Space Robotics Technologies

By PERASPERA Consortium
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This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 640026

OUTLINE

- Space robot specific constraints
- Perception and perception processing
- Control/Autonomy
- Motion control
- Robot-user interfaces
- Ground support equipment

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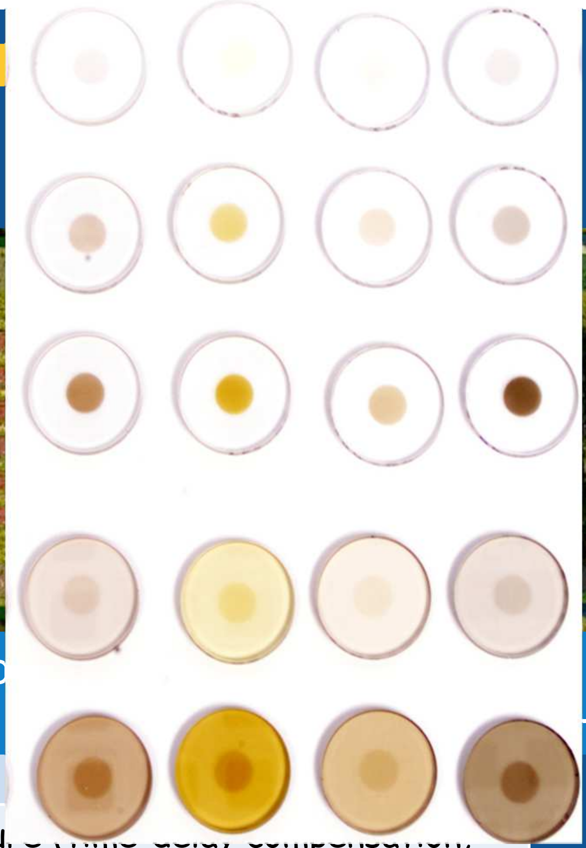
SPACE ROBOTICS CONST

Specific environmental constraints	Impact on rob
Vacuum or low pressure	- Mechanical de - Electronic co
High vibrations during launch	- Design of mec
Wide temperature ranges	- Electronics de
High radiative environment	- Rad-hard com capability
No gravity	- Testing facilit representation
Communications limitations (time-delay, data rate)	- Telerobotics architectu force feedb
Drastic weight and volume allocations	- Overall rob deployment
No maintenance capability	- Higher reliab autonomy requirements - Intensive ground testing

Electro
(right)

-up



Optical lenses of four different materials (top) being tainted by increasing radiation exposure

(below)

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PERCEPTION AND PERCEPTION PROCESSING (1/3)

Specific needs and constraints

Orbital robotics

- Measure the relative position and attitude of a non cooperative target over various ranges → pose detection and visual tracking with possibly poor quality images

Planetary lander

- Self-localization w.r.t. the celestial body surface by landmark tracking / Detection of potential hazards → very high rate requirements

Planetary rover

- Construct an accurate 3D mapping of the rover's surrounding terrain by stereo images / Self localization by visual odometry / landmark tracking → non structured images processing
- Self-localization w.r.t. others planetary assets → visual tracking of structured objects immersed in unstructured images)

→ High reliability and performance requirements to be achieved with low resources in unfriendly environments (rad hard electronics)

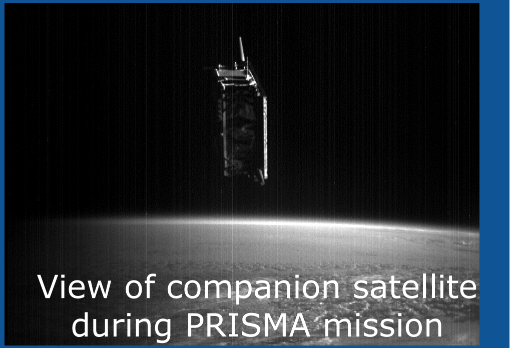
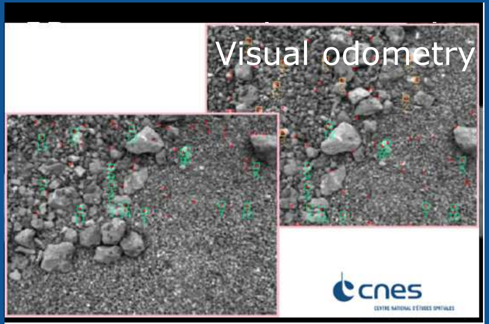

