Robótica Espacial
Space Robotics

Introduction

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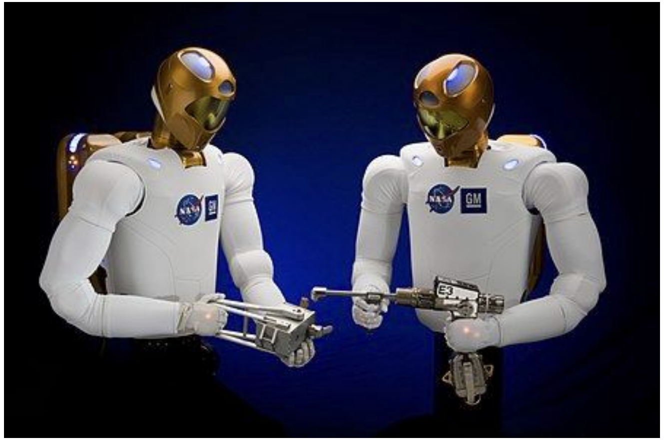
Why Space Robotics?

- **Why do we need robotics in space?**
  - Exploration beyond human reach
  - Harsh conditions: vacuum, temperature extremes, radiation
  - Cost and safety of human space travel
- **Applications**
  - Planetary exploration
  - Satellite servicing and repairs
  - Space station operations

Space Robotic Manipulation

Overview of Space Manipulators

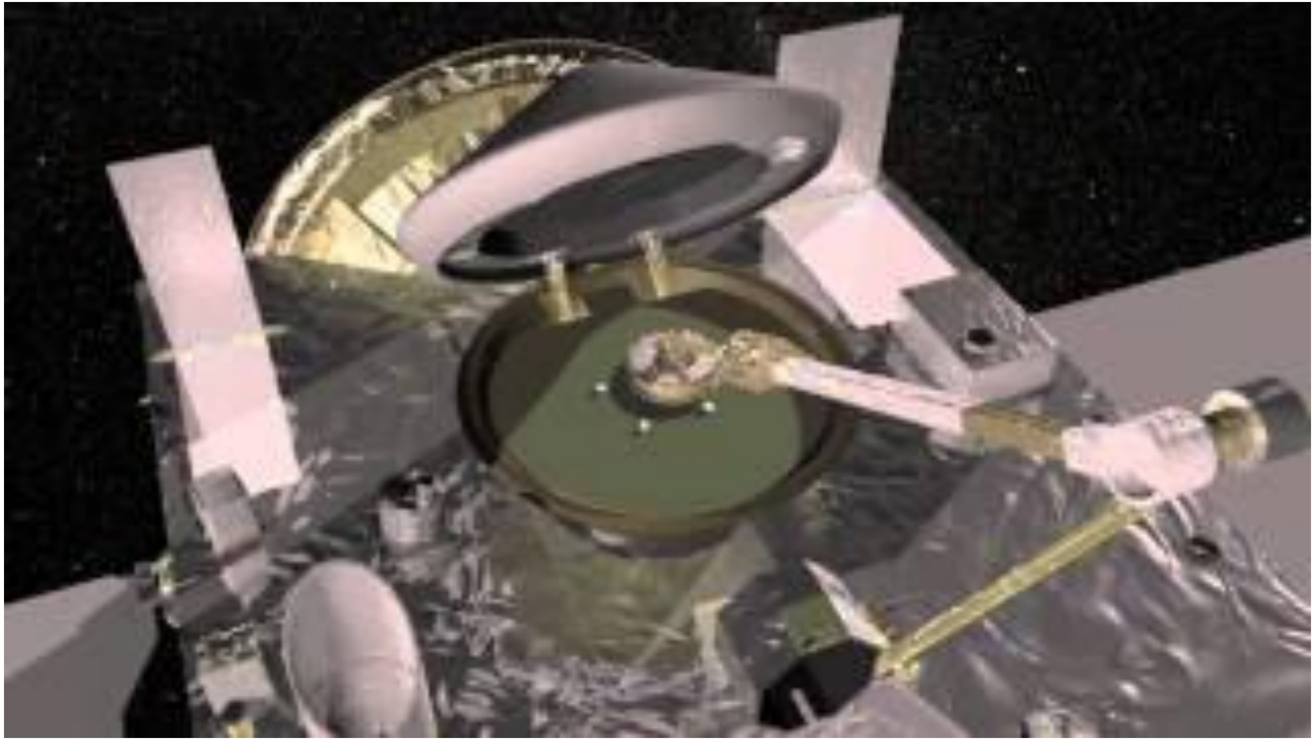
- **Definition:**
  - Robotic arms and manipulators used in space
- **Examples:**
  - Canadarm2 (ISS operations)
  - Robonaut (assisting astronauts)
  - OSIRIS-REx (asteroid sampling)



