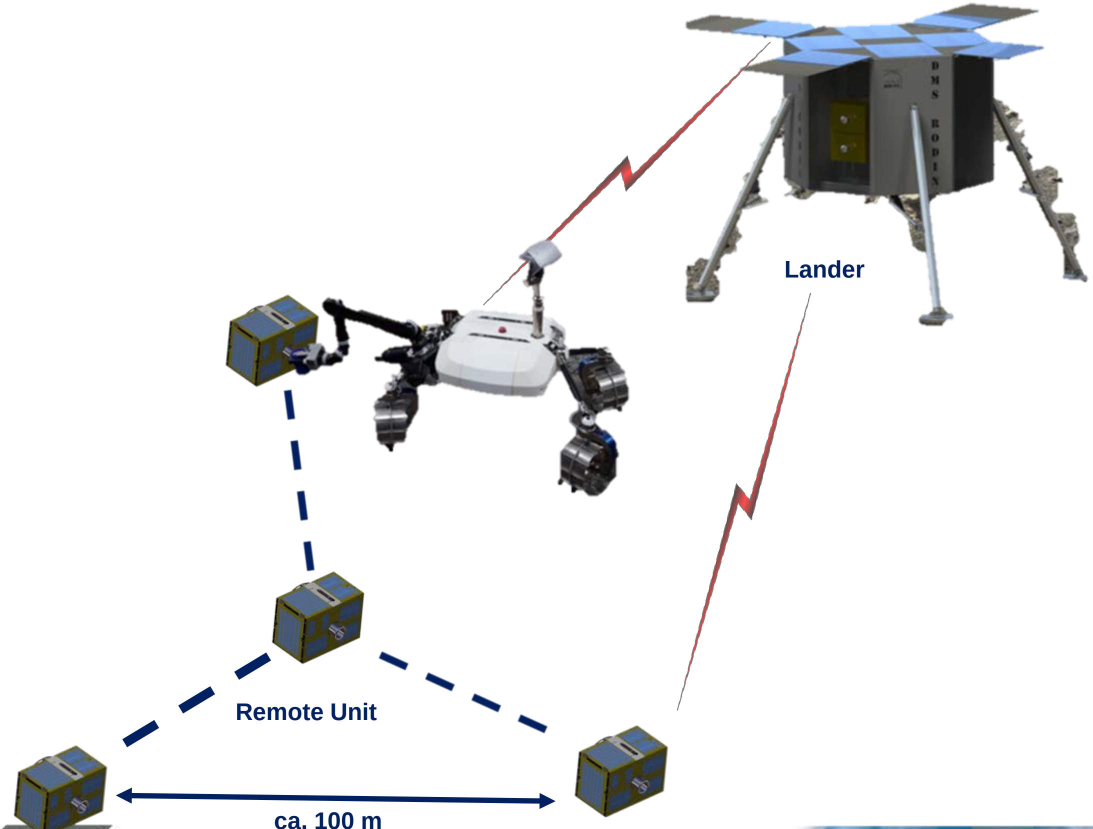


quadruped Bert

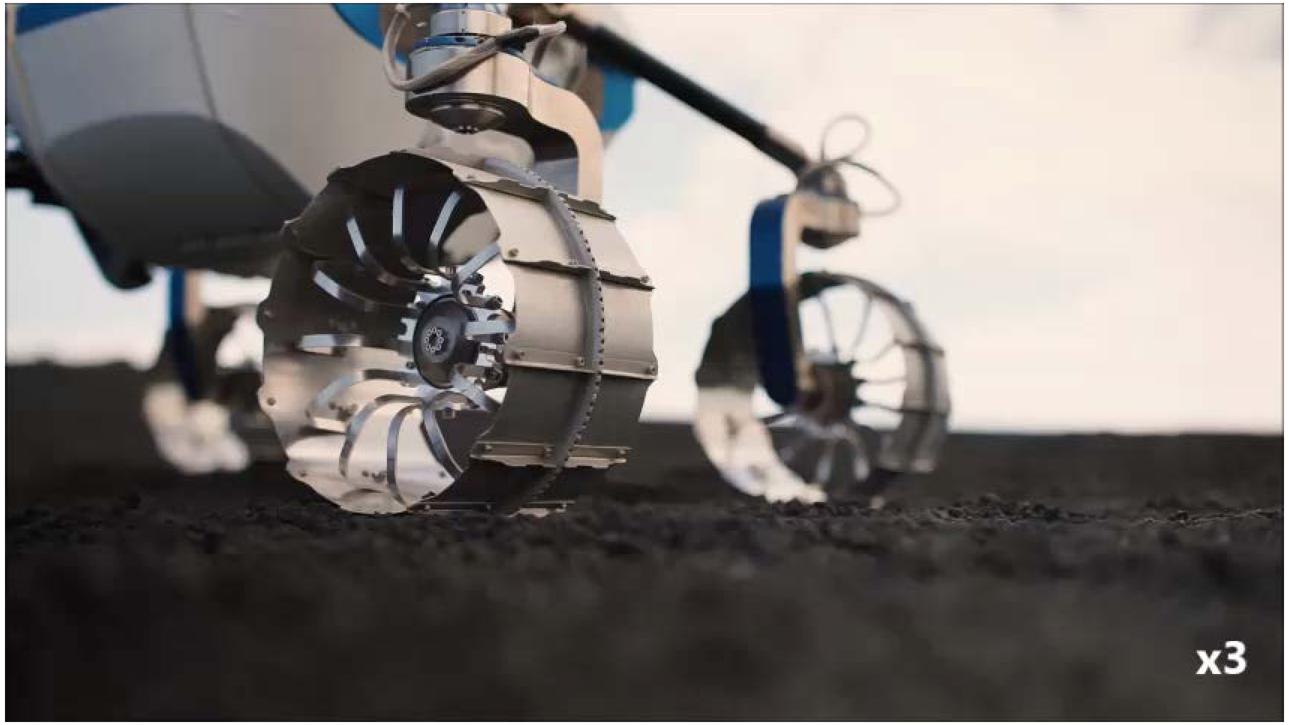
Planetary Exploration

ROBEX – Robotic Exploration of Extreme Environments

- lunar mission demonstrator in analog environment
- scientific task: precise deployment of seismometer formation for researching the geological properties of the moon



Mt. Etna, Sicily



final experiment: September 2017
first demonstration: June / July 2016
new project: teams of cooperative robots

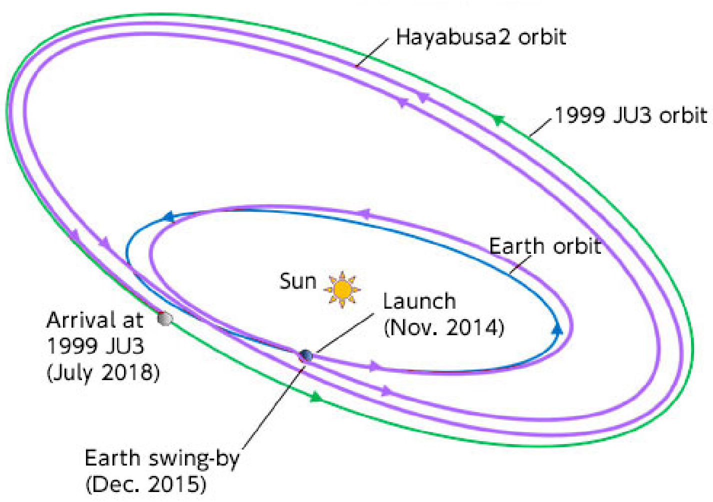
Planetary Exploration

Mobility Concept for the MASCOT-Lander, Part of the JAXA Hayabusa-II Mission

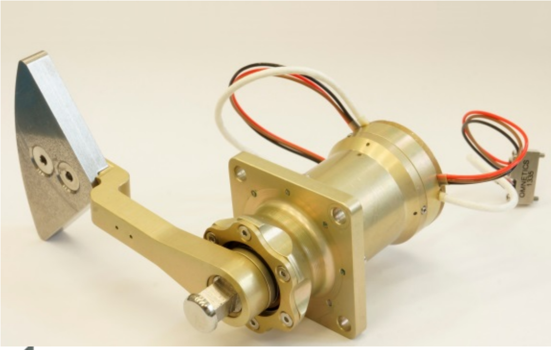
- Mobile Asteroid Surface Scout (MASCOT)

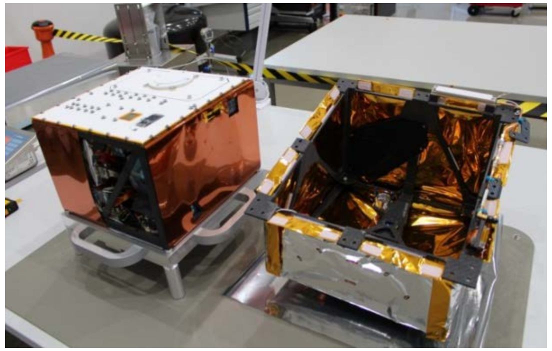
- Robotic mobility unit (10 kg)
    - mechatronics, dynamics, mobility experiments

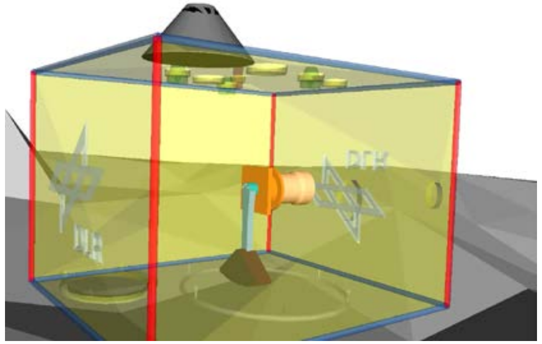
- Asteroid 1999 JU3
    - very low gravity
    - escape velocity 30cm/s



- All health-checks and calibration trials were successful so far

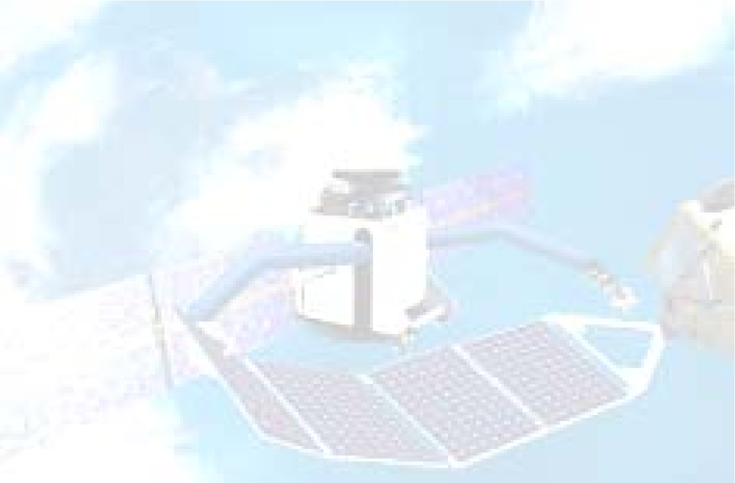




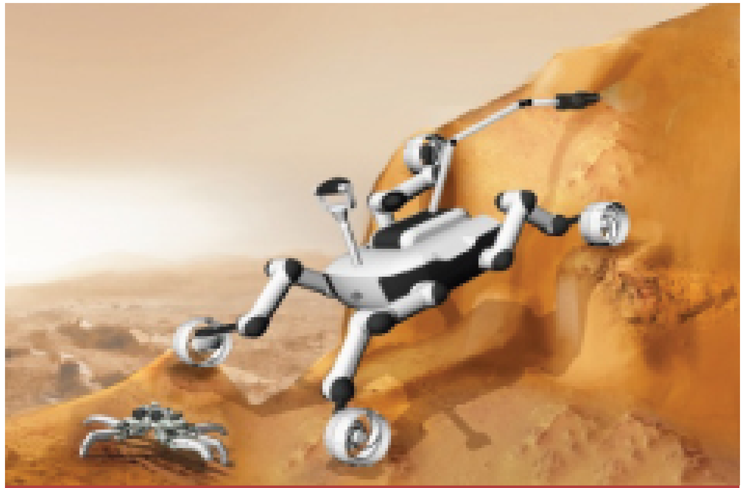


DLR

Application Domains


Orbital Robotics


Space Assistance


Planetary Exploration


Future Manufacturing

Intelligent Service Robotics


Medical & Healthcare


Field Robotics

Field Robotics

- (collaborative) robotic systems to manage
  - post-catastrophic scenarios
  - search & rescue scenarios
  - industrial inspection & maintenance
  - environmental monitoring
  - communication

