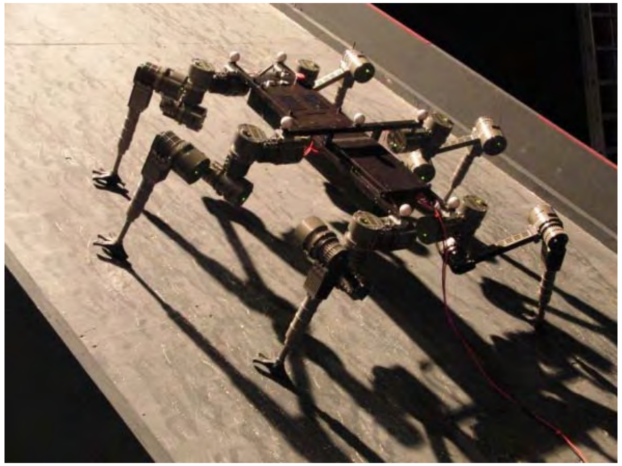
Heterogeneous Robotic Teams for Exploration of Steep Crater Environments



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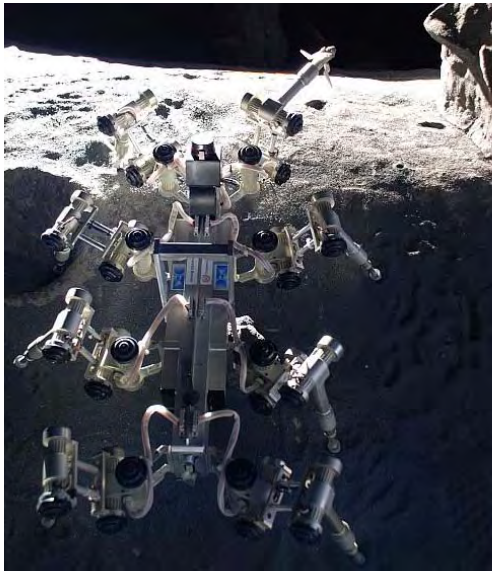
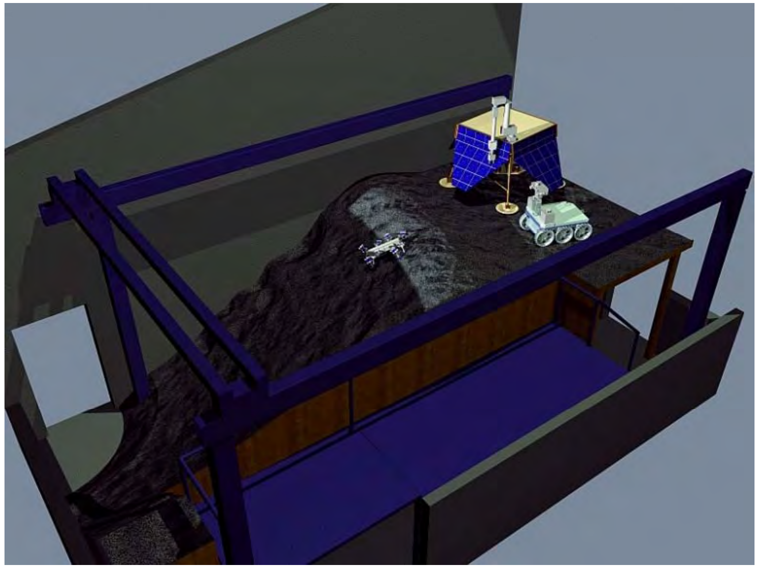
LUNARES – Project Overview

- Demonstration of sample retrieval from permanently shaded crater
  - Artificial crater environment with varying slopes of 30° to 45°
  - Landing Unit with robotic arm and sensor tower
  - Wheeled Rover (energy efficient locomotion in moderate terrains)
  - Legged Scout (high locomotion capabilities in steep slopes)
- Usage of available state of the art robotic systems
- Combined in a heterogeneous overall system





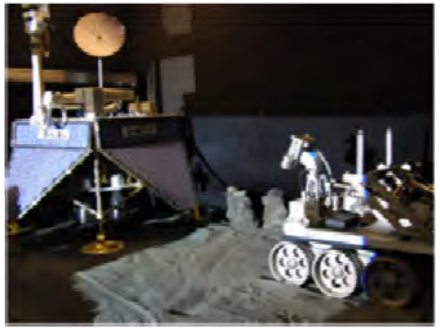
Project Partners:

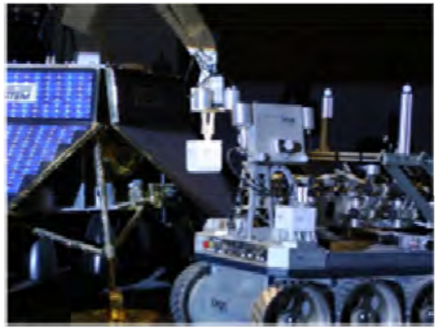
Deutsches Forschungszentrum für Künstliche Intelligenz GmbH

