Taxonomy and Systems Review of Planetary Exploration Rovers

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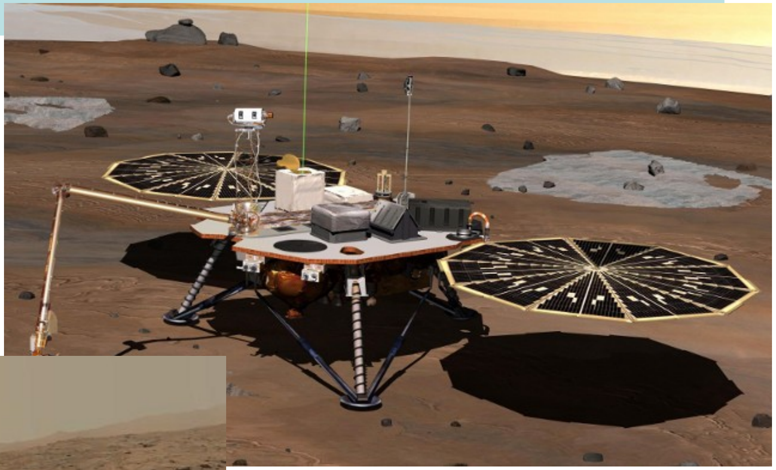
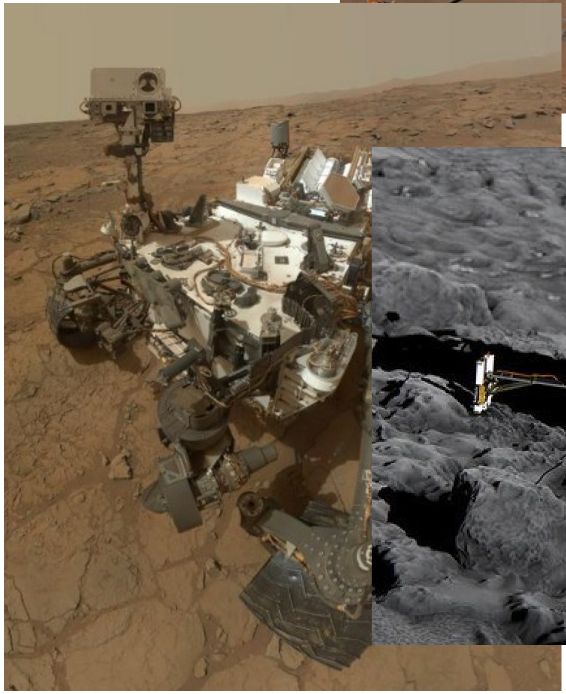
MARS Lab'

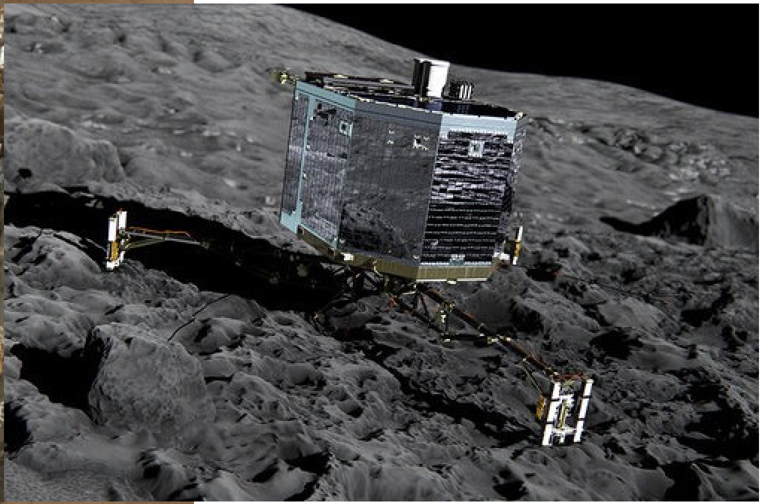
Mars Artificial Surface Lab'

Introduction (I)

- Autonomous robotic exploration of celestial bodies necessary for expansion in space
- Unmanned missions
  - ✓ Rovers
  - ✓ Stationary landers
  - ✓ Hoppers
  - ✓ Probes







Images: NASA, ESA

Introduction (II)

- Focus on rovers: Mobile, traverse terrain, overcome obstacles and can explore a large area to achieve the mission’s scientific objectives
- Rovers as Robotic Field Geologist:
  - Exploration
  - Mapping
  - In-situ surface analysis
  - Sample Collection

Motivation

- Rovers: usually wheels for mobility
- But also: legs, tracks or a combination (hybrid)
- Goal: move efficiently and reliably through a challenging & unknown terrain and execute required motion manoeuvres

- Locomotion subsystem moves the rover across the terrain
- It consists of: mobility type, actuation, suspension and chassis
- Performance of the locomotion subsystem is essential for the overall success
- Different configurations are possible

➢ How can we categorize the different configurations of the locomotion subsystem (taxonomy)?