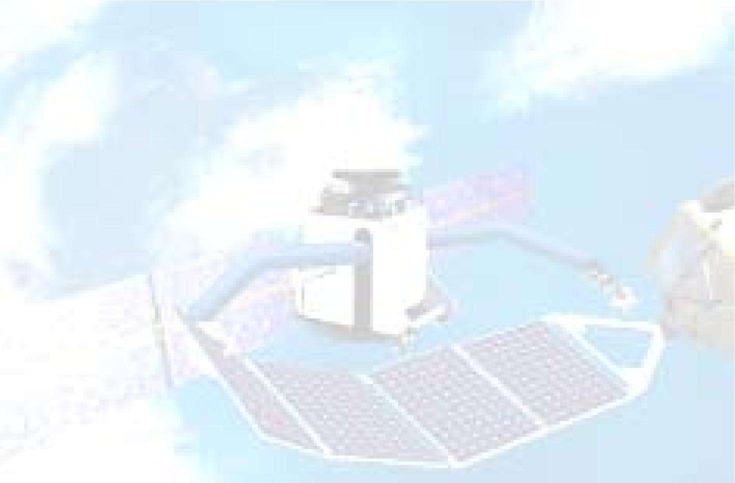
- research areas
  - aerial manipulation
  - high-altitude platforms (HAPs)
  - landing of UAS on mobile platforms
  - modular autopilot systems
  - autonomous multicopters

Aerial Manipulation

Autonomous Multicopters

DLR

Application Domains


Orbital Robotics


Space Assistance

Planetary Exploration


Future Manufacturing

Intelligent Service Robotics

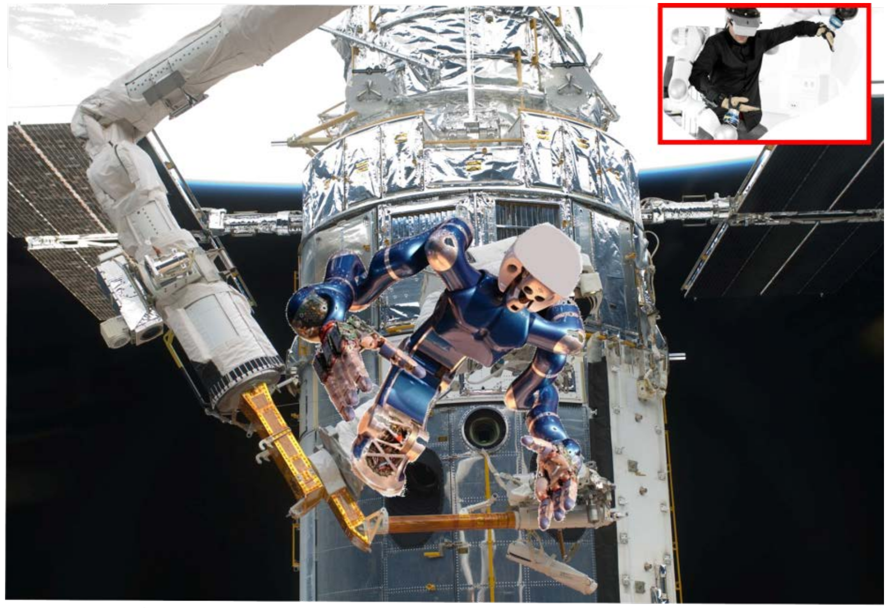
Medical & Healthcare

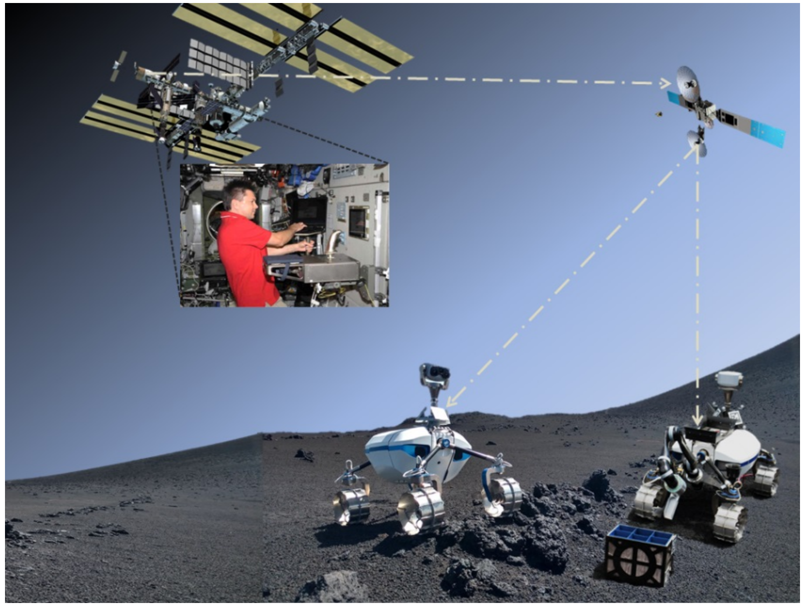

Field Robotics

Space Robot Assistance

From Immersive Feedback Telepresence to Full Autonomy

- Development and validation of
  - infrastructure for robot teleoperation in Earth orbit, from ground or from a space station (ISS, later Planetary Orbiter, etc.)
  - assistance robots for planetary exploration
  - astronaut support for long term missions



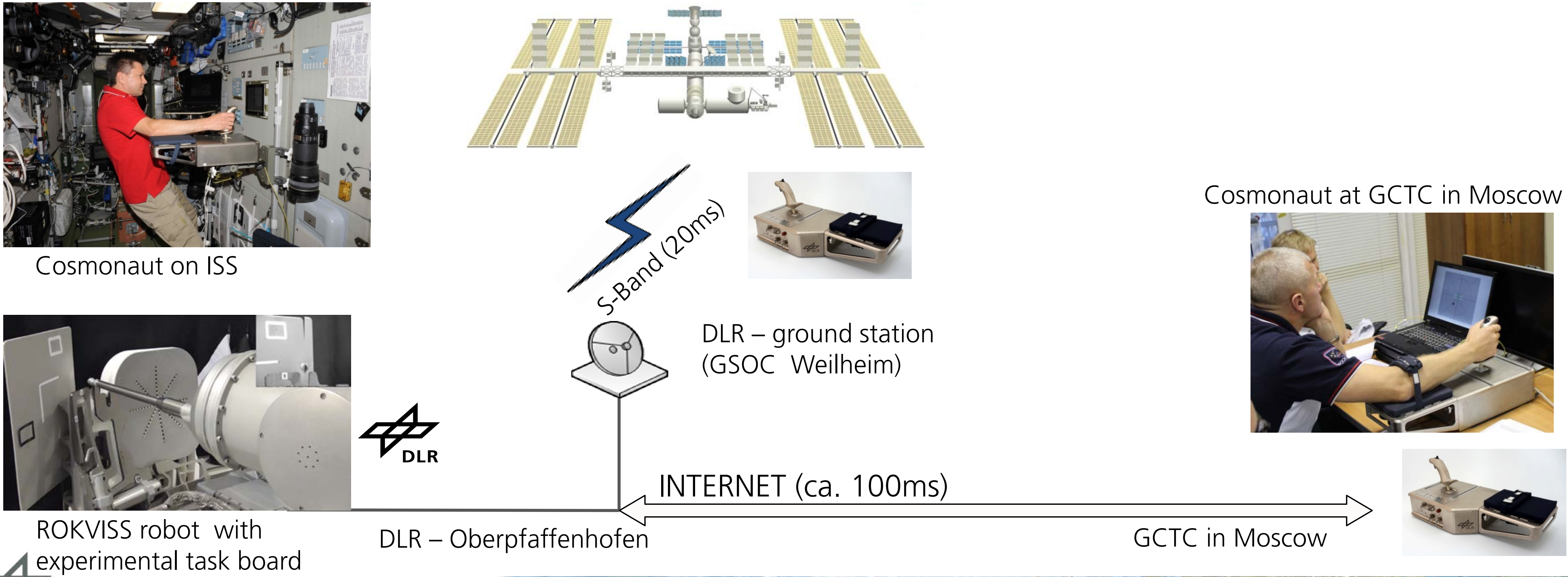


Space Robot Assistance – Kontur 2 (Germany/Russia)

1st Experiments on Direct Teleoperation with Force Feedback from Space (ISS)

- 1st ergonomic and performance tests on interactive tasks
  - Lower performance at µg compared to 1g
  - The effect can be compensated by adaptation of virtual stiffness, damping and mass