EADS astrium

OHB SYSTEM
Ein Unternehmen der OHB Technology AG

LUNARES – Demonstration Mission


(a) Autonomous docking of rover to lander


(b) Equipment of rover with new payload


(c) The manipulator is retracted


(d) Rover and scout on their way to the crater's rim


(e) Deployment of scout

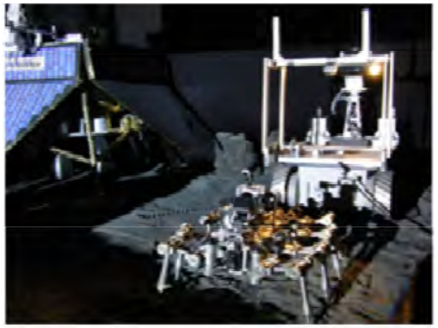

(f) Scout leaves docking adapter by changing its posture

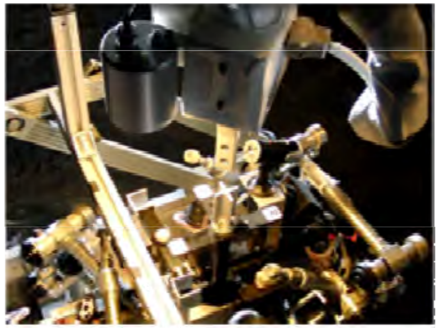

(g) Scout is about to climb into the crater


(h) Scout arrives at crater bottom. Light is enhanced for the picture.


(i) Sample pick up in the crater


(j) Scout climbs up the crater slope


(k) Autonomous docking of Scout and Rover


(l) Sample container is picked up by the landers manipulator arm

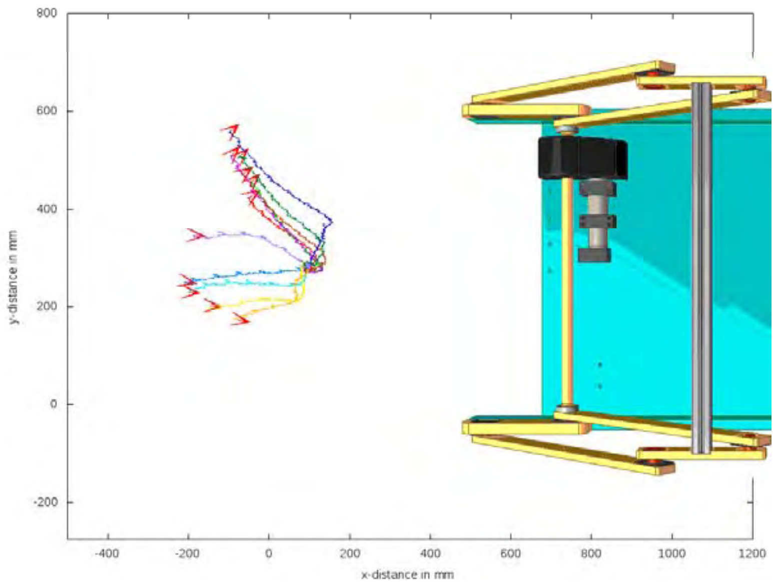
Experimental Results (Docking)

- Docking experiments with scout and rover
  - Motion tracking system (MTS) for recording trajectories of scout
  - Starting distance varies between 20cm and 40cm
  - At least 3 visual markers have to be visible in video image of rover's sensor head
  - All 13 runs of this series successful, 2 runs with corrupted MTS-data
- Experiments showed high precision relative positioning is possible with legged robot having play in joints
- General suitability of the chosen approach for docking between rover and scout could be proved

Video: Docking Process

	σ_X	σ_Y	σ_Z	σ_{Yaw}
Max allowed tolerance	30mm	10mm	20mm	5°
Achieved std. dev.	9mm	4mm	12mm	0.7°

Table: Allowed mechanical tolerances and standard-deviation of target position



Experimental Results (Locomotion in Slope)

- Locomotion experiments with different parameter sets:
  - Pulse, Max Lean, Body Height
  - P {3000, 4500}
  - L {0, 50, 100}
  - B {150, 180}
- Constant Phase shift of 0.7
- Reflexes important for stable locomotion in steep slope
- Implementation of stumbling correction, hole reflex and lean behavior

Video: Body Height 150 (L100, P3000)

