AI-based Space Robotics

Reconfigurable Robot Teams for Exploration

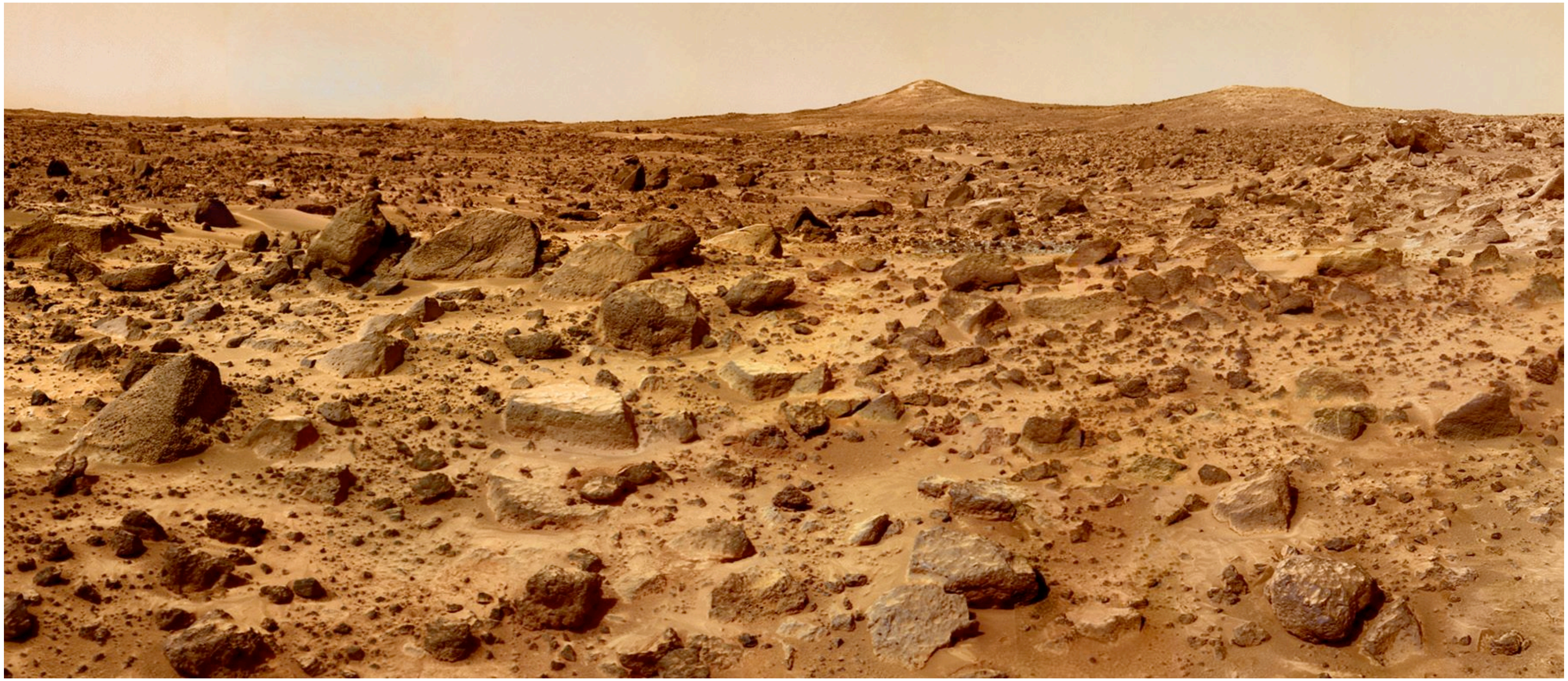
Frank Kirchner
DFKI-Robotics-Lab

Universität Bremen

Overview

- Planetary Exploration
  - Why Robots
  - State of the Art
    - Lunokhod I & II
    - Sojourner
    - Spirit & Opportunity
    - ExoMars
  - Alternative Concepts
    - Crater Exploration
  - Future Challenges

