

AI AND SPACE ROBOTICS TECHNOLOGY AT JAXA

Takashi Kubota

JAXA/ISAS, 3-1-1, Yoshinodai, Chuo-ku, Sagami-hara, 252-5210 Japan, E-mail: kubota.takashi@jaxa.jp

ABSTRACT

This paper describes AI and robotics research activities at JAXA. This paper introduces Japanese deep space exploration plans such as lunar, Mars and small body exploration including current missions. Then this paper also presents AI and robotics technology developed for lunar or planetary missions. JAXA has developed some test-bed robots for the future missions and performed field tests to demonstrate the feasibility. This paper shows the developed robots in detail and some experimental results. This paper also presents the intelligent robotic systems for the future missions.

1 INTRODUCTION

JAXA has earnestly studied and developed a new exploration roadmap[1] and planned lunar or planetary exploration missions[2] as shown in Fig.1. In recent years, small body exploration missions have received a lot of attention in the world. In small body explorations, especially, detailed in-situ surface exploration by tiny probes is one of effective and fruitful means. Surface explorers are expected to make strong contributions towards scientific studies for small body as well as the moon or Mars.

JAXA is currently promoting Hayabusa-2 mission[3] for sample and return attempt to/from the near-earth asteroid. Hayabusa-2 spacecraft was launched to the asteroid in 2014 and performed the rendezvous for the target C-type asteroid Ryugu on June 27th in 2018. 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? Hayabusa-2 succeeded in deploying two exploration robots, which could hop and perform the in-situ surface exploration. The impactor also succeeded in exploding the surface and making an artificial crater. Then Hayabusa-2 successfully performed two trials to collect less altered materials. AI and robotics technology developed in Hayabusa-2 mission[4], are presented, such as pin-point guidance, visual navigation, automatic sampling, autonomous exploration rovers, etc.

JAXA is developing a smart lander for the landing demonstration mission SLIM (Smart Lander for Investigating Moon). After SLIM mission, a lunar

polar robotic mission is under study to explore high interest sites where orbital data indicate the presence of water ice. New technologies[5] are under development, such as mobility, digging, instruments, high-sensitivity camera etc.

A new lunar mission[6] on vertical hole exploration on the moon is also under study. The lunar spacecraft 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 also considered important candidate sites for base camp in the future. However, exploration of vertical hole is not so easy for the conventional robots. A new type of robot is required to go down and explore. Then an exploration system for the vertical hole is under study.

JAXA has studied MMX (Martian Moon eXploration) mission, which will travel to Mars and survey the red planet's two moons; Phobos and Deimos. The spacecraft will explore both moons and collect a sample from Phobos to bring back to Earth. The goal of the mission is to reveal the origin of the Martian moons and progress our understanding of planetary system formation and primordial material transport around the boundary between the inner- and outer-early Solar System.

This paper presents future exploration plans in detail. Then this paper presents AI and robotics technology roadmap for deep space exploration. This paper introduces the detail of the developed robots by JAXA and shows some experimental results[7][8][9][10]. This paper also presents the intelligent robotic system for the future exploration missions.

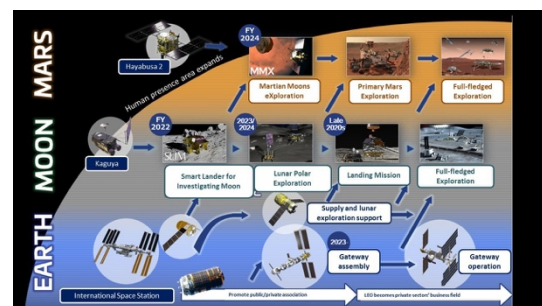


Figure 1: Lunar or Planetary Exploration.

2 SMALL BODY EXPLORATION

JAXA is earnestly promoting Hayabusa-2 mission. 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 visited a C-type asteroid 1999JU3, which is also rock quality. However it is thought that their rocks contain much more organic matters and water.

