Rover Missions and Technology for Lunar or Planetary Surface Exploration

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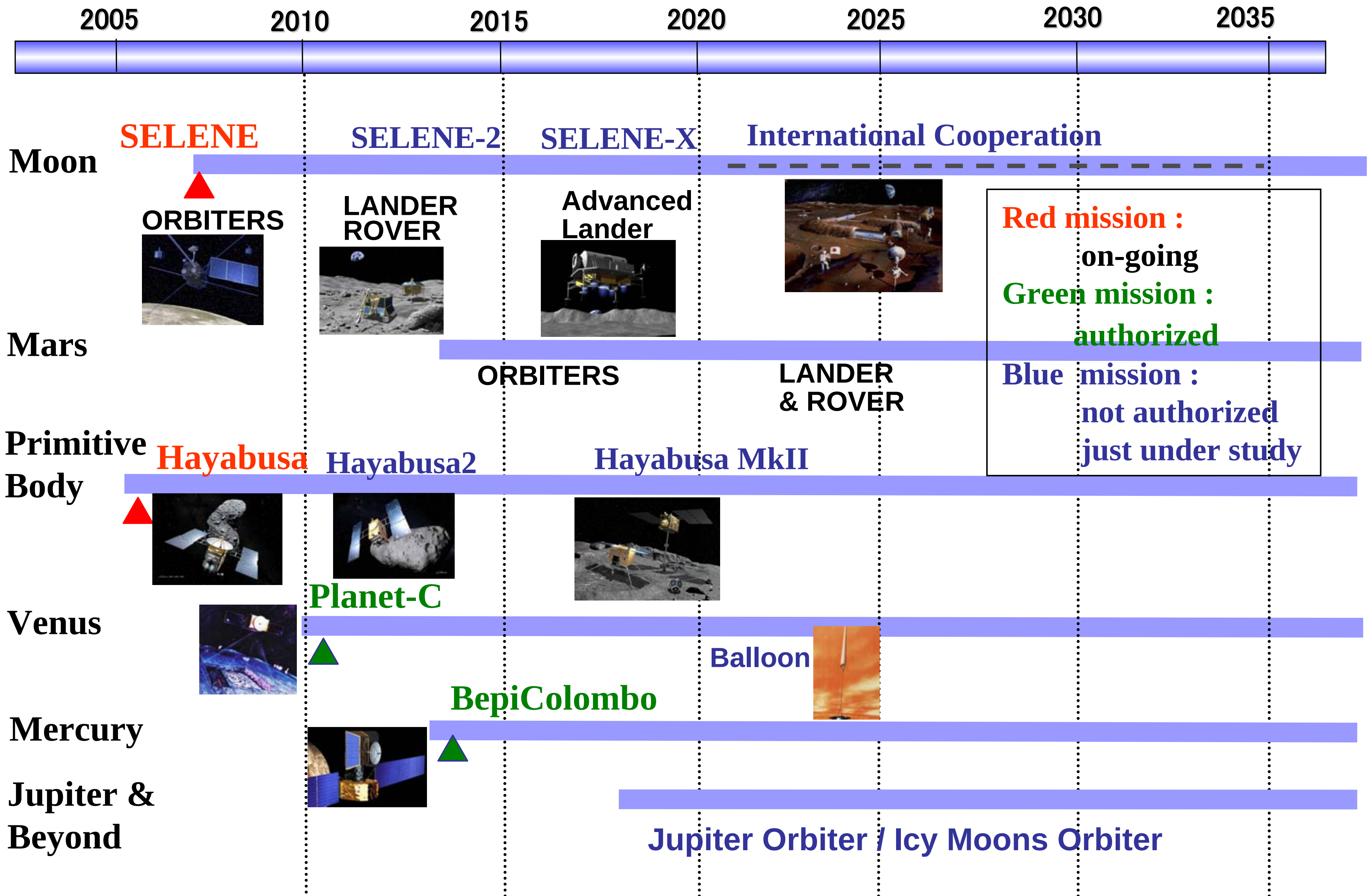
JAXA Exploration Road Map

Roadmap of JAXA Exploration



Principle for Space Exploration

To achieve lofty themes such as expansion of human activities and contribute to evolution of civilization.

Political Objectives:

- Expand human activities to the Moon as the nearest celestial body and prepare for the beyond.
- Contribute to formulation of international collaboration and framework

Technology development and innovation:

- Develop infrastructural systems such as landing, returning, mobility, etc. for enabling autonomous, robust and flexible space exploration.

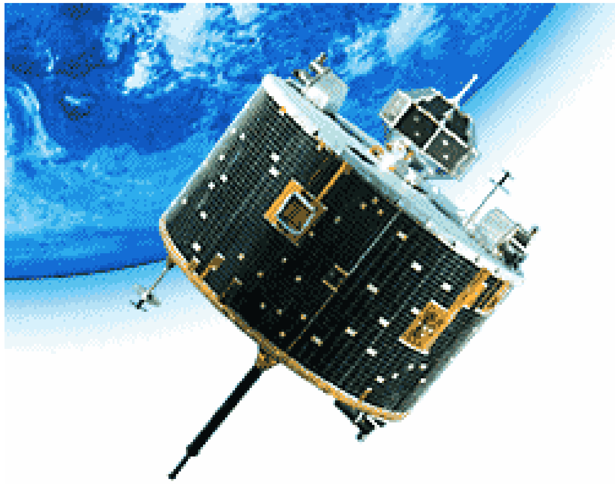
Science and knowledge:

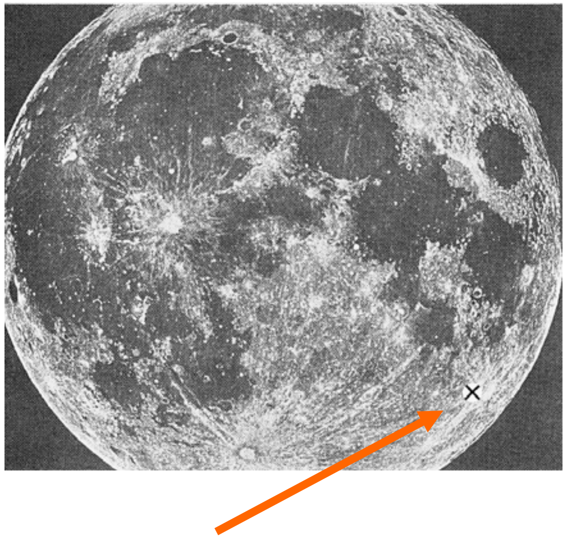
- Lead the top science, obtain new knowledge, and contribute for creation of new culture.
- Investigate the environment for full scale manned exploration to the moon and the beyond.