Planetary Exploration



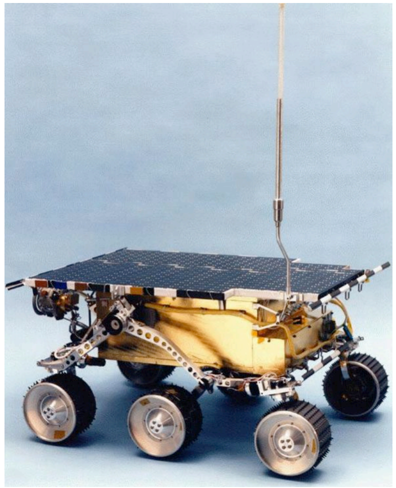
View of Twin Peaks, during Pathfinder-Mission to
Ares Vales, Mars (1997) © JPL

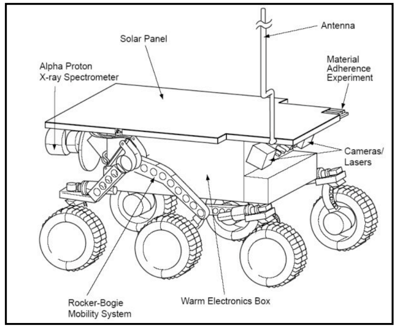
Planetary Exploration with Rovern

- Russian Lunokhod I & II (Mond, 1971-73)
- 8 Wheels
- Sturdy Chassis
- ~ 850kg Mass
- 1.6m Length
- Sensors/Experiments:
  - 4 Cameras
  - Solar X-Ray Experiment
  - Astrophotometer
  - Magnetometer
  - Radiometer
  - Photodetector for Laserdetection experiments
  - Laser Reflector
- Results:
  - 10.54 Km (Lunokhod I) &
  - 37km (Lunokhod II) Terrain covered.

Planetary Exploration with Rovers

- Pathfinder (1996/1997)
  - First Mission to Mars using Rover
  - Costs 265M Dollar
  - First Mission using Airbacks
  - Landing Site: Ares Vallis
    - Very rocky,
    - Different geological findings expected,
    - Formerly flooded terrain
  - Sojourner left Lander 05.07.1997
    - Mass 10.5 kg
    - Alpha Proton X-ray Spectrometer
    - 3 Cameras
    - Speed 1cm/sec
    - Several 100m of travel in 83 SOL
    - Placing of Instrument took several days
  - Command Sequence based Control(2-3/SOL)
  - Results:
    - 16,500 Pictures
    - 550 Pictures from Rover
    - 15 chemical Analysis
    - + further environmental data





Micro-Rover Sojourner

View from Lander on Sojourner

Planetary Exploration with Rovers

- MER-Mission (2003- now)
  - 2nd Mars mission with 2 Rovers Spirit & Opportunity
  - Landing Sites: Gusev Crater & Meridiani Planum
  - Search for Water
  - Cost to date > 1B$
  - Design
    - Mass 180 kg
    - Panoramic Camera (Pancam)
    - Miniature Thermal Emission Spectrometer
    - Mössbauer Spectrometer
    - Alpha Particle X-Ray Spectrometer
    - Magnets: Collection of magnetic dust
    - Microscope Camera (Close Up's)
    - Rock Abrasion Tool (RAT)
  - Control:
    - Pre-planing + Simulation of plan + Image based Navigation (2 time/day Upload)
  - Results so far:
    - Planed lifetime extended
    - Over 100.000 Pictures
    - Exploration of shallow craters
    - Aprox. 9km traveled with Opportunity)

