Workshop on Planetary Rovers, ICRA 2013

Path Planning and Navigation for Intelligent Exploration

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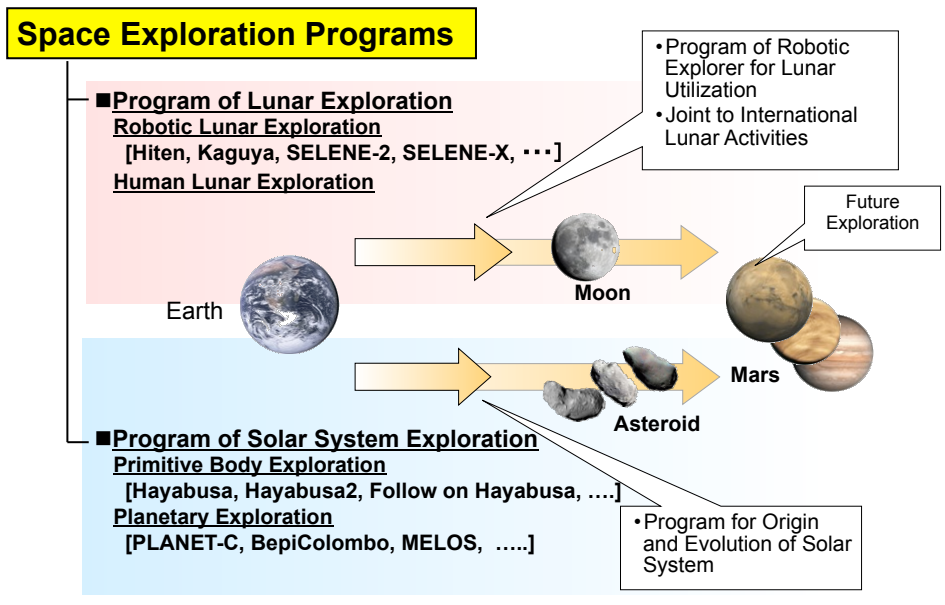
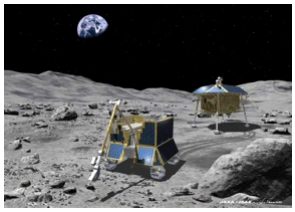
JAXA Space Exploration Program

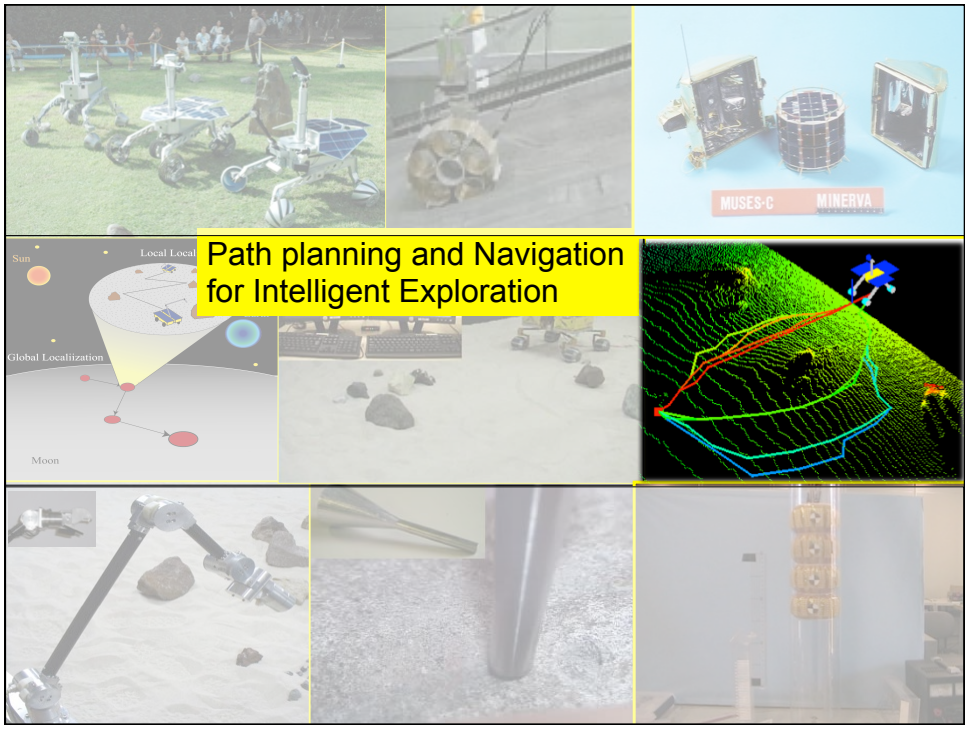


Surface Explorer Missions

JAXA is planning direct exploration on lunar or planetary surface for in-situ observation and scientific investigation, and future planetary utilization