The problems identified in Hayabusa mission are improved and new technology is aggressively adopted in Hayabusa-2. Hayabusa-2 spacecraft reached the target asteroid Ryugu in 2018, stayed there for scientific observation[11] about one and half years, departed from the asteroid to return to the earth at the end of 2019, and will come back to the earth at the end of 2020.

MINERVA-II robots[12] were deployed from the Hayabusa-2 spacecraft on September 21st in 2018. Twin rovers could succeed in landing, staying and hopping on the surface as shown in Fig.2. Twin rovers could observe the surface in detail by sending about 600 images to the Earth.

SCI(Small Carry-on Impactor)[13] is newly developed and mounted on Hayabusa-2 spacecraft. SCI was separated above the asteroid and exploded there after Hayabusa-2 hides behind the asteroid as shown in Fig.3. Then an impactor of approximately 2 [kg] hit the surface of the asteroid and succeeded in making a crater of several meters in diameter. Then Hayabusa-2 tried to collect materials inside of the crater. Hayabusa-2 performed a trial to collect less altered materials.



Figure 2: MINERVA-II Robots.

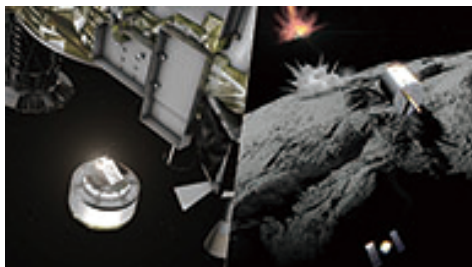


Figure 3: SCI Missions.

3 LUNAR OR PLANETARY EXPLORATION

JAXA is engaged in international collaborations to tackle the challenge of human and robotic exploration missions in and beyond low-Earth orbit (LEO). The current focus is exploration missions to the Moon and Mars (including the Martian moons), targeting future human activities.

That is why, the JAXA Space Exploration Center (JSEC)[14] was established focusing on international collaborations for sustainable human space exploration. JSEC works closely with government, industry, and academia in Japan, as well as space agencies outside Japan, to develop strategies, investigate space systems, and comprehensively expedite project management. JSEC brings together JAXA's joint activities in scientific understanding and technological development to tackle the challenges in human and robotic exploration.

JAXA is continuing discussions for participation in the US-proposed Lunar Orbital Platform -Gateway and sustainable human lunar surface exploration, contributing knowledge and technology gained from the ISS program and space science missions. For the Gateway program, JAXA is engaged in detailed technical deliberations of how we can make contributions based on our core competencies, including human space habitation technologies and resupply missions.

For activities on the lunar surface, JAXA is developing the Smart Lander for Investigating the Moon (SLIM), which will utilize data acquired from the JAXA lunar orbiter SELENE (Kaguya) to demonstrate precision landing technology essential for future lunar and planetary exploration.

JAXA is also planning the Lunar Polar Exploration Mission with the goal of a 2023/2024 launch. This mission will investigate the abundance of water and the possibilities for resource utilization in the lunar polar region. Additionally, the Medium-sized Cargo Lander will demonstrate key technologies needed for human exploration of the lunar surface. This mission will return lunar samples to Earth through the Gateway. Moving from the Moon to Mars, JAXA is leading the Martian Moons eXploration (MMX) mission to return samples from Phobos. The mission will build on lunar exploration techniques and discoveries, and is planned for launch in 2024. JAXA identifies these missions as means of gaining scientific knowledge and expanding activities, and will continue to strive toward those goals in the future.

3.1 SLIM Mission

SLIM (Smart Lander for Investigating Moon)[15] aims to demonstrate “landing where it is desire to land”, pin-point landing technique and obstacle detection technique as shown in Fig.4. This is a lunar lander that aims to achieve a lightweight probe system on a small scale and use the pinpoint landing technology necessary for future lunar probes. The project will aim to cut weight for higher function observational equipment and to land on resource scarce planets with an eye towards future solar system research probes.