➢ Is there a baseline design for planetary rovers?

➢ How can we compare systematically those varied configurations?

Roadmap

- Taxonomy based on the locomotion subsystem configuration
- Review of flown planetary rovers
- Review of representative experimental designs
- Baseline design & future trends
- Metrics for systematic comparison
- Conclusions

Taxonomy (I)

- Four criteria to categorise the locomotion subsystem designs:
  1) **Mobility type**: what propels the rover across the terrain
  2) **Steering method**: depending on mobility type, how is it actuated
  3) **Chassis**: structural support, withstand forces applied
  4) **Suspension**: maintain stability, overcome obstacles, absorb loads

1) Mobility type:
   - Continuous: wheeled, tracked, crawling, tumbling
   - Discrete (point to point): legged (two or more legs), hopping
   - Hybrid: wheels on legs, tracks and wheels

- Wheels: technologically mature, energy efficient, less complex, good for average to moderate terrain
- Tracks: good for soft terrain, reliability issues, heavy
- Legs: best overall performance, less mature, complex to control

Taxonomy (II)

2) Steering: for wheels
- Wheel is driven: directly actuated with a motor
- Wheel is steered: wheel can change heading (requires a motor)
  - Independent: all wheel drive, some steer. If all are steered point turning is achieved and can also move sideways ('crab')
  - Skid: all wheels on one side have the same input. Each side can be rotated independently and point turning is achieved.
  - Coordinated: single or double axle steering (e.g. cars), each pair of left and right wheels are pivoted together, differential for turning

- Skid Steering for tracks
- Legs require more complex actuation, usually at least one actuator is used per leg – simplest is for one leg hop

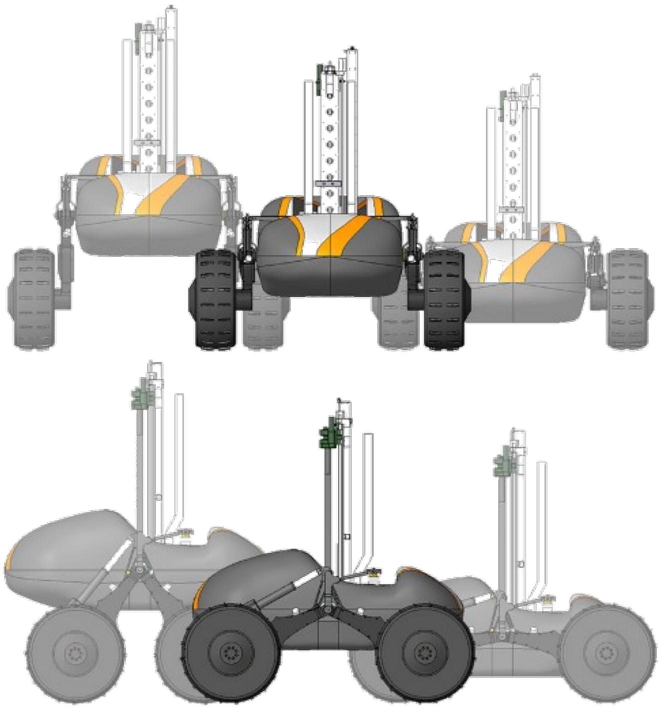
➢Rovers: all wheels driven

➢Independent: precise but may require many motors when all wheels are steered

➢Skid: always turns on the spot but the overall movement is less precise

Taxonomy (III)

3) Chassis:
   - Fixed: rigid
   - Articulated: part of the chassis can move in respect to the other part, e.g. to adjust the height or to lean to one side



➢Articulation may passive or active

➢Useful for positioning scientific instruments

➢Active articulation requires motors, which increases power requirements.