View of companion satellite during PRISMA mission


Image taken during landing


Visual odometry

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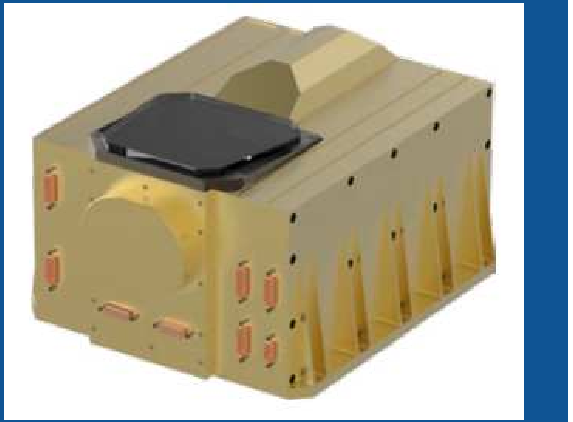
PERCEPTION AND PERCEPTION PROCESSING (2/3)

Specific sensor developments

3D LIDAR (Jena-Optronix) tested on ATV5 flight

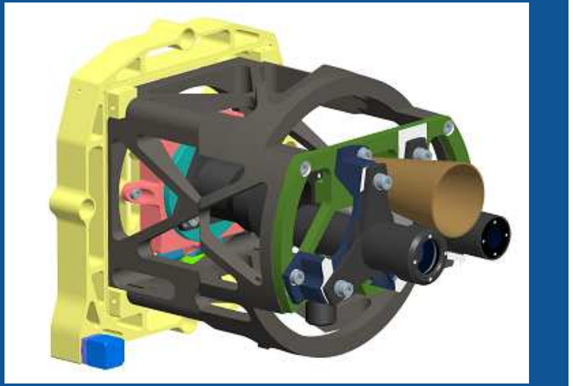
- Field of View: 40°x40° - 1°x1°
- Operating range: 1 m – 1000 m
- Power: 35 W average (60 W max)
- Weight: 8.5 kg / Volume: 286 x 310 x 195 mm3
- Applicable to planetary landing



RVS 3000 3D for RDV/docking with non cooperative targets

ZoomOb – Afocal Field of view changer (Jena-Optronik)

- Goal: reduce the number of cameras for applications with large operating ranges (rendezvous, landing, surface roving)
- More compact, accurate and robust design than a continuous zoom camera
- Prototype of a stereo camera system under development



Afocal field of view changer CAD design draft

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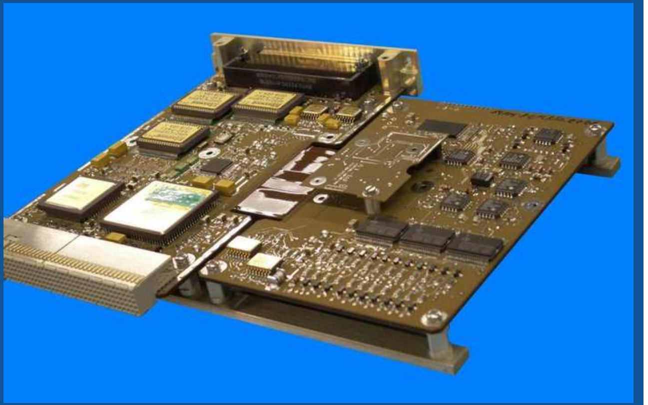
PERCEPTION AND PERCEPTION PROCESSING (3/3)