Robotic Manipulation in Space

https://youtu.be/svIPpeE9NBs?si=17YYih1OVxMf8-Cf&t=15

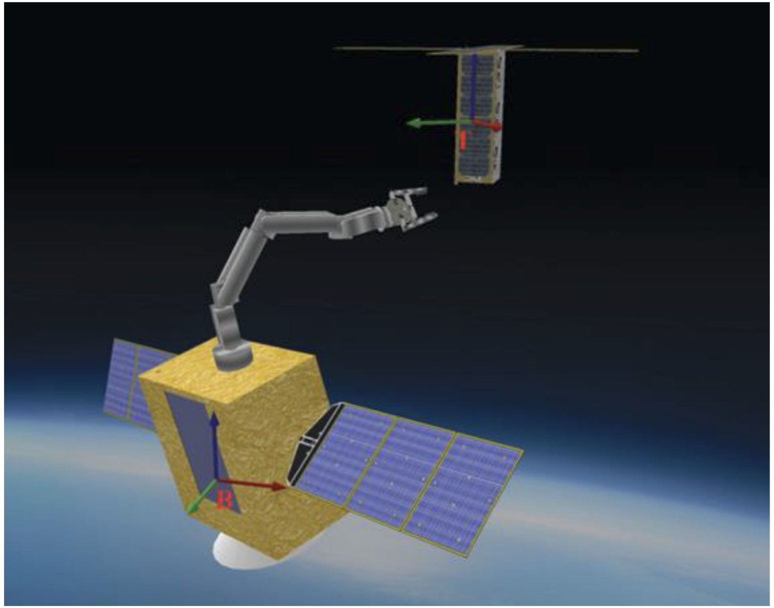
OSIRIS-REx Robotic Arm Operation



https://youtu.be/Asw9UZ_O8wc

Challenges of Manipulation in Space

- **Microgravity effects:**
  - No ground reaction forces
- **Precision issues:**
  - Docking and servicing satellites
- **Communication delays:**
  - Autonomy vs. teleoperation



Key Sensors for Manipulation in Space

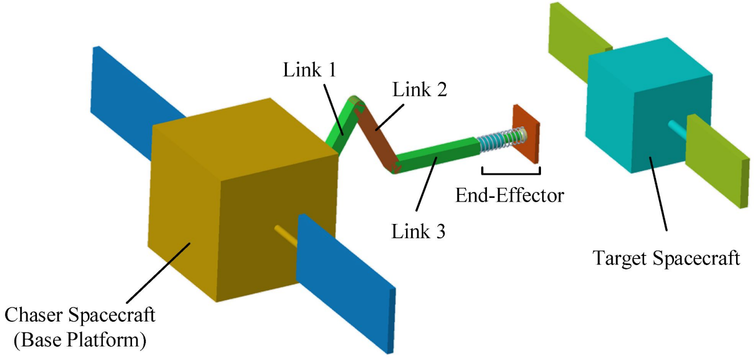
- **Force/Torque Sensors:**
  - Contact-sensitive tasks
- **Cameras:**
  - Visible, infrared, stereo vision
- **IMUs:**
  - Motion tracking for robotic arms
    - Base Motion Compensation (Mobile Manipulators)
    - Force Estimation in Free-Floating Manipulators
    - Teleoperation with Haptic Feedback, etc.

The Astrobee Free-flying Robot onboard ISS

https://youtu.be/LaW6YxN62vM

Control and Algorithms in Space Manipulation

- **Teleoperation vs. Autonomy**
  - Direct human control via remote operation
  - Semi-autonomous operation with limited human intervention
- **Impedance control:** Handling delicate objects
  - Adjusting robotic arm stiffness based on interaction force
  - Used for satellite servicing and docking procedures
- **Machine learning:** Adaptive grasping and control
  - AI-driven manipulation for unknown objects
  - Reinforcement learning techniques to optimize precision
- **Vision-based control:**
  - Object recognition and tracking using computer vision
  - Integration of LiDAR and depth cameras for grasping in microgravity