The SLIM project is a mission for researching the pinpoint landing technology necessary for future lunar probes and verifying this on the surface of the moon with a small-scale probe. By creating the SLIM lander, humans will make a qualitative shift towards being able to land where we want and not just where it is easy to land, as had been the case before. By achieving this, it will become possible to land on planets even more resource scarce than the moon.

Nowadays, there has been an increase in the knowledge of target astronomical objects and the details which should be studied have grown more specific so that high accuracy landings near the target of study have become necessary. Furthermore, a need will arise for equipping probes with higher function observational devices for future solar system research probes. Probe systems are being made lighter in preparation for this time and the reduced weight of probes will be essential so as to be able to distribute resources for observational devices. The SLIM lander aims to achieve a small scale, light weight probe system and pinpoint landing technology, in addition to contributing to future lunar probes.

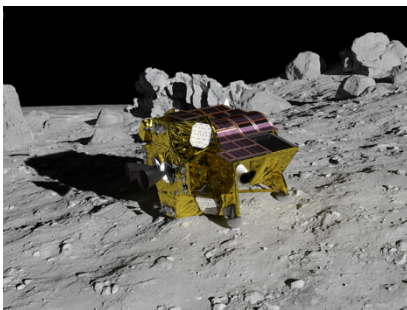


Figure 4: SLIM Mission.

3.2 Lunar Polar Exploration Mission

The analysis of observational data on the moon has suggested the existence of water in the polar regions of the Moon. JAXA is working with ISRO to plan an

international collaborative mission to obtain the data on the quantity and forms of the water resources present on the Moon, in order to determine the feasibility of utilizing such resources for sustainable space exploration activities in the future.

The aim of the mission is to obtain actual data (ground truth data) regarding the quantity of water (H_2O) from in-situ observations of areas where water is anticipated to exist, based on the available past observational data. The mission aims to understand the distribution, conditions, form and other parameters of the lunar water resources through in-situ observations in the polar regions of the Moon. Through this mission, JAXA also seeks to improve the technology needed to explore the surface of low-gravity celestial bodies in order to support future lunar activities. These advancements include technology for mobility, lunar night survival and mining excavation.

At the lunar north and south poles where the Sun angle is low, there exist so-called ‘permanently shadowed regions’ (PSRs) that do not receive sunlight for long periods of time. As example of a PSR would be an area that is lower than the surrounding ground, such as the inside of a crater as shown in Fig.5.

In January 2020, JAXA established the “Lunar Polar Exploration Pre-Project Team”[16] to achieve the following goals. By obtaining key data on lunar water resources, including quantity and location, a judgement can be made regarding the feasibility of the Moon’s water for utilization during sustainable space exploration missions in the future. This mission can develop autonomous exploration capabilities on celestial bodies with significant gravity through utilizing and furthering the landing technology gained through the SLIM project, and by demonstrating surface investigation technology. Working as part of an international collaboration allows the mission design and development to be informed through global expertise, maximizing the scientific and technological impact for the future of human exploration.



Figure 5: Lunar Polar Exploration Mission.

3.3 OMOTENASHI

OMOTENASHI[17] is a CubeSat which will be launched by NASA SLS rocket after 2020 as shown in Fig.6. Its total mass is 12.6 kg, size is 6U. OMOTENASHI plans to land on the moon surface. And then, OMOTENASHI will explore the lunar surface as an option.

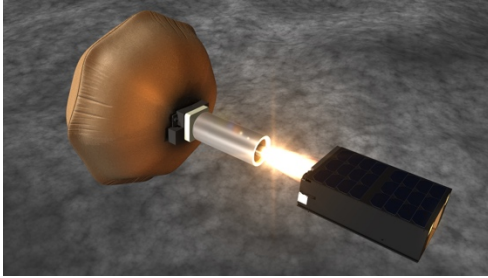


Figure 6: OMOTENASHI Mission.