Processing constraints

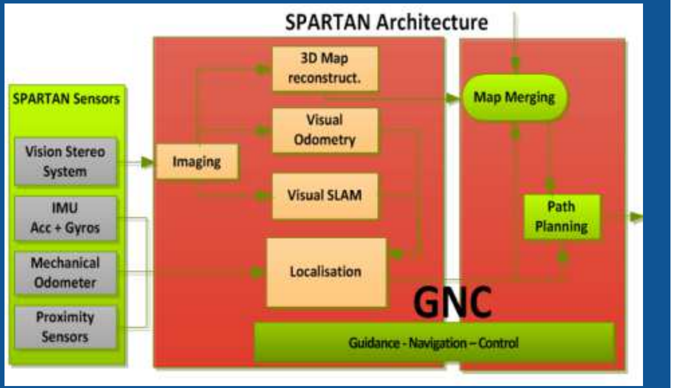
- Limited computing power and memory (LEON processors)
  - Impact on : camera resolution, radiometric correction, robustness, algorithms design, environment model accuracy, …
  - CPU time : LEON2 ~30 times slower / desktop
  - Data format: compact representation required
- Limited available energy
  - Strong constraints on algorithms & scheduling



LEON2-FT chip (ESA Credit)

Current developments – SPARTAN project

- HW/SW co-design and prototyping of a fast computer vision FPGA based architecture for rover navigation
- Tests showed speed-up factors 10x to 1000x
- Future work: SW optimization – multi-FPGA design



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CONTROL/AUTONOMY (1/4)

Control Architecture

Control architecture of space systems driven by:

- the communication constraints (duration of the comms slots, data bandwidth, latency)
- the mission complexity (number of assets) and the project organisation (i.e. multiple control centres)

Robotics in orbit

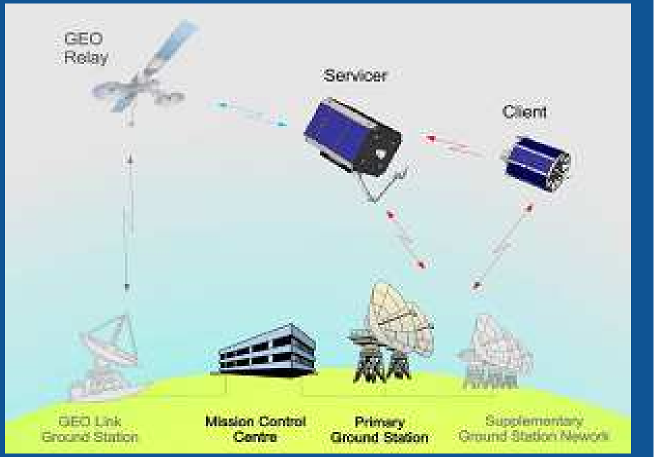
- Permanent visibility possible with GEO relay (600 ms time delay) but limited video rate

➔ Reactive autonomy + telerobotics: ground operator in the loop for critical operations (i.e. satellite capture)

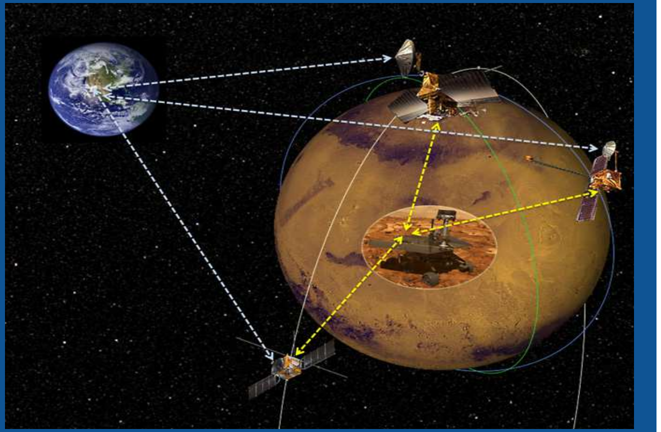
Planetary exploration (Mars)

