Space Robotics Planetary Exploration - a DLR Perspective

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Planetary Exploration

Search for traces of past and present life
Characterize planetary environment
Prepare for human exploration

Exploration technologies for Moon, Mars or other celestial bodies in our solar system.

**DLR Robotics and Mechatronics Center:**
*We are contributing since many years to this ambitious endeavour.*
Major Topics of R&D:

(1) Development of mission scenarios for robotic exploration
(2) Mobility analyses and realizations for exploration in complex planetary surface topologies
(3) Modelling, simulation and optimization of mobile system dynamics behaviour on uneven surfaces
(4) Verification and validation of simulated dynamics and performance proving of optimized mobile systems in realistic ground-based testbeds
(5) Autonomy increase while using in-house developed localization and navigation methods and algorithms based on visual odometry and others.
Development and Utilization of Robotics Exploration Technologies

with Example on

Planetary Wheeled Rovers
**Localization and Navigation, Autonomy and Perception:**
DTM / DEM: 3D-Mapping of environment based on stereo cameras, accommodated on rover and on orbiter
Visual odometry $\rightarrow$ SGM algorithm (Semi-Global Matching)

**Manipulability**
Positioning and deployment of scientific instruments on planetary surface; Acquisition, transport and handover of soil samples, for processing on rover; Set-up and assembly of modules $\rightarrow$ Build a base station; Inspection

**Mobility**
Not only wheels: also legs, legs + wheels, hybrids, …

Robotics based HRSC planetary processing based on innovative SGM image processing
At DLR’s RMC
Developed Technologies
to be Utilized for Exploration
Motorization: Actuatorics & Sensorics

LBR 3rd Generation

- Link Position Sensor
- Cross Roller Bearing
- Power Converter Unit
- Joint- and Motorcontroller Board
- Power Supply
- Torque Sensor with digital interface
- Harmonic Drive Gear Unit
- DLR RoboDrive with Safety Brake and Position Sensor
- Carbon Fibre robot link
Some Selected (Terrestrial) R&D Applications

DLR 4-Finger Hand

Rollin’ Justin with 51 DOF

DLR crawler, 6-legged

Rovonaut - Simulation

ExoMars BB1
Rollin-Justin
Rovonaut = Rover + Astronaut
Autonomous Navigation:
3D Mapping and Self-localisation (egomotion)

Visual odometry based on stereo camera overlayed with IMU and other sensors
DLR - Crawler

Walking robot equipped with stereo cameras and IMU.
Our Begin → Mars Rover ExoMars (ESA 2018)

Trafficability:
Modelling,
Simulation &
Verification by
Testing

Movie:
Planetary
Exploration Lab -
Mars Rover Testbed
Planetary Exploration Lab PEL at DLR:

Verification of Simulations for driveability dynamics etc. by testing in appropriate test facilities with almost realistic Moon and Mars soils, i.e. ‘soil simulants’
3D mapping (DEM) of testbed surface (SGM) → integration into software simulation
Multibody System and Contact Dynamics

PCM based on Elastic Foundation Model

- Multiple contacts
- Wheel-soil slip
- Deformable wheels

MBS Multibody System
Simulation of important driveability effects of soft and rigid soils, 'bulldozing + multipass', more generally compound terrains.
Rover driving over rigid and soft surfaces
A different modeling approach: Particle based methods, mesh-free
DEM Discrete Element Modeling of soft soils interacting with rigid wheels
Basic Technologies
Developed at RMC

Participation in
Planetary Exploration Applications
(1) Mobile Payload Element MPE – Moon Rover ~ 15 kg
(lead by KayserThrede)

Stowed Configuration
**Movie:**
MPE – Mobile Payload Element for Next Lunar Lander Mission
(2) Mars: ROV-E EU-Projekt (2011→3 years)

**Challenge:**
Reduce weight for all subsystems

**DLR-RMC:**
- responsible for innovative / optimized locomotion system
- modelling, simulation, optimization of driveability performance
- development & set-up of innovative actuator concept
  for wheel driving and steering;
- torque and slip control.
- breadboarding: single wheel or double wheel testing
(3) **MASCOT - Mobile Asteroid Surface Scout Mission**  
(German payload on 2014/15 Hayabusa-2 Japanese mission)