Surface or Subsurface Explorer is one of good means for direct, detailed, and wide exploration.



Path planning and Navigation for Intelligent Exploration

Path Planning and Navigation

Camera-based Navigation

- Exploits visual image to obtain terrain feature.
- Time-consuming task (Stereo matching) for 3D representation of terrain feature.
- Intensity of sunlight/shadows would degrade its accuracy.

LRF-based Navigation

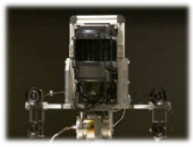
- Direct measurement of 3D distance from the sensor to objects.

An autonomous mobility with LRF-based terrain mapping, path planning, and navigation

Research Highlight

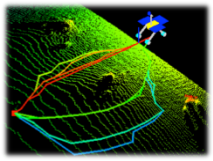
TERRAIN MAPPING

- LRF-based terrain scanning
- Terrain representation with C^2DEM technique



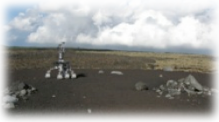
PATH PLANNING

- Multi-path planning
- Navigation scheme



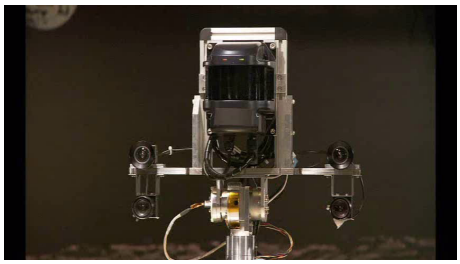
FIELD TESTS

- Lunar/Martian analog site
- Long-range navigation test



Terrain Mapping

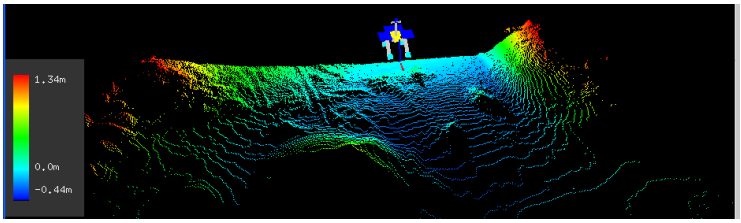
- LRF-based scanning system
  - 2D scanning LRF + Tiltable stage



Laser Range Finder: UXM-30LX-EW (Hokuyo Corp.)	
Measurable Distance	0.1 ~ 30 m
Scanning range	+/- 95 degrees (Res. 0.25 deg)
Tilting range	0 ~ 60 degrees (Res. 0.33 deg)

Point Cloud Data & DEM

- The LRF provides a “point cloud data” of terrain feature.

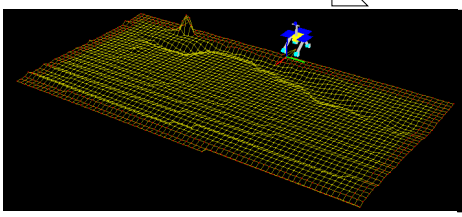


- A digital elevation map (DEM) is generally used to convert the point cloud data.

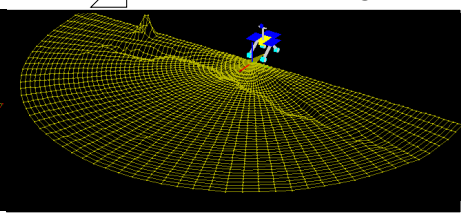
  ➔What is a feasible approach for the DEM conversion from point cloud data?

DEM vs. C²DEM

Conventional DEM



C²DEM



- The DEM restricts a rover to change its heading of 45 degrees increments.

