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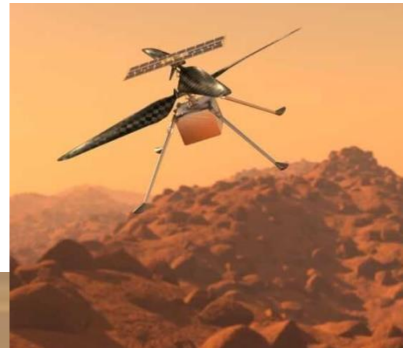
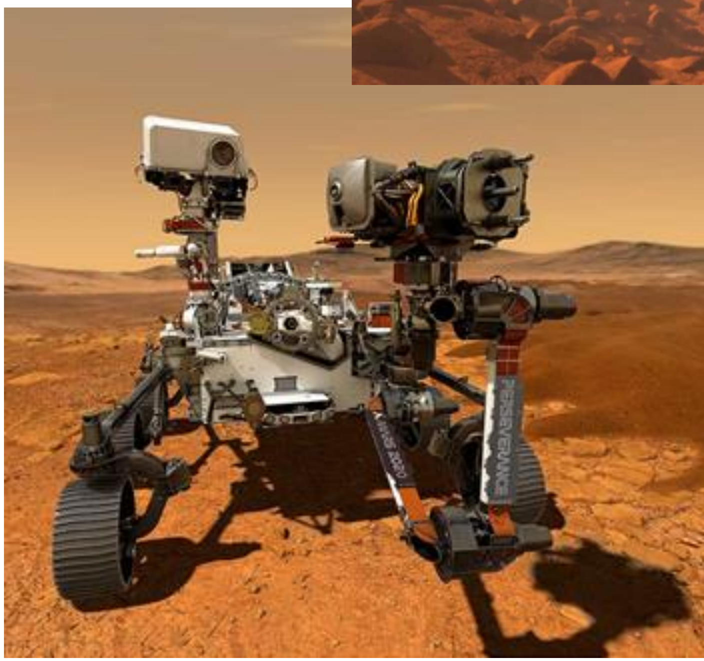


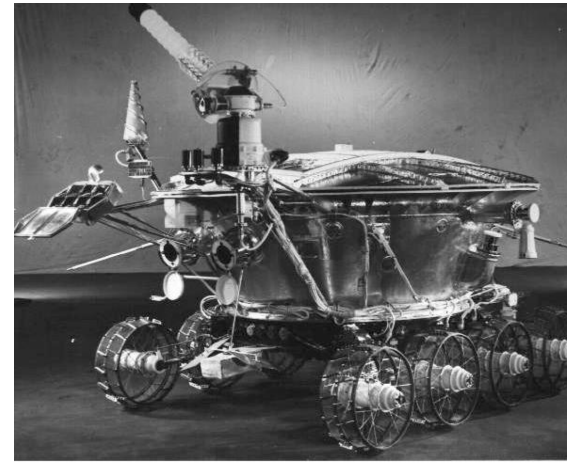


Robotics in Space applications challenges for research

ONERA

Robotics in Planetary Exploration

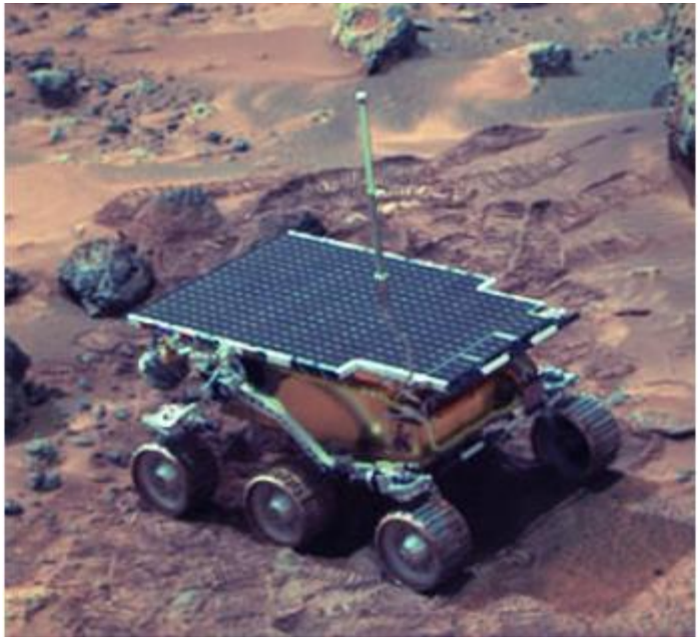
Lunokhod 1 is the **first rover sent to the Moon** by the Soviet Union **in 1970**. It integrates cameras and measuring devices, takes samples and communicates with scientists on Earth. A more sophisticated version, Lunokhod 2, was sent to the Moon in 1973.



The Soviet missions Luna 17-21 (1970-1973) showed that fairly long range exploration was possible with the Lunokhod rovers, teleoperated from ground. The missions Luna 16,20 and 24 (1970,1972,1976) even managed to return Lunar samples to Earth.

August 20, 1975, **NASA's Viking** project started when *Viking 1* was launched to explore Mars,. Shortly thereafter, on September 9, 1975, an identical spacecraft by the name of *Viking 2* was launched with the same mission.

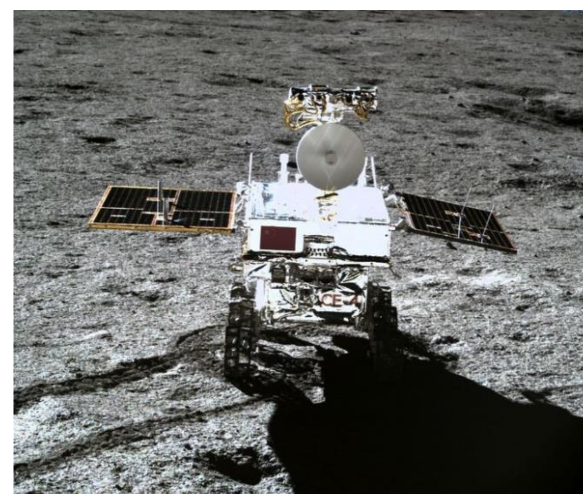
Robotics in Planetary Exploration



on July 4, **1997 Mars Pathfinder** mission,landed Sojourner -- on the surface of Mars using an air bag landing system and innovative petal design, which have been used since in various incarnations to land other rovers on the Red Planet.

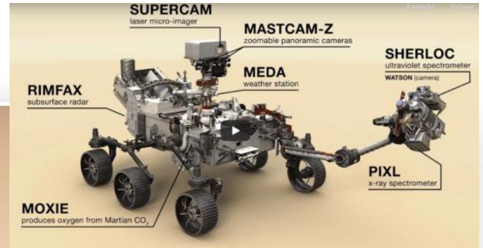
Sojourner spent 83 days of a planned seven-day mission exploring the Martian terrain, snapping photographs and taking chemical, atmospheric and other measurements.

Chinese rover Yutu-2 taken by the Chang'e-4 probe lander, January 11, 2019



Robotics in Planetary Exploration

https://www.youtube.com/watch?v=gm0b_ijaYMQ
www.youtube.com/watch?v=WAPqPCWQGI8



Le rover Perseverance / NASA

Perseverance arrives on Mars Feb 18th. 2021 is largely based on the engineering design for the previous Curiosity rover. The Perseverance long-range mobility system allows it to travel on the surface of Mars over 3 to 12 miles (5 to 20 kilometers). Improvements on Perseverance include a new, more capable wheel design.

(ATHLETE an All-Terrain Hex-Limbed Extra-Terrestrial Explorer) vehicle concept based on six 6 DoF limbs, each with a 1 DoF wheel attached. ATHLETE uses its wheels for efficient driving over stable, gently rolling terrain, but each limb can also be used as a general purpose leg. In the latter case, wheels can be locked and used as feet to walk out of excessively soft, obstacle laden, steep, or otherwise extreme terrain.

Robotics in Planetary Exploration

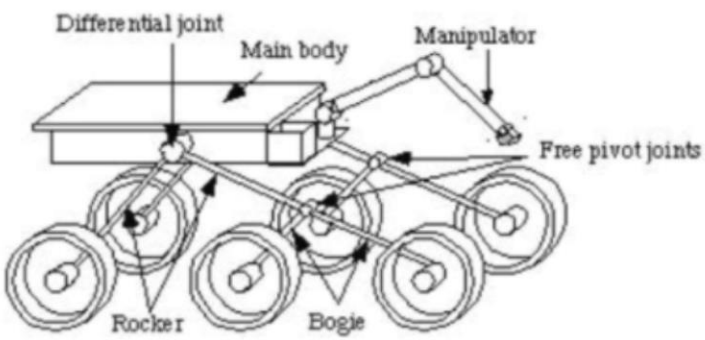
NASA: Humanoid Robot Valkyrie designed for Journey to Mars

Valkyrie (R5) est un robot humanoïde développé par la NASA. Le robot a été conçu et construit par le Johnson Space Center pour participer au DARPA Robotics Challenge de 2013.