- 2 communication slots per sol - low bandwidth and data rate – ~30’ round trip delay

➔ Full autonomy is required for the vehicles (single cycle science objective)



DEOS data network



Mars coms network

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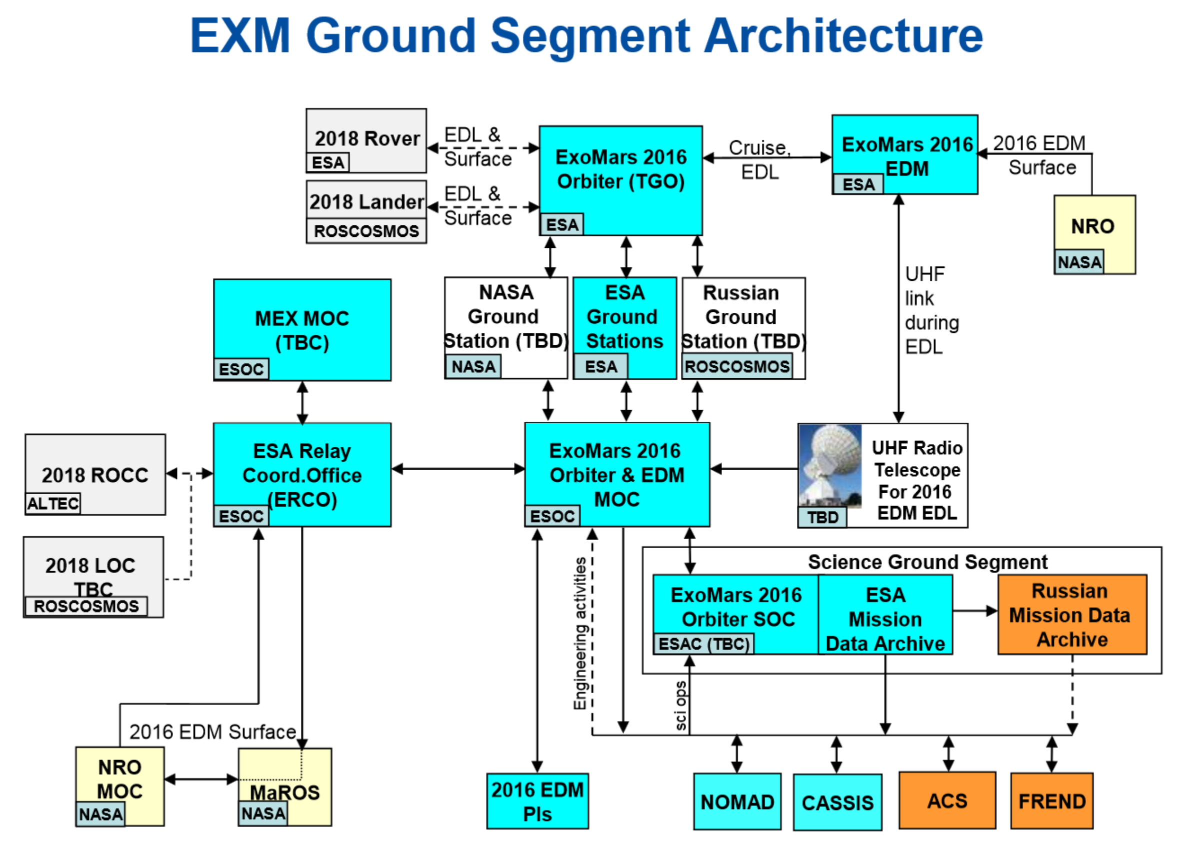
CONTROL/AUTONOMY (2/4)

Ground segment complexity (ExoMars)