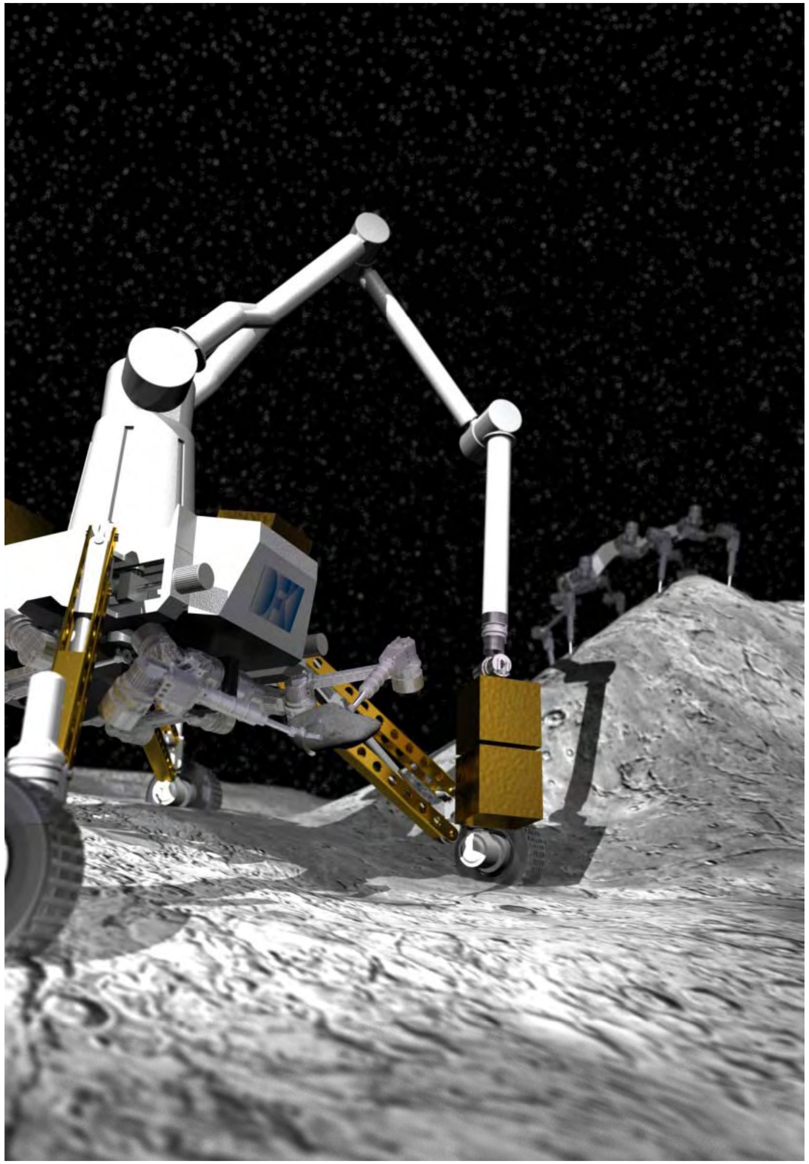
Video: Body Height 180 (L100, P3000)

Locomotion with leg failure

- Even with seven legs, climbing out of the crater can be achieved
- Locomotion sufferes more slippage

Video: Scout climbs with one leg disabled

Heterogeneous Team RIMRES



- Picks up and extends ideas from LUNARES
- Dedicated systems are built up
  - Wheeled Rover; Legged Scout; Immobile Modules
- Identical mechatronic interface for connecting mobile units and immobile modules
- Modules used to build up more complex scientific and technical payloads, for example
  - Energy Module + Radio Module
  - Energy Module + Radio Module + Science Pack
- Sliding Autonomy approach for system control

Project Partners:

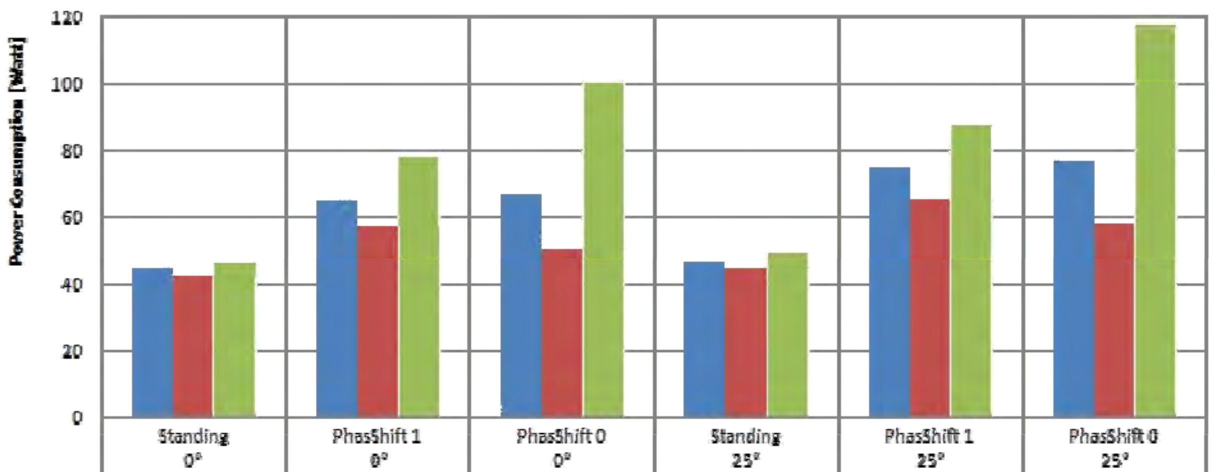
Deutsches Forschungszentrum für Künstliche Intelligenz GmbH