Le robot pèse environ 140 kg possède 44 degrés de liberté, il mesure 1,88 m de hauteur et a deux processeurs Intel Core i7 embarqués.

One of the 5 prototypes is accessible for cooperation Northeastern University (Prof. Taskin Padir)

Rover’s locomotion

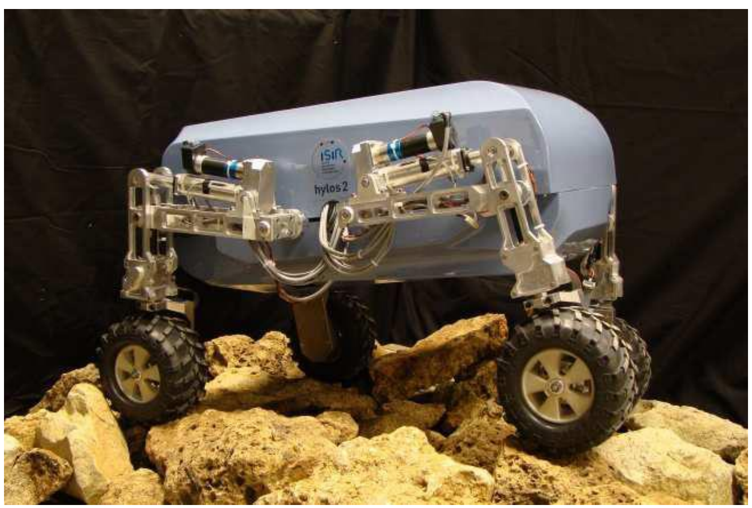


Taken from Hervé Hacot, Steven Dubowsky, Philippe Bidaud

Analysis And Simulation Of A Rocker-Bogie Exploration Rover (1998)

- **Contact stability and tipover stability**
- **Obstacle clearance**
- **Manoeuvrability**
- **Traction distrubution**
- **Odometry**
- **Etc.**

Stability and the controllability limits increase by active locomotion.



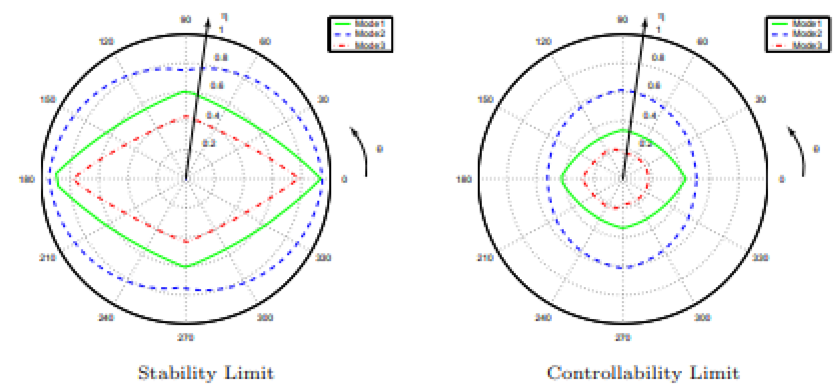
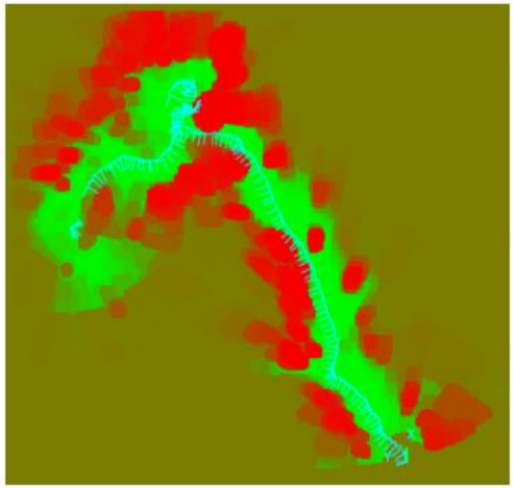


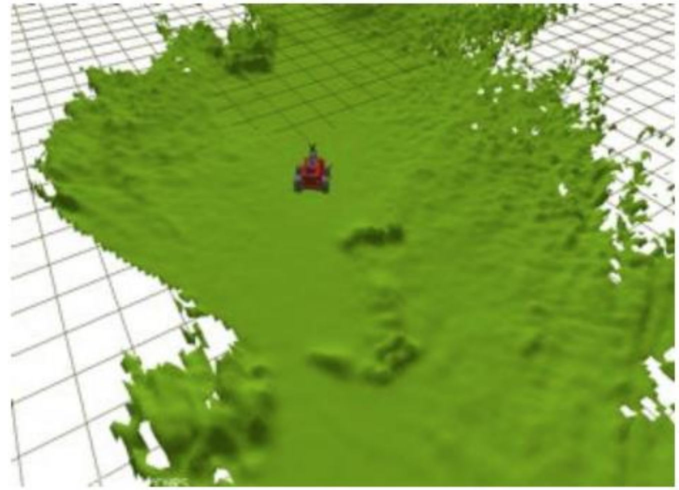
Fig. 4. Evaluation of Gradeability of different locomotion modes on hard soil

Active hybrid wheel-legged rovers *to enhance the locomotion performance terrain. The redundancy of such a system is used to optimize the balance of traction forces and tipover stability.* ***Stability and Traction Optimization of a Reconfigurable Wheel-Legged Robot - Int Jour. Rob Resaerch October 1, 2004***

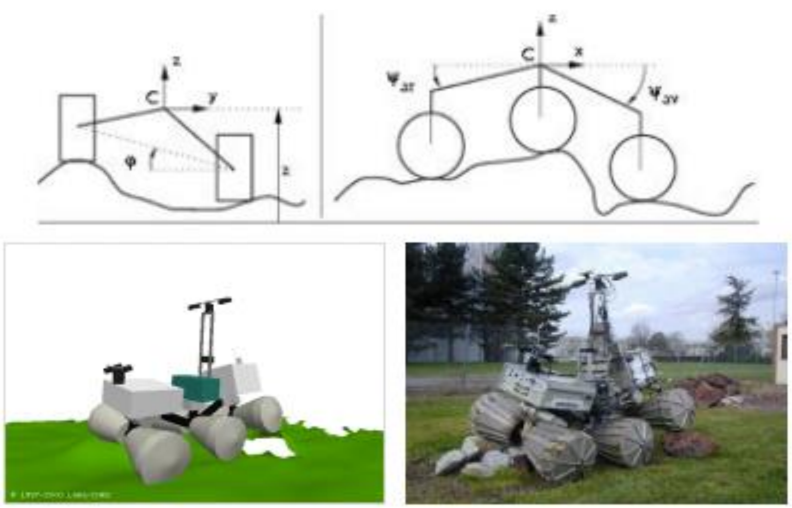
Rover’s terrain traversability



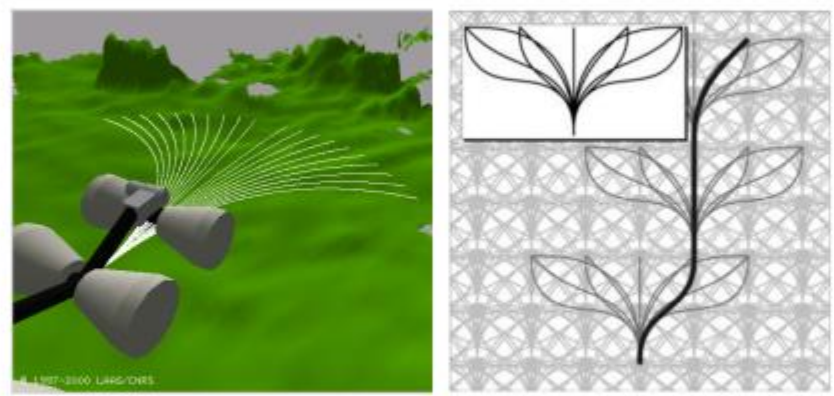
Probabilistic obstacle model



Digital elevation map



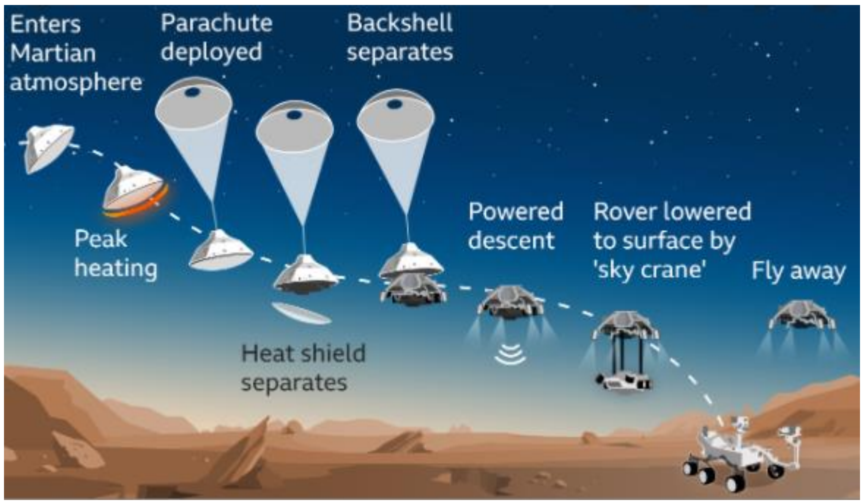
Convolution of the robot model with the terrain model Kinematics (only)



Search

Rover's autonomous landing system (guided by vision)

Perseverance Mars Rover (February 2021) **technology TRN (Terrain Relative Navigation)** consists of two elements : 1) an onboard map of the landing area with elevations and hazards, 2) a navigation camera. As Perseverance approaches, the camera **compares its real-time images with the onboard map and pilots the lander's rockets to a desired target site**.