Planetary Rovers

Historical Landmarks in Planetary and Lunar Exploration

- **Lunokhod Rovers** (Soviet Union, 1970s)
    - First remotely operated planetary rovers on the Moon
    - Equipped with cameras, scientific instruments, and solar panels
- **Viking Probes** (NASA, 1976)
    - First successful landers on Mars
    - Conducted experiments searching for signs of life
- **Huygens Probe** (ESA, 2005)
    - First landing on Titan, Saturn's largest moon
    - Captured images of Titan's surface and atmospheric data

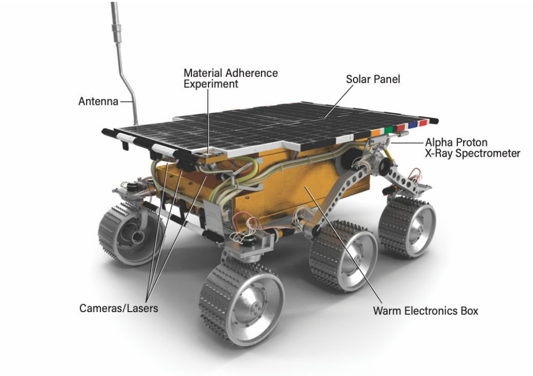
Lunokhod 1 - 1970

https://youtu.be/gLmFiCqIavU

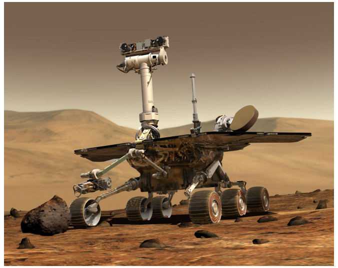
Viking Probes on Mars, 1976

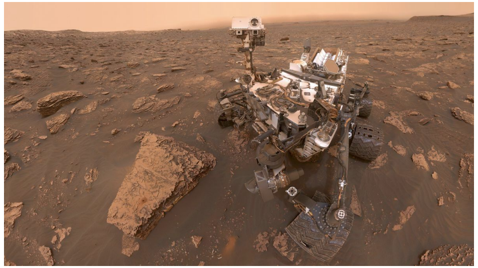
https://youtu.be/JPAyg7-p9oM

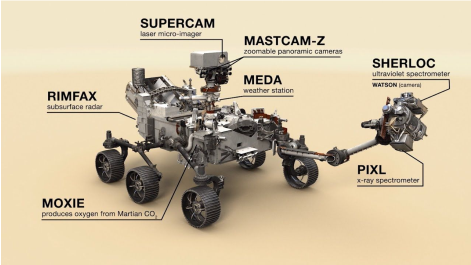
Overview of Mars Planetary Rovers



- **Definition:**
    - Mobile robots exploring planetary surfaces
- **Key Missions:**
    - Sojourner (1997, Mars Pathfinder)
    - Spirit & Opportunity (2004, Mars)
    - Curiosity (2012, Mars)
    - Perseverance (2021, Mars)





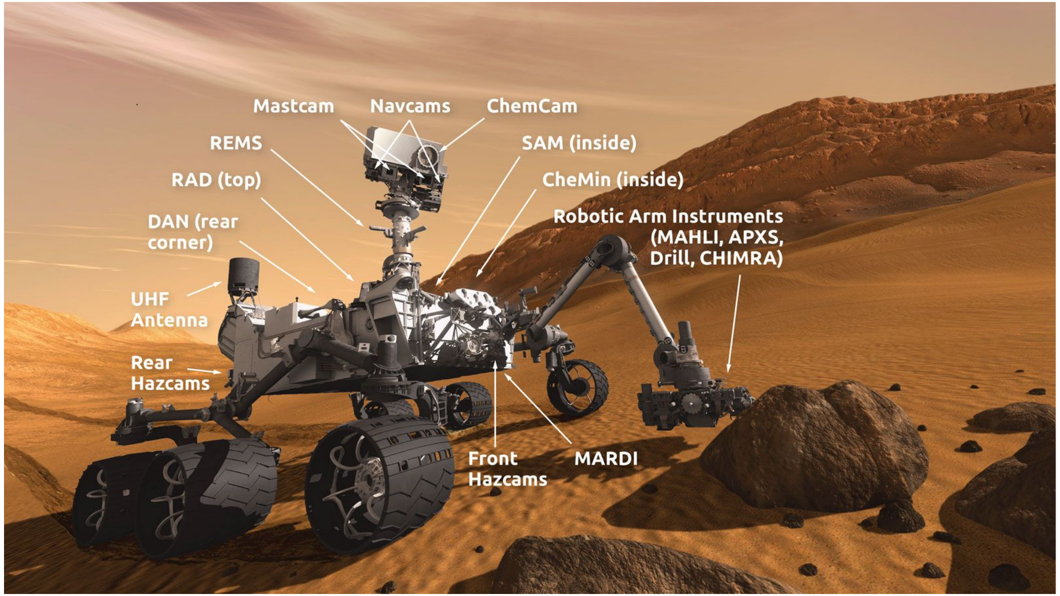


Challenges in Rover Navigation

- **Terrain:**
  - Unpredictable and rough landscapes
- **Communication latency:**
  - Delayed commands from Earth
- **Energy management:**
  - Solar vs. nuclear power