Very low gravity: $10^{-5}$ g

Provide mobility by
1. self-uprighting &
2. hopping over planetary surface

**Zero-g flight testing in Feb 2012:**  
Parabola flights by NoveSpace Bordeaux
MASCOT

First design approach: 2 eccentric masses + 1 motor, controlled

Conventional concept: two arms (2 paddles) controlled

New design: only 1 eccentric mass + motor, contr.
(4) **InSight**

- Phoenix mission lander
- Launch: March 8 - March 27, 2016
- Landing: September 20, 2016
- Surface operations: 720 days
- End of Mission: September 18, 2018

**Goal:** understanding the processes that shaped the rocky planets of the inner solar system
DLR payload contribution
(lead by DLR Inst. PF, Berlin):
HP³ Mole - Heat Flow and Physical Properties Package
(5) ROBEX - visionary long-term cooperative (national) endeavour

5 years: Oct 2012 – Sep 2017

http://www.robex-allianz.de/

Space and Deep Sea come together
Benefit from each other:

- Autonomy
- Autonomous localization, mapping & navigation
- Autonomous vehicles
- Autonomous manipulation
- Docking / interfaces
- Energy supply
- Communications
- and more

Partners:

- HG centers: DLR, AWI, Geomar
- Universities: TUKL, TUD, TUB, TUM, JUB, Marum
- DFKI
ROBEX –
Making use of capabilities for mobility and manipulability on Moon’s surface
Pilot scenario Moon: ASN Active Seismic Network Deployment

Movie: ROBEX - ASN Visualization
(6) Optimization - 2 well-known examples:

**ExoMars Rover** (ESA)

**Rocker-Bogie Rover** (NASA)
Example of optimization process for rover geometric parameters

Terrain scenario: first driving on soft soil and over a rock, then driving on hard soil a step downwards including a rock as obstacle

Movie:
Optimization of ExoMars rover locomotion subsystem - geometric and kinematic properties using genetic algorithms
Advanced Kinematics Concepts

Legs and Wheels combined – a first approach

Design features:

- 6 articulated legs + 6 wheels
- 3 legs suspended in front and 3 legs in rear, passively
- central body coupled by differential gear
- each leg has 3 dof
- connecting plate for 3 legs attached to central body replaces bogie suspension in ExoMars type rovers
Large ground clearance and high CoM (Center of Mass)

Passive suspension on rough terrain with low CoM
(8) Potential Exploration Scenarios on Moon:
- working vehicles
- manipulation skills
- energy and comms. stations
- docking and interface elements
- almost fully autonomous ops.
ISECG – Internat. Space Exploration Coordination Group

DLR is partner in ISECG

The Global Exploration Roadmap

August 2013

ISECG
International Space Exploration Coordination Group

What is New in the Global Exploration Roadmap?

The initial release of the Global Exploration Roadmap in September 2011 provided an opportunity for stakeholders across the globe to engage in national and international dialogue about space exploration to destinations where humans may someday live and work. Ideas and feedback generated through the dialogue have strengthened agency planning efforts and led to some of the changes included in this update.

The initial roadmap identified two competing pathways toward the driving goal of human exploration of Mars: “Ares 2/Next” and “Mars Direct.” Each pathway was expanded through conceptual mission scenarios, which served as reference trajectories and propelled awareness. Building on that work, the 2013 roadmap includes a single reference mission scenario that reflects the importance of a stepwise evolution of other capabilities that are necessary for executing increasingly complex missions to multiple destinations leading to human exploration of Mars. The roadmap demonstrates how vital capabilities can enable a variety of missions in the lunar vicinity, responding to diverse and competing goals and objectives, while continuing to build the partnerships required to sustain human space exploration.

Participating space agencies continue to prepare for human exploration beyond Earth orbit. The expanded chapter on preparatory activities reflects accomplishments in the five engine areas: ISS utilization, robotic missions, advanced technologies, in-space generation capabilities, and analogues. A subsection has been added, focusing on human health and performance risk mitigation.