2015-2017

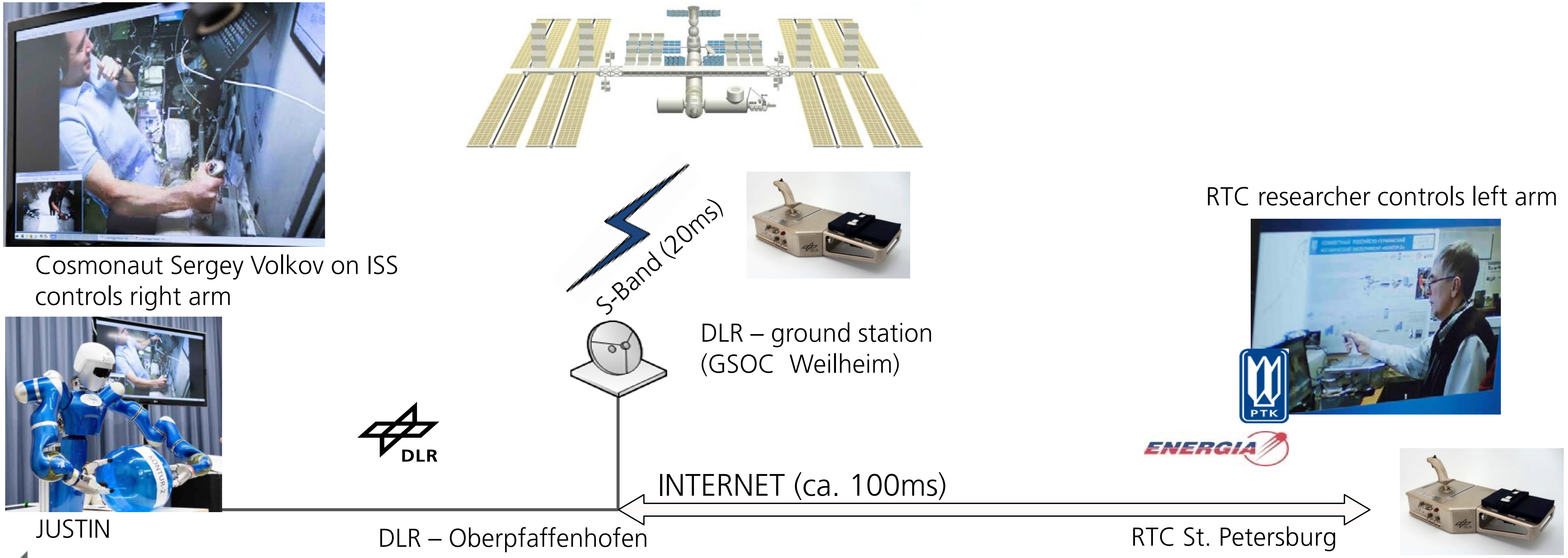


Space Robot Assistance – Kontur 2 (Germany/Russia)

1st Experiments on Direct Teleoperation with Force Feedback from Space (ISS)

- 1st ergonomic and performance tests on interactive tasks
  - Lower performance at µg compared to 1g
  - The effect can be compensated by adaptation of virtual stiffness, damping and mass

2015-2017

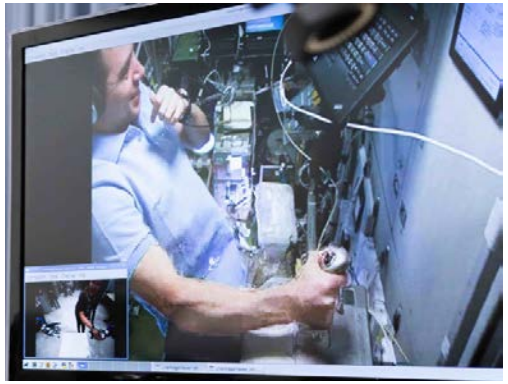


Space Robot Assistance – Kontur 2 (Germany/Russia)

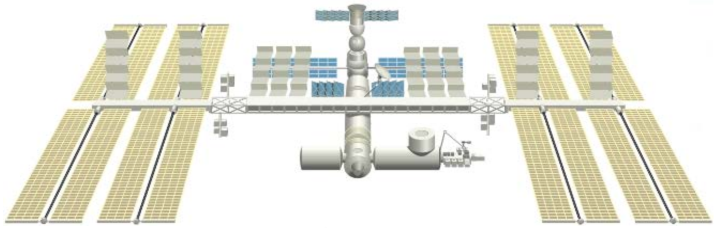
1st Experiments on Direct Teleoperation with Force Feedback from Space (ISS)

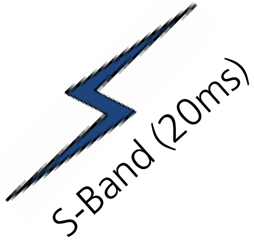
- 1st ergonomic and performance tests on interactive tasks
  - Lower performance at µg compared to 1g
  - The effect can be compensated by adaptation of virtual stiffness, damping and mass

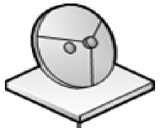
2015-2017



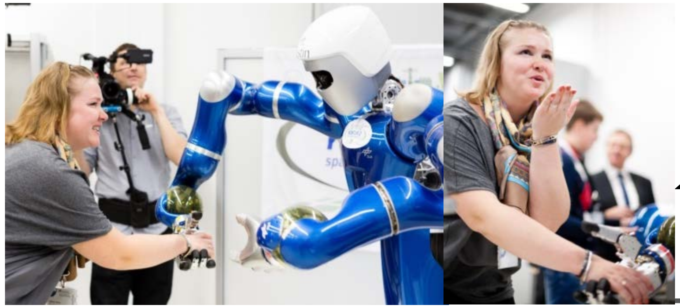
Cosmonaut Sergey Volkov on ISS controls right arm





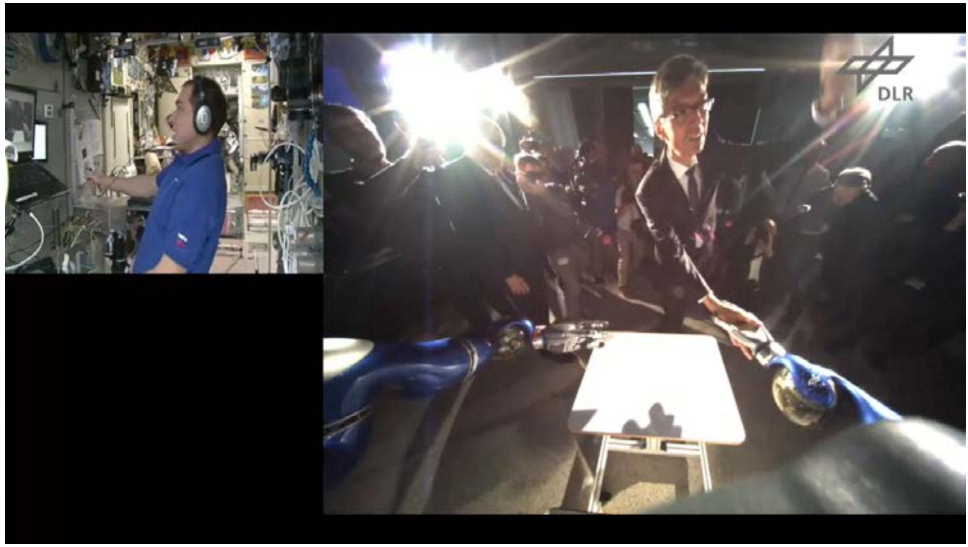


DLR – ground station (GSOC Weilheim)



Mrs. Volkova

DLR – Oberpfaffenhofen

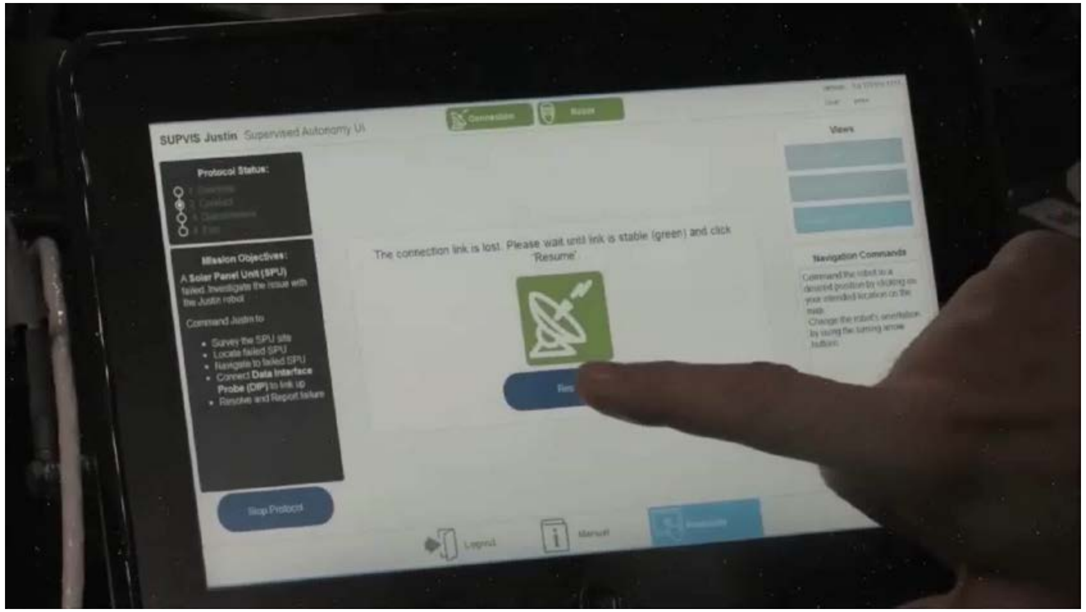


Space Robot Assistance – METERON (DLR/ESA/NASA)

Multi-purpose End-To-End Robotic Operations Network

Space Robot Assistance – METERON (DLR/ESA/NASA)

1st teleoperation of an intelligent, semi-autonomous humanoid robot from ISS



ISS crew session 1: August 25, 2017
- Concept validation
  Supervised Autonomy

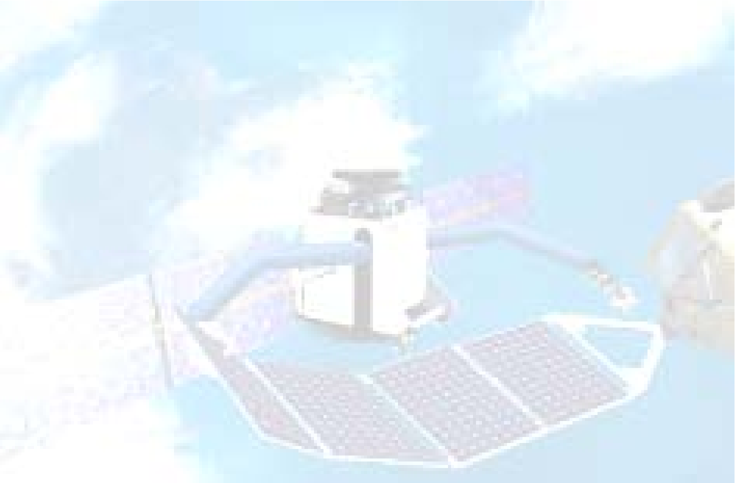
ISS crew session 2: Increment 54
- Dexterous object manipulation