- Control functionalities distributed between multiple centers



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CONTROL/AUTONOMY (3/4)

Satellite autonomy

- Stringent FDIR requirements to avoid mission loss during time critical operations (ex: collision avoidance for satellite formations) → monitoring and corrective action (activate redundancies, trigger manoeuvers)
- Two FDIR levels in FF missions (ex: PROBA3 mission):
  → spacecraft FDIR – formation FDIR

PROBA3 formation

Rover autonomous capabilities demonstrated in field tests (SEEKER, SAFER)

- Functional layer (navigation) Perception processing, Path planning, Locomotion control, Self-Localisation
- Decision layer: activity temporal planning / re-planning in case of anomalies

On-going developments: MASTER project

- autonomous science: detection of scientifically interesting sites by the robot and science activity planning

Bridget rover during SAFER tests in Atacama desert

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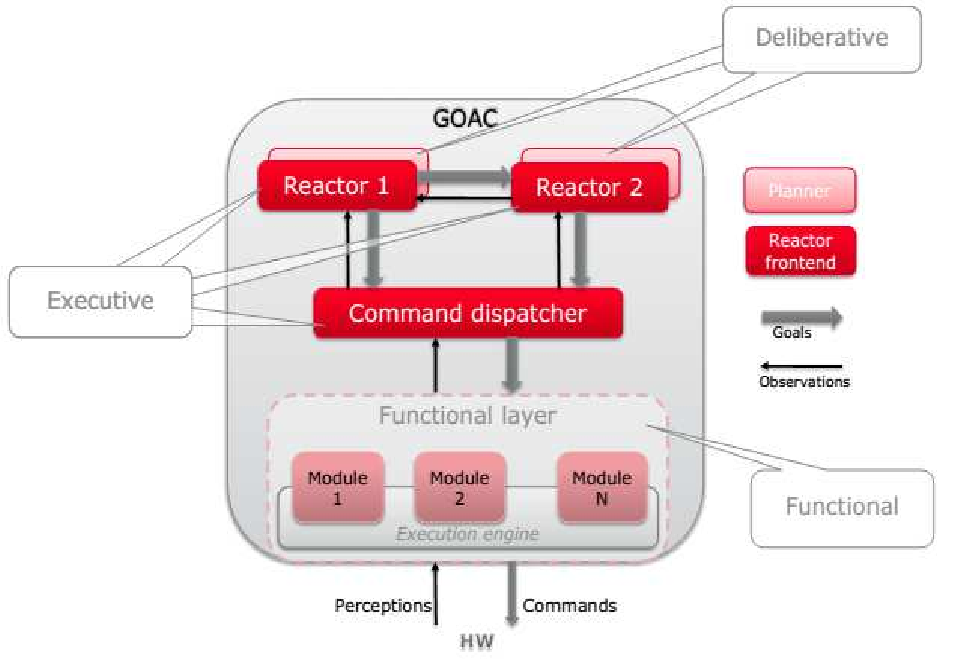
CONTROL/AUTONOMY (4/4)

Goal Oriented Autonomous Controller (GOAC)

➔ Implemented for planetary exploration

- Deliberative reasoning: on-board planning and scheduling
- Reactive: reaction to dynamic external or internal conditions
- Goal based operations: autonomous high level goal decomposition into low level commands
- Flexible approach applicable to all space systems

→ Further optimization required to cope with on-board CPU limitations



Project team: GMV, CNR-ISTC, LAAS-CNRS, Verimag, MBARI – funded by ESA

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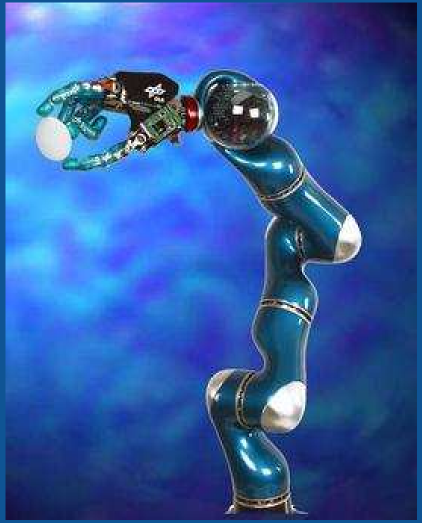
MOTION CONTROL (1/2)