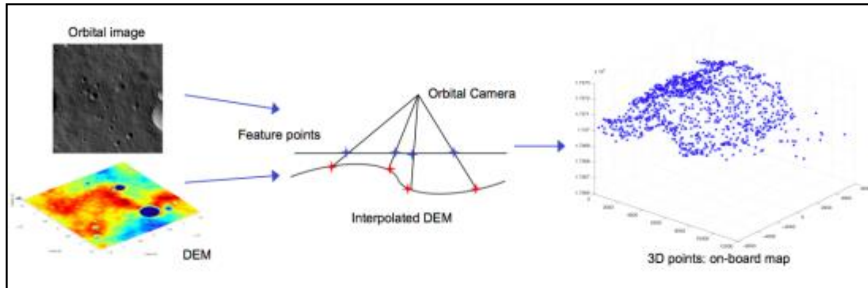


Figure 4.2 – *Map generation process. The 3D landmark coordinates are recovered by tracing the rays back-projected from the Harris features extracted in the orbital image, and then interpolating them with the DEM.*

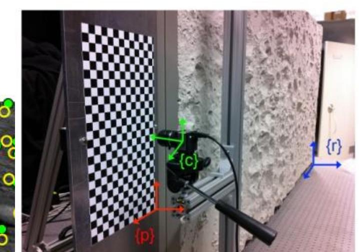


Figure 5.13 – *Visilab frames with the camera in initialization pose facing the calibration pattern. Only the frame {w} is not visible here, it represents the working pose of the camera when it is translated over the mock-up to acquire navigation test images after initialization.*

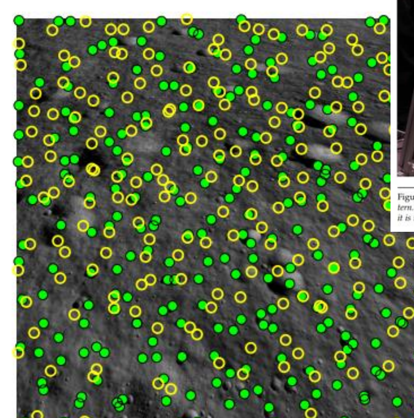
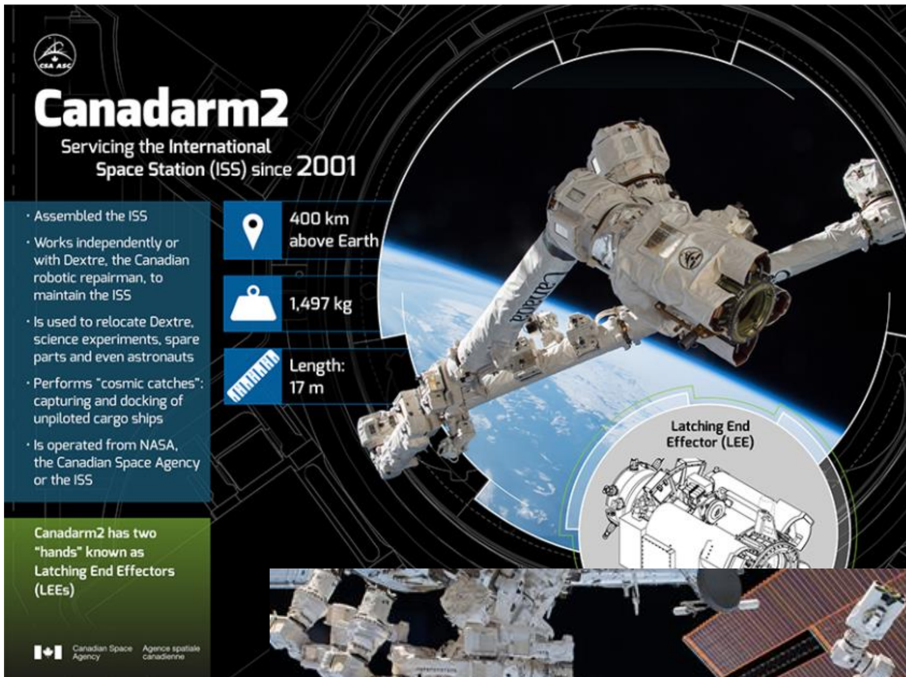


Figure 4.3 – *Harris image features extracted online and predicted by the filter. The descent feature measurements are the green dots and the reprojected filter predictions are the yellow circles.*

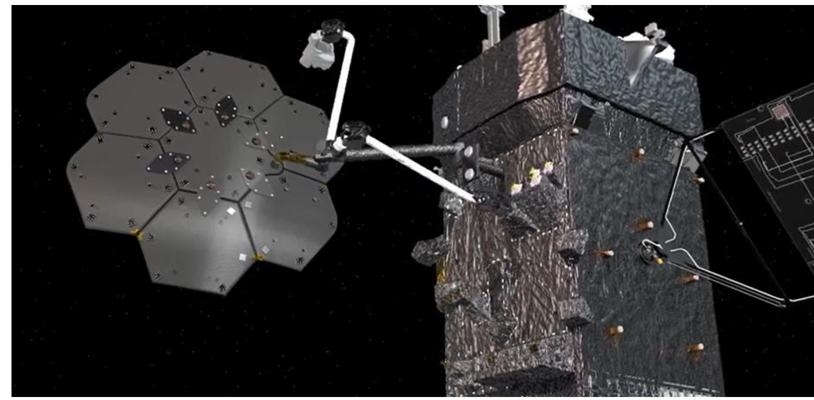
On-Orbit Robotics (Tele)-Manipulators

Canadarm2 (Canadian space robot) was launched aboard Space Shuttle Endeavour on April 19, 2001.



SPIDER On orbit Servicing, Assembly, and Manufacturing

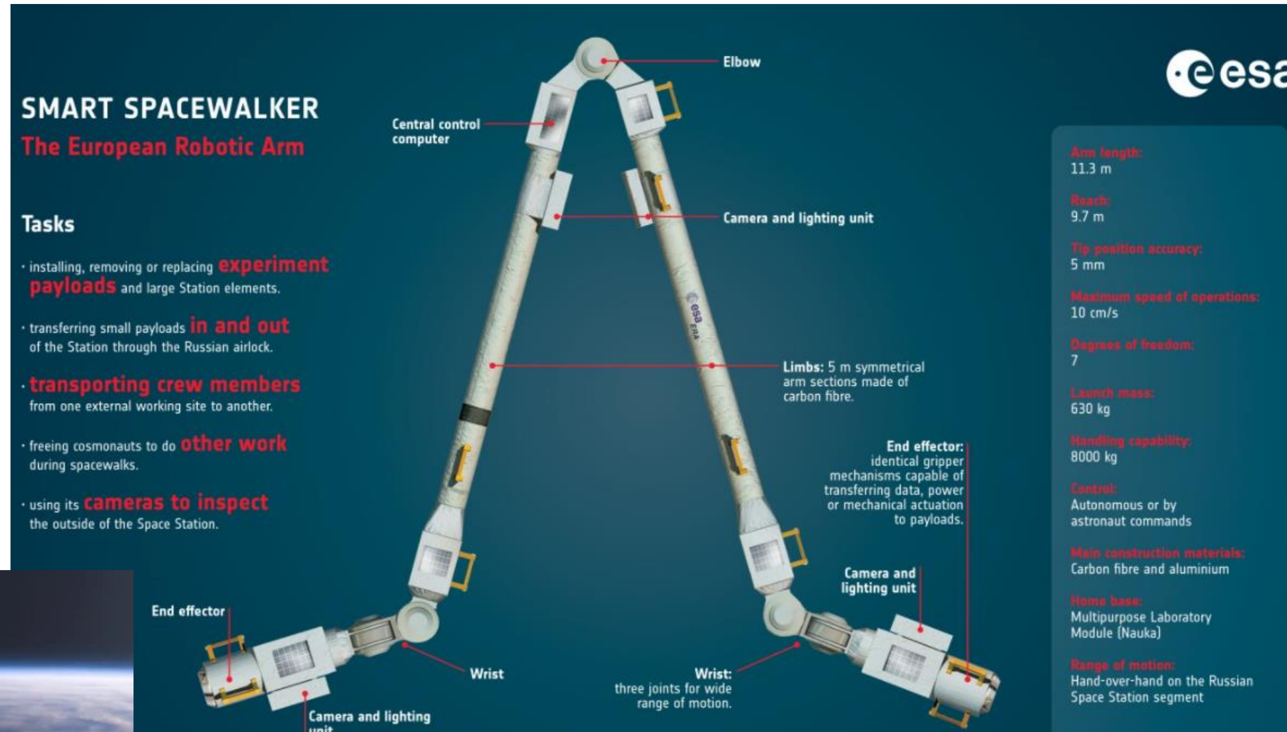
https://www.youtube.com/watch?v=gverl0Ypf0k