Hiten (MUSES-A)

Technology demonstration
- Lunar gravity assist
- Lunar orbit insertion
- Optical navigation
- Aero braking with earth atmosphere

1990.1 Launch
1990.3 1st Lunar gravity-assist and Hagoromo (small sat) Lunar orbit insertion
1991.3 1st aero-braking
1992.2 Lunar orbit insertion of HITEN
1993.4 Hard-landing to the lunar surface



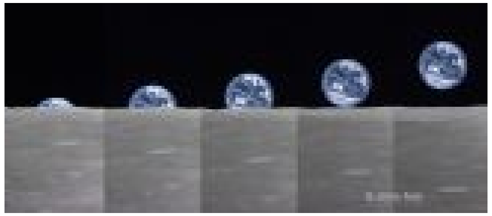


Landing point

Kaguya (SELENE)

- **Spacecraft configuration:**
  Main orbiter Kaguya,
  Relay satellite (Rstar) Okina,
  and VRAD satellite (Vstar) Ouna
- **Missions :**
  – Origin & Evolution :
    - Global Map of Lunar topography, gravity, soil, material, magnetics, sub-surface structure
  – Lunar orbiter Tecnology :
    - Guidance & navigation, thermal control, etc.
  – Data Acquisition for future lunar lander
- **Mission period :** 1 year nominal and extend
- **Mass:** Total 3020 kg, wet
  Science instruments: ca. 300 kg
  Sub-satellites: ca. 50 kg each
- **14 Science instruments** onboard
- Launch by H-2A-13 rocket from TNSC
  (14th Sept. 2007 10:31:01)

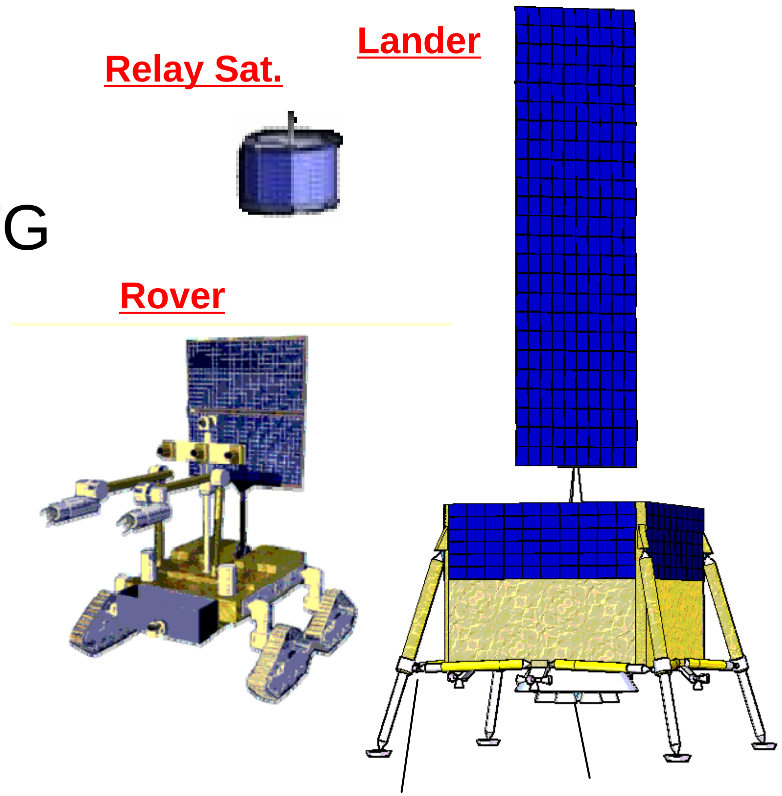



SELENE-2: Landing Observation

The landing candidate area is at such as Quasi- eternal sun-light area either in polar region or some other locations, and the mission life for the Lander shall last one month at least.

- Infrastructure for Exploration
  - Landing
  - Roving
  - Moon night survival without RTG
- Lunar Science
  - Origin and evolution
- Environmental study for future utilization
- Int. collaboration and cooperation



Launch: H-2A @ 2010s'
- 1000kg (Dry)
- 200～400kg Payload

start of Phase-A team

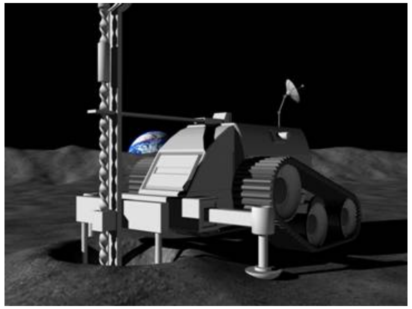
SELENE-X under Study (Examples)

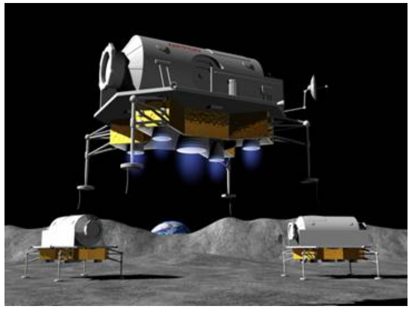
It will appear in late 2010s, in view of the Japan's participation in Humans Lunar Activity foreseen. The SELENE-X may perform either of the following demonstrations.

- Option-1: Technology Demonstration for Building Outpost such as the Excavation for Construction of Infrastructure.
- Option-2: Logistics Capability Demonstration for Building Common Landers for both Transportation and JAXA's own robotic missions.
- Option-3: Highly sophisticated In-situ Robotic Lander or Returning Sample of the Surface Soil to the Earth, including the Development of High Speed Reentry Capsule.

There are other options under study and will be determined after the international exploration strategy have been clarified.