Motion Control Chip (MCC)

Goal: Improvement of motor performance in manipulator arms and rovers by placing the controller close to the motors

- Reduce harness and save weight
- Reduce thermal leakage from main body
- Simplify final assembly



Challenges:

- Survive wide temperature range
- Sustain vibrations and possible dust contamination
- Low weight and low volume design

Status: breadboard designed and tested under TRP project (AAC, Aeroflex, CSEM, Selex Galilieo, Astrium UK, DLR)

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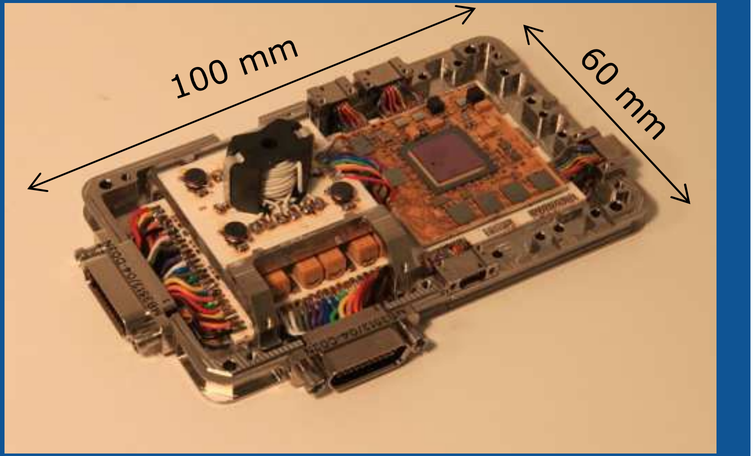
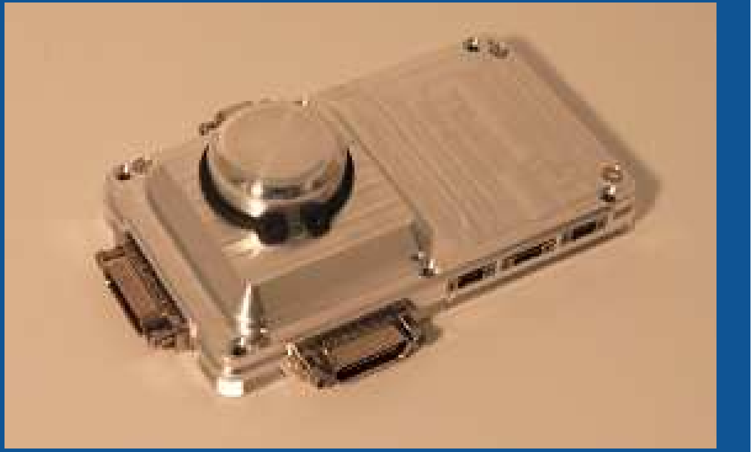
MOTION CONTROL (2/2)

MCC design features

- **Survives -120°C outside temperature**
- Motor driving (3 brushed or 1 brushless motors) for a total power up to 150 W
- Motor heater driving for a total power up to 90 W
- Sensor interfaces: 3 resolvers, 3 digital encoders
  3 potentiometers, 1 strain gauge, 3 thermistors,
  1 Hall sensor, 6 end switches
- Two isolated CAN-bus interfaces
- Embedded auxiliary power unit for generating all necessary voltages from a 28V bus
- Isolated temperature measurement
- Computing power to run a variety of control algorithms (e.g. position, velocity, and torque)



Assembled MCC-stack in casing with cabling and connectors



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ROBOT USER INTERFACES (1/3)