3.4 MMX Mission

JAXA is promoting the Martian Moons eXploration (MMX) mission[18] as shown in Fig.7, which is a project to explore the two moons of Mars, with a planned launch in the mid-2020s. Approximately one year after leaving Earth, the spacecraft will arrive in Martian space and enter into an orbit around Mars. MMX spacecraft will then move into a Quasi Satellite Orbit (QSO) around the Martian moon, Phobos, to collect scientific data and gather a sample from the moon's surface. After observation and sample collection, the spacecraft will return to Earth carrying the material gathered from Phobos. The current schedule has a launch date in JFY 2024, followed by Martian orbit insertion in JFY 2025 and the spacecraft will return to Earth in JFY 2029.

The mission objectives of MMX are as followed.

- To investigate whether the Martian moons are captured asteroids or fragments that coalesced after a giant impact with Mars, and to acquire new knowledge on the formation process of Mars and the terrestrial planets.
- To clarify the mechanisms controlling the surface evolution of the Martian moons and Mars, and to gain new insights into the history of the Mars Sphere, including that of the Martian moons.

"Understanding the origin and evolution of the planets that leads to the start of life" is one of today's key scientific goals. As Mars is thought to have once had a surface environment similar to the Earth with the potential for life, the planet is one

of the most important exploration targets. The Martian moons are expected to have accumulated sediment that was been ejected from Mars over billions of years. Observing the moons will therefore provide information on the evolution of the Martian surface. Moreover, if the moons were formed during a collision between Mars and gigantic asteroids, the moon material will reveal the original conditions on Mars during this early time, offering insights into the planet's formation and its young environment. Alternatively, if the moons are captured asteroids, their composition will help clarify the transport process of volatile components (such as water) needed for habitability. In other words, exploring the Martian moons is important for not only understanding the moons themselves, but also for future planetary science.

To achieve the purpose of the MMX mission, the spacecraft needs to achieve various requirements. After separating from the launch rocket, the spacecraft must satisfy:

- Important requirements to maintain the spacecraft functionality, such as electric power, heat, and communication with the Earth.
- Requirements from the science instruments, such as altitude and timing of scientific observations.

In-depth studies are being conducted to design a spacecraft that meets these requirements. In addition to collecting samples, MMX will also perform remote sensing of Mars and its moons using a suite of observational instruments. It is still not clear how the two small Martian moons were formed and what processes they have undergone. The surface of Phobos seen in visible and near infrared light is not uniform, suggesting the possibility of different constituent materials. Discussions are being held with both Japanese and international scientists to determine where samples should be collected. Observational data obtained by the remote sensing instruments onboard MMX will be used to determine the sampling locations.

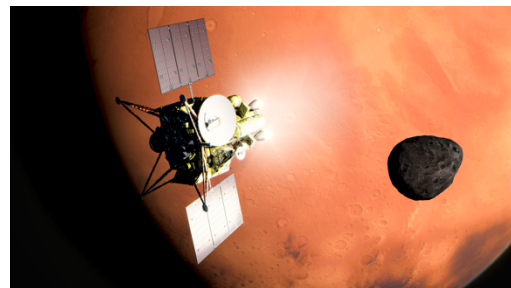


Figure 7: MMX Mission.

4 SPACE ROBOTICS TECHNOLOGY

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

JAXA formed Space Exploration Innovation Hub Center (TansaX)[19] on April 1st, 2015. This new center was established to help fulfill the 2014 policy entitled “Comprehensive Strategy on Science, Technology, and Innovation 2014 – A Challenge for Creating Japan in a New Dimension.” Consequently, public research institutions and agencies have had to perform strongly and contribute to innovation. Through the Innovation Hub Center, research projects will be developed and established within JAXA in an unprecedented way as shown in Fig.8. Knowledge and specialists from various fields have been sourced to form a new research team. The center is located on the JAXA Sagami-hara Campus and, as of April 2015, has approximately 30 staffs. The work is focused in three areas: 1) Exploration technology in a wide range of unexplored areas, 2) Automatic and autonomous exploration technology, and 3) In-situ resource utilization (ISRU) technology. Space Exploration Innovation Hub Center develops game-changing technology in space exploration. The center is aiming for a revolution in terrestrial technology while also improving space exploration methods.