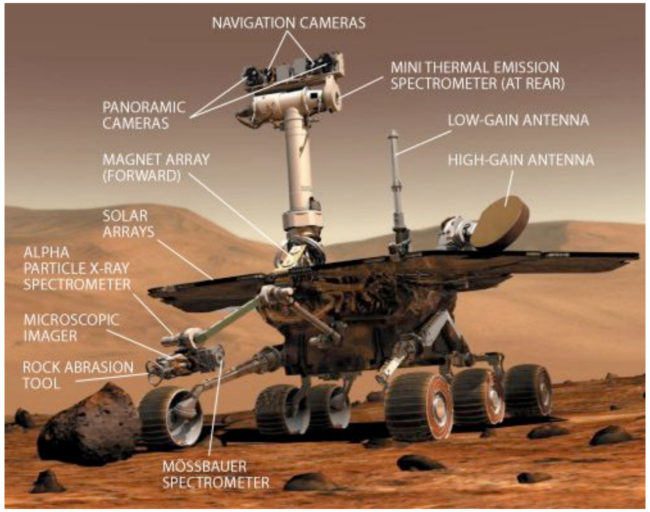
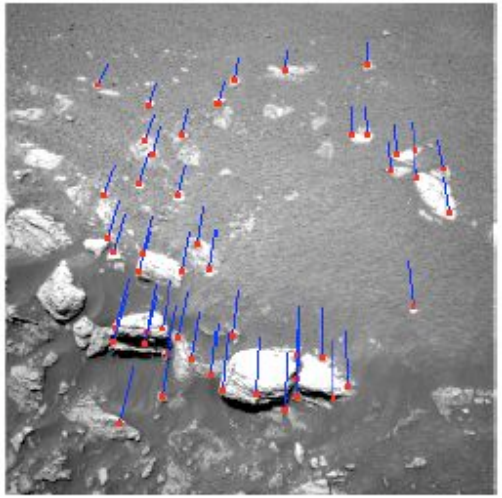


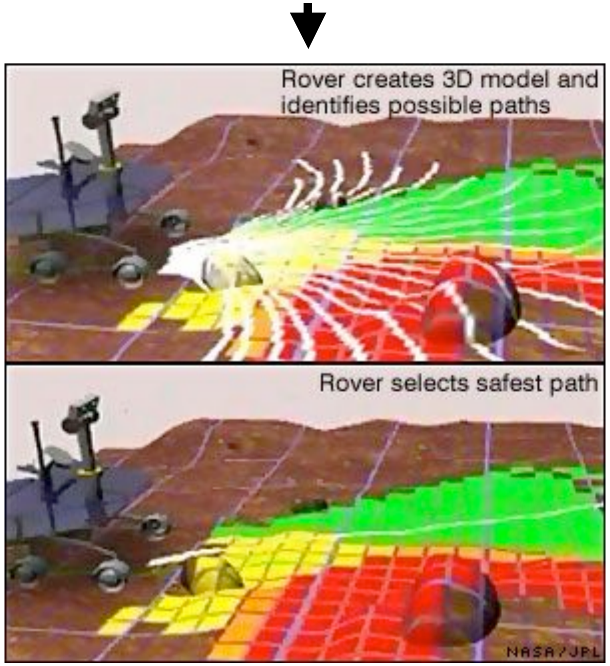
Fig. Spirit und Sojourner Model

State of the Art: AI-Planing / Navigation

- Navigation / Locomotion Control
  - Plan & Visualization on Earth
  - Plan send to Rover 2 times/day
  - Rover creates 3D-Elevation-Grid from Panoramic pictures
  - Planer calculates safest path to next waypoint (30cm)
  - Visual Odometrie for localization
  - Autonomy-Problems:
    - Correct Model
    - Correct Rules
  - In case of doubt max. conservative approach



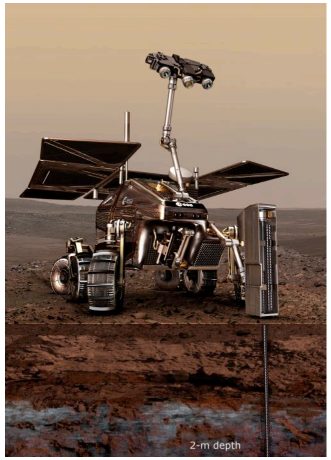
Visual Odometrie



Planing with Elevation-Grid

Planetary Exploration with Rovers

- Exo-Mars (2011 or 2013)
  - Search for life
  - Planed:
    - ~120kg Mass (was more / Costs!)
    - 180 SOLS planed
  - Scientific Payload
    - Panoramakamera
    - IR-Spektrometer
    - Ground Penetrating Radar(GPR)
    - Mössbauer >Spectrometer
    - Bohrer bis 2m Teife
    - Laser-Induced Breakdown Spectroskop (LIBS)
    - Mikroskop
    - X-Ray Diffractometer
    - More... (under definition)



Bilder: ESA

Conclusion: State of the Art

So far:

Mission with 6-8 wheeled Rovers

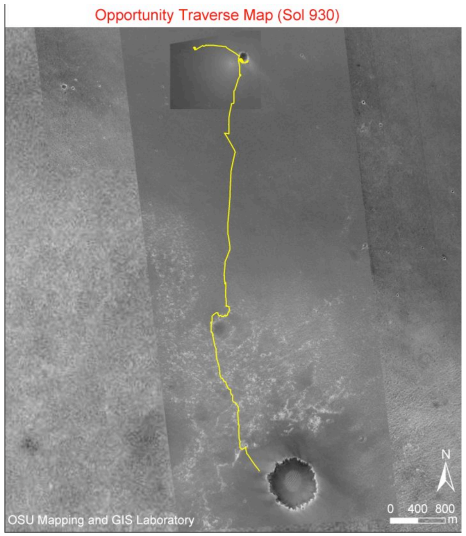
- Missions with a single Rover
  - No Cooperation / no complex infrastructures
- Strictly scientific Missions focusing on:
  - Exobiology
  - Exogeology
- Missions in easy terrain without Autonomy
  - Crater/Canyons can not be well explored because:
    - Autonomy (dynamic Environments)
    - High Mobility

  is missing

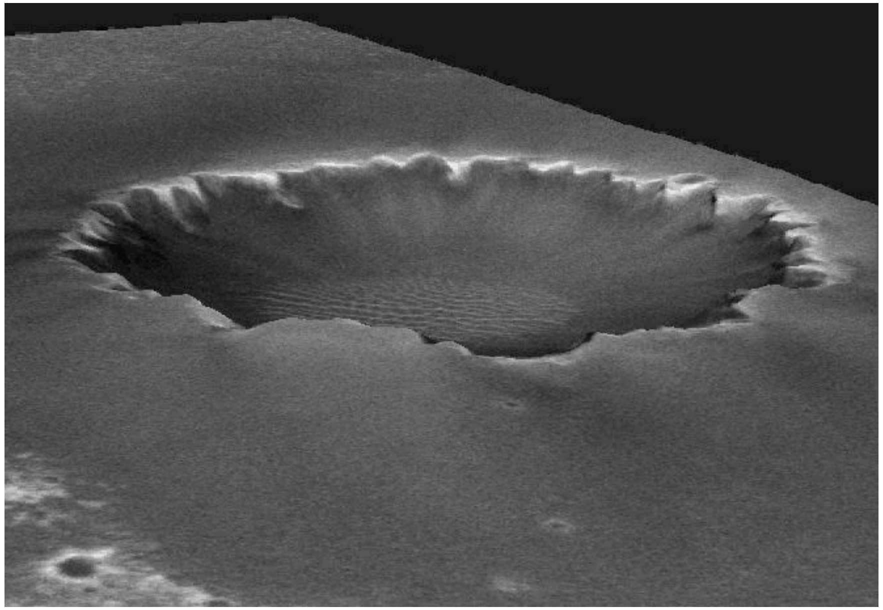
Craters on Mars

Fig. Panorama-Picture
Endurance Crater (Opportunity)

So far only limited exploration of craters and canyons, but they are of high scientific interest.