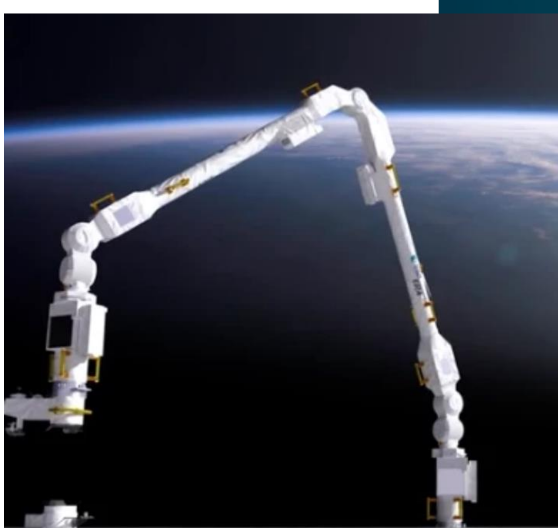


Movie

On-Orbit Robotics (Tele)-Manipulators

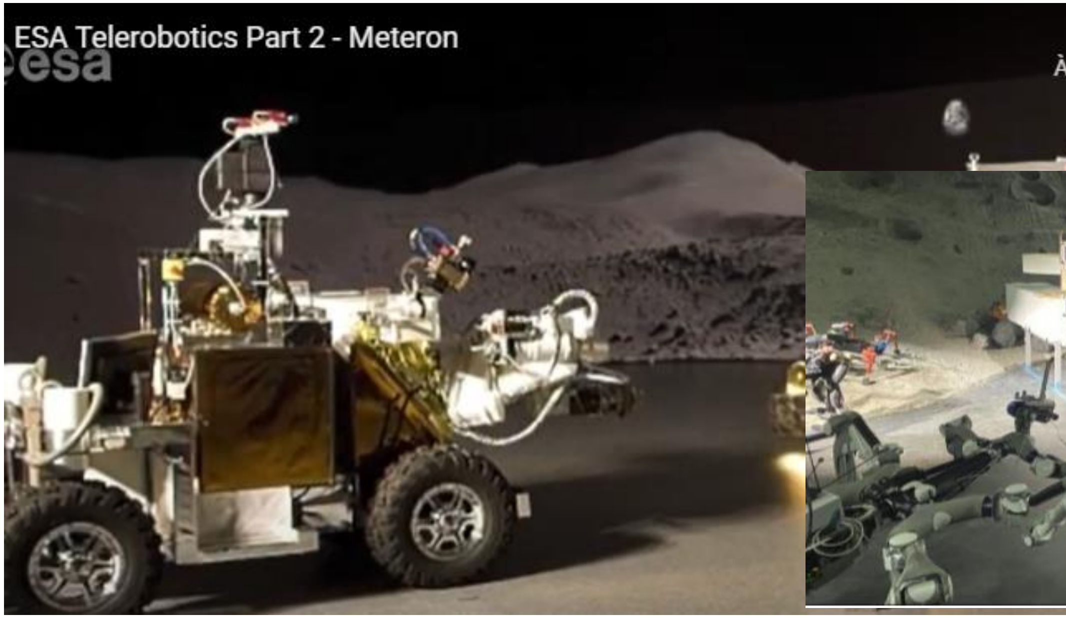
ESA's European Robotic Arm (ERA) installed onto the Russian Multipurpose Laboratory Module (MLM).

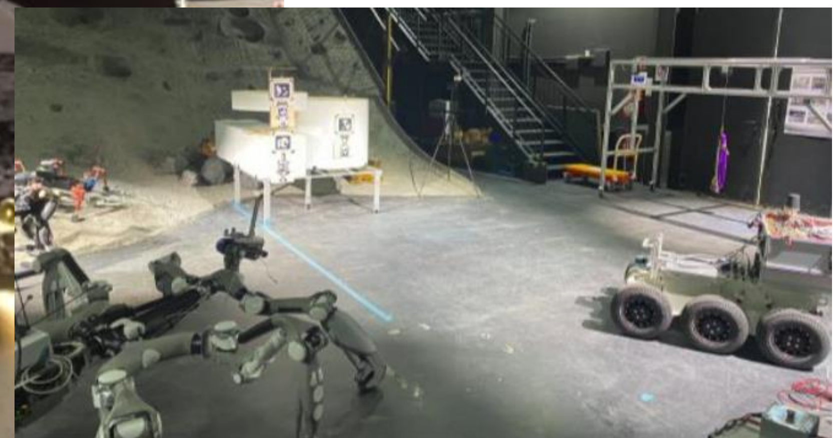


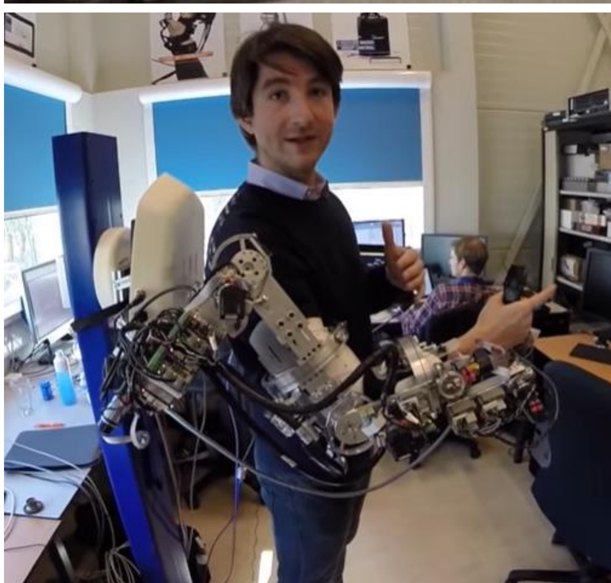


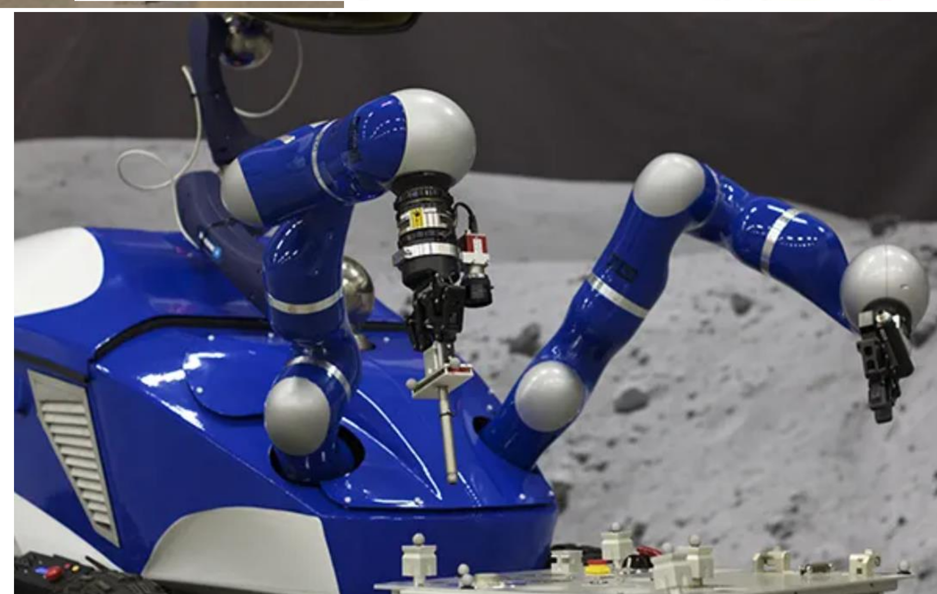
ERA installed on the ISS has the ability to perform many tasks automatically or semi-automatically, can be directed either from inside or outside the Station, and it can be controlled in real time or preprogrammed.