Key Sensors for Planetary Rovers

- Stereo cameras:
  - Depth perception
- LiDAR:
  - 3D terrain mapping
- IMU + Wheel odometry:
  - Localization

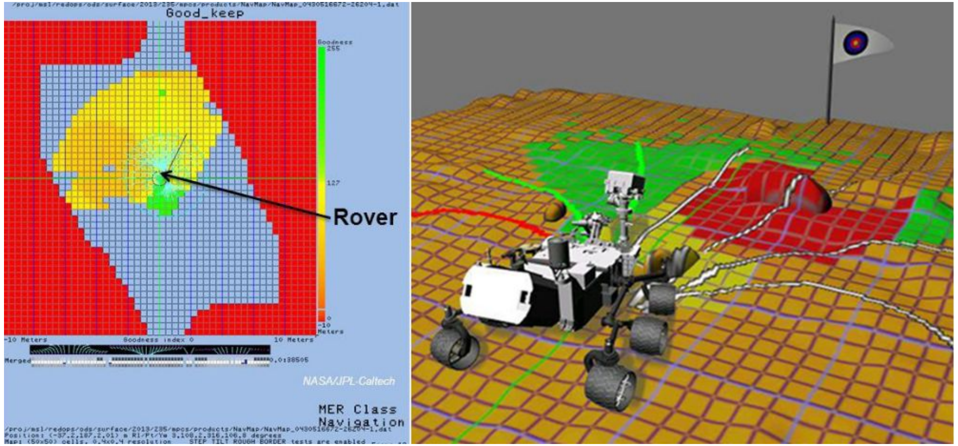


LiDAR barely used so far

Wheel odometry very imprecise

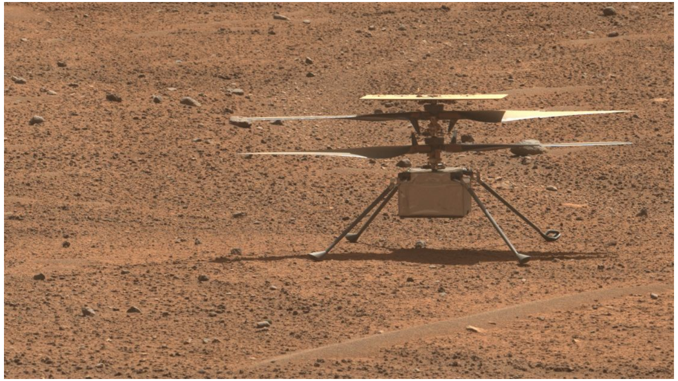
Autonomous Navigation and Path Planning

- **SLAM**
  - Simultaneous Localization and Mapping
- **Vision-based navigation**
  - Using AI and other techniques
- **Path planning:**
  - Reactive vs. global planning