ZARM

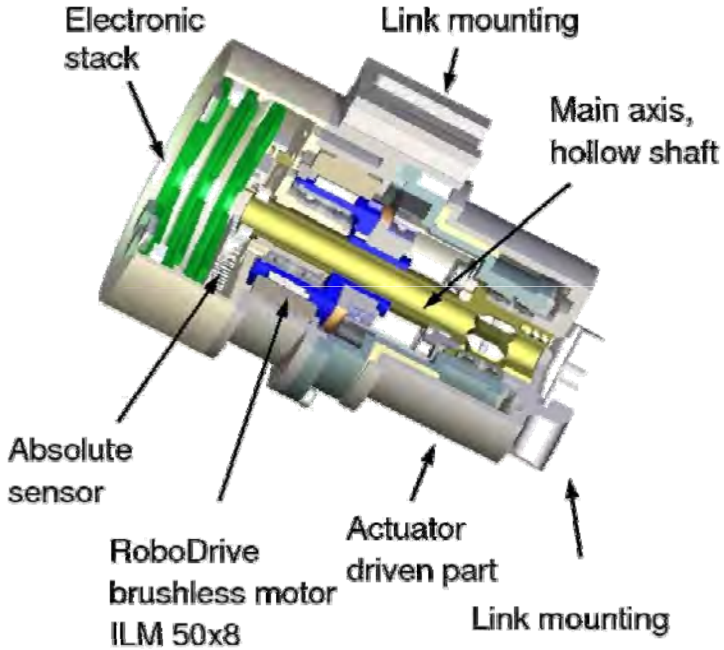
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.

SpaceClimber as Scout System

- Six-legged walking/climbing robot
  - 4 active/ 1 passive DOF per leg
  - “Intelligent Joints” with integrated controller and power electronics
- Biologically inspired walking patterns
- Robot applicable to steep slopes with varying surface materials



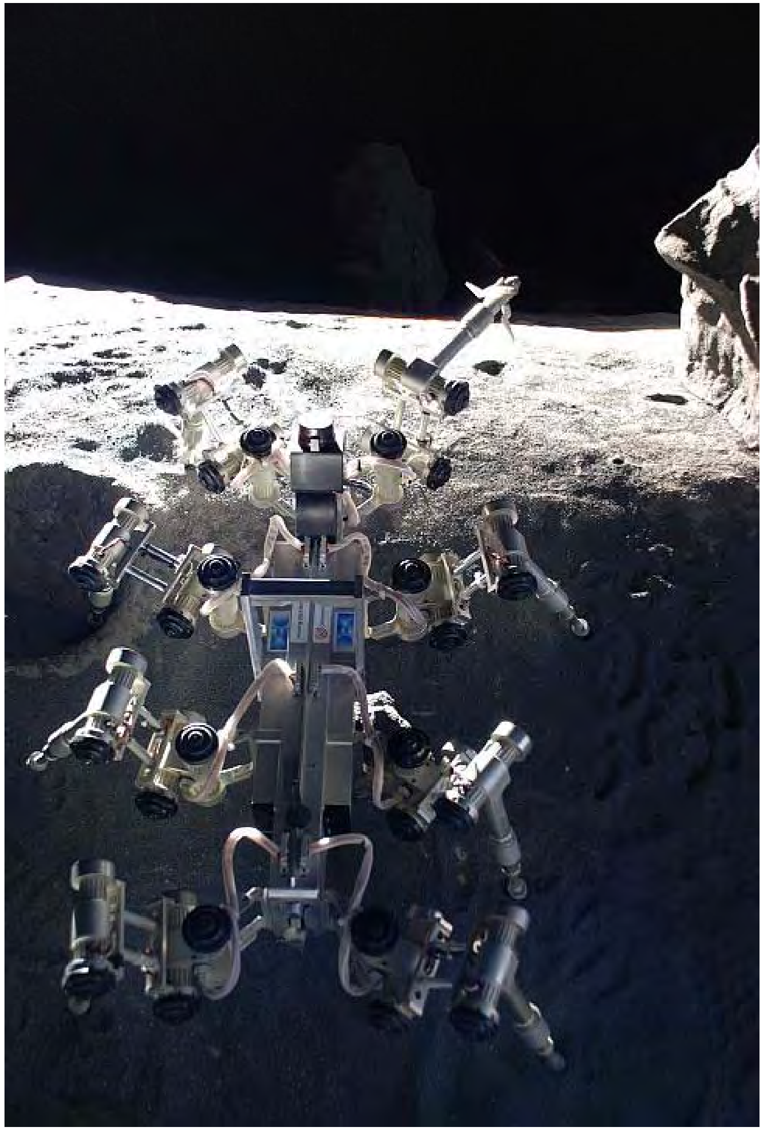
	Standing 0°	PhasShift 1 0°	PhasShift 0 0°	Standing 25°	PhasShift 1 25°	PhasShift 0 25°
Average	45	65	67	47	75	77
Min	43	57	51	45	66	58
Max	47	78	101	49	88	118