ISS crew session 3: Increment 56/57
- Device retrieval and installation

2017/08 2018/02 2018/H2

DLR

Application Domains



Orbital Robotics

Space Assistance

Planetary Exploration

Future Manufacturing

Intelligent Service Robotics

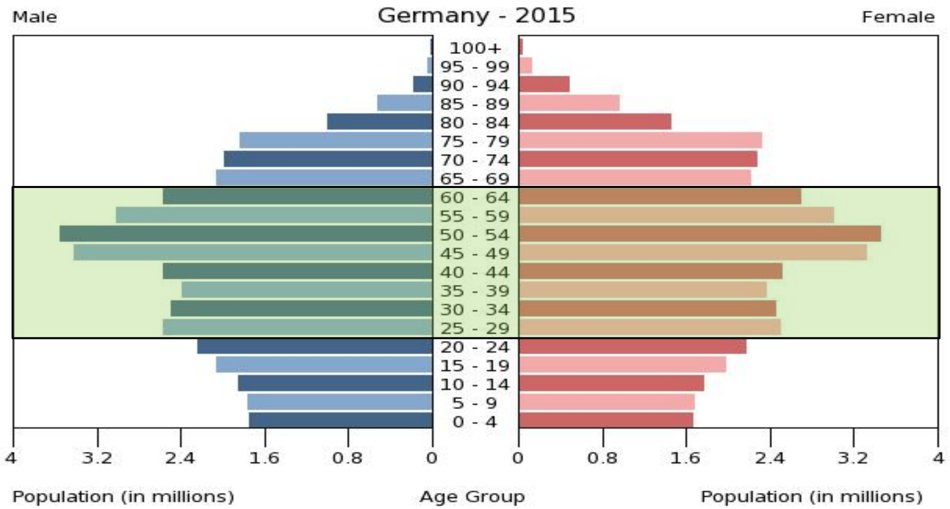
Medical & Healthcare

Field Robotics

Intelligent Service Robotics – SMILE

Technology Transfer for Support to Elderly and Disabled People

- Addressing major societal challenges with space robotics technology



Family member

Intuitive teleoperation by smart-phone or tablet-pc

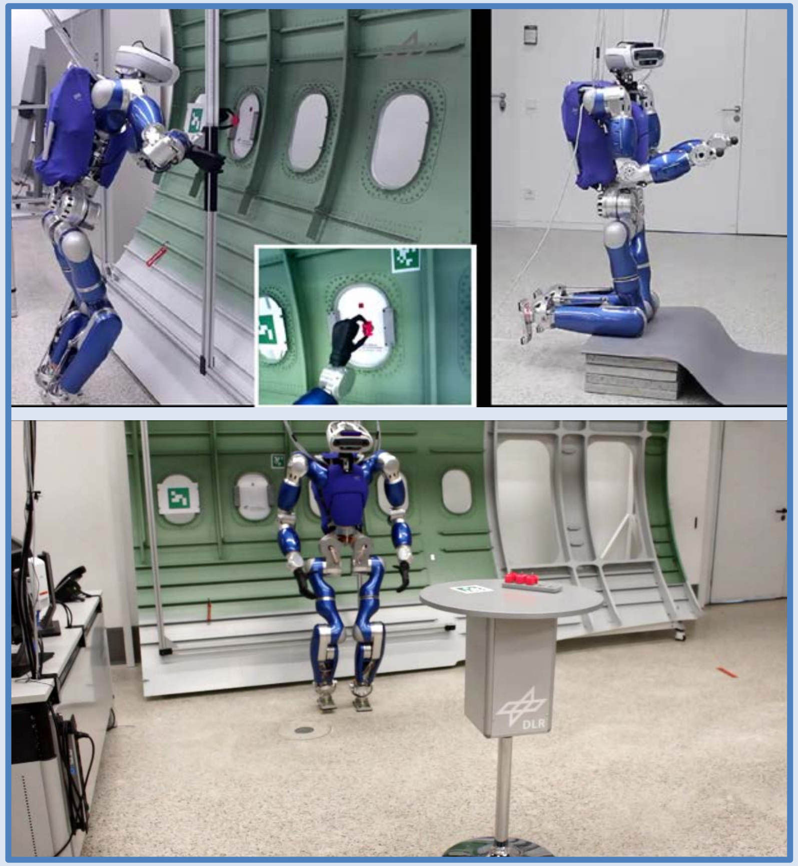
Operator

Haptic telepresence by a remote expert

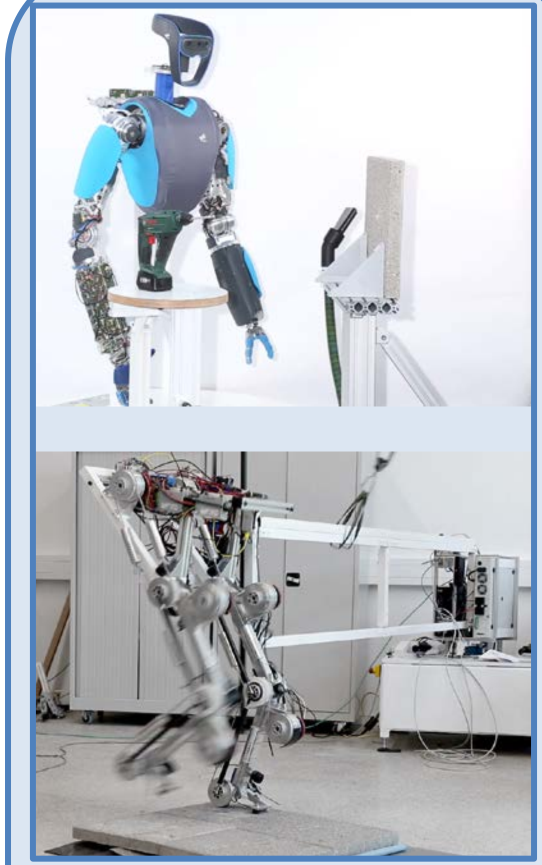
gefördert von
Bayerisches Staatsministerium für
Wirtschaft und Medien, Energie und Technologie

DLR

Intelligent Service Robotics
Technological Driver for Future Humanoid Robots

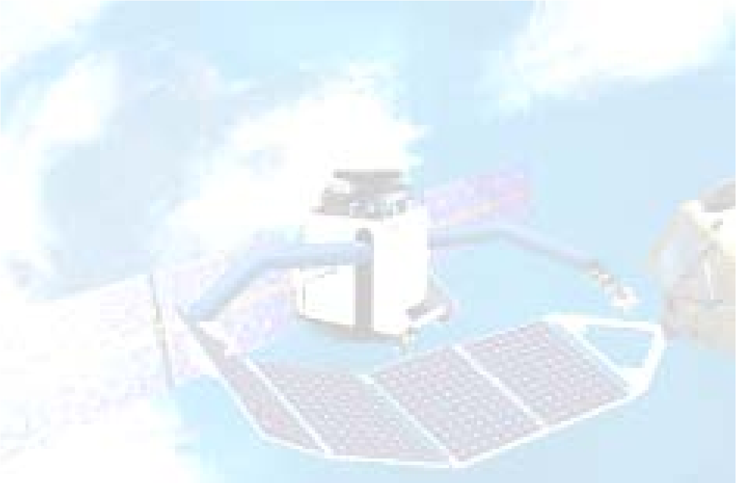


JUSTIN and TORO are based on
LWR III – Torque Controlled Flexible Joint Technology



DAVID and C-Runner are
based on SEAs and VSAs

Application Domains



Orbital Robotics

Space Assistance

Planetary Exploration

Future Manufacturing

Intelligent Service Robotics

Medical & Healthcare

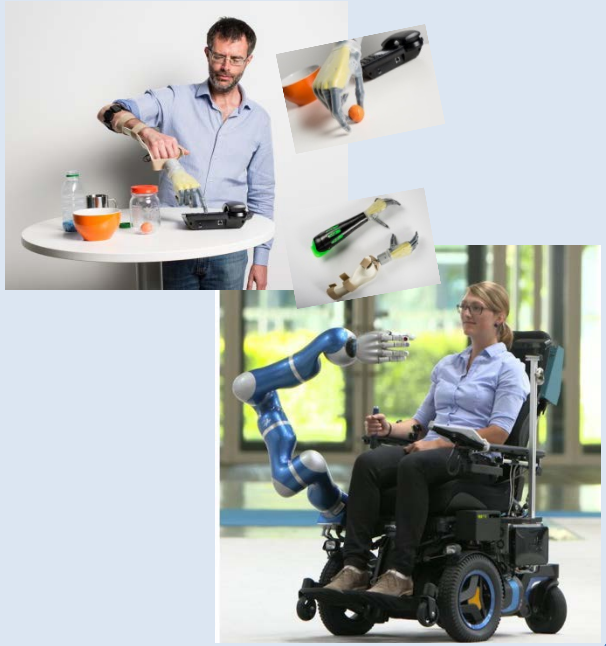
Field Robotics

Medical & Healthcare

- Utilizing of
  - Light-Weight Robotics Technology
  - Telemanipulation Methods
  - Shared and Autonomous Control Approaches

  to transfer into society with direct benefit

(Re-)enabling Systems

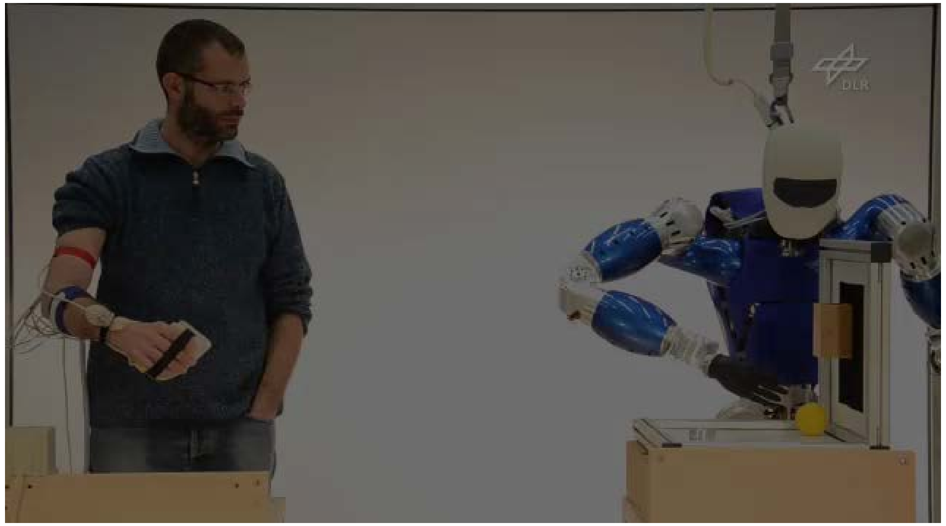


Surgical Robotics

Medical & Healthcare – (Re-)enabling Systems

Prosthetics and Assistive Robotics

- Telemanipulation based on bio signals
- Arm-, hand movements and interaction force can be derived from bio signals (EMG, brain currents)
- Support based on semi-autonomous functions (Shared Control) increases significantly the performance and reduces cognitive load



EMG-Interface for hand-position & hand-forces

EMG-Interface for arm-position & hand-actions

Medical & Healthcare

- Utilizing of
  - Light-Weight Robotics Technology
  - Telemanipulation Methods
  - Shared and Autonomous Control Approaches

  to transfer into society with direct benefit

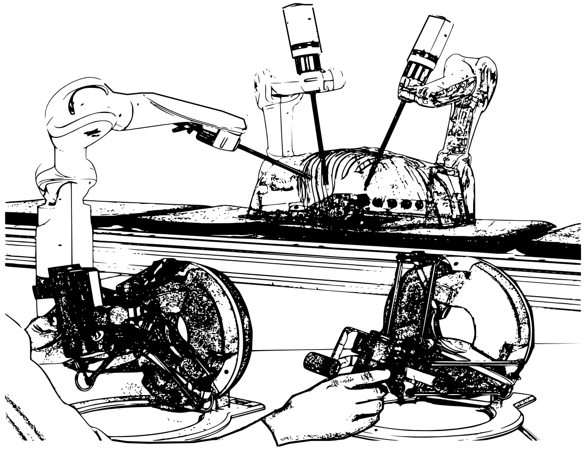
(Re-)enabling Systems

Surgical Robotics

DLR

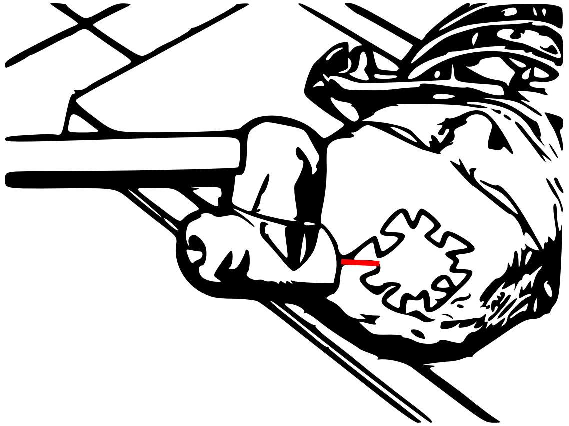
Medical & Healthcare – Surgical Robotics