- **Detailed representation** of the terrain feature near a rover.
- A heading angle of a rover varies along with the reference grid shape.

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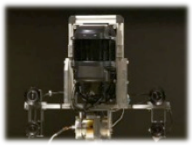
- Terrain representation with C²DEM technique



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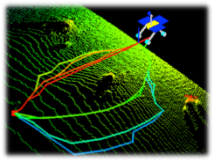

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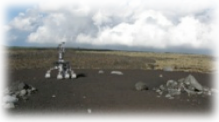

Path Planning

- Cost function for path planning

$$C(\boldsymbol{p}) = \sum_{n_i \in \boldsymbol{p}} \left(W_{\theta_x} \frac{\Theta_{xij}}{N_{\theta_x}} + W_{\theta_y} \frac{\Theta_{yij}}{N_{\theta_y}} + W_B \frac{B_{ij}}{N_B} + W_L \frac{L_{ij}}{N_L} \right)$$

Terrain inclination index | Terrain roughness index | Path length index

- Each index can be calculated based on the terrain data represented by the C²DEM.

W_{θ_x}, W_{θ_y}, W_B, and W_L : Weighting factors

N_{θ_x}, N_{θ_y}, N_B, and N_L : Normalization factors

$\boldsymbol{p} = \{n_{start}, \cdots, n_i, n_j, \cdots, n_{goal}\}$: Path (a series of nodes)

Multi-path Planning

- Cost function for path planning

$$C(\boldsymbol{p}) = \sum_{n_i \in \boldsymbol{p}} \left(W_{\theta_x} \frac{\Theta_{xij}}{N_{\theta_x}} + W_{\theta_y} \frac{\Theta_{yij}}{N_{\theta_y}} + W_B \frac{B_{ij}}{N_B} + W_L \frac{L_{ij}}{N_L} \right)$$

- Smaller values of the indices result in lower mobility hazard levels. ➔ *Least cost search problem*
- HOWEVER, the least cost path varies with the values of weighting factors.
  - Larger weightings for the path length generate a shorter path, but possibly induce more chance of mobility hazards.
  - Larger weightings for the terrain inclination reduce the mobility hazard levels, but increase the path length.

⇨ Multi-path planning

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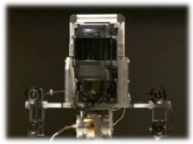

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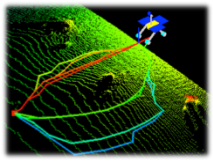

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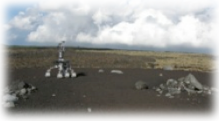
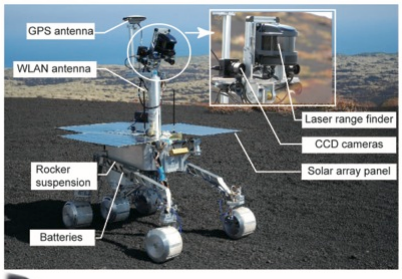
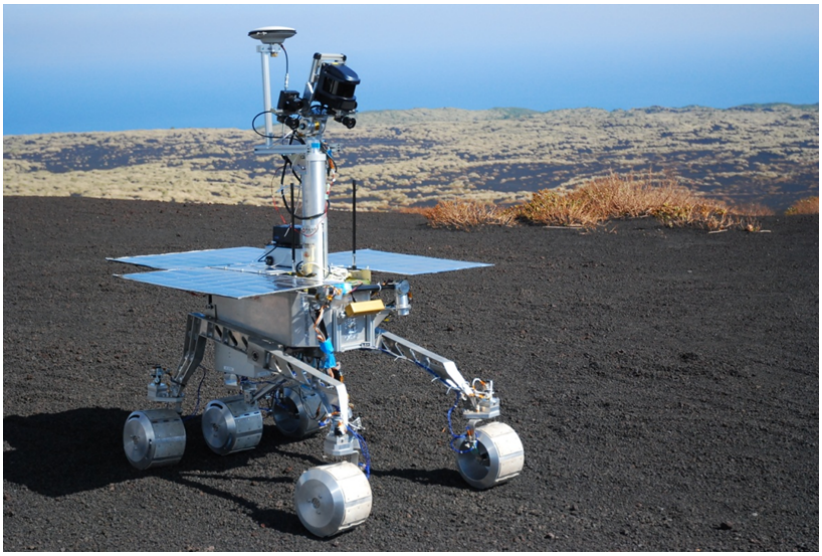