Conclusion and Outlook

- Approach of heterogeneous robotic team showed to be feasible
- Even preexisting robots were successfully brought together in a system to retrieve a sample from within a crater
- Design of systems particularly for cooperation in a team
- Rover design with active chassis is expected to provide high mobility in cragged environments with moderate slopes
- SpaceClimber as scout for RIMRES with efficient locomotion in steep slopes

Thank you!



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Supplementary Slides

The following slides contain additional material

- Further Reading (References to publications on presented projects/systems)
- More Information on the LUNARES-Space-TestBed
- New Space Exploration Hall at DFKI RIC Bremen
- RIMRES Scenario illustration and rover
- Information on power consumption of SpaceClimber robot

Further Reading

Cooperating Reconfigurable Robots for Autonomous Planetary Sample Return Missions

Florian Cordes, Steffen Planthaber, Ingo Ahrns, Timo Birnschein, Sebastian Bartsch, Frank Kirchner; In: *ASME/IFToMM International Conference on Reconfigurable Mechanisms and Robots, (ReMAR-2009)*, June 2009.

Cooperative Docking Procedures for a Lunar Mission

Thomas Röhr, Florian Cordes, Ingo Ahrns, Frank Kirchner; In: *Proceedings of Joint 41st International Symposium on Robotics and 6th German Conference on Robotics, (ISR/Robotik'10),* June 2010, accepted.

Performance Evaluation of an Heterogeneous Multi-Robot System for Lunar Crater Exploration

Sebastian Bartsch, Florian Cordes, Stefan Haase, Steffen Planthaber, Thomas M. Röhr, and Frank Kirchner; In: Proceedings of the 10th International Symposium on Artificial Intelligence, Robotics and Automation in Space (iSAIRAS'10), September 2010, accepted.

Robot Design for Space Missions using Evolutionary Computation

Malte Römmermann, Daniel Kühn, Frank Kirchner; In: *IEEE Congress on Evolutionary Computation, (IEEE CEC-2009), May 2009.*

Development of an Intelligent Joint Actuator Prototype for Climbing and Walking Robots

Jens Hilljegerdes, Peter Kampmann, Stefan Bosse, Frank Kirchner; In: *Mobile Robotics - Solutions and Challenges, (CLAWAR-09), September 2009.*

SpaceClimber: Developement of a Six-Legged Climbing Robot for Space Exploration

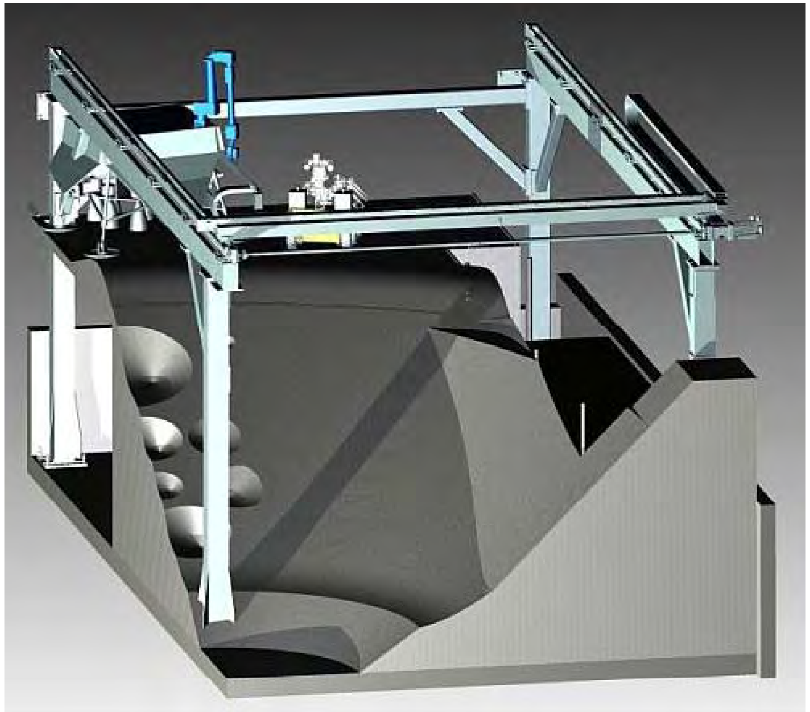
Sebastian Bartsch, Timo Birnschein, Florian Cordes, Daniel Kühn, Peter Kampmann, Jens Hilljegerdes, Steffen Planthaber, Malte Römmermann; In: *Proceedings of the 41st International Symposium on Robotics and 6th German Conference on Robotics, (ISR/Robotik'10)* June 2010, accepted.