- Modular and versatile platform for a range of surgical applications



Telepresence Applications

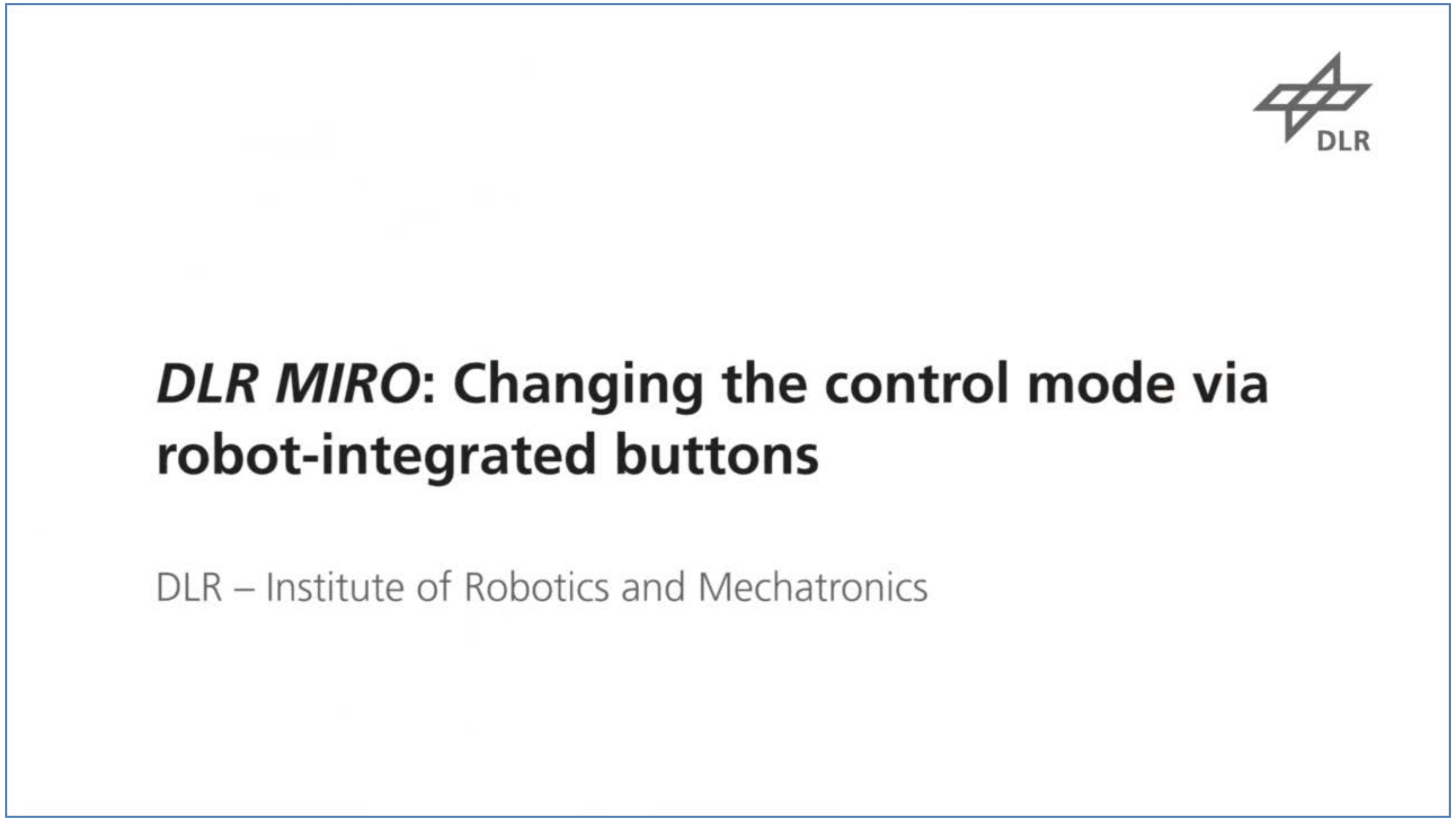
Shared-Control Applications



Autonomous Applications

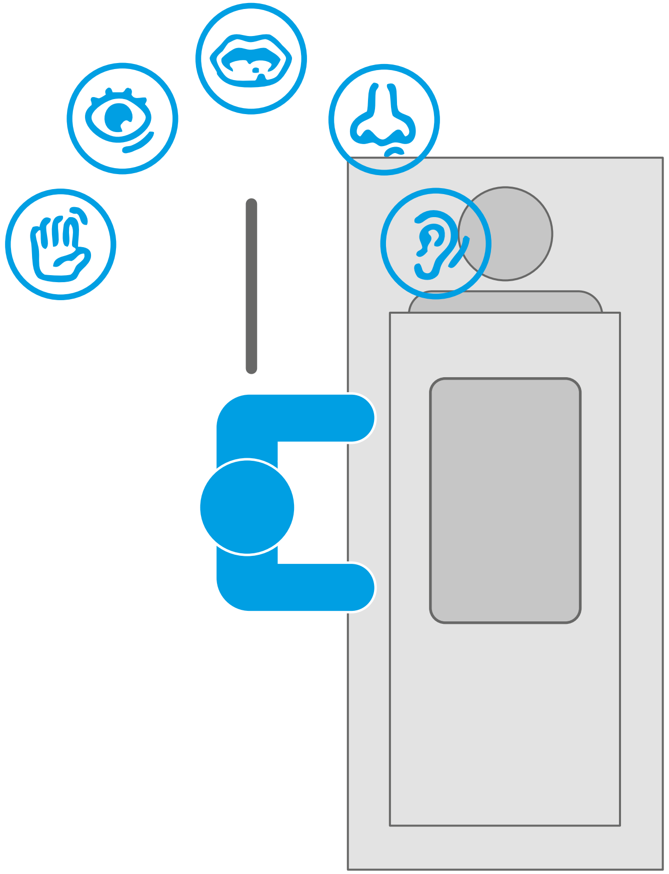
Medical & Healthcare – Surgical Robotics
Core Technology – Versatile Lightweight Robot MIRO for Medical Applications

- lightweight robot
  - payload 3 kg
  - weight 9,8 kg
- redundant, anthropomorphic kinematics
  - 7 DoF
  - length 1130 mm
  - optimized
- motor control cycle 96 kHz
- control cycle 3 kHz
- integrated electronics
- hollow wrist
- torque sensors

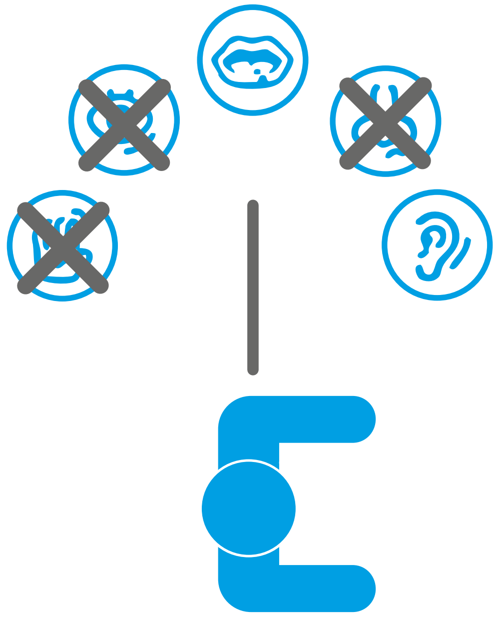


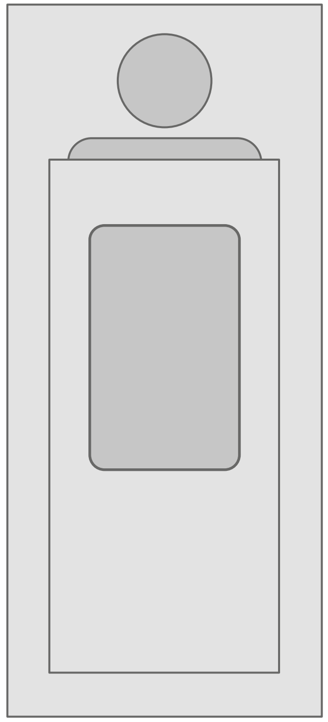
Specialization to different medical procedures by dedicated instruments