On-Orbit Robotics (Tele)-Manipulators



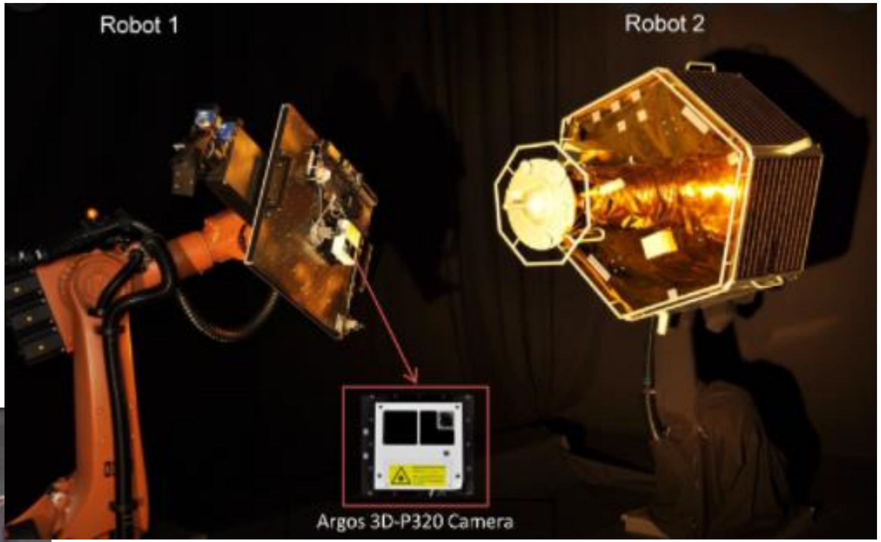


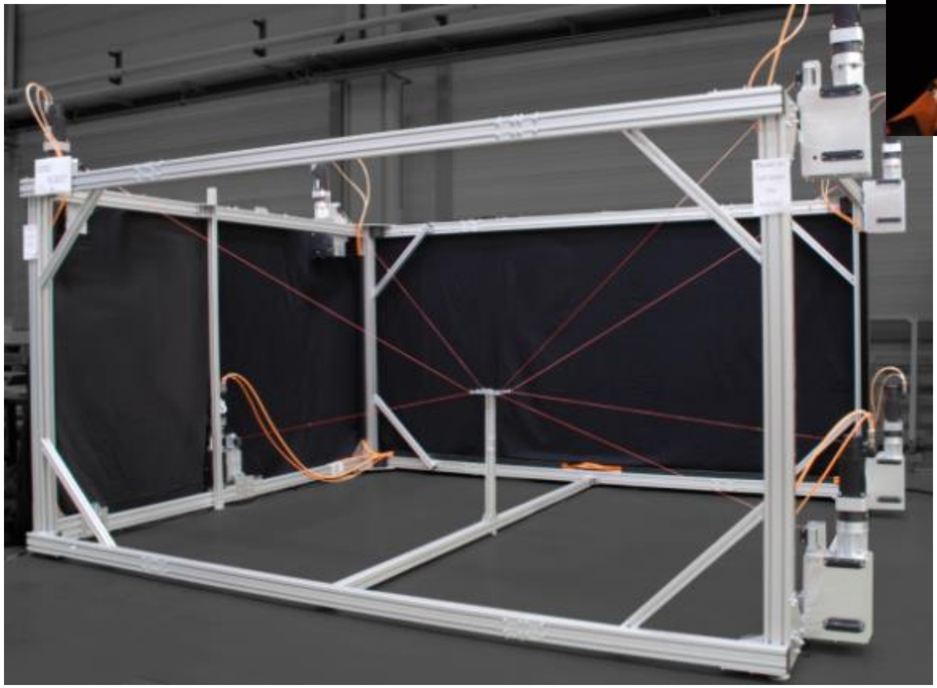


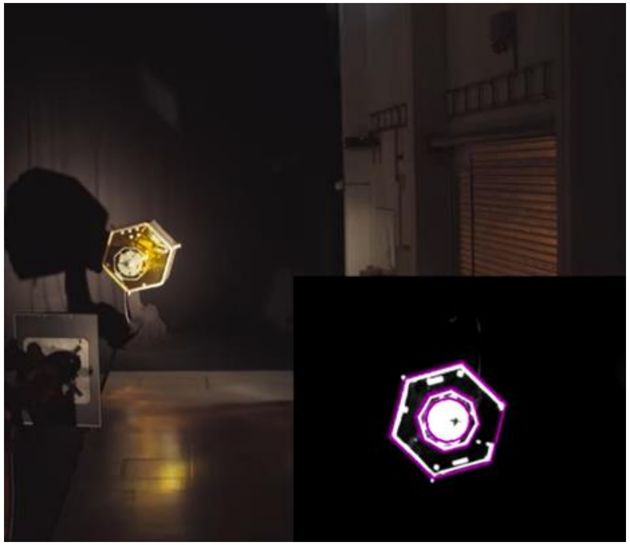


Floating base robotics

In-Orbit vision based RdV and automatic docking platform.
An hardware in the loop simulator which a cable robot to simulate free flying bodies.







On-Orbit operations simulator

An Orbital Simulator : A physics-based space flight simulator to operate virtualy spacecrafts : Orbitography models - Space environment models (electric charge models, radiation belts, residual atmosphere and earth magnetic field). Simulation of terrestrial sensor positions (radar, optical, telecommunications). Satellite models for orbit and attitude control will be defined in a library included in the Spacelab.