Towards an Intelligent Foot for Walking and Climbing Robots

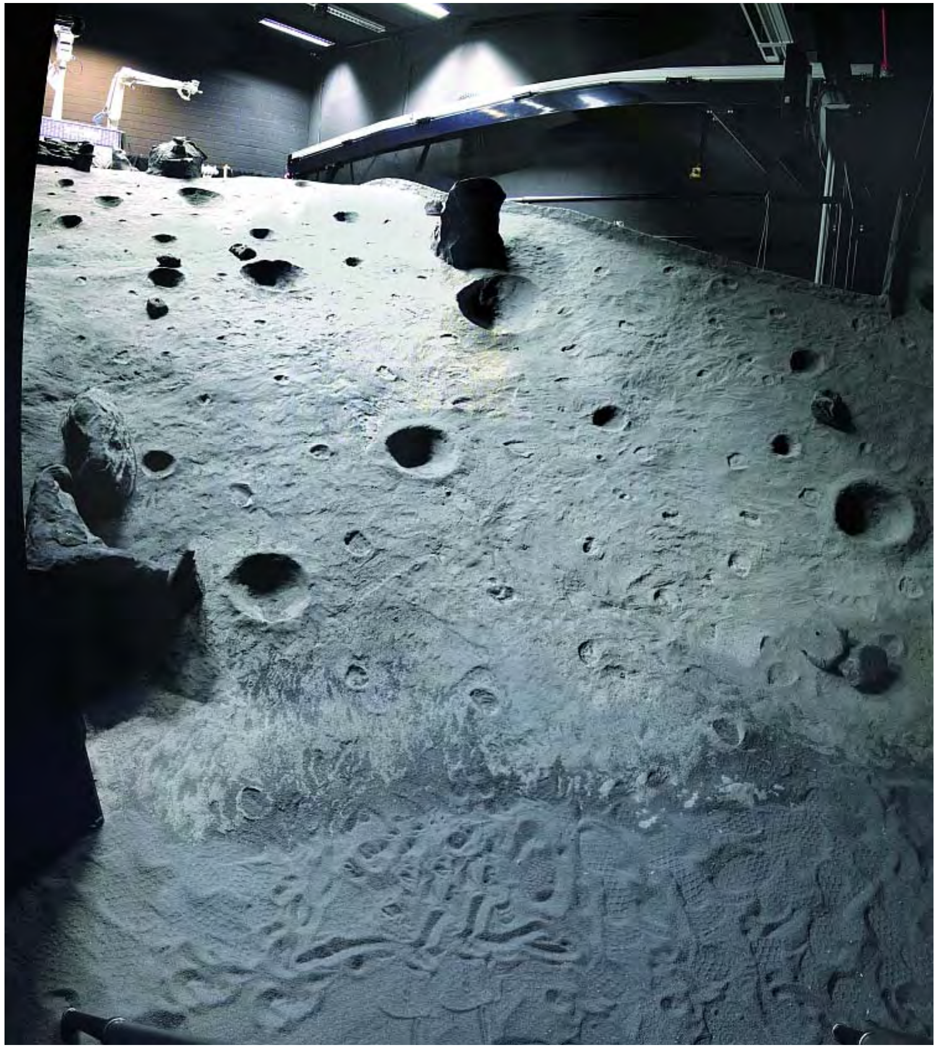
Florian Cordes, Sebastian Bartsch, Timo Birnschein, Daniel Kühn; In: *Proceeding of Joint 41st International Syposium on Robotics and 6th German Conference on Robotics, (ISR/Robotik'10)*, June 2010, accepted.