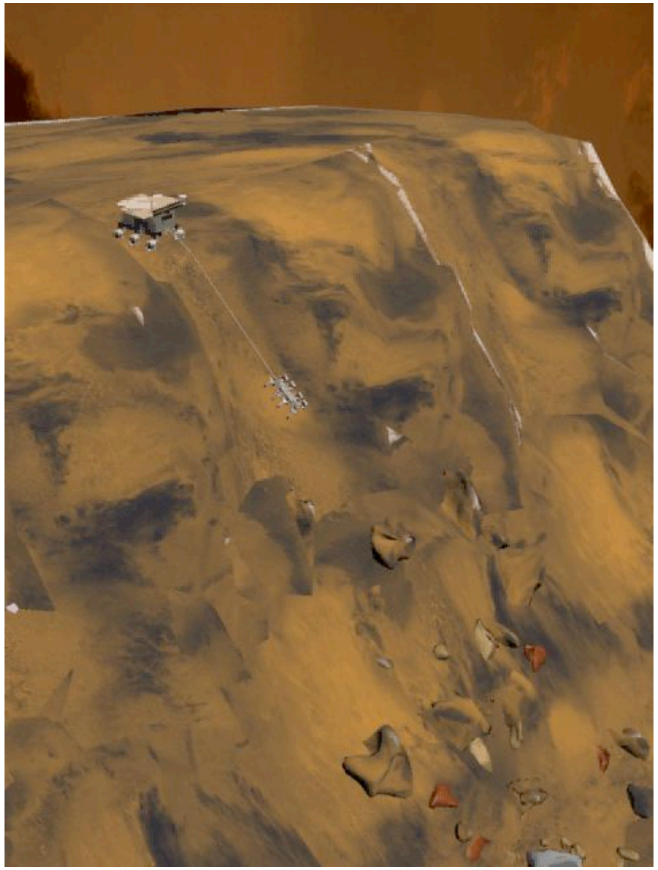
Opportunity at Victoria Crater



Animation of Victoria Crater

Exploration of Craters

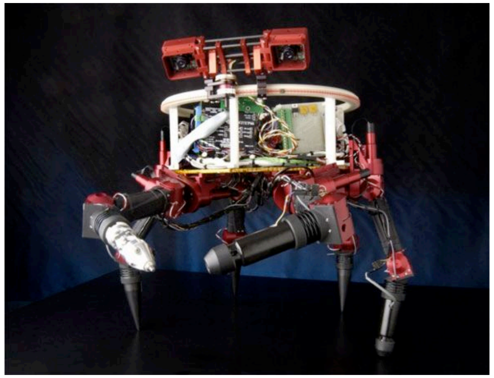
- Missions into craters demand higher levels of Mobility and Autonomy
- Walking Systems provide that mobility
- Interest in Craters and Canyons:
  - Access to different sediment layers
  - Access to iced water
  - Possible micro habitats in fissures and caves
    - Different climate than on surface
    - ‘possible location of biological organisms’



Animation: Cooperative Exploration

Walking Systems in Space Applications

- Projects:
  - Dante (NASA/CMU)
  - Lemur(NASA/JPL)
  - SCORPION (DFKI Lab Bremen, NASA)
  - ARAMIES (DFKI Lab Bremen, ESA/DLR)



Lemur IIa (NASA/JPL)

Lemur IIb (NASA/JPL)

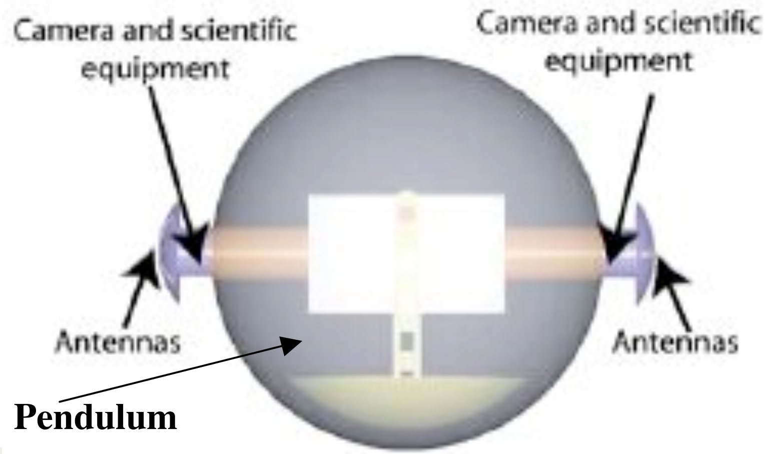
SCORPION (DFKI Lab Bremen)

ARAMIES (DFKI Lab Bremen)