Field experiments

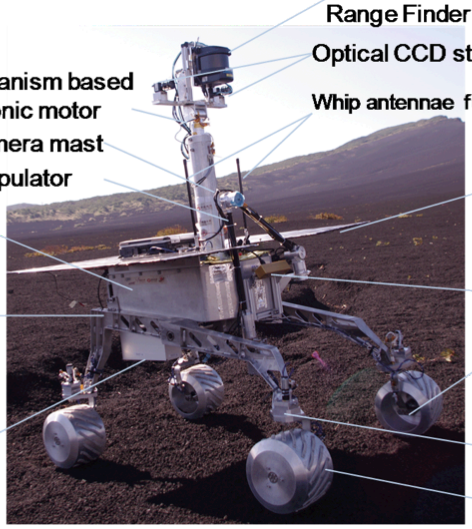


1. Comparison between the conventional DEM and the C²DEM.
   - Highlights the usefulness of the C²DEM.
2. Multi-path planning tests
   - Tests the applicability of the proposed method in different types of terrain.
3. Long range navigation.

Test-bed rover : Micro6



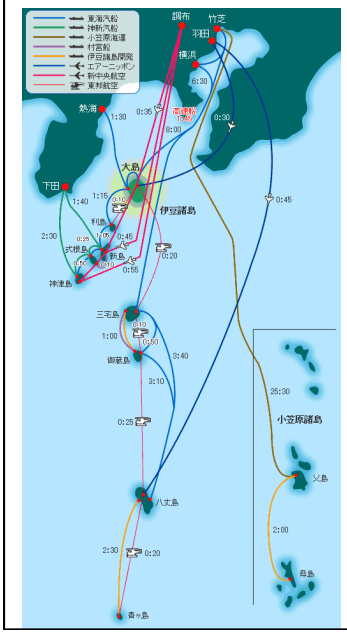
Test-bed rovers: Micro6



Smart Manipulator

- Smart manipulator is developed for Micro 6.
- USM is applied on each joint, because USM has high static torque and posture keeping is possible without any power.
- Smart manipulator has a special end-effecter to pick-up samples and scoop some regolith.

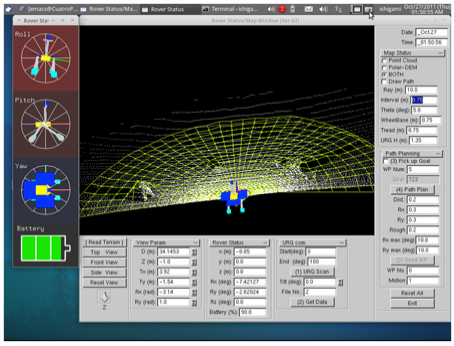
Field Tests



Field tests have been conducted in Izu-Oshima in 2011 and 2012.

Field Tests

1. Terrain Recognition by 3D LRF
2. C²DEM (Cylindrical Coordinates DEM)
3. GUI based Ground System
4. Path Planning
5. Navigation and Guidance