Robotic Assistance for Medical Diagnostics and Interventions

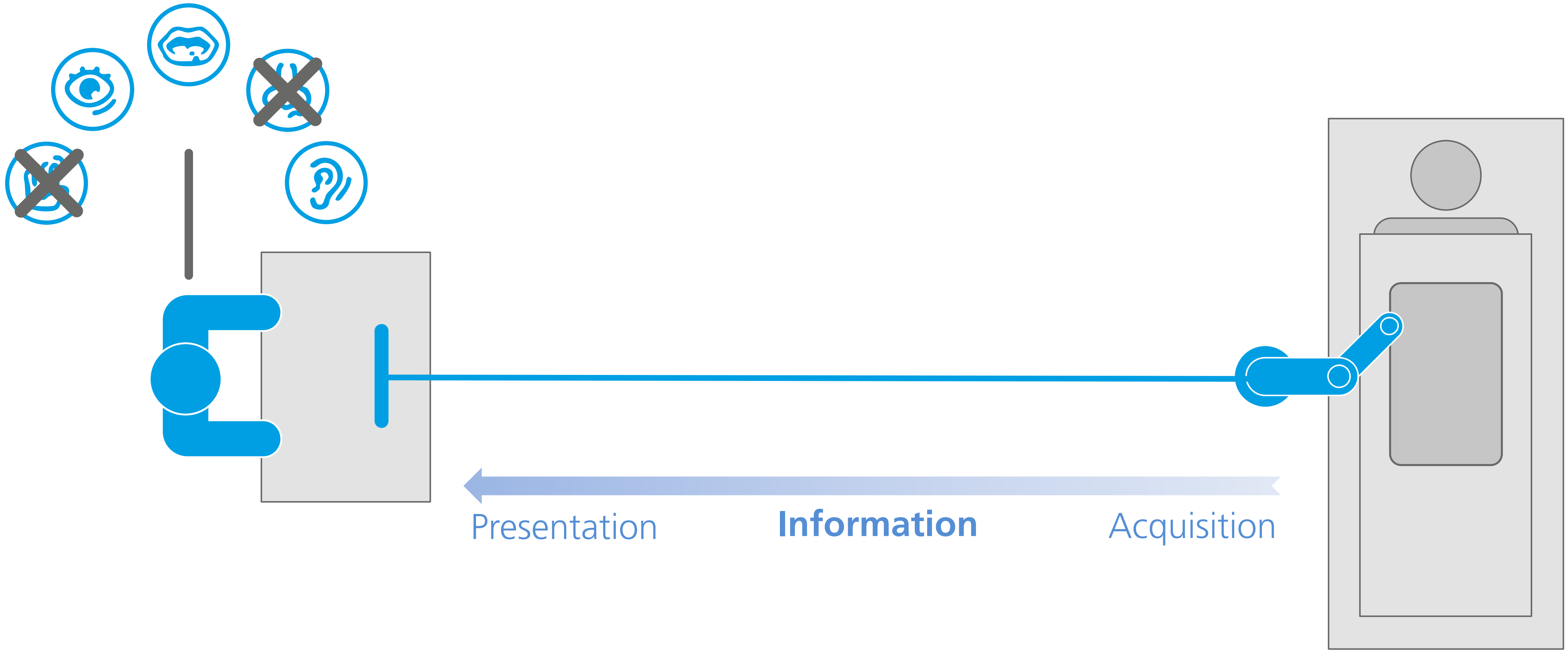


Robotic Assistance for Medical Diagnostics and Interventions

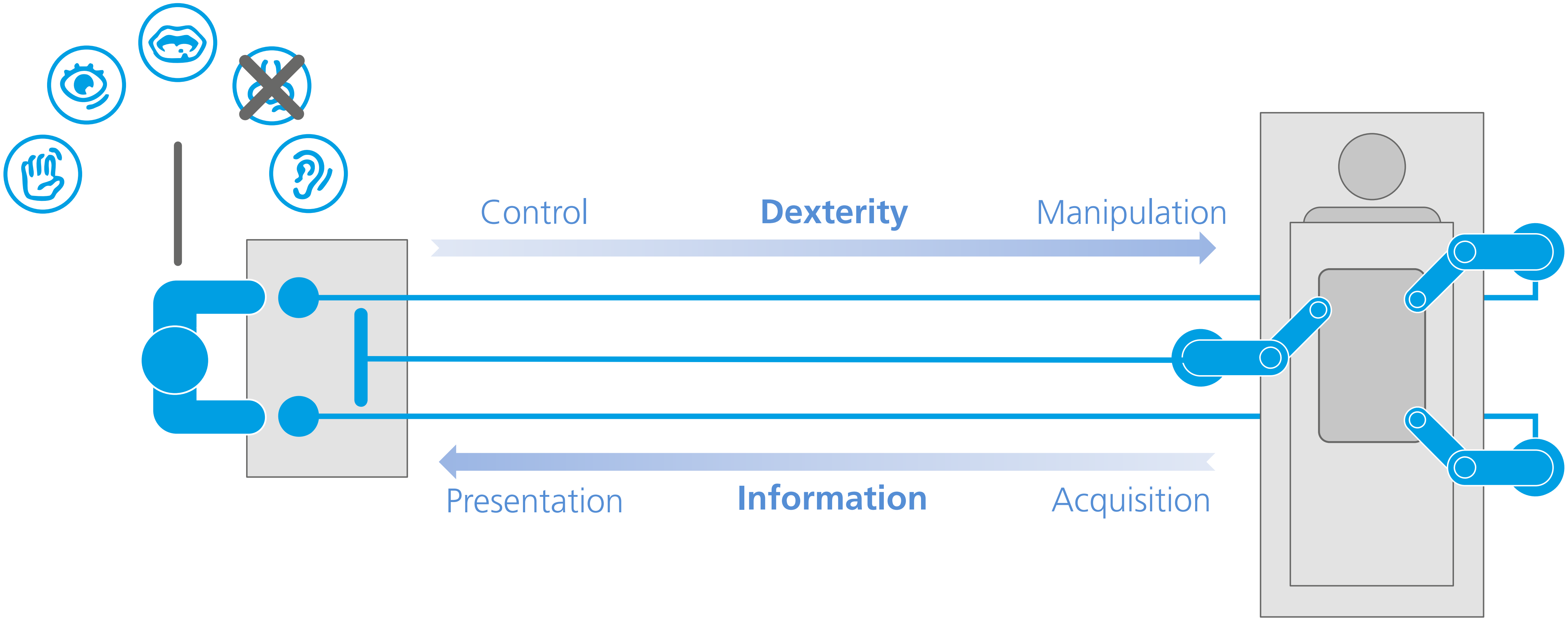




Robotic Assistance for Medical Diagnostics and Interventions



Robotic Assistance for Medical Diagnostics and Interventions



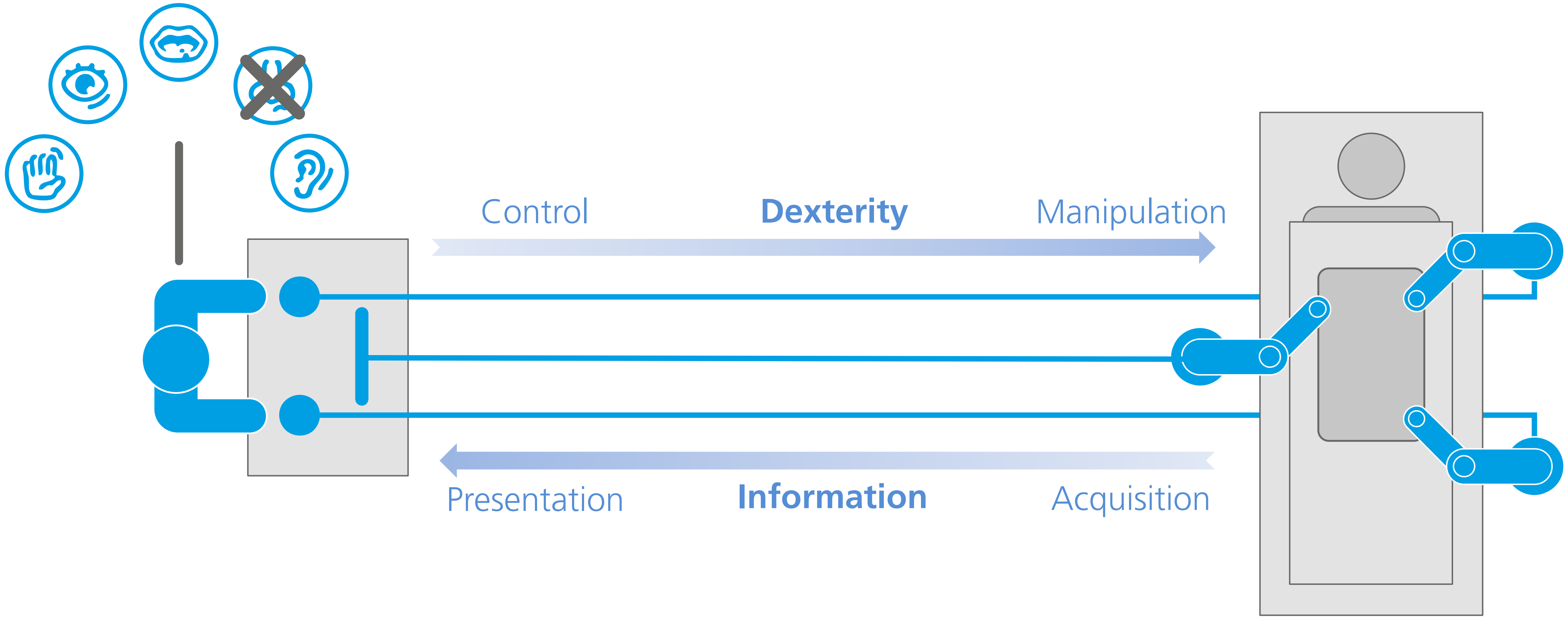
Application in Minimally Invasive Surgery – MiroSurge

Research Platform for Teleoperation in Minimally Invasive Surgery

- Telemanipulated System
  - Surgeon controls the slave manipulators using the Master Console (Mapping of Surgeon's Dexterity into Patient)
  - Surgeon is provided with a 3D Visualization of the patients inside via the stereo endoscope
- Licensing of technological components to Covidien in 2013
  - 1st revenue expected in fiscal 2019
  - components still DLR property
  - available for research with academic, medical & industrial partners