https://www.youtube.com/watch?v=l0mksnGj3VY

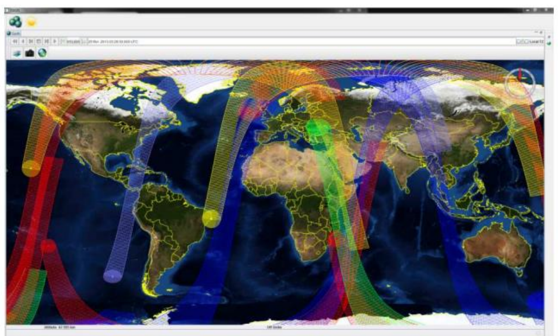


Figure 6 : Capture de l'outil OASIS, vue intervisibilité des satellites

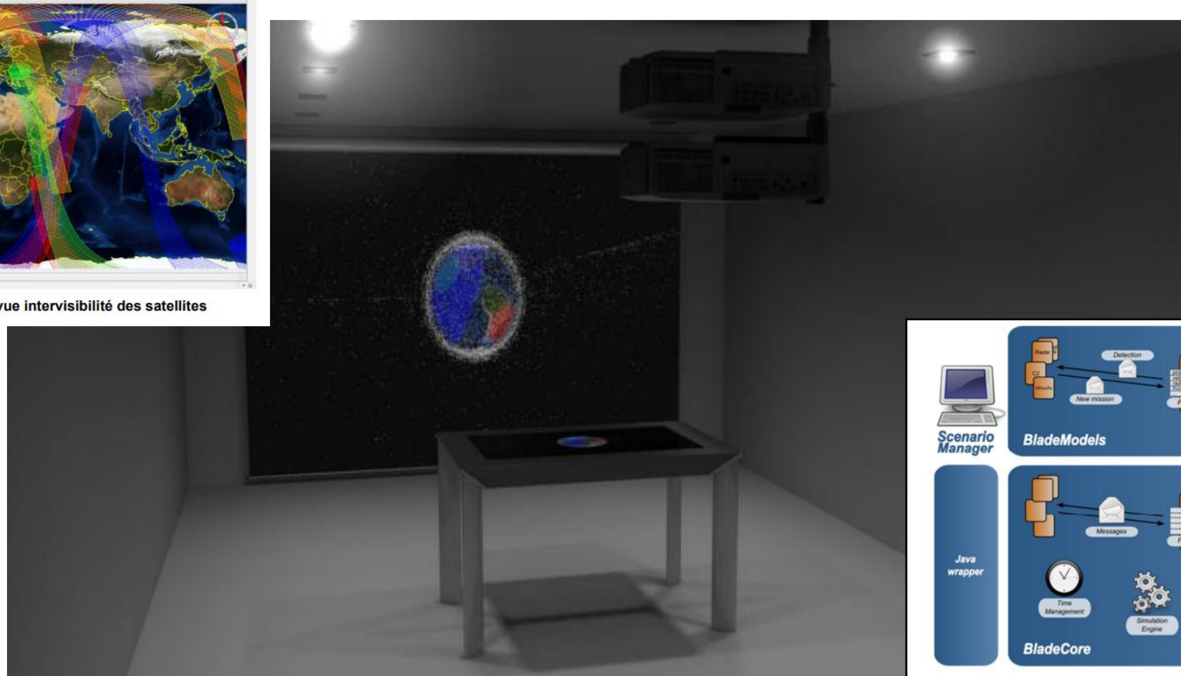


Figure 2 : Vue d'artiste du showroom SpaceLab

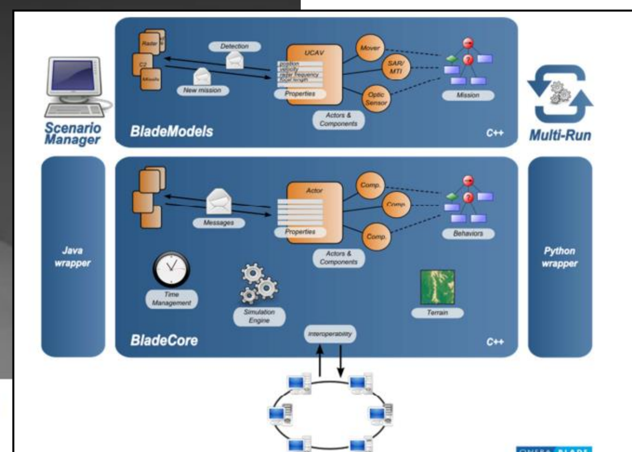
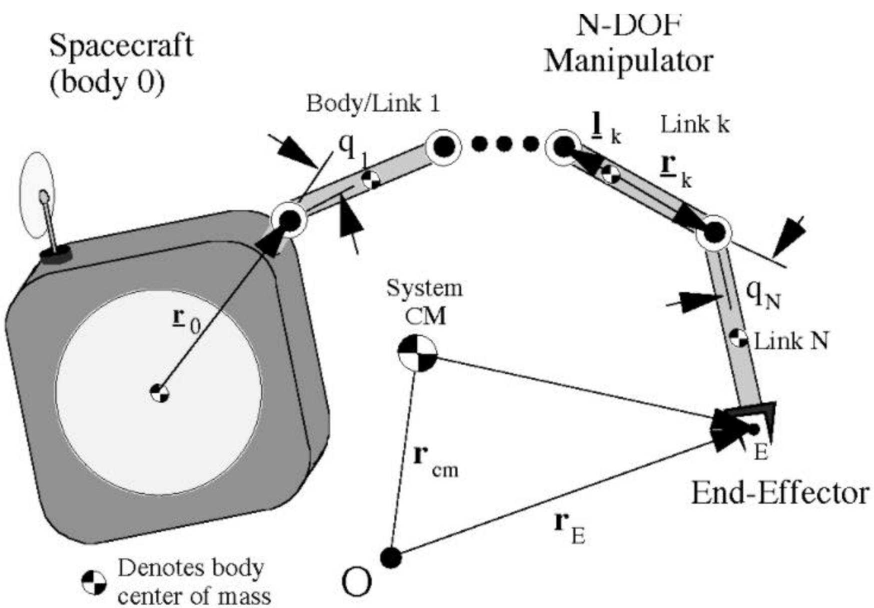


Figure 5 : Architecture logicielle de BLADE

Floating base robotics



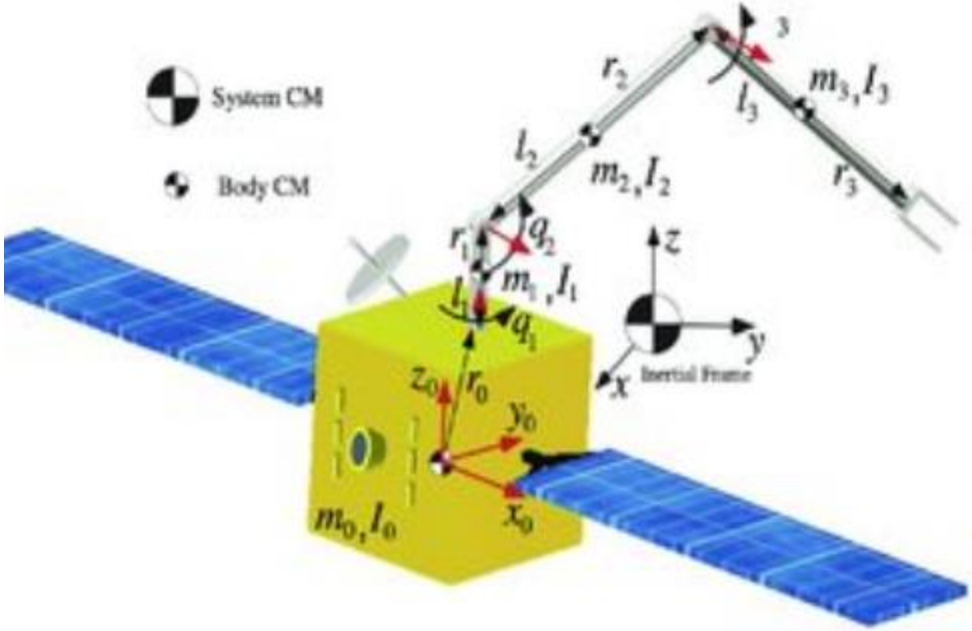
Reseach topics :

- **Mechatronics** of manipulators (with their end-effectors) optimized for floating operations
- **Coordinated control** of floating base and manipulator
- **Cooperative control** of multiple floating manipulators
- **Perception** and precise **localization** for floating manipulation
- **Physical interaction** of floating base manipulators
- Techniques for **assisted remote manipulation**
- **Learning techniques** for floating manipulation
- **Motion planning** of floating manipulators
- Fault tolerant **(FDIR)** approaches for floating manipulators
- Etc.

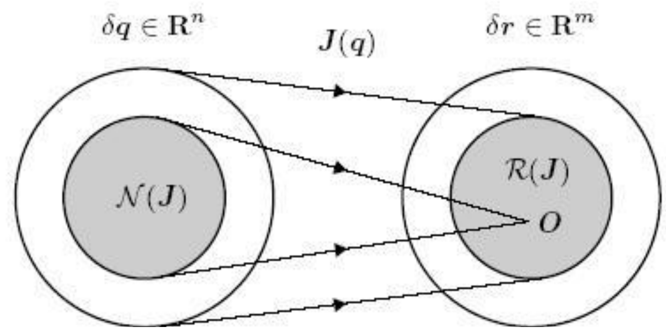
$$\mathbf{I}_s\dot{\boldsymbol{\theta}} + \mathbf{I}_M\dot{\mathbf{q}} = \mathbf{L}_0$$

où $\mathbf{L}_0$ est le moment cinétique total, constant, $\mathbf{I}_s$ la matrice d'inertie du satellite, $\mathbf{I}_M$ la matrice d'inertie regroupant les matrices des corps du manipulateur et $\boldsymbol{\theta}$ l'attitude du satellite. Des manœuvres de désaturation sont habituellement réalisées pour avoir $\mathbf{L}_0 = \mathbf{0}$.

Floating base robotics



Use of **kinematic redundancy** to satisfy constraints and optimize tasks



$$\dot{q} = J_1^{+}\dot{X}_1 + P_{\mathcal{N}(J_1)}(J_2^{+}\dot{X}_2 + P_{(\mathcal{N}(J_1)\cap\mathcal{N}(J_2))}Z_2)$$

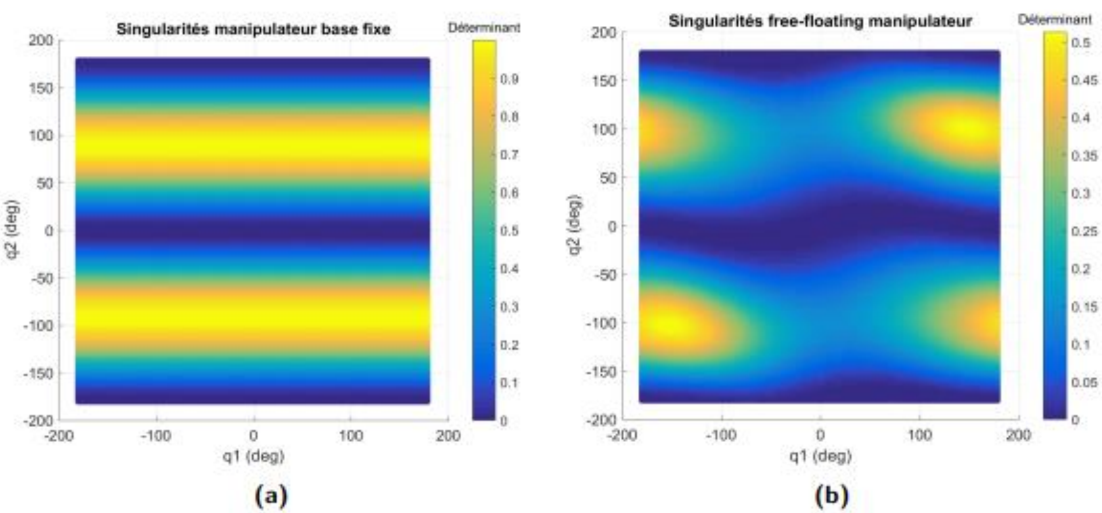


Figure 9.3 – (a) Distance aux singularités pour un manipulateur à base fixe. (b) Distance aux singularités pour un manipulateur sur un free-floating satellite, avec une attitude de 40^o