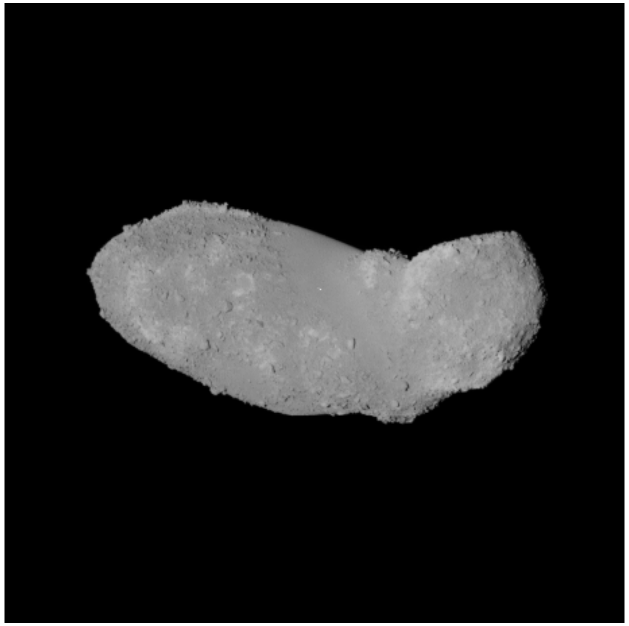
Future activities after SELENE-X





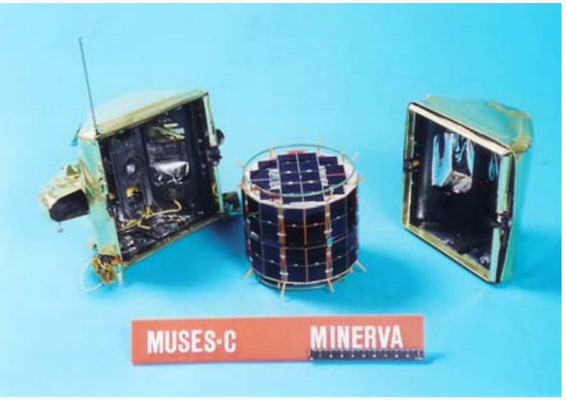
Hayabusa Mission

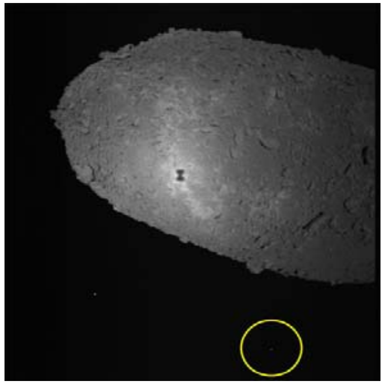
- Hayabusa Spacecraft was launched at Kagoshima Space Center on May 9th 2003 by M-V rocket.
- Hayabusa Spacecraft arrived at the Asteorid Itokawa (1998SF36) on September 12th 2005 and touched down the surface of Itokawa twice for sampling in November 2005.
- Hayabusa is going to return to the earth in June 2010.

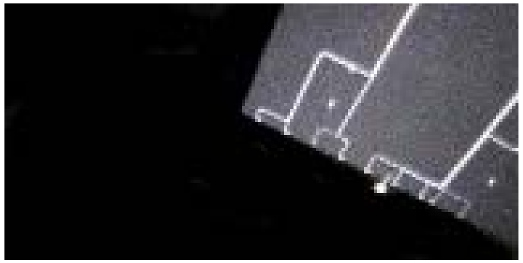


Overview of MINERVA

- The rover was deployed on Nov 12, 2005,
- Deployment was triggered by sending a command from the earth.
- Unfortunately Hayabusa failed in releasing MINERVA.
- The releasing velocity was bigger than the escape velocity.
- MINERVA could not land on the asteroid
- It rotates around the sun with Itokawa.
- MINERVA became an artificial planet.







Only one image was transmitted to Hyabusa after the deployment. The rover can evaluate the obtained images autonomously. The region with no objects in the image is not stored.

Hayabusa-2: Sample Return from Primitive Body

Hayabusa-2:

- Primitive body exploration
  - Programmatic follow-on of Hayabusa
  - from Type-S to Type-C
  - Hayabusa-Mk2 for Type-P,D
  - from asteroid belt
- Sample return
  - from type-C asteroid 1999 JU3
- Window 2010-2012

- Possible Missions for
  - Science
  - Human exploration
  - Earth protection
  - In-situ resource utilization
- International collaboration based on JAXA's experience

start of Phase-A team

Rover Mission & Technology

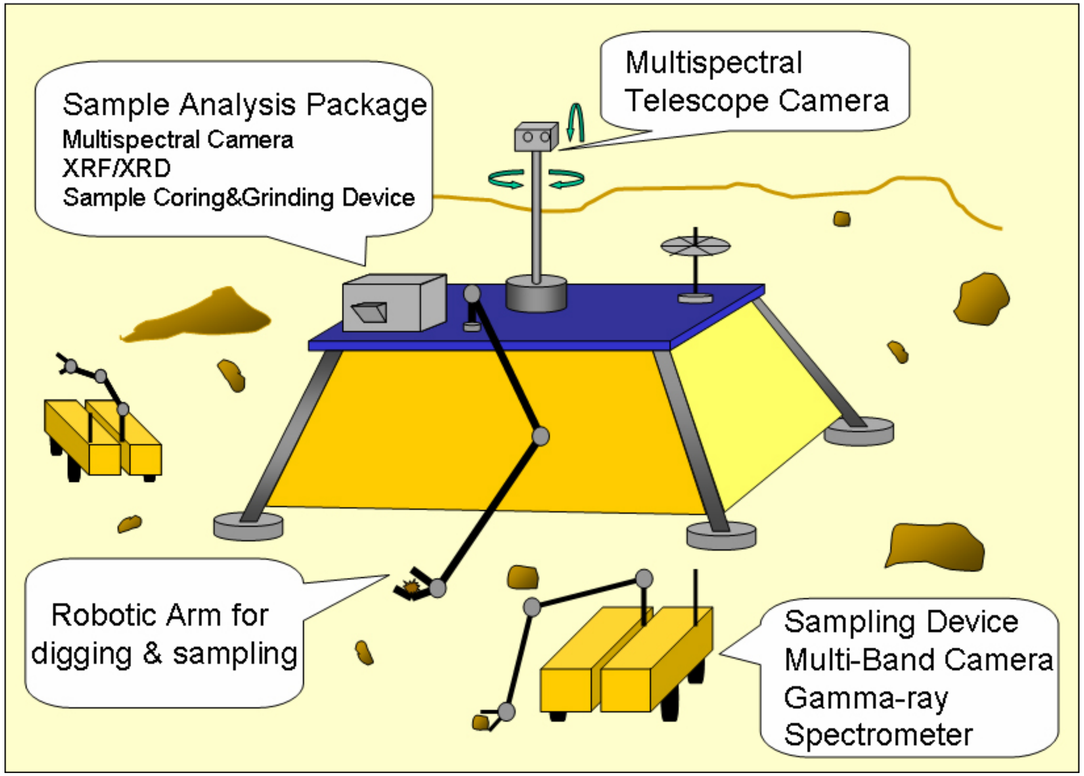
Missions of SELENE-2

Landing on the moon surface for

1. Development and demonstration of key technologies for future exploration.
   - Safe and accurate landing technologies
   - Surface mobility by rover
   - Night survival technologies
2. In-situ observation and investigation for science and future lunar utilization.
   - Detailed and sub-surface geological observation
   - Geophysics to know interior structure
   - Measure dust, radiation, soil environment
3. Contribution to international lunar activity and public interest.
   - International payload (TBD)
   - Outreach payload (TBD)

Lander and Rover Exploration

To achieve the efficient and effective exploration, lander and rover cooperation is under study.



Rovers travel in wide area and observe featured terrain by scientific instruments and take selected samples back to lander.

Lander has sample analysis package to observe collected samples in detail.

This system leads to sample return technology.

