Images Obtained by MINERVA-II Rovers of Hayabusa2 Mission and Their Process on the Ground

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ABSTRACT

The authors developed a surface mobile exploration package named "MINERVA-II" for the Japanese asteroid mission "Hayabusa2." MINERVA-II included twin rovers named "Rover 1A" and "Rover 1B."

The rovers were deployed onto the target asteroid on 21 September 2018. The rovers then made autonomous surface explorations by hopping, which were evidenced by the status data and images transmitted to the Ground. This paper describes the onboard camera system of the rovers as well as the image processing techniques made on the Ground.

1 Introduction

Hayabusa2 was an asteroid explorer aimed to get some fragments from the C-type asteroid "Ryugu" and bring them back to the Earth. It was launched in December 2014, arrived at the target asteroid in June 2018, got some fragments by landing to the surface in 2019, and dropped a capsule containing samples into the Earth's atmosphere in December 2020[1]. Currently it is heading for another asteroid and will encounter it in 2029.

The authors developed two tiny rovers for Hayabusa2 spacecraft shown in Fig.1[2] . The rovers had a fully autonomous capability to explore the microgravity surface of the asteroid by hopping.

The rovers were deployed onto the asteroid on 21 September 2018 and then made autonomous surface explorations by hopping as planned, which were evidenced by the status and image data transmitted from the rovers.

One of the rovers survived for more than 100 asteroid days and sent more than 600 images obtained during the ballistic motion by hopping and on the surface. The other one had a shorter life of 10 asteroid days with 39 images transmitted to the Earth.

The rovers did not know where they were positioned on the asteroid surface. Thus the obtained images were matched to the global model of the asteroid which had been created by the images obtained by the mother spacecraft in order to identify where the images were taken.

This paper describes the onboard camera system of the rovers as well as the image processing techniques made on the Ground.

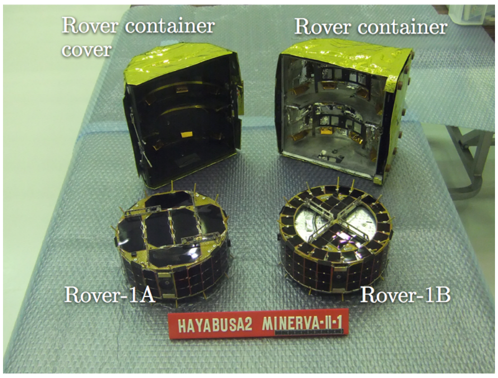

Fig. 1: Twin rovers (Rover-1A, Rover-1B)

2 Rovers

Table 1 shows the specifications of the twin rovers. Two rovers looked like a cylinder and had a mass of approximately 1.1[kg]. The slight differences of two rovers came from their appearances and the installed sensors.

The solar cells were the electric source of the rovers and were attached on every face of the rovers which enabled power generation at any attitude. The average power generation was slightly more than the consumption of the onboard computer and the communication module. The residual power was charged into the onboard double layer capacitors. The activations of cameras and motors required addition power, which was supported from the capacitors.

The rover transmitted the telemetry data at the maximum spped of 32[kbps]. There were two antennas on the both sides of the rovers. The onboard commuication module automatically selected the better antenna, judged by the incoming radio strength from the relay module onboard the mother spacecraft.

The rovers did not directly communicate with the Earth since they did not radiate sufficient power.

There was a relay module installed inside the mother spacecraft. The relay module communicated with the rovers.

The commands obtained from the Earth were once stored in the relay module and then transmited to the rovers after the communication link between the destination and the relay module had been established. The telemetry data sent from the rovers were also once stored in the relay module and then transferred to the spacecraft onboard computer.

There were several sensors installed. Some of them were used for the autonomous capabilities of the rovers, the others were used for purely scientific observations. Two types of cameras, photo diodes, thermometers, potentiometers, gyroscope, and accelerometer were installed. The rovers had many pins getting out of the body. Some of the pins had the probes of the thermometers and the potentiometers. When the rover was on the surface, some of the pins directly touched the surface and the temperature and potential were measured with these probes.

Table 1: Specifications of twin rovers

size	diameter: 18[cm] height: 7[cm]
mass	1,151[g] (Rover-1A) 1,129[g] (Rover-1B)
actuator	DC motor × 1
mobile system	hopping
power supply	solar cells generating 2[W] @1.4[AU] from Sun capacitors
communication	max 32[kbps] (telemetry link)
sensor (navigation)	photo diodes, thermometers, gyro, accelerometer
sensor (observation)	camera × 4 (Rover-1A) camera × 3 (Rover-1B) thermometers, potentiometers

The rover had a hopping mobile system to move over the microgravity environment of the asteroid surface There was a torquer inside the body and rotating the torquer made the rover hop into free space by a repulsive force against the surface. During a short duration after the start of the torquer, the interaction between the rover body and the surface acquired a lateral acceleration by the friction, which eventually provided the rover with a horizontal hopping speed.