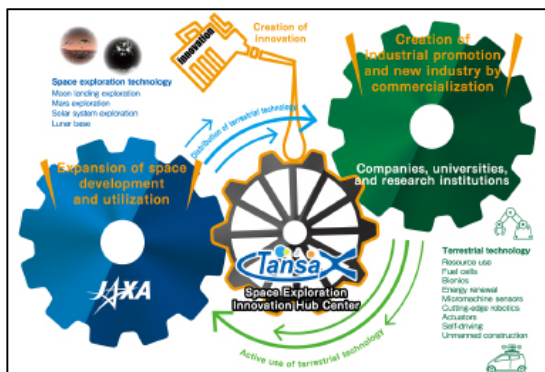


Figure 8: TansaX Concept.

4.1 Multi-robot Exploration Technology

With traditional large spacecraft, exploration of space takes a lot of time and cost. Since opportunities for exploration are limited, the locations for exploration also become limited. Therefore, by switching from a strategy of focusing all efforts in one area to one of distributed and cooperative works in wide areas, and by distributing functions through multiple small spacecraft, wide-ranging yet in-depth exploration of

unexplored areas can be actualized, leading to an innovation in exploration methods.

For example, the center aims to develop an innovative technology, in which multiple small robots are launched in one rocket, and are placed within a radius of 10 km on the Moon or Martian surface to explore the areas all at once. Distributed robots can cooperate with each other, and engage in high-level observation, cooperative work, location identification, and with a reliability that cannot be achieved with one robot. The center can create the own unique exploration program through fusion of robot technologies, which are the pride of the nation, and achieve a global leadership role in space exploration. Applications to the building of a new observation system for natural phenomena, such as volcanoes, typhoons, disasters, etc., measurement and examination of large structures and plants in factories, and a wide-range of automatic observations on Earth are expected to flow from this program as shown in Fig.9.

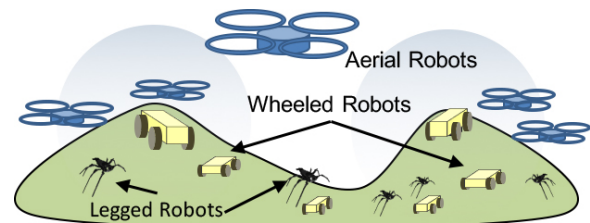


Figure 9: Multi-Robot Exploration.

4.2 Autonomous Exploration Technology

The center aims to develop the construction technology for manned bases to be constructed on the Moon and Mars in the future. Since a large number of people cannot be sent to the Moon and Mars, construction of the bases will be done largely on an unmanned basis. The challenge is to step away from the total-command system from Earth, gather and acknowledge information of the surrounding areas to the site, and to develop a construction technique that combines remote control and automatic or autonomous operations. Various technologies such as ICT technology and environment recognition technology, are necessary to achieve this, and application of terrestrial technology that has been proven on Earth is expected. From these developed technologies, humans and machines are efficiently integrated, and new developments, such as remote operations on Earth, can be considered.

4.3 In-situ Resource Utilization Technology

The transportation costs to the Moon and Mars are about 10 times higher than those to low Earth orbit. Therefore, for sustainable activities on the Moon and Mars, a paradigm shift from “shipping all necessities from Earth” to “procuring necessities on site” becomes necessary. The center aims to develop a system, in which Japan’s strengths in energy conservation, recycling technology, resource purification technology, agricultural technology and biotechnology, are applied to use the local resources and energy to produce necessities more efficiently. These technologies will be applied toward effective use of untapped low-quality resources, production of goods with low environmental impact, local production of resources on islands and in remote areas on Earth and efficient food production as well.

5 CONCLUSION

This paper presented the near future lunar or planetary exploration plans in Japan. Then this paper introduced AI and robotics technology for deep space exploration. Especially newly developed robots and intelligent technology were presented in this paper. JAXA is currently updating the space exploration programs. Japanese space robotics technology including AI would contribute to promote those missions effectively.

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