Research & Development

- Mobility system
- Guidance & Navigation
- Tele-Driving system
- Tele-science by manipulator
- Digging Robot

Rover Test-bed

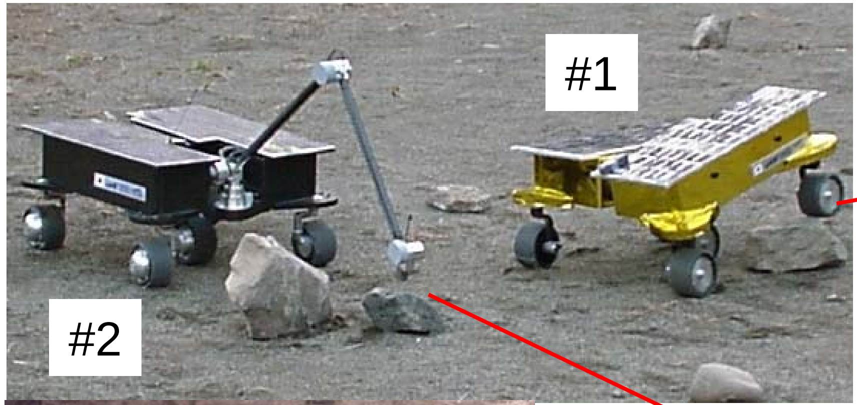
To construct effective rover systems,
some test-beds have been developed in Japan.

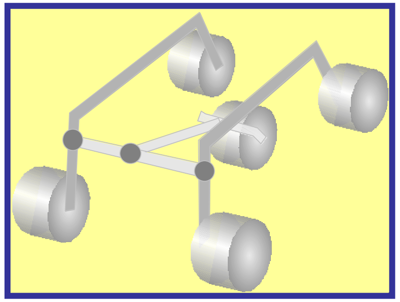
The purposes of test-beds

- to investigate the mobility system
- to test software algorithm
- to evaluate navigation and guidance system
- to demonstrate mission strategy
- to demonstrate the functions by field tests

Test-bed rovers : Micro5 Series

#1, #2, #3 Micro5 series



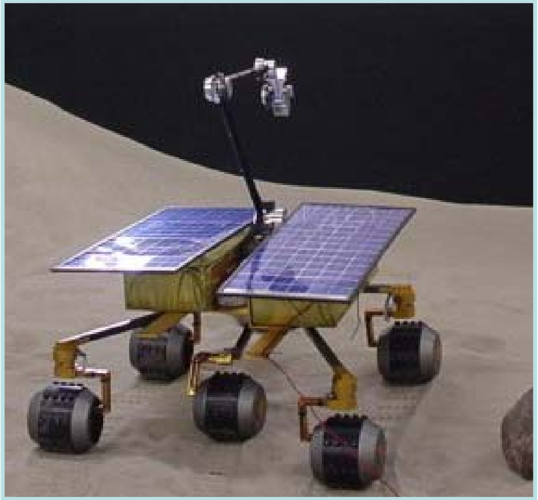


PEGASUS

1st generation

#4 (TOURER)

#5 (SciFER)



2nd generation

Surface mobility

Trade-off study on moving mechanisms

– Hard wheel, Crawler, Low pressured ring tire etc.

Component Tests

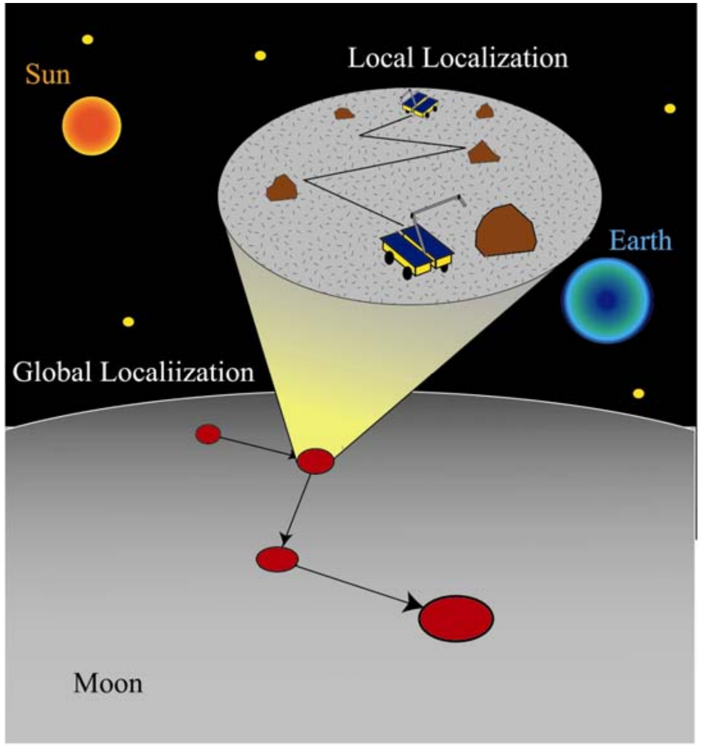
– Regolith seal

Rover Guidance & Navigation

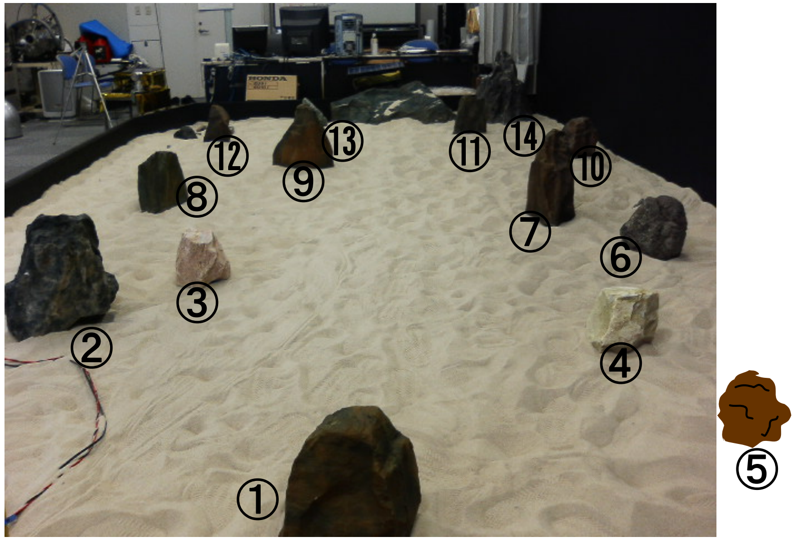
For the communication delay and low bit-rate communication, even lunar rover requires advanced guidance and navigation system to travel safely in wider area during limited mission period.

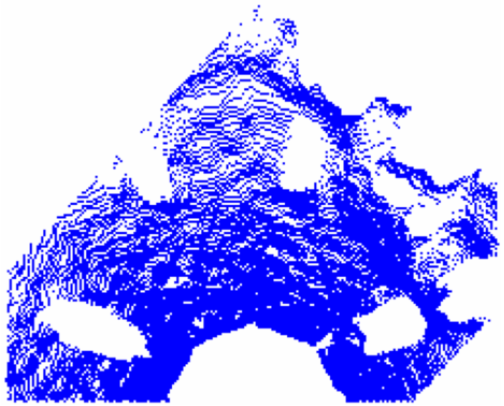
Conventional Move&Wait method is not efficient for long range exploration rover.