Bio-inspired Control & Locomotion in difficult terrain

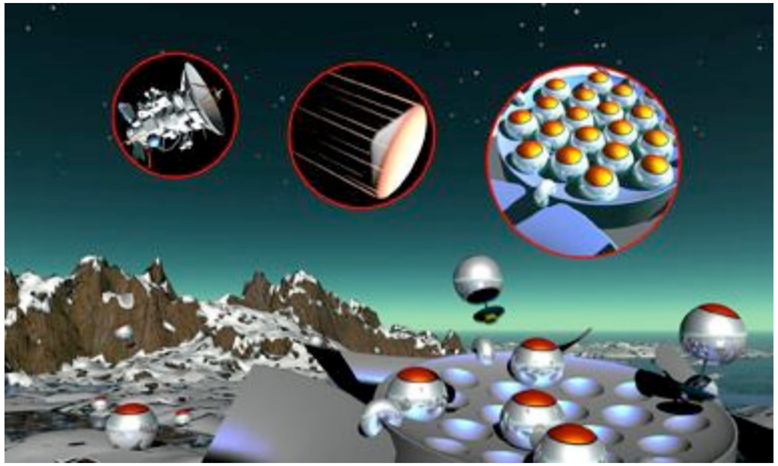
Alternative Concepts

- E.G. Spherical Mobile Investigator for Planetary Surfaces (SMIPS) *(Ångström Space Technology Centre, Rotundus, Uppsala, Sweden)*
  - Simmilar studies at NASA (Inflatable Rover)
  - Low mass (5.5kg)
  - Diameter (0.44m)
  - Theor. Large opperational range
  - Hull consists of 11 layers
    - MEMS-Sensors
    - Isolation
    - Power
    - Etc.---

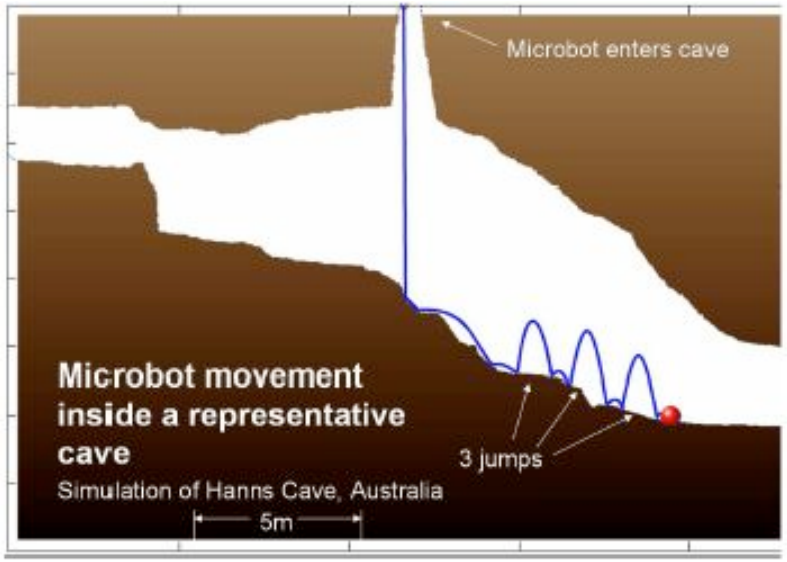


Alternative Concepts

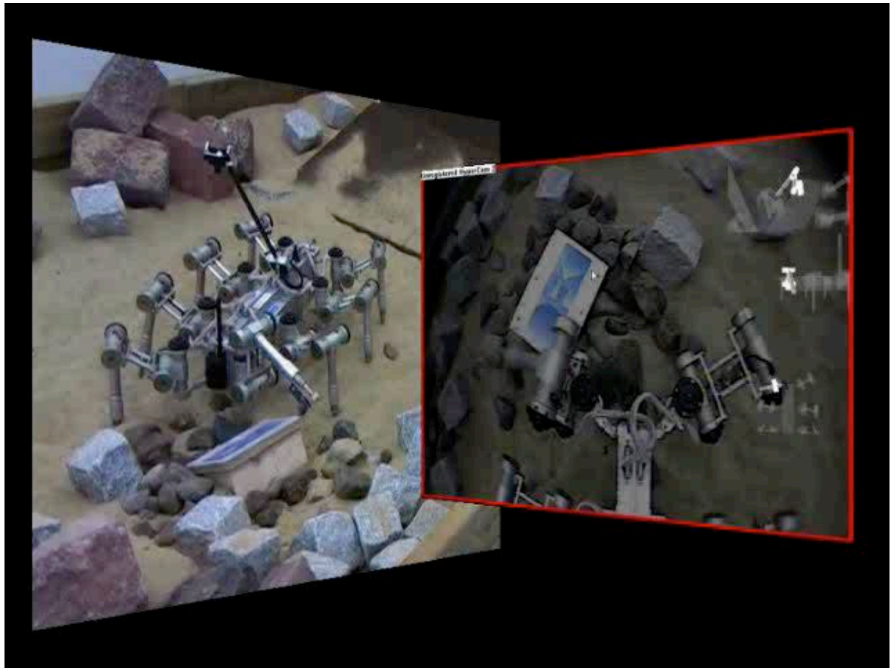
- Microbots for Large-Scale Planetary Surface and Subsurface Exploration (MIT Field and Space Robotics Lab, New Mexiko Tech)
  - Robot Swarms
  - Exploration of Cratrs and Caves