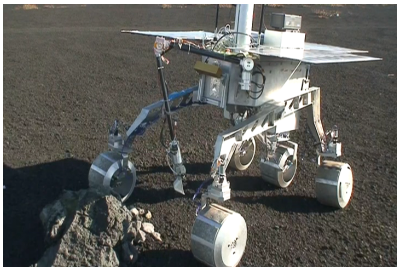
Field Test Results

Steep Slope

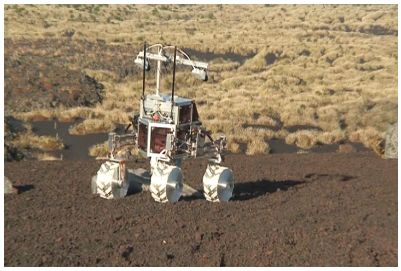
Rough Terrain

Rough Terrain

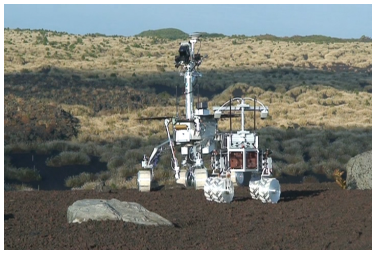
Field Test Results



Manipulation

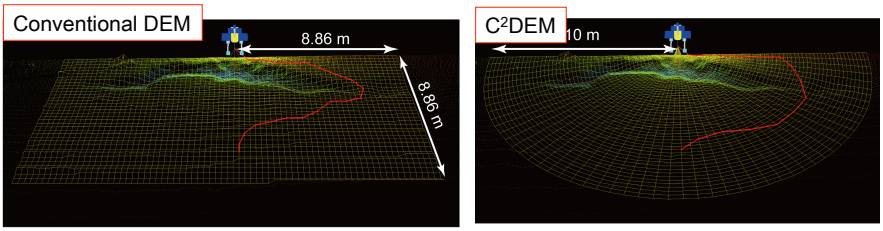


Cuatro Mobility



Cooperative Exploration

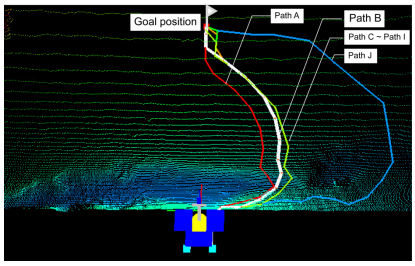
Conventional DEM vs. C²DEM



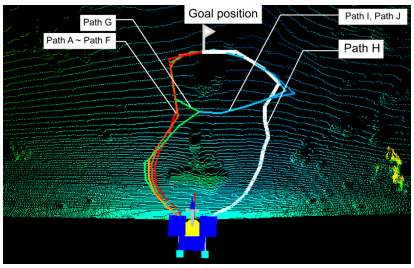
- The C²DEM has a potential to generate a safer path than the conventional DEM does.
  - Dense representation near the rover ➔ The multi-path planning can carefully select appropriate nodes for travel.

Multi-path planning

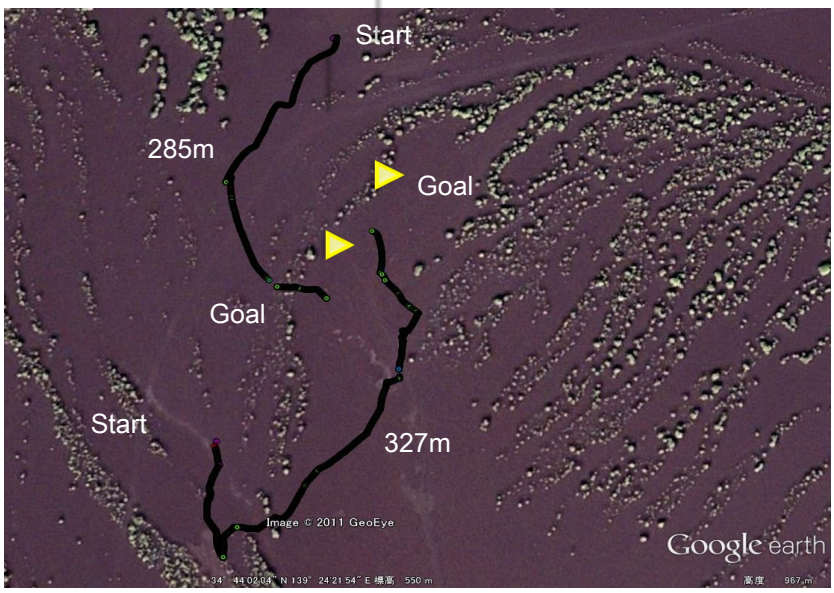
Ditch crossing scenario



Obstacle avoidance scenario



Long-range Navigation



Summary

- An autonomous mobility that employs LRF-based terrain mapping, path planning, and navigation.

- Terrain representation with C^2DEM technique

→ useful for detailed representation of the terrain feature.

- Multi-path planning & evaluation

→ adaptively generates a feasible path in any different types of terrain feature.

Thank you for your attention !

Thanks to Dr.Volpe and Dr.Yoshida for their nice organization of the fruitful workshop on planetary rovers.