Perseverance and Ingenuity: A Case Study

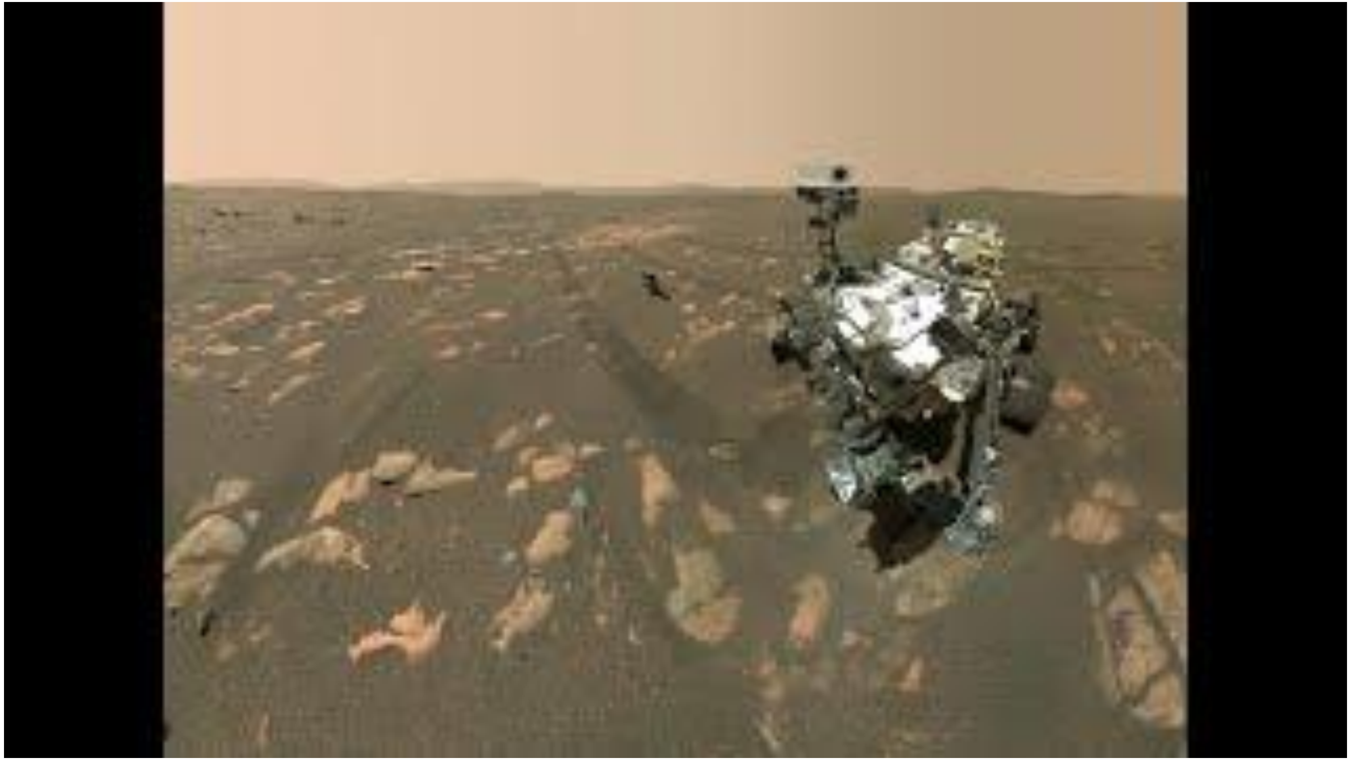
- **Perseverance Rover:**
  - AI-powered hazard detection, rock sample collection
- **Ingenuity Helicopter:**
  - First powered flight on another planet



Ingenuity first flight

https://youtu.be/wMnOo2zcjXA

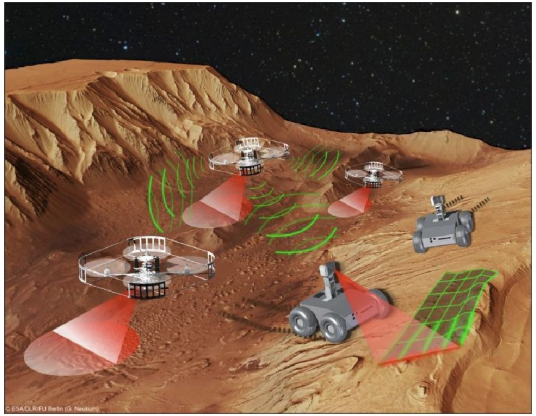
How does Perseverance do to take a selfie?

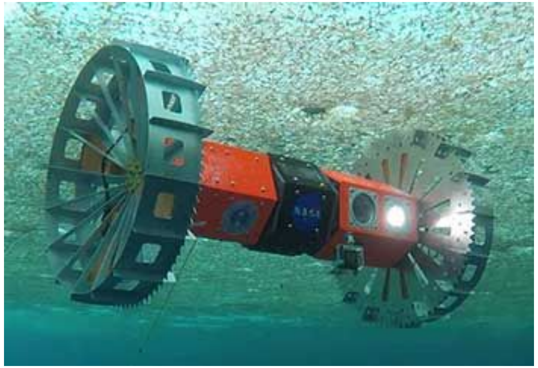


https://youtu.be/aKNjQhIAUp0

Future of Space Manipulation and Planetary Rovers

- **AI-powered robotic assistants** for astronauts
- **Self-repairing robots** in orbit
- **Autonomous space construction** for habitats
- **Swarm robotics** for collective exploration
- **AI-driven decision-making** in real-time
- **Under-ice rovers** for Europa and Enceladus missions





Conclusions and Open Questions

- The role of robotics in deep space missions
- Ethical and safety concerns in autonomous exploration
- Next steps in research and development