- Frogbot: Jumping Robots (P. Fiorini, JPL)



Virtual Immersion

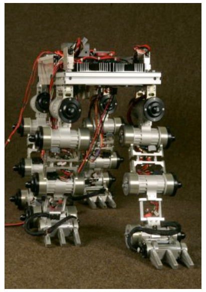


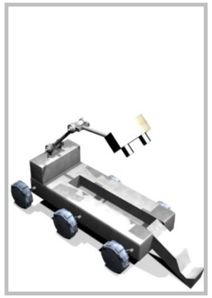
- Operator remotely operates surface robots
- Operator support through multi-modal interfaces:
  - Tactile feedback (Gloves, Exo-skelleton)
  - Natural Speech control
  - Haptic Feedback

Alternative Concepts: Robot Teams

2 Base Rovers (Mother ships)

- Autonomous 6-wheeled rover for even terrain
- Transporter for ARAMIES & SCORPION
- Winch System
- High performance Computer & Communication units
- High Capacity Energy Supply
- Recharging Capability
- Advanced Sensors and Processing
- Connection to Lander or orbital Systems





Specialists for each Task

ARAMIES (ESA/DLR funded):

- Autonomous 4-legged Scout for heavy Terrain
- Active Feet for Manipulation and Climbing
- Payload: >5.0kg
- Operational Range : 2000m

SCORPION:

- Autonomous 8-legged System for steep and heavy terrain
- Payload: 2.0kg
- Operational range: ~1000m
- Light Weight (11kg)

Robot Teams: an Approach towards reconfigurable Robots

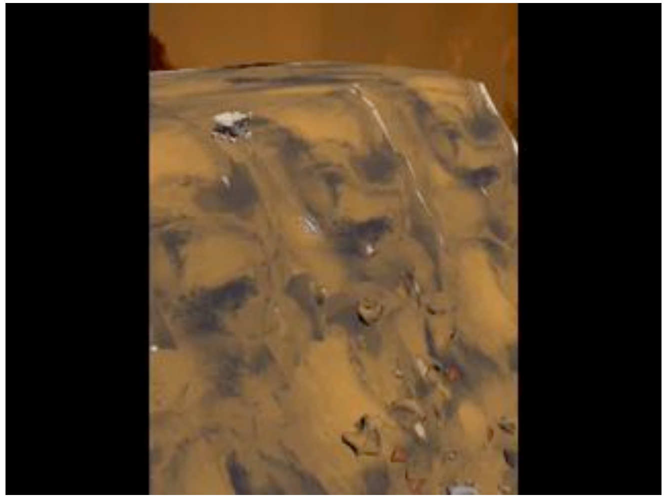
<u>Properties:</u>

- **Ressourcensharing reduces overall weight and energy requirements.**
- **Redundancy of Sensorsystems minimizes errors**
- **Base-Rover is energy efficient Transporter on flat terrain**
- **Base Rover is Communications Relay**
- **Base Rover is Mission Control (Team Leader)**
- **Scout enables accsess to difficult terrain and in-situ analysis (or sample return)**

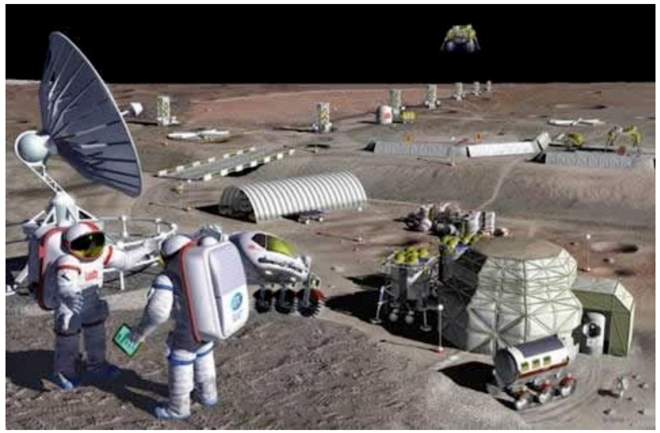
LUNARES: An earth based test for a lunar mission

