An Overview of JAXA Space Robotics Activities

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ABSTRACT

This paper presents JAXA robotics research activities. Firstly this paper introduces Japanese future exploration plans such as lunar, Mars and small body exploration. Then this paper also describes a robotics technology roadmap based on deep space exploration missions. JAXA has developed some test-bed robots and performed field tests. This paper shows the developed robots in detail and some experimental results. This paper also presents the intelligent systems for navigation, path planning, and sample collection schemes.

1 INTRODUCTION

Nowadays ISAS/JAXA has studied and developed a new roadmap for deep space exploration[1] as shown in Figure 1. Some working groups have earnestly studied new future lunar or planetary exploration missions[2] including landers, rovers, and sample return etc. Those missions follow up a lunar global remote sensing mission, KAGUYA. One of main missions for lunar robotics exploration in post SELENE mission is to demonstrate the technologies for lunar or planetary surface exploration and human activities on the moon in the near future. They will cover some technologies[3] such as pin-point landing technology, reliable landing scheme with obstacle avoidance, safe landing mechanism on rough terrain, exploration rover, tele-science and tele-operation technology, automated construction etc. JAXA started developing a lunar landing demonstration mission SLIM.

A new lunar mission on vertical hole exploration on the moon is under study. Kaguya firstly discovered Moon holes in 2009. It is believed that moon holes are useful for learning about the formation of the moon because bedding plane is exposed. In addition, because inner holes are sealed from solar wind, and moon holes are also considered important candidate sites for base camp in the future. However, exploration of vertical hole is so difficult by the conventional robots. A new type of robot is required to go down and explore a moon hole. Then an exploration system for the vertical hole is under study.

The other exploration research group in Japan has studied Japanese Mars exploration[4]. In the preliminary study, an orbiter and some landers cooperatively explore Mars. Some explorers, such as surface exploration rovers, and wide area exploration by airplanes, are also under study. Subsurface exploration by mole

Figure 1: Japanese deep space mission plans

type robots is also under development.

Recently small body exploration missions[4] have received a lot of attention in the world. In small body explorations, especially, detailed in-situ surface exploration by tiny probe is one of effective and fruitful means and is expected to make strong contributions towards scientific studies. JAXA is currently promoting Hayabusa-2 mission, which is the post Hayabusa including sample and return attempt to/from the near earth asteroid. Hayabusa-2 spacecraft will take the tiny probes, which are expected to perform the in-situ surface exploration by hopping.

This paper firstly presents future lunar or planetary exploration plans in detail, such as lunar surface exploration, Mars satellites exploration and asteroid sample return exploration. Then this paper presents a robotics technology roadmap based on deep space exploration. JAXA has developed some test-bed robots. This paper shows the developed robots and some experimental results. This paper also presents the intelligent systems for navigation, path planning, sampling, etc.

2 Surface Exploration Missions

This section describes future lunar or planetary exploration programs in detail.

2.1 Asteroid sample return mission

In small body explorations, especially, detailed in-situ surface exploration by tiny probe is one of effective and fruitful means and is expected to make strong contributions towards scientific studies. JAXA is currently promoting Hayabusa-2 mission as shown in Figure 2, which is the post Hayabusa including sample and return attempt to/from the near earth asteroid. This is a similar mission to Hayabusa. However, the target asteroid is different from the Asteroid Itokawa explored by Hayabusa. Itokawa is rock-rich S-type one. On the other hand, Hayabusa-2 will visit a C-type asteroid 1999JU3, which is also rock quality. However it is thought that their rocks contain much more organic matters and water. Hayabusa-2 challenges very interesting objectives: what are original organic matters and water existed in the solar system? Or how are they related to life and ocean water?

The problems identified in Hayabusa mission are improved and new technology is aggressively adopted in Hayabusa-2. Then Hayabusa-2 will observe and collect the sample, based on the C type of Asteroid. The Best timing to launch to the asteroid for this sample return mission is 2014. Hayabusa-2 is supposed to reach the asteroid in the middle of 2018, stay there about one and half years, depart from the asteroid to return to the earth at the end of 2019, and come back to the earth at the end of 2020.