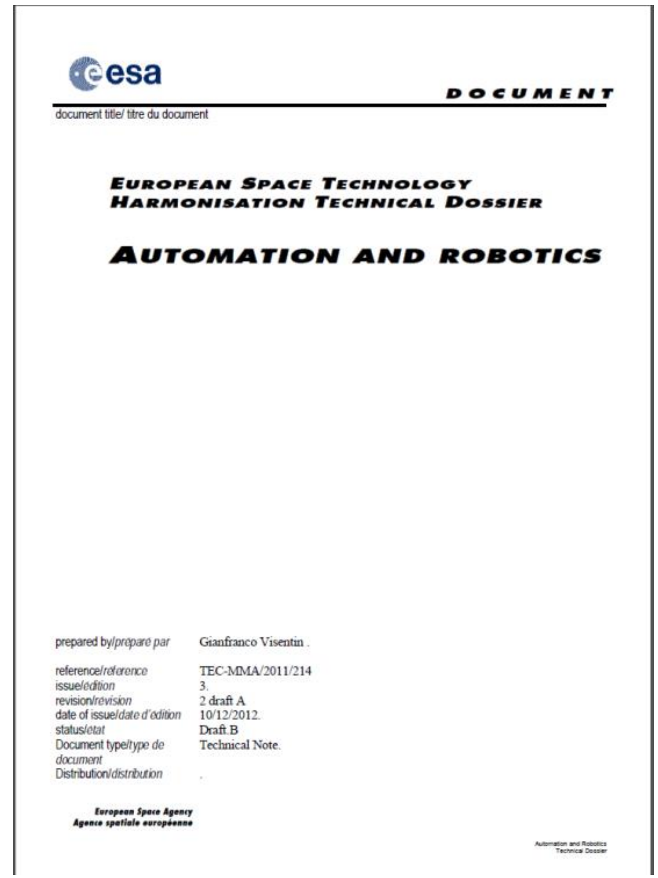
The **dynamic coupling** between an uncontrolled spacecraft and its manipulator can make a system dynamically singular at configurations which cannot be predicted by the system's kinematic properties.

ESA Technology roadmap : Automation and Robotics :

ESA's Automation and Robotics group is responsible for the creation and maintenance of an industrial technology base for the automation and remote control of space based operations (Link : http://www.esa.int/TEC/Robotics/)

The Roadmap addresses activities in 7 areas :

Aim A: Debris Capturing and Deorbiting
Aim B: Satellite refuelling provisions
Aim C: Immersive teleoperation
Aim D: High performance planetary locomotion
Aim E: Autonomous explorers
Aim F: Sustained Field Testing
Aim G: Other activities



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HARMONISATION TECHNICAL DOSSIER

AUTOMATION AND ROBOTICS

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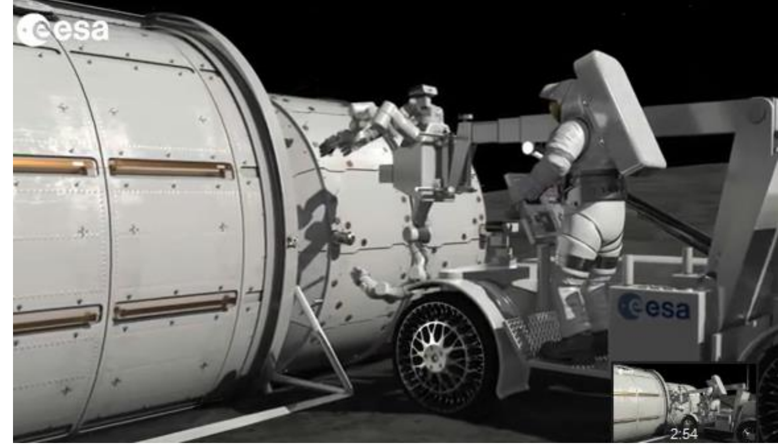
European Space Agency
Agence spatiale européenne

Automation and Robotics
Technical Dossier

http://www.dlr.de/rd/Portaldata/28/Resources/dokumente/rp6/veranstaltungen/H2020_Brussels/d1-02-ket_esa_sme/Williams.pdf

ESA robotics and automation past and <u>current programs</u>



Applications in Earth Orbit

Automation and Robotics systems are today used in low Earth orbit, mainly for building and operating the International Space Station. On the ISS two categories of use are possible: Module Internal Robotics Module External Robotics

Applications for Planetary Exploration

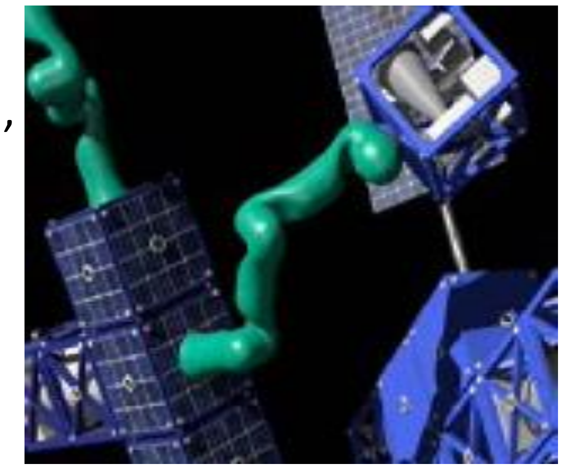
Automation and Robotics is an essential technology for the exploration of the Solar System. ESA has worked on A&R Systems for Mars Exploration
Moon Exploration, Exploration of other bodies

Core technologies
Manipulation Systems, Mobility Systems (articulated-deployable rovers), Robotics Perception, and Control, Autonomy and Intelligence, robot-user Interface

Illustration of ESA conceptual view :
http://www.youtube.com/watch?v=RZ06r9aWhfg

Robotics as <u>key technology</u> in space exploitation

The program considers transformation of advanced robotics for their exploitation techniques in different frameworks

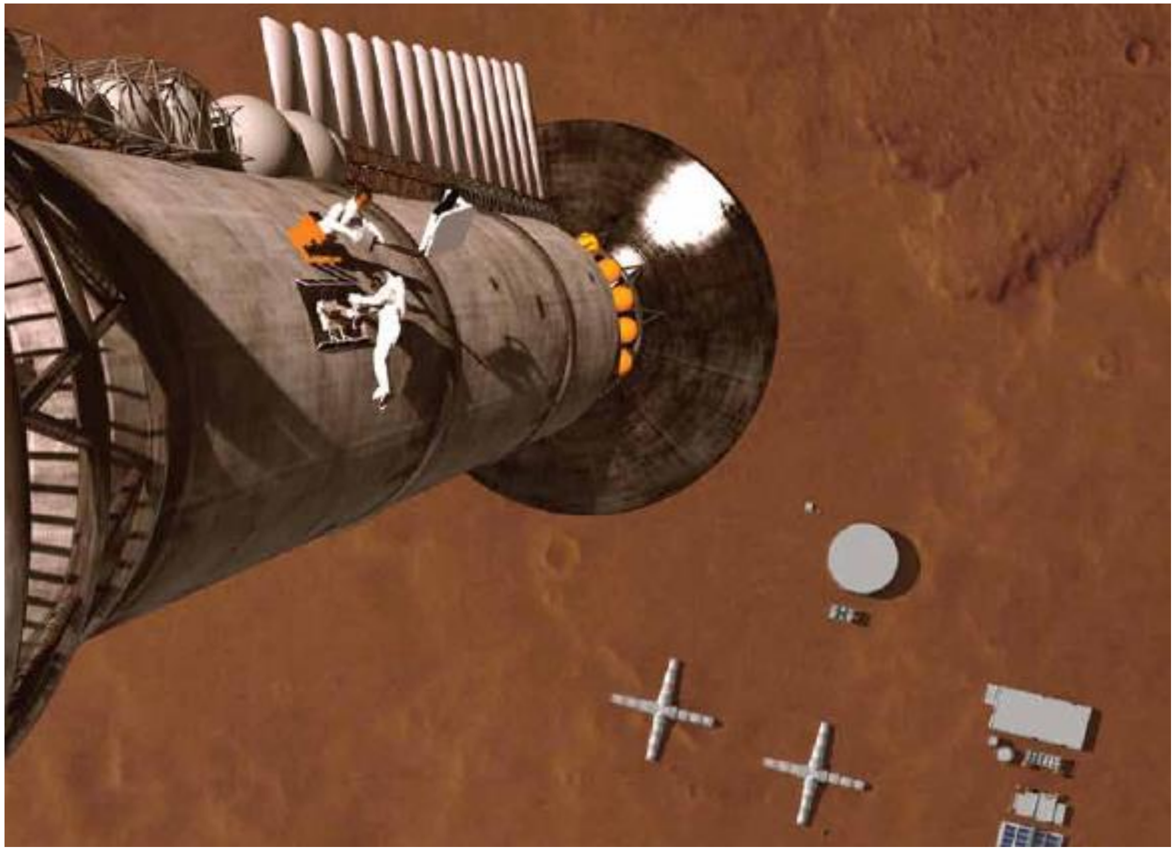


Orbital infrastructure : Dexterous grasping and manipulation, assisted tele-manipulation, adaptive physical interaction, HS Interfaces integrating virtual reality, constrained optimal trajectories, high-level planning system integrating decision capabilities, etc.