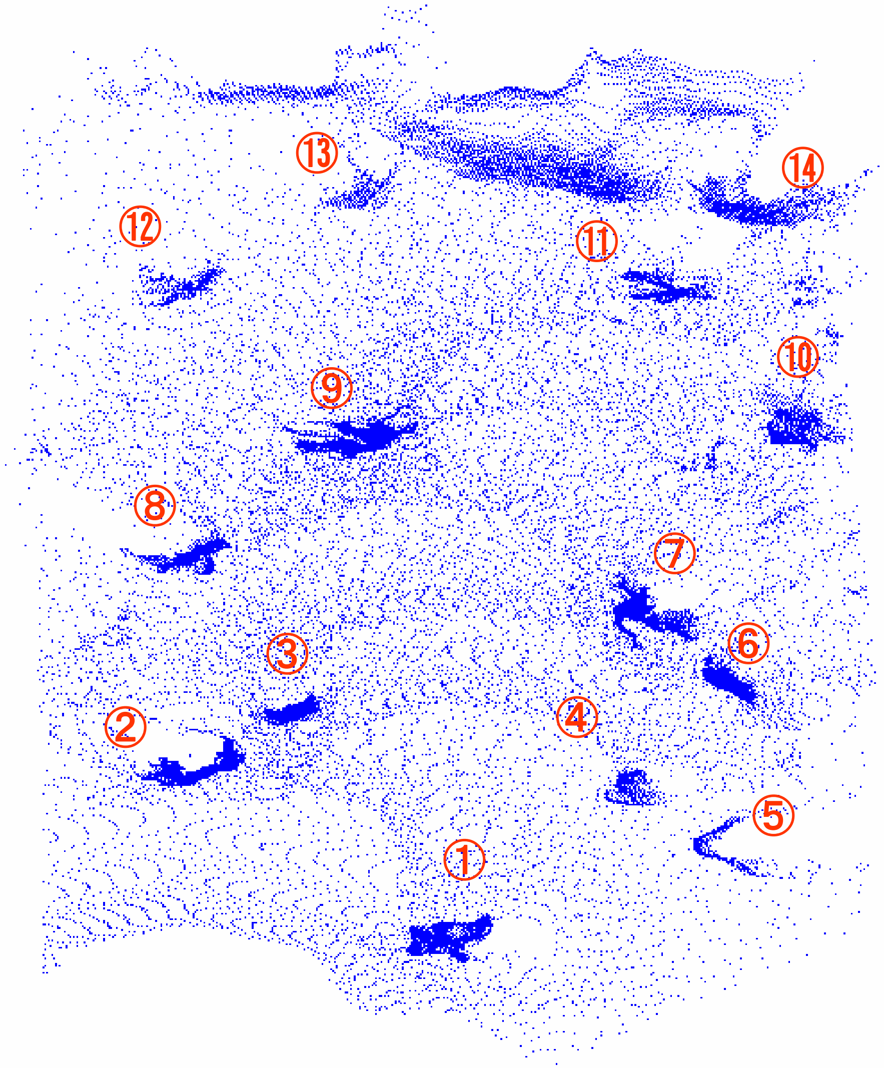
So autonomous system and intelligent tele-operation system are under development.



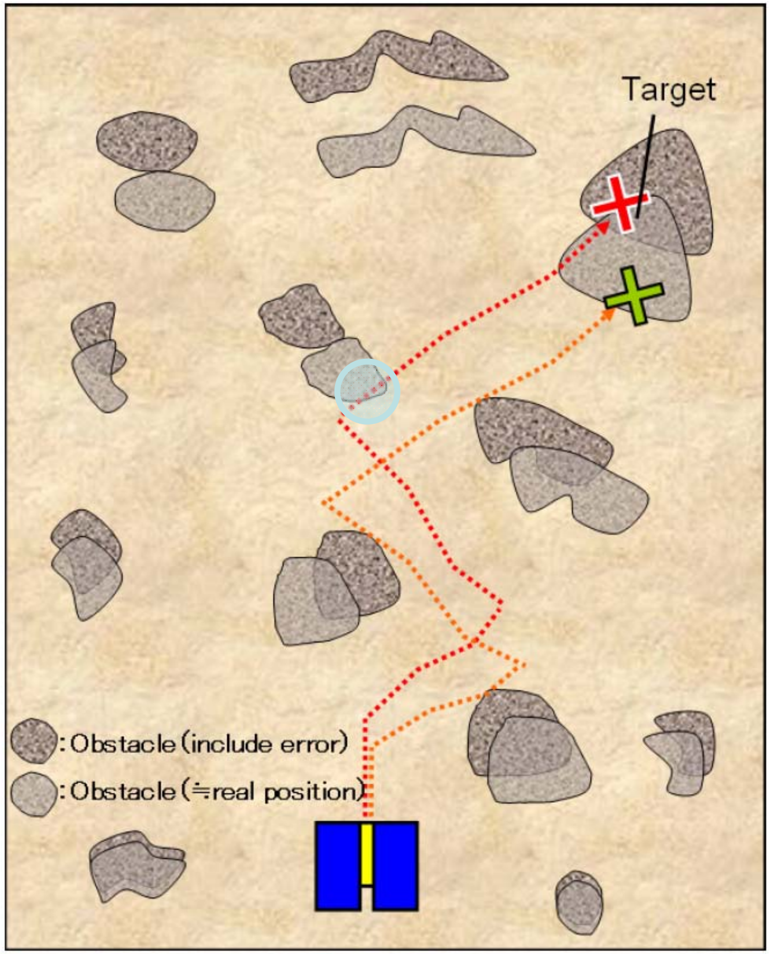
Map Building







Traverse in Natural Terrain



1. **Getting Environmental data**
   → **Measurement error on DEM**
2. **Commanding of Path and goal**
   → **Miss matching of position between internal coordination and image**
3. **Starting Autonomous traverse**
   → **Error of Self position estimation**

There are possibility of obstacle collision or rover cannot reach the goal

Problems and Solutions:

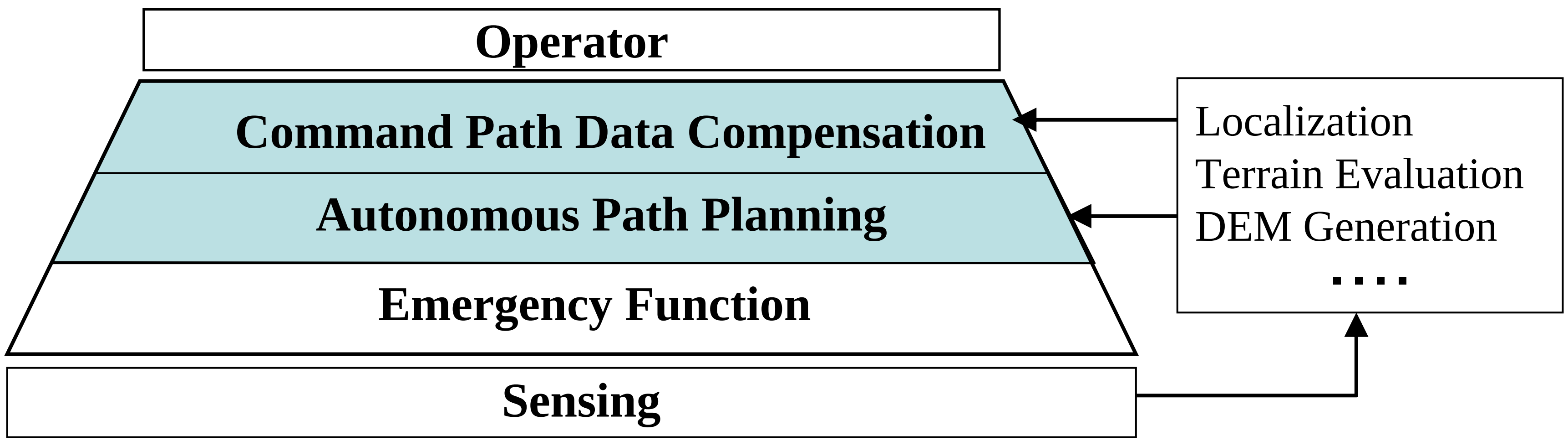
- Complexity of Environment ⇒ Commanding by Human Operator
- Occlusion Problem
- Human Error

⇒ Autonomous Path planning
Emergency Function

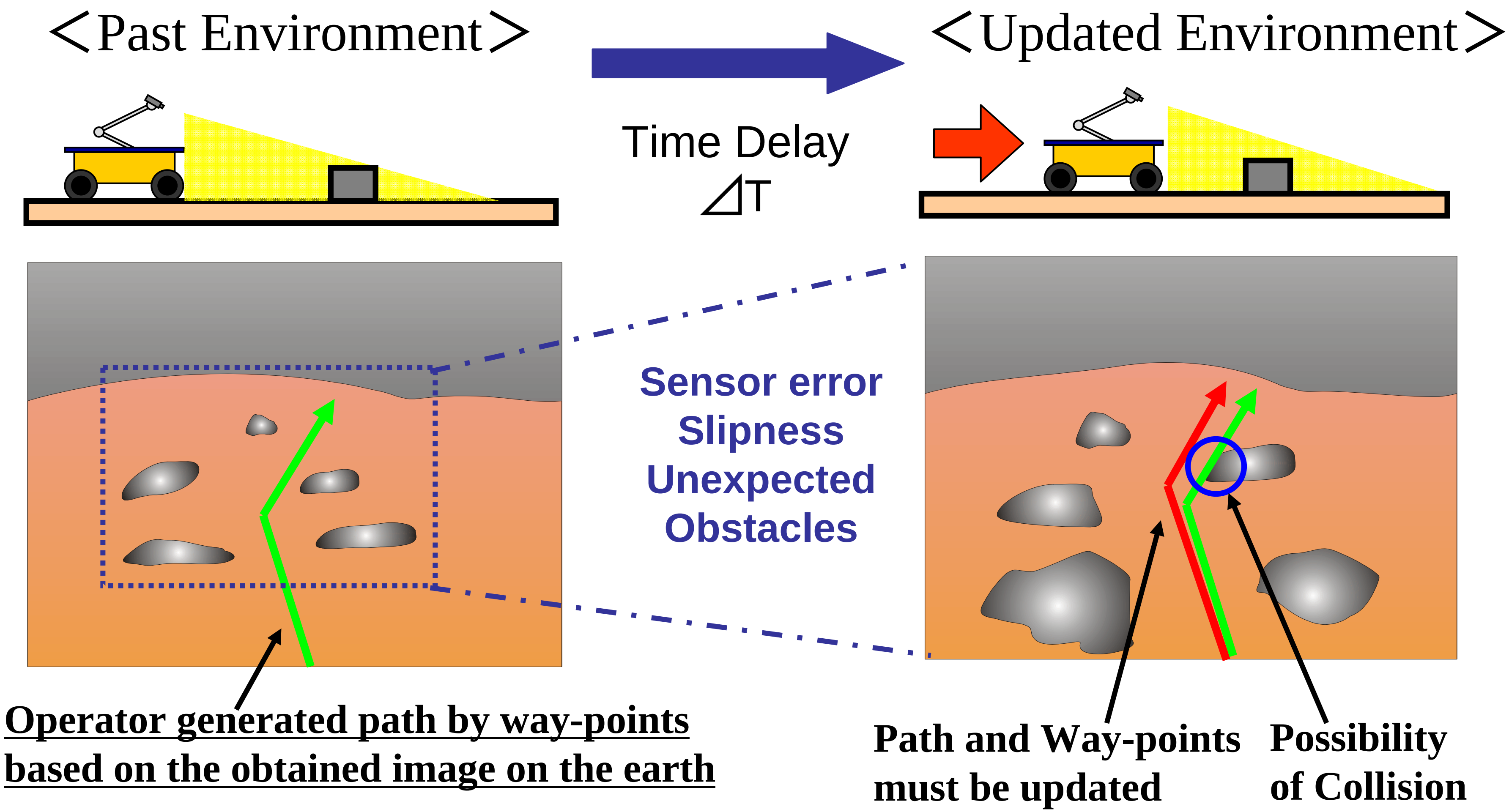
- Measurement & Position Estimation Error
- High Slip Rate of Wheels

⇒ Command path Data Compensation

Multi-layered Autonomous Functions



Intelligent Tele-driving System



Rover corrects the path with localization and map-building by on-board stereo cameras.

Command path Data Compensation

Assumption:

•the Difference between the latest measured data and the old data
⇨ Almost Linear

Relationship of each measurement data of LM(Land Mark) is

$$\bar{X} = XA$$

$$A = X^{+}\bar{X}$$

X : LMs used by operator

$\bar{X}$: LMs measured by rover

A : Distortion compensation matrix

Pseudo inverse Matrix $X^{+} = \left[X^{T} X^{-1} \right] X^{T}$

$$W_{P\_new} = W_{p\_old} A$$

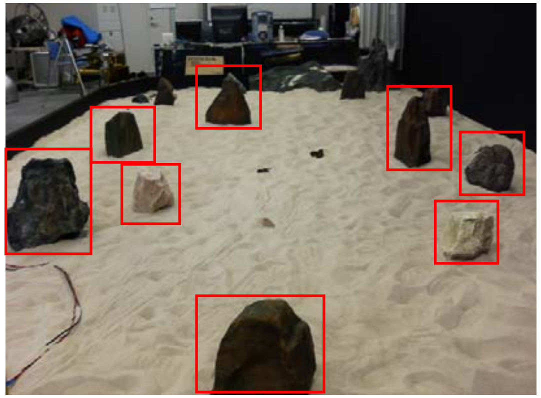
W_{p_old} : Waypoint commanded by operator