Lunares – Artificial Lunar Crater

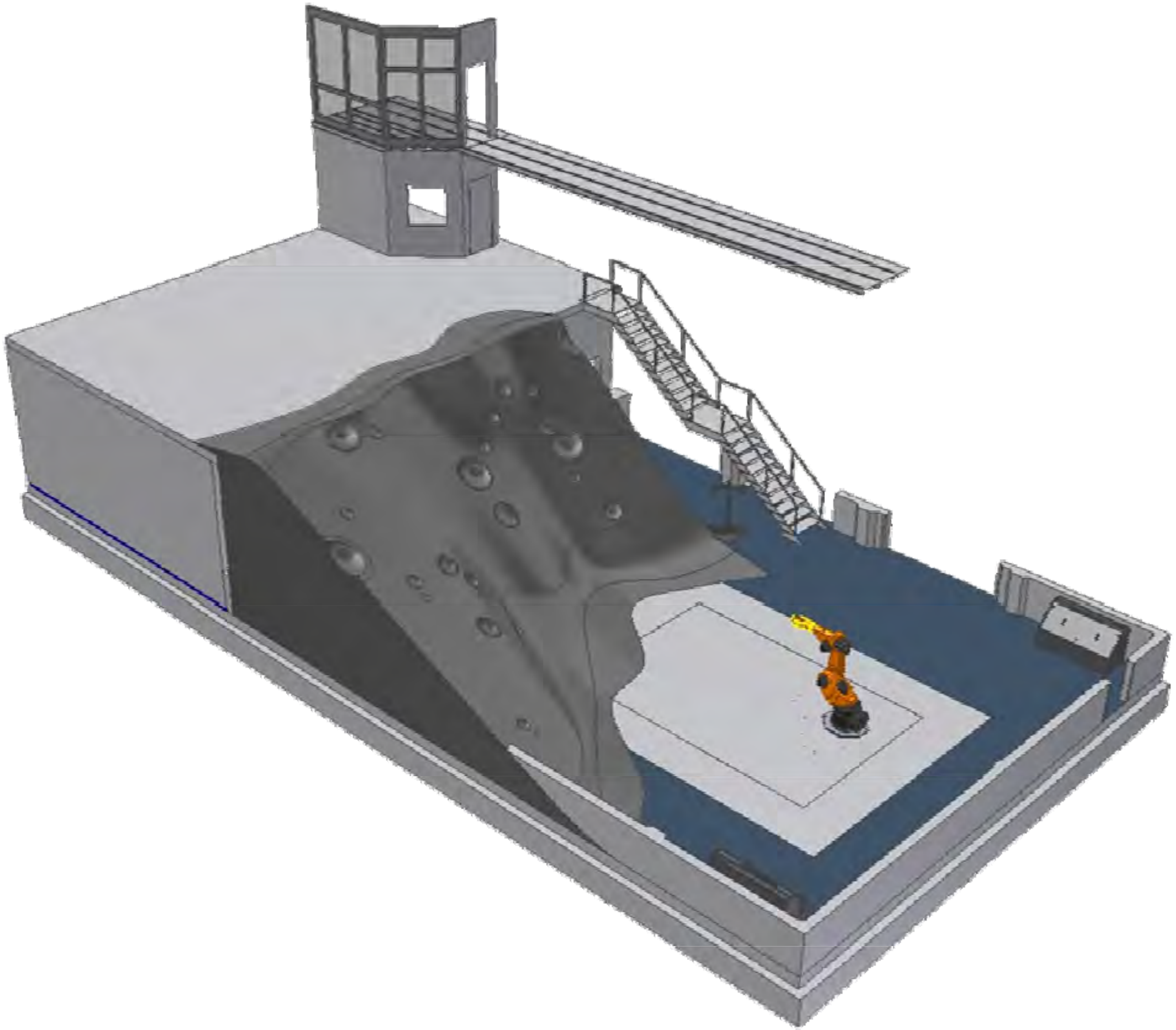
- Space-TestBed
  - Slope from 30° up to 45°
  - Small impact craters
  - Small rocks fixed or loose
  - Realistic lighting conditions
  - Gantry crane for gravity compensation
  - Motion tracking system
  - Surveillance cameras
  - Crater area of approx. $45m^2$