Exploration : Deployable systems, surface mobility, reconfigurable robotic agents, operation of robot teams.

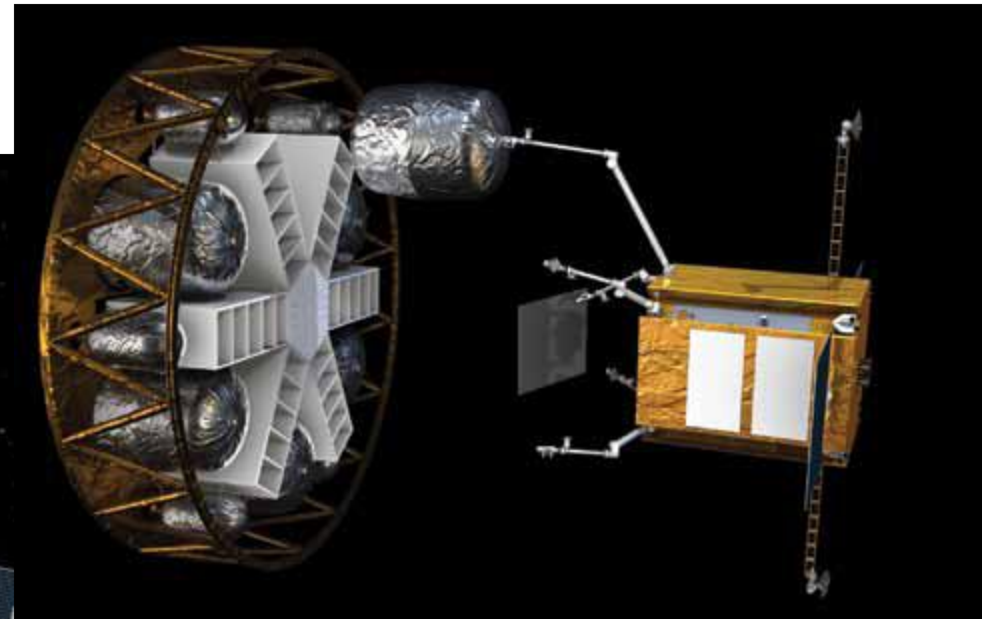
Transfer from and to terrestrial robotics :
Intervention robotics, undersea robotics, intelligent transportation systems (see France Robots Initiatives)

Robotics as key technology in space exploitation



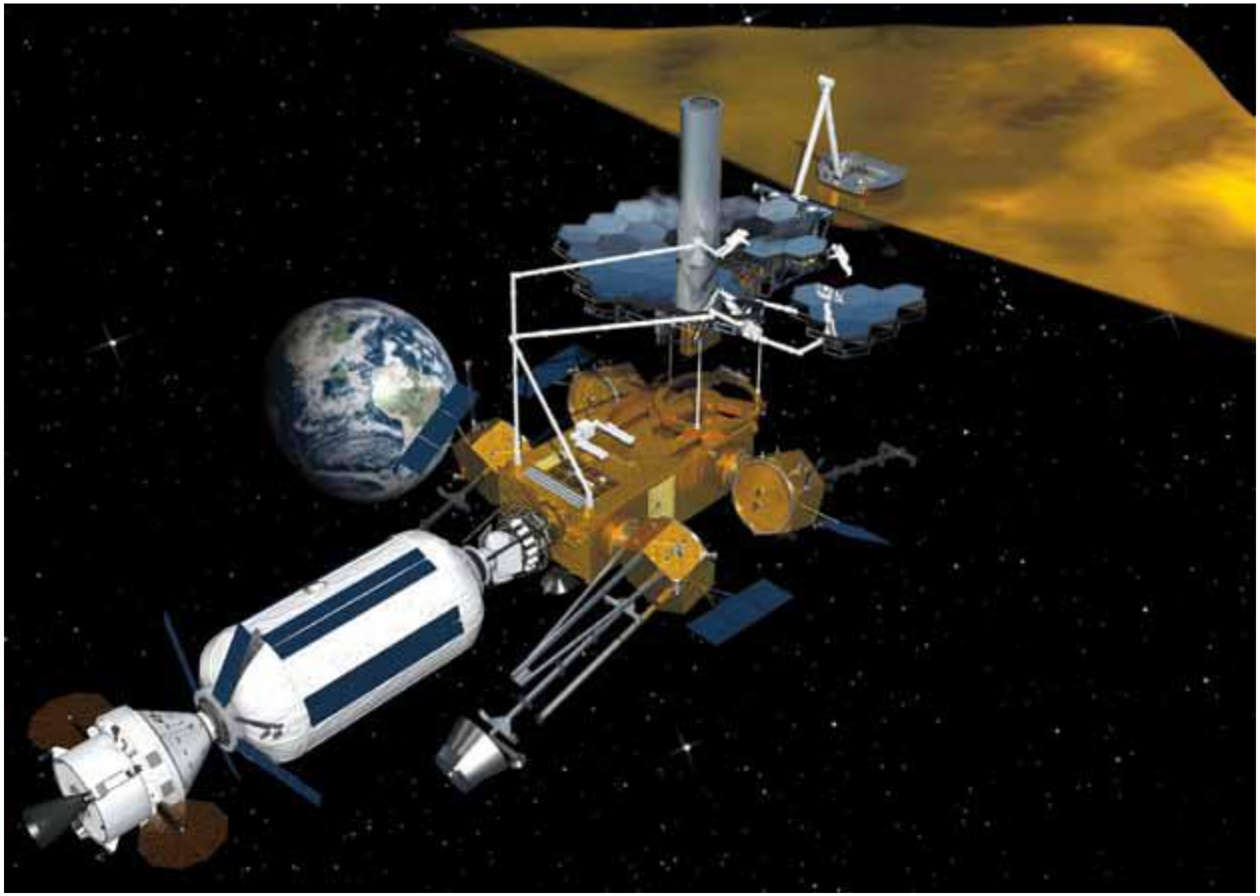
Returning from Mars – This conceptual rendering shows an astronaut with a robotic assistant preparing a spacecraft at Mars for return to Earth. It represents one of the more important future goals of in-space servicing.

Robotics as key technology in space exploitation



Refueling service : a refueling servicer (left) capturing and refueling a typical communications satellite Construction of a orbiting fuel depot - Rendez-vous and capture of satellites

Robotics as key technology in space exploitation



On-Orbit Assembly – This conceptual rendering shows a human and robotic servicer (left) assembling a larges pace telescope (right) in space.

Mission sequence
(chronology and increased complexity)

Specific expertise related to SRT issues

Nota : Here we consider mainly technical and not only technical objects to which they are applied.

- **Control** : Robust control, on-line estimation of dynamic parameters (structural and interaction), adaptive control, RT-trajectory generation, sensor-based control, FDIR.

- **System design** : vehicle+manipulator design, distributed action, optimal trajectories, coordination, system evaluation including HSI.

- **Human-System Interaction** : assisted tele-operation, haptic and force feedback, neuro-ergonomy, augmented perception, distributed perception, etc.

- **Co-manipulation** and secure-HR interaction : human physical activity estimation, person detection and tracking, predictive control, etc.

Specific expertise related to SRT issues

Nota : Here we consider mainly technical and not only technical objects to which they are applied.

- **Multi-modal perception** : 3D vision, detection and tracking, motion estimation, 3D geometrico-physic reconstruction and trajectory planning 3D SLAM (Simultaneous Localization and Mapping), dynamic obstacle avoidance

- **Decision and planning** : Task oriented control strategies (online adaptation), action and trajectory planning, execution control, etc.

- **Multi-robot cooperation :** distributed sensor based control, coordination, reconfiguration, etc.

- **Control Architecture** : Embedded hardware, multi-processing, reconfiguration, ROS, software architecture for control/decision.

- **Mission preparation and evaluation :** multi-physic simulation**,** hybrid simulation with human in the loop.