Image: SR-II, U. of Oklahoma

Taxonomy (IV)

4) Suspension: for wheeled rovers
Legged: uses the legs to walk and also the legs stabilise

- Active: Independent (on each wheel), dynamic
  - Springs, dampers, actuators to control damping ratio
  - Dynamic: additionally torsion tubes, high speed actuators, fast response
- Passive: Independent , Kinematic (e.g. Rocker – Bogie)
  - Springs, dampers - damping ratio does not change
  - Kinematic: freely pivoting joints connected with passive undamped linkages, good for low speeds

➢ Max. rover velocity is < 5 cm/s so kinematic suspensions are suitable
➢ Rocker – Bogie and is the most common for rovers

Taxonomy (V)

- Rocker – bogie assembly for a 6 wheel rover:
  - Bogie: two wheels
  - Rocker: one wheel
  - Connected with a passive, freely pivoting joint
  - Right and left assemblies: connected via a passive joint and a differential that equalises the pitch angle between the two sides
  - Front, back wheels are driven & steered, middle are driven.

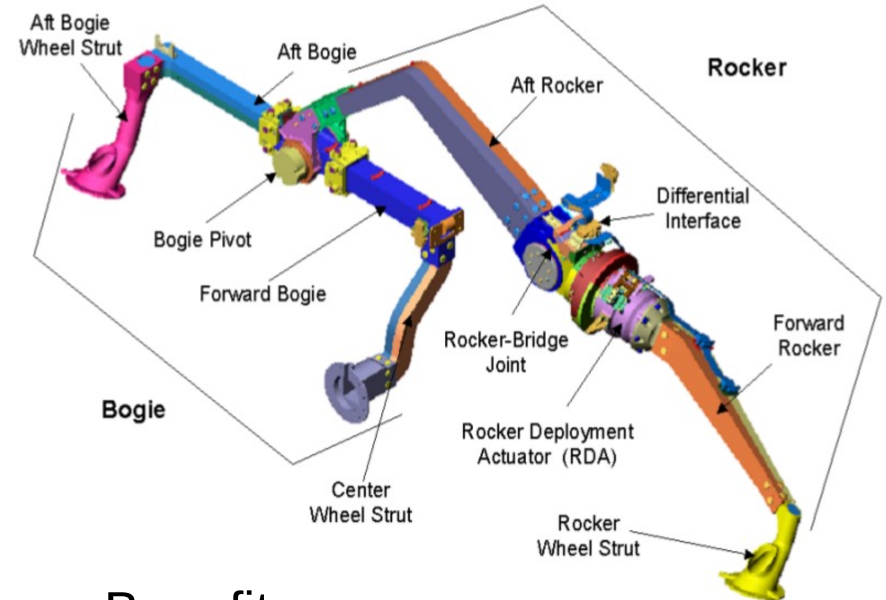


Image: NASA

- Benefits:
  - Keeps rover level
  - Wheels always in ground contact
  - Adaptable for 4 wheels
  - Obstacles of at least one wheel diameter

Systems Review (I)

Planetary Exploration Rovers

- 6 successful missions:
  - Apollo LRV (NASA, 1971, 1972): Moon
  - Lunokhod (USSR, 1971, 1973): Moon
  - Sojourner (NASA, 1998): Mars
  - Spirit & Opportunity (NASA, 2003): Mars
  - Curiosity (NASA, 2011): Mars
  - Yutu (China, 2013): Moon
- Future:
  - ExoMars (ESA, 2018): Mars
  - Mars 2020 (NASA, 2020): Mars

•LRV: astronaut operated

•Lunokhod: teleoperated

•All other: Increased autonomy in each mission

•All rovers flown since Sojourner: similar design

•6 rigid wheels, rocker – bogie, 6WD, 4WS

ExoMars:

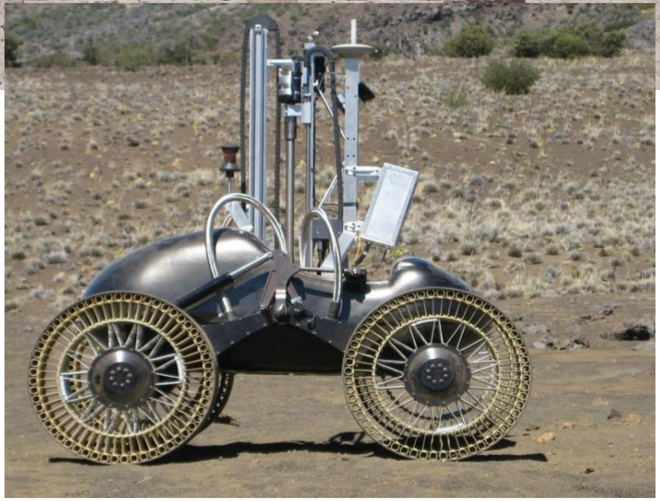
•flexible wheels, 6WD / 6WS

•wheel – walking: each wheel can be individually pivoted to adjust its height and angle