It is considered to mount "Crackup installation" on Hayabusa-2 that Hayabusa spacecraft did not have. It will be separated above the asteroid and explodes there after Hayabusa-2 hides behind the asteroid. Then an impactor of approximately 2 [kg] hits the surface of the asteroid and it will make a crater of several meters in diameter. After that, it tries to collect materials inside of the crater. Hayabusa-2 will collect materials of underground not only the ones on the surface. By doing that, Hayabusa-2 performs a trial to collect less altered materials.

Figure 2: Hayabusa 2 Mission

2.2 Lunar landing mission

JAXA is promoting SLIM (Smart Lander for Investigating Moon) mission for FY2019 launch. SLIM is a mission to demonstrate the technology for pin-point soft landing on lunar or planetary surface as shown in Figure 3.

SLIM will perform the following technology demonstration by tiny spacecraft technology,

- Image-based Navigation utilizing Lunar Terrain
- Autonomous Obstacle Detection
- Robust Pin-point Guidance
- Landing Shock Absorber

- High-performance Propulsion
- Exploration using Tiny Rovers (option)

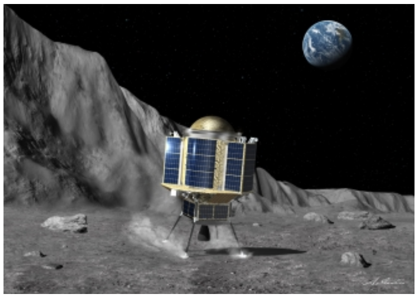

Figure 3: SLIM Mission

2.3 Martian Moon Exploration Mission

JAXA is proposing MMX (Martian Moon eXploration) mission for FY2022 launch. MMX is a mission to demonstrate the deep space exploration technology as well as scientifically investigate the origin of Phobos and Deimos. MMX will perform sample return from the most famous small body, Phobos in the solar system as shown in Figure 4.

The scientific purpose of MMX mission is to reveal the origin of a Mars moon (Phobos or Deimos), that is whether it is a captured D-type asteroid (A), or piled fragments made by a giant impact event (B). Only sample analysis will give the end to the ever-lasting-argument between (A) or (B). Material analysis will approach to the formation and transition of Mars.

MMX mission includes the following engineering challenges.

1. A Round Trip to a Martian System
   A round trip to a planetary moon is a major engineering challenge. Trade-offs in spacecraft configuration in balance with mission requirements is a challenging subject.

2. Proximity Operation around a Martian Moon
   Remote sensing, landing and sample retrieval from a far distant small body is one of the most challenging operation in space missions with Hayabusa experience and heritage.

3. Sample Retrieval Mechanism
   Requirements on the sample retrieval are supposed to be higher in quality and quantity compared with the previous missions (Hayabusa & Hayabusa2).

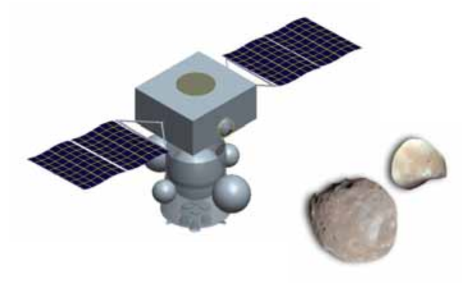

Figure 4: MMX Mission

2.4 Human outpost mission

Human Lunar Systems Team in JAXA works for the conceptual system study on the future human lunar outpost as shown in Figure 5. Based on the achievements and lessons learned from the International Space Station Program, system architecture on the basis of the international cooperation and the way of Japan's contribution are discussed continuously.

JAXA is actively participating and playing a major role in the ISECG: International Space Exploration Coordination Group, a mechanism for technical research toward manned space exploration via international cooperation.

Figure 5: Lunar Outpost Mission

2.5 Mars surface exploration mission

The other exploration research group in Japan has studied Japanese Mars exploration. In the preliminary study, an orbiter and some landers cooperatively explore Mars. Some explorers, such as surface exploration rovers, and wide area exploration by airplanes, are also under study. Subsurface exploration by mole type robots is also under development.

3 SPACE ROBOTICS TECHNOLOY

To realize lunar or planetary exploration, space robotics technology makes important roles. This section presents some of developed robotics technology for lunar or planetary exploration.

3.1 Developed Test-bed Robots

To investigate the performance of mobility or autonomous functions of surface explorers, various kinds of test-bed rovers[5][6][7][8] have been developed and tested as shown in Figure 6.