Contexts

Robot-user interfaces to be implemented in various contexts depending on the applications:

- user in orbit and located near the robot with direct view access (Shuttle arm)
- user on the ground interacting with a remote robot (in Earth orbit or on the Moon)
- user in orbit interacting with a remote robot (robot on Mars and user in Mars orbit)

Interface modalities and challenges

- Intuitive manipulator control with force feedback

  → **Force feedback** in presence of time delay and compatible with µG environment
- Immersive telepresence with context dependent visual aids

  → **MMI auto-adaptation** taking into account operator mental state

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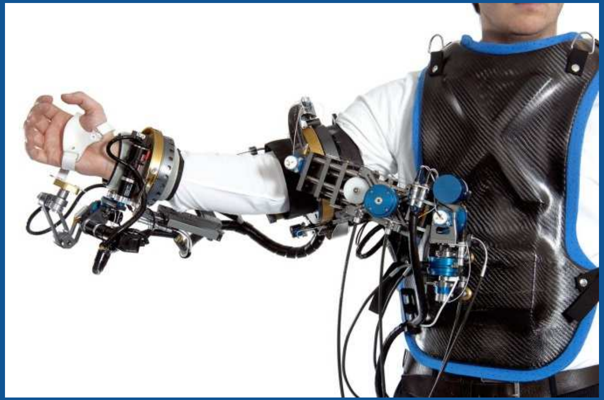
ROBOT USER INTERFACES (2/3)

Exoskeletons with haptic feedback

Provide intuitive and efficient means to control a manipulator arm (particularly useful for dual manipulators)

- Low volume and weight requirements
- Force feedback capability
- Compatible with µG utilization (fixed to the operator)



ESA-X-arm-2 exoskeleton

Current developments and activities

- Several exoskeletons prototypes available in Europe
  - ✓ ESA–X-arm-2: 8 active DOFS + 6 passive DOFS (14)
  - ✓ CAPIO (DFKI): 20 active DOFS + 9 passive DOFS (29)
- Force feedback has proved to be efficient up to 500 ms time delay
- Multiple experiments already performed with remote robots within Europe or between Europe and USA

CAPIO exoskeleton (DFKI)

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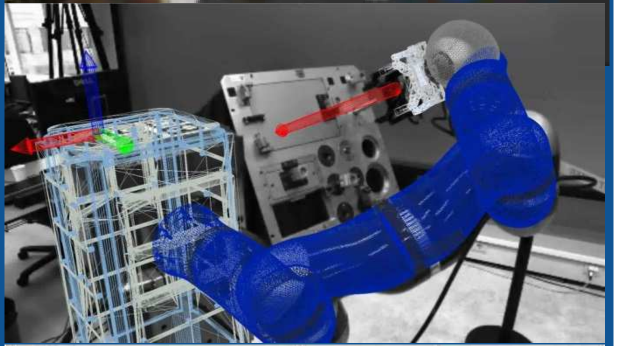
ROBOT USER INTERFACES (3/3)

3D augmented reality to improve immersive telepresence

- Virtual scene display with force / torque direction and magnitude information inlayed in video images to complement haptic feedback
- Virtual robot / object images overlayed on low bandwidth compressed video to improve situation awareness
- Addition of predictive display to compensate with time delay during robot motions



Intelligent Man Machine Interface

- Adaptive brain reading: detection and interpretation of specific changes in the brain waves (ex: mental load, stress) in order to adapt the information display (on-going project at DFKI-GmbH)

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GROUND SUPPORT EQUIPMENT (1/4)

Simulation environment for system development
→ EPOS (European Proximity Operations Simulator)

Goal: Test and verification facility for the full RDV & docking procedures of on-orbit servicing

- HIL simulator (includes the real sensor suite)
- need to simulate the relative motion over a range of several tens of meters
- need to simulate the 6 d.o.f. dynamics of two satellites during contact /docking operations