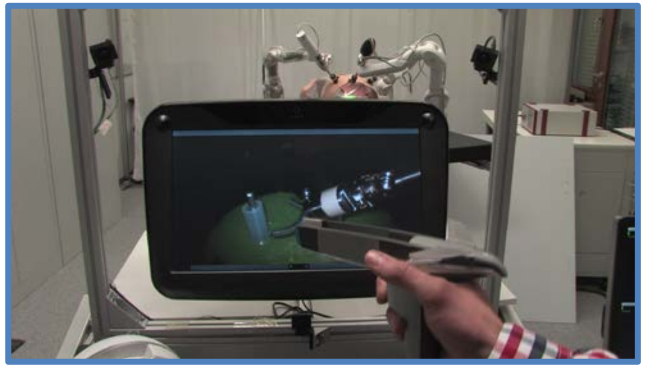
Medtronic COVIDIEN

Robotic Assistance for Medical Diagnostics and Interventions

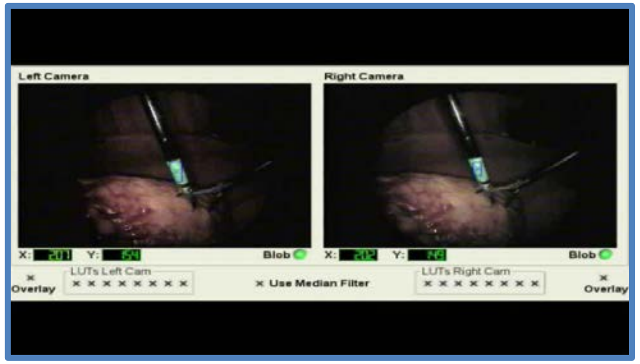


Application in Minimally Invasive Surgery – MiroSurge

Dexterity – Projection of the Surgeons‘ Capabilities into the Patient

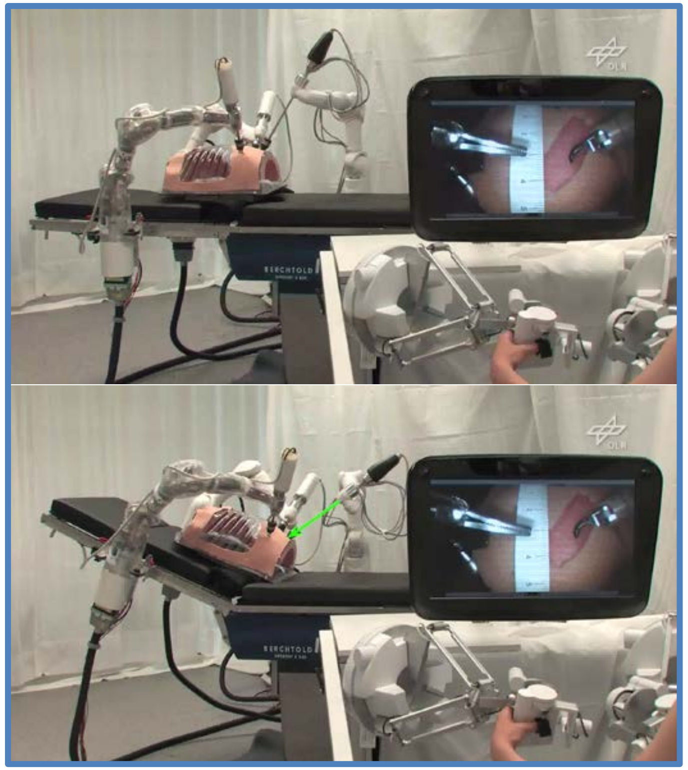


Optically-Inertially Tracked Input Device

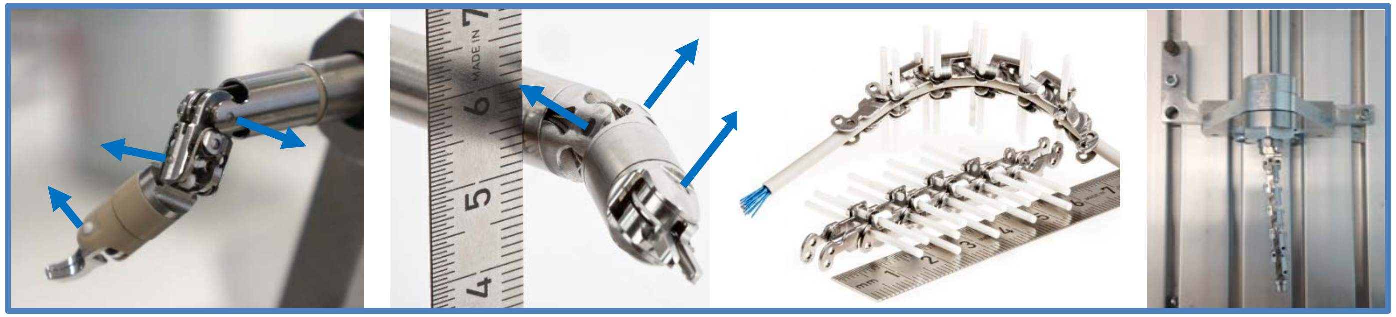


Automated Endoscope Guidance

Setup Planning

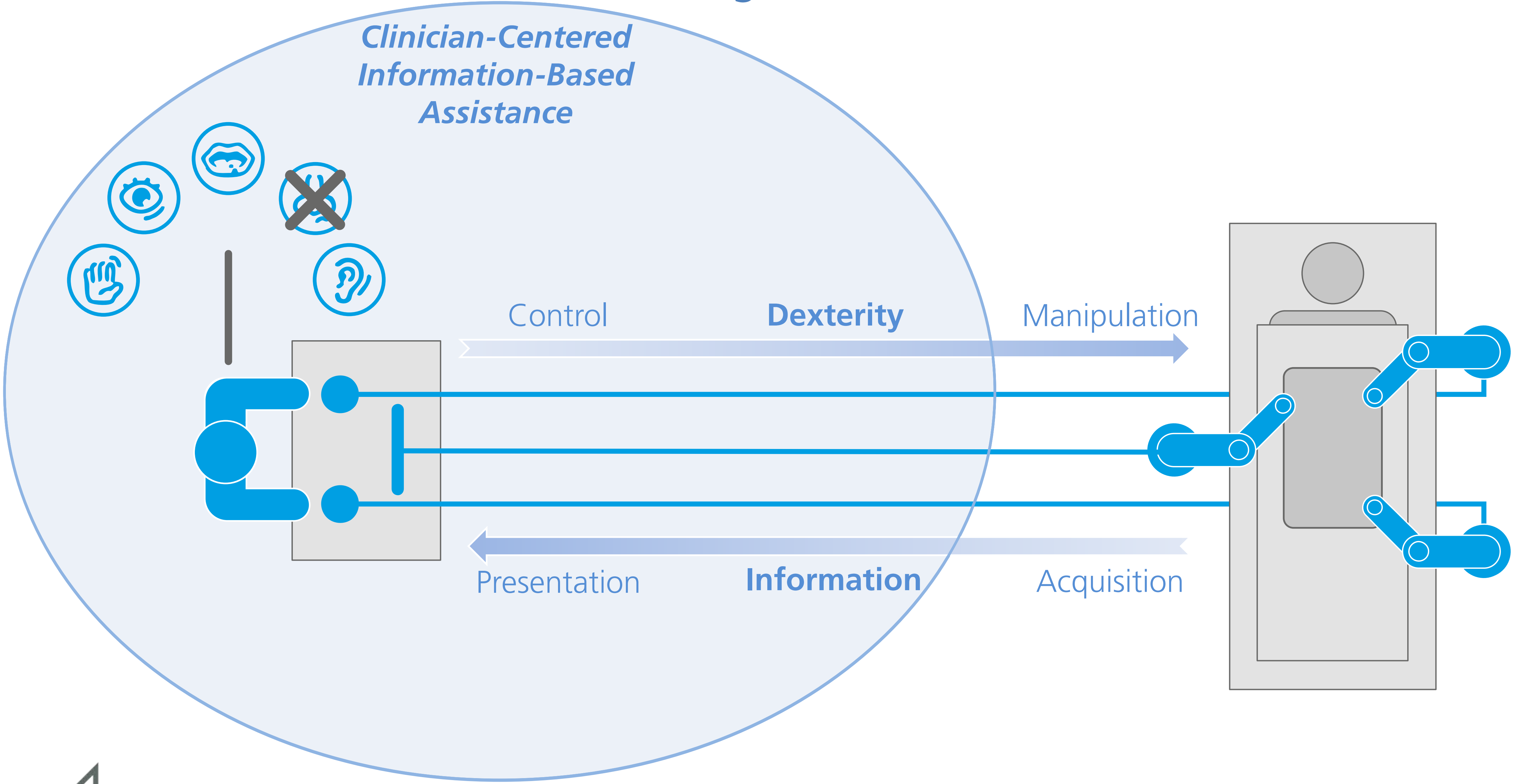


Full Integration of Robotized OR Table



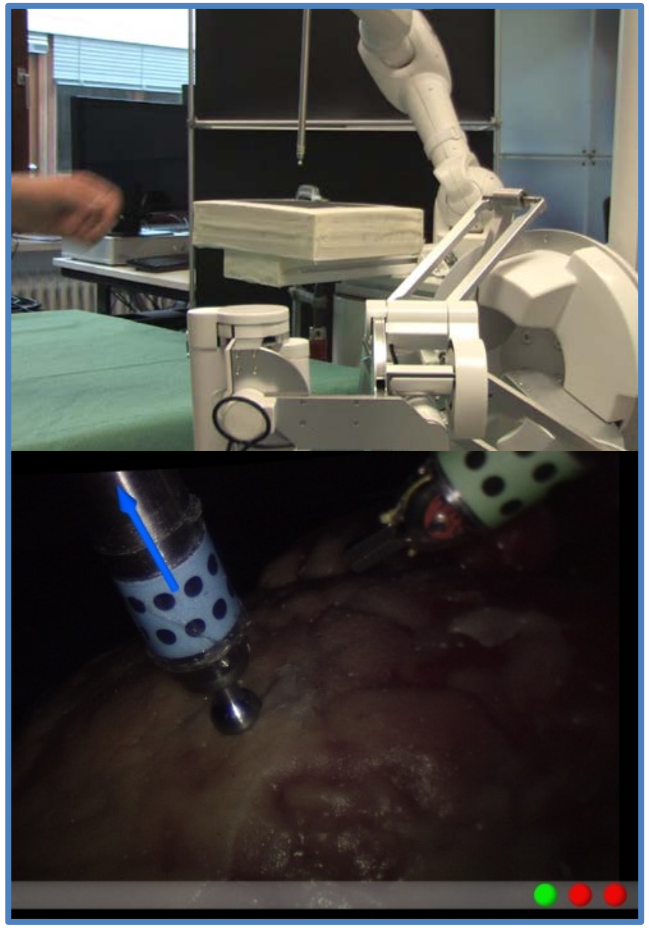
Mechatronic Design of Specialized Instrumentation

Robotic Assistance for Medical Diagnostics and Interventions



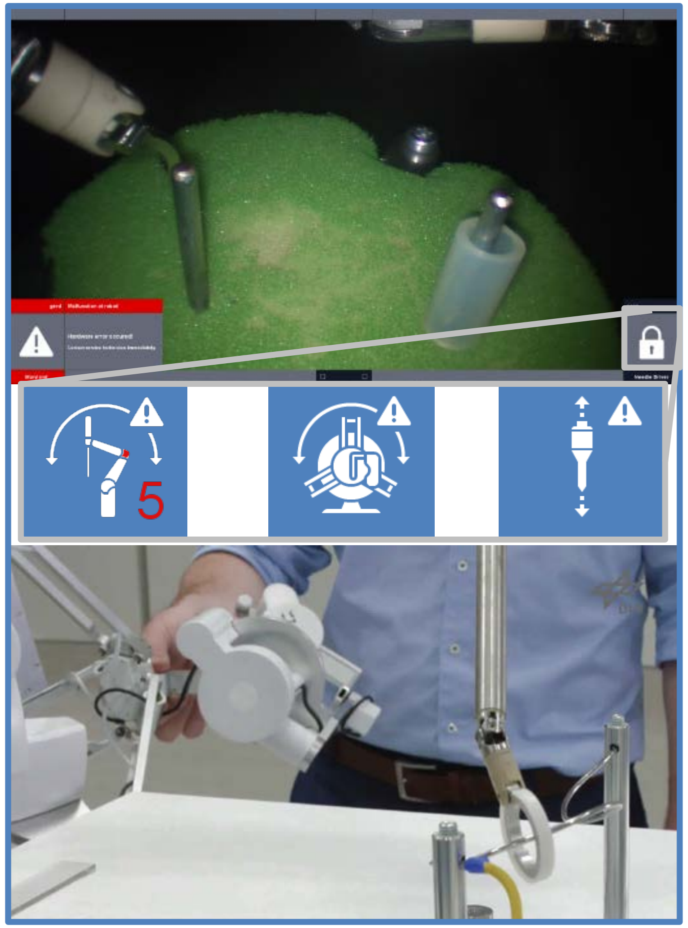
Application in Minimally Invasive Surgery – MiroSurge

Information Based Support Functions – Extending the Surgeons' Perception Capabilities