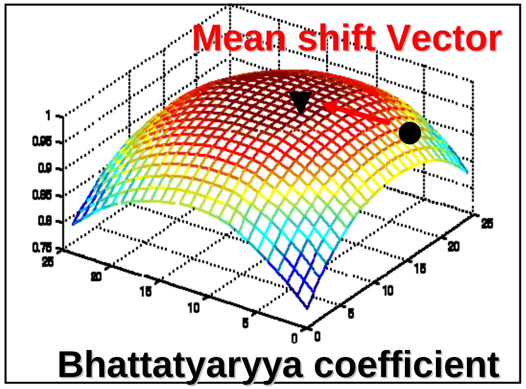
W_{P_new} : Waypoint compensated by CDC

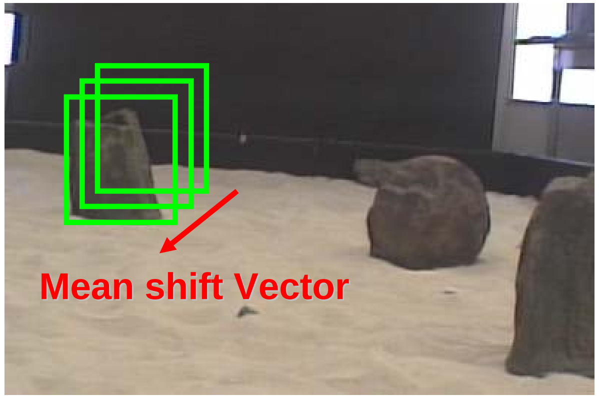
Target tracking for Compensation

Mean-shift Algorithm

Using Texture information of Template ⇒
- •Robust correlative surface
- •Mean shift vector







Scale adaptation

Occlusion detection

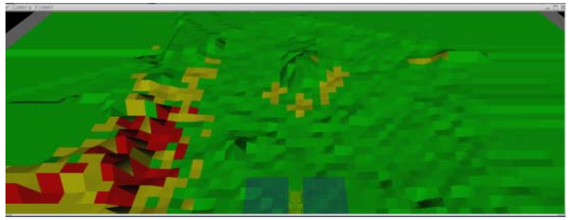
Experimental Results for Tracking

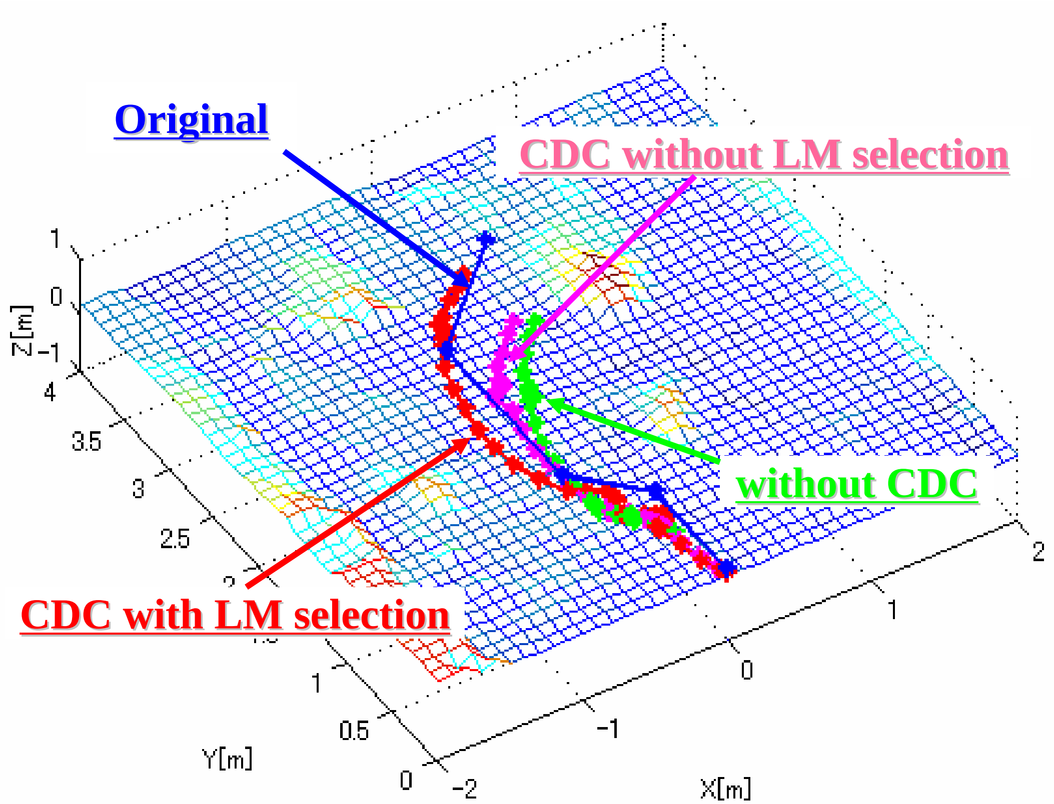
Indoor Experiments

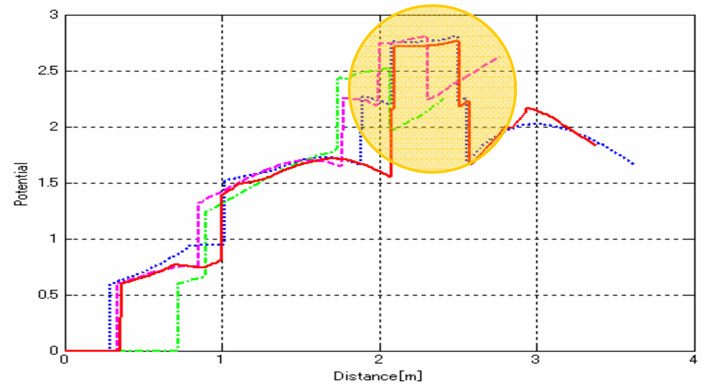
Tele-driving based on Waypoint

Sand & Rock
8 m× 4 m

Experimental Results







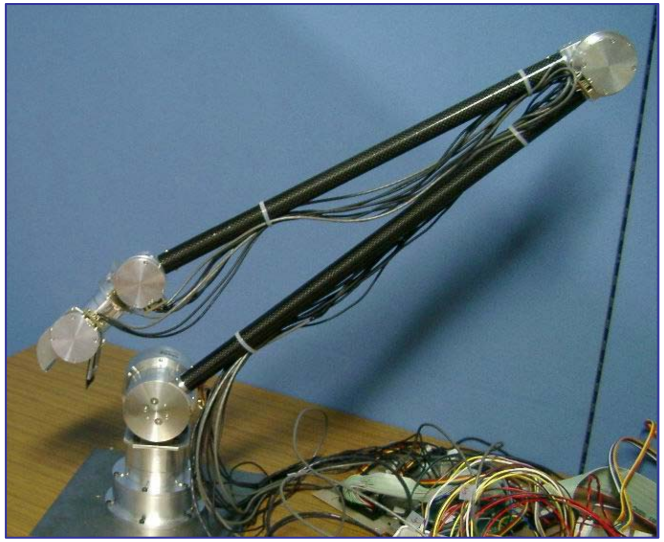
Position Error at Goal point

	X[m]	Y[m]	Z[m]	Error[%]	SR
Directions Goal Point	0.30	3.20	0.15	----	----
Without Compensation	0.19	2.09	0.20	35.39	0.770
With Compensation	0.09	2.54	0.21	22.66	0.976
With Selection Compensation	0.05	3.04	0.20	11.63	0.947