As a new test-bed, Micro6 has been developed with capability to carry out a variety of the novel mission sequences as shown in Fig.3(a). Micro6 is not designed for the mission specific, but for pushing the technology advance. The Micro6 has the novel suspension system called HEXUS which has failure tolerant feature. Wheel design must be done for mission oriented, because its performance is seriously affected by surface condition. The Micro6 installed a smart manipulator system for detailed surface exploration. The key technology of Micro6 project is to develop intelligent software architecture. Figure 3(b) shows the test-bed rover, which is called Cuatro, which was developed to investigate the autonomous functions.

(a) Micro6 Rover (b) Cuatro Rover

Figure 6: Test-bed Rovers

3.2 Intelligent Navigation System

To identify the position and orientation of a rover, a stereo Visual Odometry(VO)[9] and SLAM technology[10] have been studied. There are several technical problems in untextured terrain including the diversity of terrain appearance, the lack of well-tracked features on surfaces, and the limited computational resources of onboard-computers. So a method is proposed to enable efficient and accurate visual localization independently of terrain appearance. Several key techniques[11] are developed including a framework for terrain adaptive feature detection and a motion estimation method using fewer feature points. Field experiments have been conducted in volcanic fields for validation and evaluation of the system effectiveness and efficiency.

3.3 Intelligent Path Planning System

In the case of a remote environment like the moon or planets, time-delay occurs between the ground station on the earth and the explorers due to their distance and the limited capacity of communication bandwidth. It is thus difficult to compose a closed loop control structure between the ground station and the explorer system. Conventional tele-operation methods cause the behavior called “Move & Wait” to a movement of an explorer. An explorer has to wait for commands while the operator’s planning the path, and as a consequence, that is time consuming. Moreover, to avoid collision between the waypoint path and obstacles, a rover requests the operator to regenerate its waypoint path, which causes further delay until new path data are received. Therefore, an advanced navigation and path planning scheme[12] is necessary for efficient and safe exploration by rovers.

For lunar exploration, basically it may be possible to operate surface explores from ground station. Because of time delay and limited telemetry data, however, an advanced navigation and path planning scheme is also required even for safe and efficient exploration on the moon. A rover itself causes position estimation errors and dead reckoning errors, because of slips of wheels etc. For corresponding to an unknown obstacle, a conventional autonomous path-planning algorithm is a solution, and it can be applied for short range path planning between each waypoint. On the other hand, a rover is continuously updating the environment data set. The original path may result the rover to follow a trajectory that might cause a collision to obstacles. Therefore, it is required to compensate waypoints by using the latest measurement data[13].

3.4 Smart Asteroid Surface Explorer

An intelligent small robot for asteroid surface exploration was developed in Hayabusa mission, called MINERVA for MIcro/Nano Experimental Robot Vehicle for Asteroid. MINERVA is also the first asteroid exploration rover to ever be developed and deployed. The major objectives are as follows: to establish a novel mobility in micro gravity environment such as a small planetary body, to demonstrate the autonomous exploration capability, and to perform the first-ever planned scientific observations on an asteroid surface. In the mission phase, unfortunately, Hayabusa spacecraft deployed MINERVA at higher velocity than the escape velocity on November 12th in 2005. That is why MINERVA could not reach the asteroid surface.

Being inspired by the dramatic success, Japan announced the official development of Hayabusa2, the second sample return mission to a Near-Erath asteroid 1999JU3 of a different taxonomy. Hayabusa-2 is planning to take small rovers[14][15][16] to the target asteroid for detailed surface exploration as shown in Figure 7.

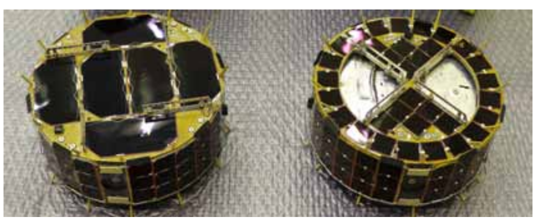

Figure 7: MINERVA-II Rovers

4 CONCLUSION

This paper presented the near future lunar or planetary exploration plans in Japan. Then this paper introduced JAXA robotics technology for deep space exploration. Especially newly developed robots and field tests were shown in this paper. ISAS/JAXA is currently updating the space science and exploration program roadmap. Japanese space robotics technology would contribute to promote those missions effectively.

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