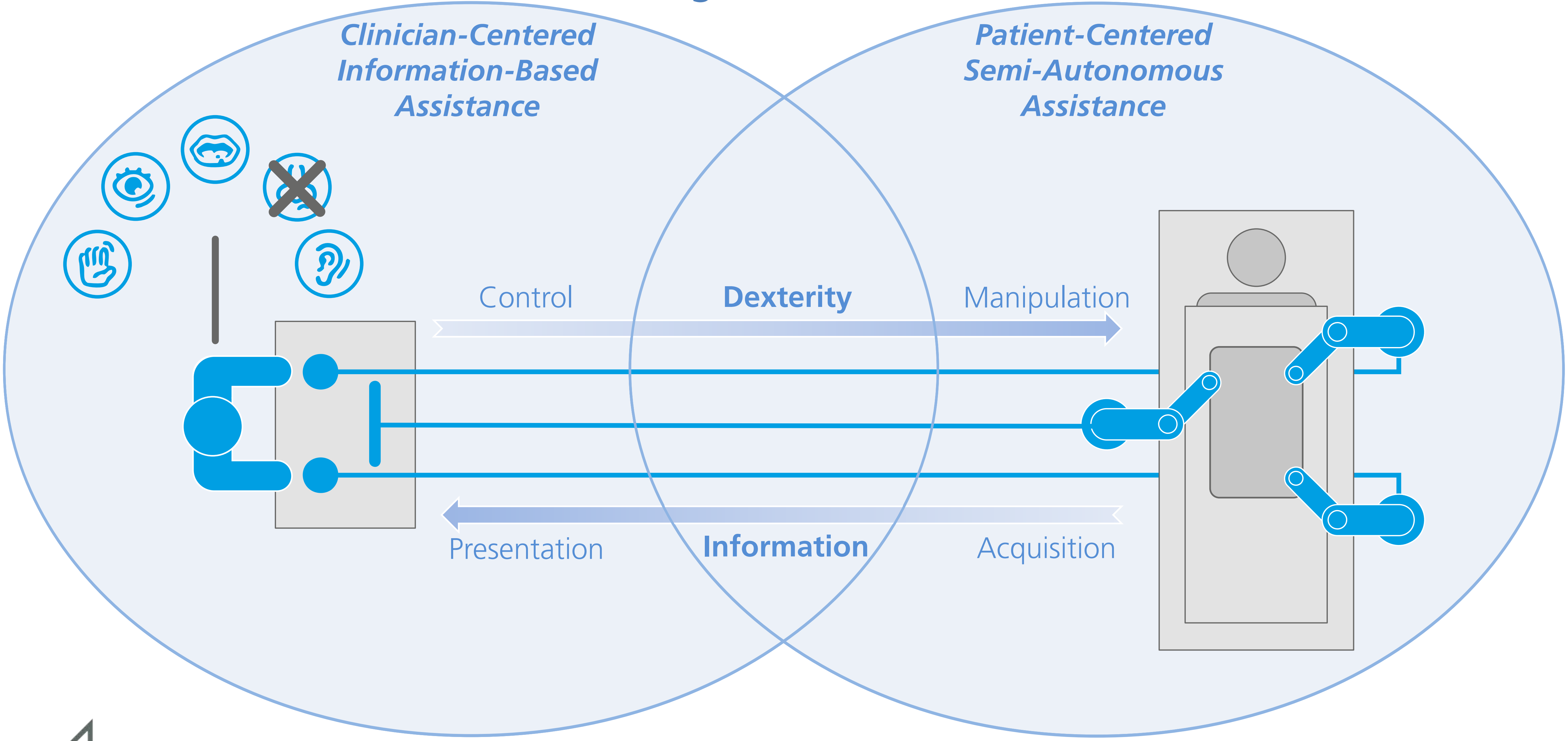
Force Torque Sensors for Haptic and Visual Force Feedback

Doppler Ultrasound Sensors for Tactile Feedback



Haptically and Visually Displayed Virtual Fixtures

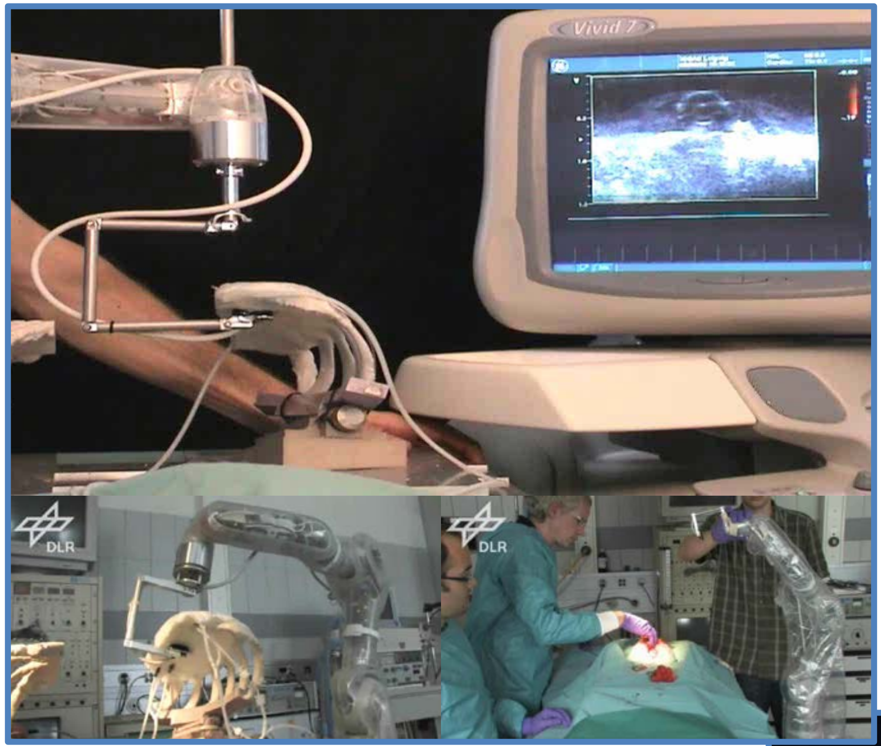
Robotic Assistance for Medical Diagnostics and Interventions



Applications of the MIRO in Various Medical Domains

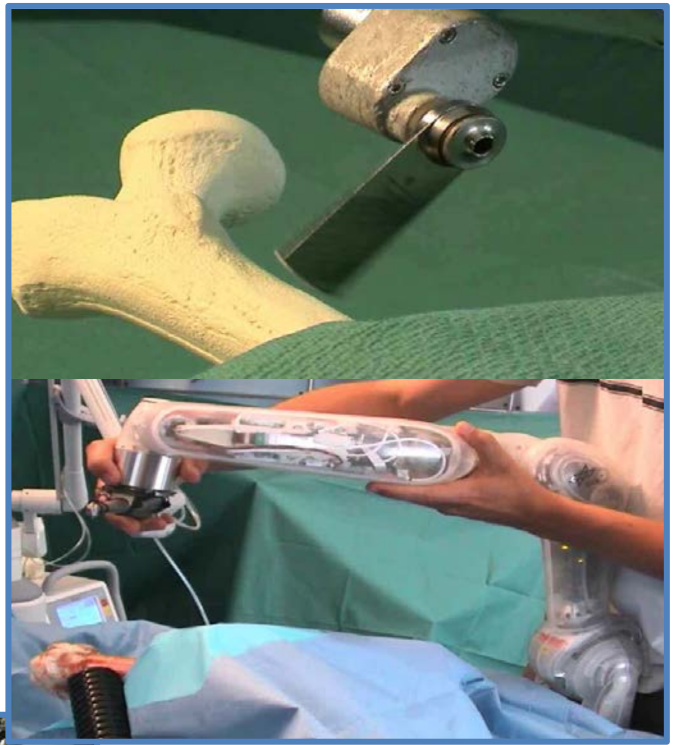
Automated & Semi-Autonomous Support Functions

Open Surgery –
Automated Tracking and Marking of Arteries

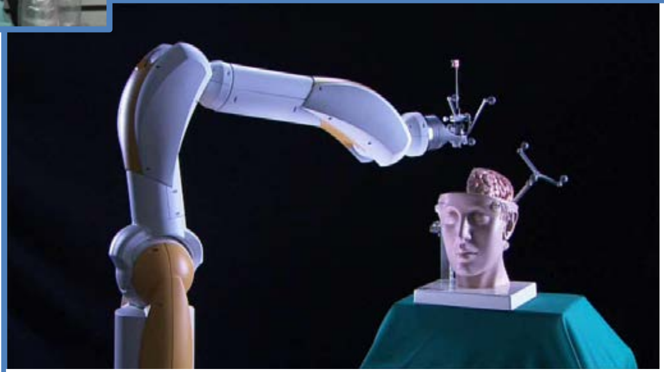


Surgical Wound Debridement

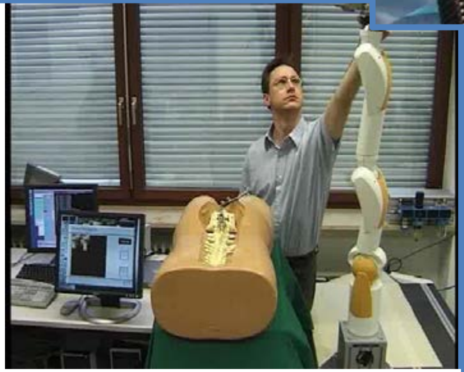
Orthopedics –
Osteotomy using Laser or Oscillating Saw



Neurosurgery



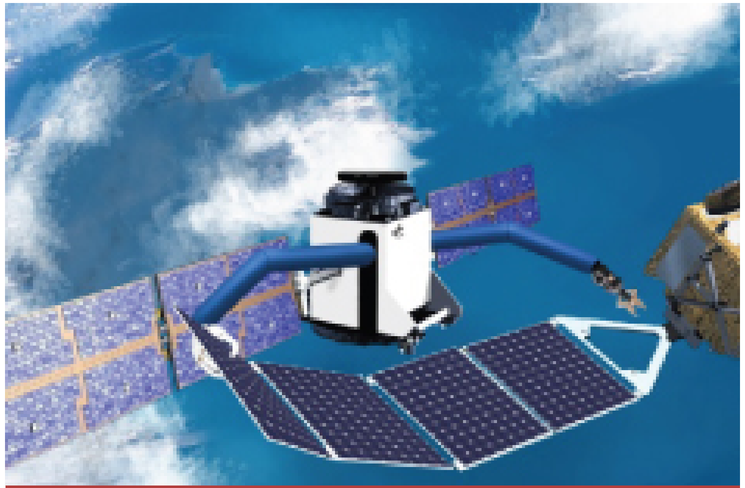
Robot Assisted Biopsy



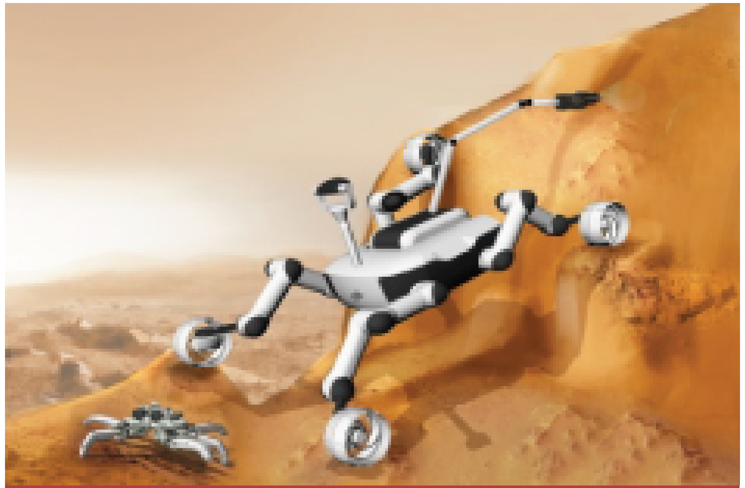
Placement of Pedicle Screws

DLR

Application Domains


Orbital Robotics


Space Assistance


Planetary Exploration


Future Manufacturing


Intelligent Service Robotics


Medical & Healthcare


Field Robotics

From Space to Terrestrial Application Domains of Robotics Research

Julian Klodmann
Institute of Robotics and Mechatronics
German Aerospace Center

DLR