Final approach simulation with EPOS (GSOC DLR)

Characteristics:

- 2 heavy duty industrial robots (250 kg load)
- 25 m motion range for the chaser
- Hardware mock-up of the docking mechanism
- Real time numeric simulator implementing a virtual dynamics contact model

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GROUND SUPPORT EQUIPMENT (2/4)

Simulation environment for system development
→ DEOS simulator

Goal: High fidelity test and verification facility for the satellite grasping / stabilizing / berthing operations
→ evaluation of strategies

Characteristics:

- 2 satellites (chaser and target) mounted on heavy duty manipulator arms
- DEOS manipulator mock-up mounted on the chaser satellite (equipped with force controlled joints)
- Impedance control is implemented on each supporting robot arm such that each satellite behaves as a free floating object (bandwidth TBD)
- Allows to represent on a limited range the dynamics of the composite during and after contact

DEOS simulator (GSOC DLR)

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GROUND SUPPORT EQUIPMENT (3/4)

Simulation environment for system operation

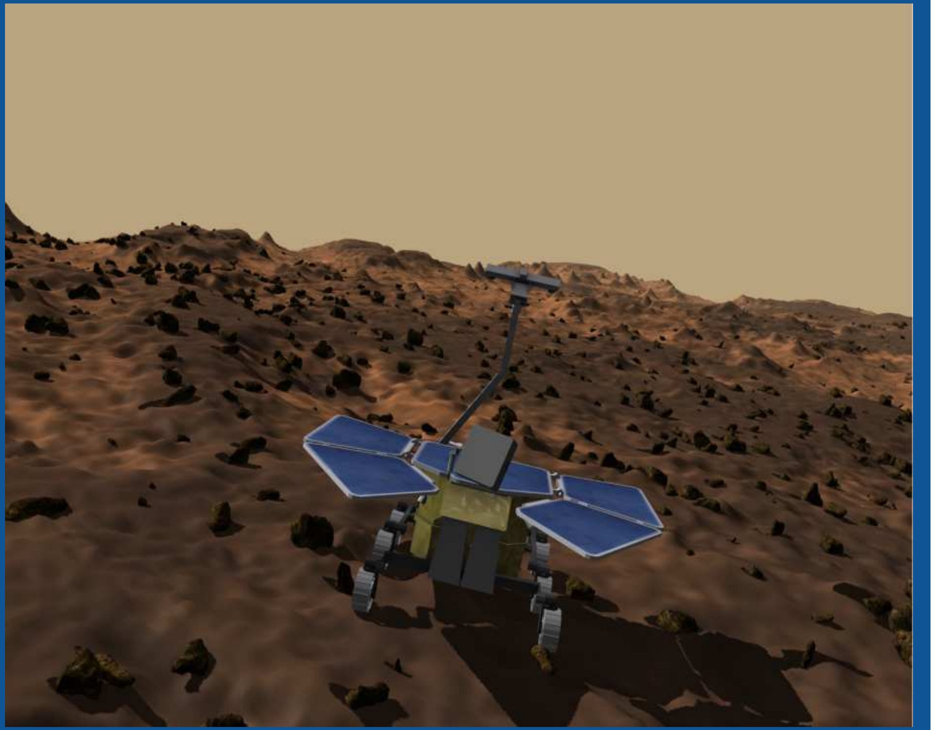
→ Exomars Rover simulator (ROCC)

Goal: Provides the Rover Operations Team with proper simulation tools for:

- procedures definition and operator training
- preparation of the rover activities (rover navigation and mechanism / arms movement) based on science provided plan and system needs / constraints,
- verification of the plan before final uplink

→ *based on a numeric simulator of all rover functionalities (soil interaction included)*

→ *rely possibly on a real rover model in case of specific anomaly diagnosis*



Example of ExoMars simulator 3D display (CNES)

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- *Thank you for your attention*

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