Space-TestBed

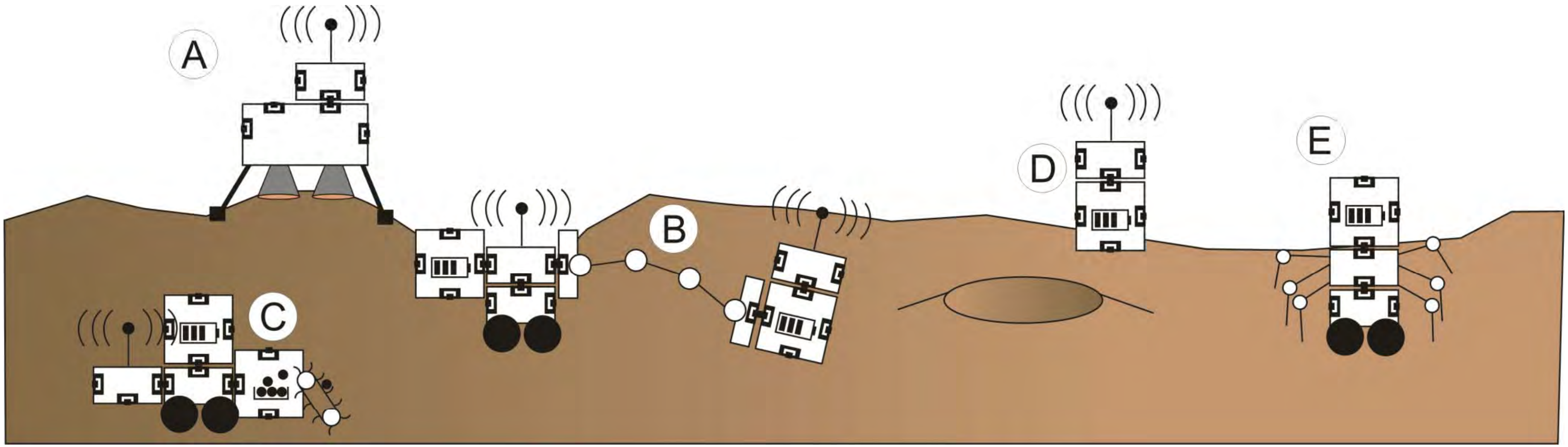


New Space Exploration Hall



- Slope from 15° up to 45°
  - Tracks of 20°, 30°, 35° 40° are modeled in the crater
  - 15° slope at the bottom
- Crater area of 105m²
- Additional ramp with adjustable inclinations (5° steps)
- Lighting conditions are simulated
- Motion Tracking System
- Surveillance Cameras for documentation

RIMRES – Illustration of Scenario



The illustrations show schematic representations of a planned scenario. (A) depicts a lander after putting down the robotic systems on the planetary surface. Here it is equipped with a radio module. (B) shows a wheeled robot with an additional battery package deploying a sensor node.

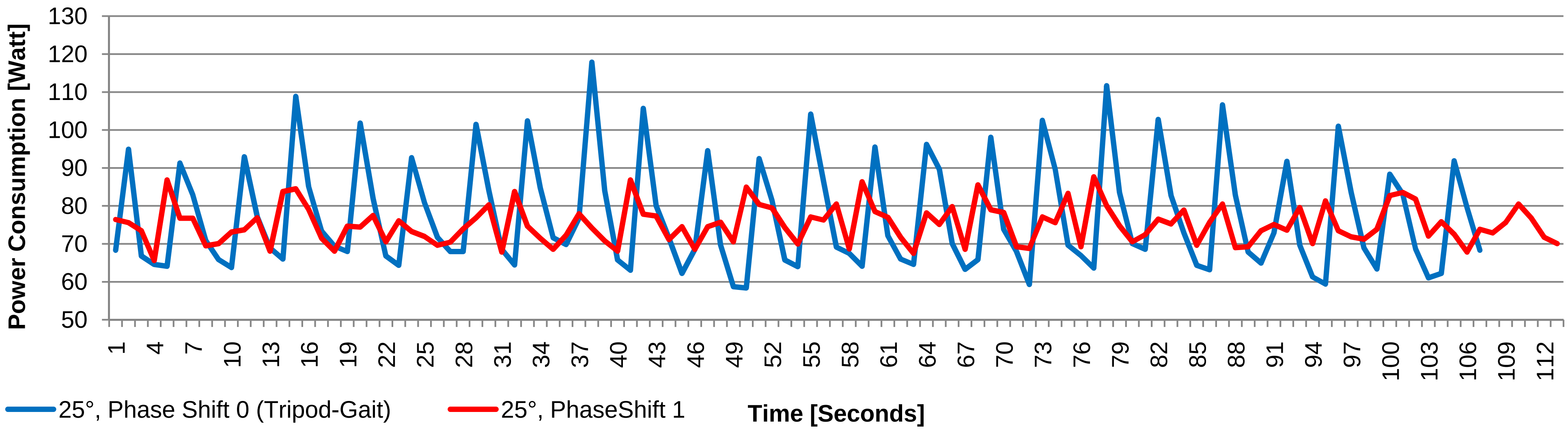
(C) illustrates a wheeled system taking a geological sample using the respective module. (D) represents an operating radio module. (E) depicts a combination of a wheeled and a legged robot. This allows energy-efficient locomotion of the wheeled system on relatively even ground exploiting its ability to transport a higher payload than legged systems.

RIMRES Rover

- Active chassis system
  - Actuation via spindle drives: No energy for maintaining body height
  - Wheels mounted on „legs“
  - Stable locomotion in slopes of around 20°
  - “Intelligent Wheels”: Self adjustment of stiffness
- Four module docking ports
- One docking port for legged scout (beneath the rover’s body)
- Manipulator arm for handling of modules
- Estimated mass: around 120kg + 20kg scout

SpaceClimber

Comparison of Phase Shift 1 ("smooth" gait) and 0 (tripod gait) in a slope of 25°



Comparison of Phase Shift 1 ("smooth" gait) and 0 (tripod gait) on level ground (0°)