Conclusion

2 mayor challenges for future robotic exploration missions:



- **Mobility:** penetrate craters, fissures and sub-terrain structures
  - Walking, rolling, jumping and drilling robots
  - Local, robust intelligence
  - Cooperative Approaches
- **Autonomy:** Construction and Maintenance of surface infrastructure.
  - Telescopes
  - Energy Supply
  - Habitats
  - Solutions:
    - Cooperative Robots
    - Multi-Tool-Robote
    - Immersed Reality

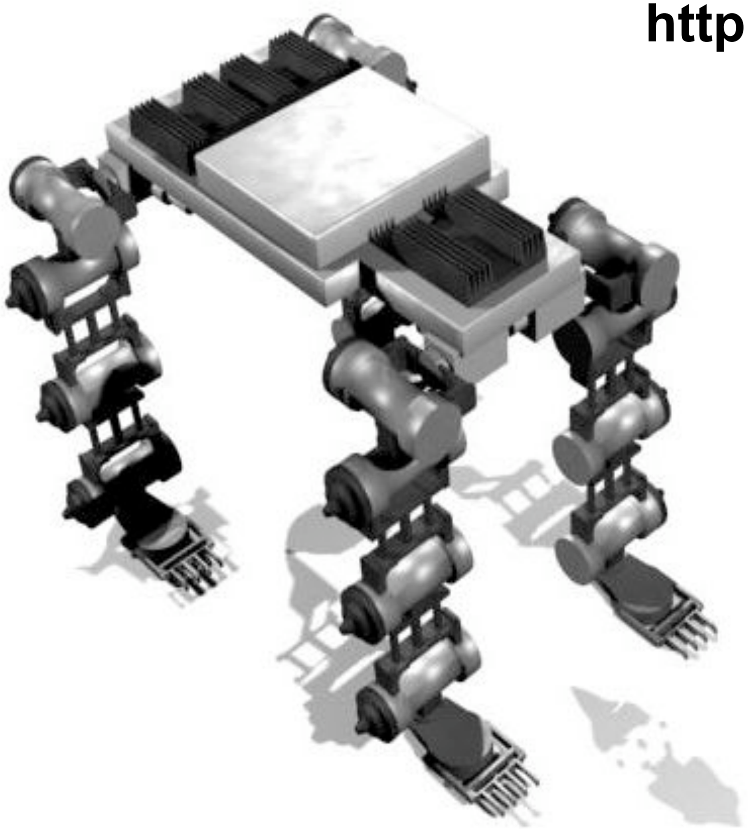


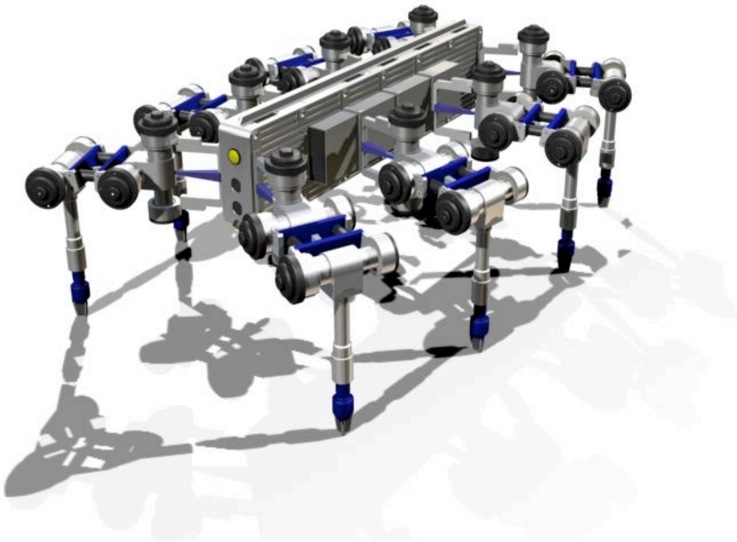
DFKI Robotics Lab &

University of Bremen

Germany

http://www.dfki.de/robotik





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