Systems Review (II)

Selected experimental designs

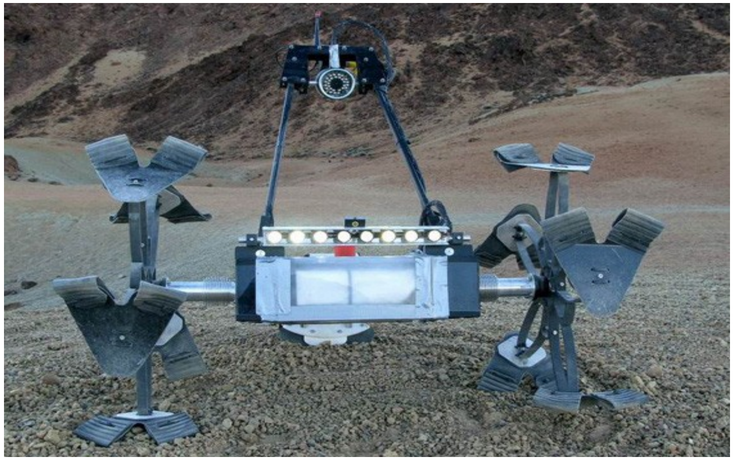
- **SR-II** (U. of Oklahoma): minimal design, 22.07 kg
  - 4 wheels driven by 2 motors and a drive train
  - passive kinematic suspension
- **Scarab** (Carnegie Mellon): carries a drill, 28kg
  - 4W drive, skid-steering, passive rocker suspension
  - actively articulated chassis height to position drill



Systems Review (III)

Selected experimental designs

- **ATHLETE** (NASA): carrying cargo in Lunar missions, up to 300 kg
  - Hybrid: 6 legs with a wheel each, wheels for moderate terrain, legs (wheel acts as a foot) for difficult terrain, independent wheel actuation
  - Legs ‘bend’ to adjust the height
- **CESAR** (ESA / U. of Bremen): crater exploration, 13.3 kg
  - Hybrid: legged wheel, 2 wheels
  - Each wheel consists of a motor driven central plate with 5 flexible spokes (‘feet’) attached.
  - Works in cooperation with a lander for communications.



Trends & Baseline Design

- Experimental designs exhibit a wide range of configurations
- Main trend: wheel – leg hybrid locomotion
  - Wheels main locomotion method
  - Legs (or ‘wheel-walking’) to get out of difficult spots
  - Combines reliability & maturity of wheels while using legs for difficult (e.g. steep slope, many obstacles) terrain
- Baseline Design:
  - 4 or 6 wheels
  - All wheel drive / min 2 wheel drive, selected wheel steering
  - Passive (kinematic) suspension
  - Rocker – bogie currently preferred

Design examples

- Two designs at MARSLab
- Aim: validate control and navigation techniques
- Setup: sandpit and two robots

- Robot A: 4 wheels, all driven, differential drive to change heading, turn on spot

  size: 35 (l) x 25 (w) x 13 (h) cm
- Robot B: scale model of Curiosity, Lego NXT, 6WD, 4WS, rocker-bogie

  size: 73 (l) x 60 (w) x 20 (h) cm

Performance Metrics

- Compare & choose from the different locomotion subsystem designs?
- Focus on wheeled rovers – measure the efficiency of the baseline design
- Three categories of Performance Metrics based on the tasks that the locomotion subsystem must perform
  - Trafficability – the ability to drive the rover through the terrain: wheel sinkage, traction, motion resistance, drive torque & power
  - Manoeuvrability – navigate and change heading when steering: steering scheme, resistance & traction when steering
  - Terrainability - negotiate rough terrain (obstacles, slopes, sand): static stability, slope & obstacle traverse (max. slope, max obstacle height)
- Metrics are also influenced by the terrain characteristics, which may not be known in advance
- Size, weight restricted by payload and launch requirements
- What is best depends on the mission objectives – no unique solution

Conclusions

- Planetary rovers have increased exploration abilities because they are mobile
- Locomotion subsystem is crucial because it must propel the rover efficiently and reliably across a varied terrain
- Taxonomy to categorize different configurations according to: mobility type, chassis articulation, steering method, suspension
- Review of systems successfully used in missions and selected experimental systems to highlight different configurations
- Baseline design: 4 or 6 wheels, all driven, passive suspension
- Wheels are preferred but a trend (esp. in experimental designs) of hybrid wheel – legged locomotion is apparent
- Performance metrics to compare locomotion subsystem configurations

Questions?