Design of Manipulator

<Requirements>

- Sampling
- Approaching equipments to samples
- Observation of Environments
- Light-weight, Low power consumption



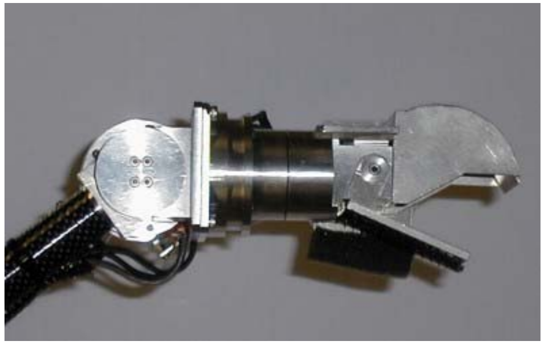
<Design of Manipulator>

- Two links with 5 DOF
- End-effecter for sampling rocks and soil

Total Length	1.05[m]
Total Weight	2.0[kg]
Payload	0.9[kg] (on Earth)

End-Effector

The developed end-effector can grasp rocks and also collect soil.



Both gripper and scoop functions are installed.

Telescience Experiments

Soil Collection

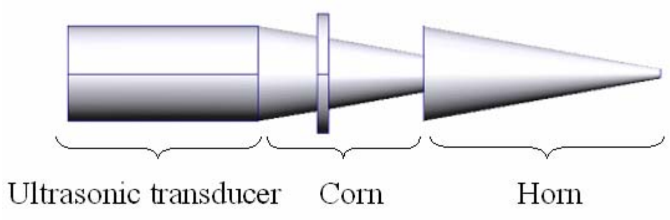
Rock Sampling

Grinding Device

Scientists strongly request to grind and polish the surface of samples to observe the fresh face.

New Grinding System with ultrasonic vibration mechanism has been developed.

Special horn can put the vibration power at the tip.
So it is possible to grind and polish the rock with small size device with light-weight, low power consumption.

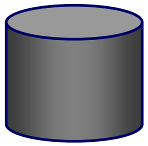


Mission Requirements

To Grasp the Lunar Interiors

- Measurement of lunar seism or internal heat flow

Long-period seismometer



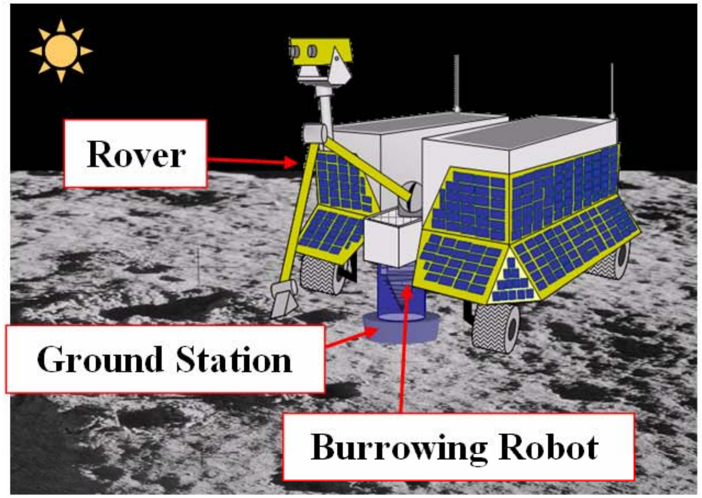
Diameter: 50mm
Length: 50mm

Burying long-period seismometer in lunar regolith layer

Low temperature at night
Very small lunar seism

Burrowing Robot

Lunar subsurface exploration system with burrowing robot

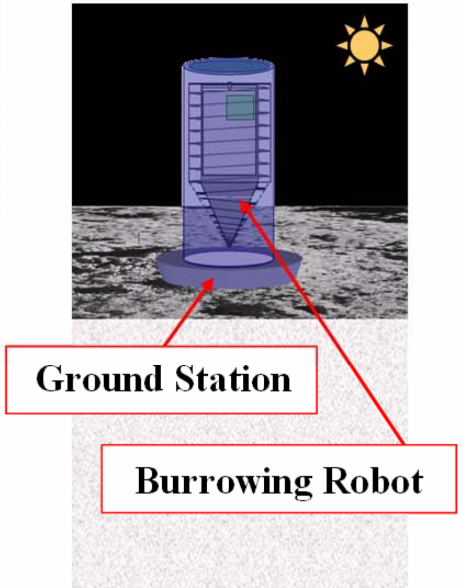


Step1

Moving on the Surface by Rover and Deploying Burrowing Robot

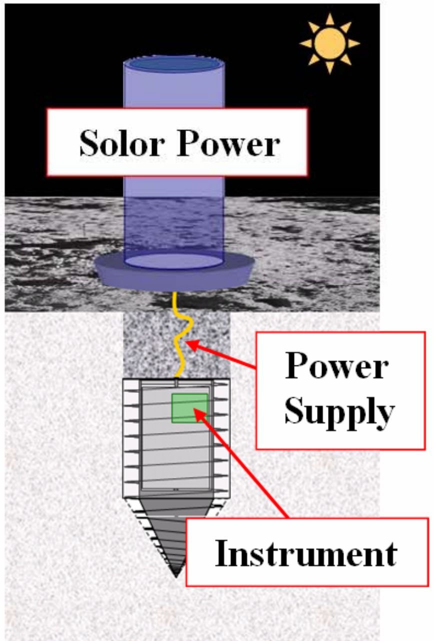
Target: Lunar Soil (Regolith)

Robot Diameter: about 10 cm



Step2

Start Burrowing



Step3

Burrowing into Subsurface

Summary

- JAXA Roadmap of lunar or planetary exploration
- Robotics exploration with lander and rover in SELENE-2
- Rover Technology
  - Mobility system
  - Tele-driving system for lunar rover
  - Tele-science with light manipulator
  - Drilling Robot for subsurface exploration

Field tests including exploration strategy and scientific observation are under planning.