Once having hopped into free space, the rover made a ballistic movement and returned to the surface sometime unless the initial hopping speed exceeded over the escape velocity from the surface.

3 Camera usage

The rovers were equipped with some cameras. The number of cameras was dependent on the budget and was different in rovers. Four or three cameras were installed in one rover.

There were two types of the cameras.

The wide angle camera had a mass of approximately 15[g]. They were used to take the asteroid surface from a distance when the rover was in free space. It had a field of view of 139[deg] with a combination of eight tiny lenses. You can get a nearly perfect perspective view with this camera since the distortion is less than 3[%] for all the region.

Pair of another cameras with a narrow FOV were installed with a baseline of 4[cm]. These were used as a stereo pair of the cameras to simultaneously capture the nearby surface when the rover was on the surface.

The rovers estimated its status whether it was in the free space or is still on the surface using the onboard gyro or the photo diodes.

When it was judged to be on the surface sitting still, it took a hopping action to move for different place after making a surface observation by the scientific sensors. During the ballistic motion in the free space, the rovers just captured the surface images periodically.

The above mentioned simple algorithm had been installed into the onboard software of the rovers.

4 Operation

The rovers were deployed onto the Northern hemisphere of the target asteroid on 21 September 2018 at the altitude of approximately 50 meters above the surface.

The rover then survived the night of the day and started mobile exploration over the asteroid surface after some commands from the Earth were received to adjust the parameters of the autonomous behavior.

The obtained data and images were transmitted by radio to the relay module of the mother spacecraft which stayed at the altitude of 20 kilometers away from the asteroid, and then downlinked to the Ground.

Rover 1A survived for 113 Asteroid days after the deployment whereas Rover 1B worked for 10 Asteroid days. Both rovers made autonomous surface explorations by hopping, and took surface images while they were on the surface or were away from the surface after the hopping action had been made.

Total of more the 600 images were transmitted to the Ground from both rovers. The images unveiled the detailed surface condition of asteroid Ryugu.

Fig.2 shows three images obatined by Rover 1B during one identical ballistic movement on 7th day. These imeages clearly showed that the rover hopped from the surface.

Fig. 2: Images obtained by Rover 1B in one identical orbit above the surface

Fig. 3 shows the images obatined by Rover 1A also from above the surface. The shadow of the rover was included in the center of the image and you can calculate the size of the surface features using the images.

The typical behavior of the rover in one asteroid days are as follows. The rover hopped soon after it woke up when the capacitors had been fully charged. Then it came back to the surface again with some bounces, and completely stopped on the surface.

There were only one hop in one day. Thus the rover had a chance to take the surrounding images in the same position and attitude of the

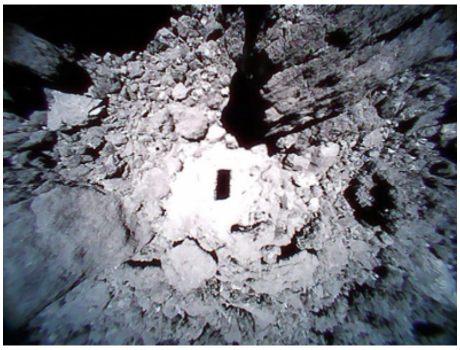

Fig. 3: Images obtained by Rover 1A with its shadows in the images

surface until the sunset. Time-lapse video on the surface was sometimes constructed which showed the changes of solar direction.

5 Image-based localization

The images obtained from above the surface when the rovers were moving in free space were matched with global images obtained by the mother spacecraft in order to detect the the position and orientation when they were shot.

Rover 1A survived for more than 100 asteroid days and it turned out that it traveled a very long distance according to the estimated position from the images obtained at the end of life.

Two rovers were deployed onto the middle latitude of the Northern hemisphere, but the final position of Rover 1A was on the Southern hemisphere with different longitude.

6 Conclusions

The authors installed two tiny rovers for Hayabusa2 spacecraft. The rovers were deployed onto the asteroid on 21 September 2018 and then made autonomous surface explorations by hopping as planned, which were evidenced by the status and image data transmitted from the rovers.

The images obtained by the rovers when they were moving in free space were matched with the global images obtained by the mother spacecraft in order to detect the the position and orientation when they were shot.

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