Osaka Prefecture University

Muroran Institute of Technology

Report on Nano-Satellite HIROGARI Operation

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Report on Nano-Satellite "HIROGARI" Operation

The Small Spacecraft System Research Center (SSSRC, Director: Nozomu Kogiso) at Osaka Prefecture University (Sakai City, Osaka Prefecture) and the Aerospace Plane System Research Center (APReC, Director: Masaharu Uchiumi) at the Muroran Institute of Technology (Muroran City, Hokkaido) have jointly developed the nano-satellite "HIROGARI" to demonstrate an on-orbit measurement system for newly deployed structures and high-speed communication technology using an amateur radio frequency (VHF). "HIROGARI", which was launched from the NASA Wallops Flight Facility (USA) on February 14, 2021 and released from the International Space Station (ISS) on March 14, 2021, is still in operation.

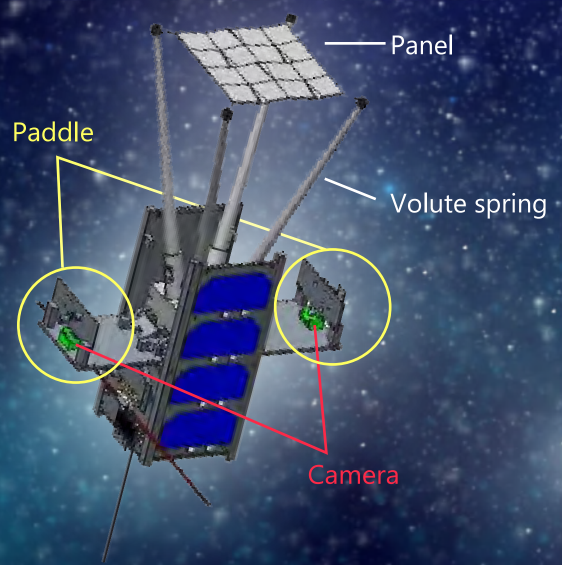


Fig. 1: "HIROGARI"

Mission and Results

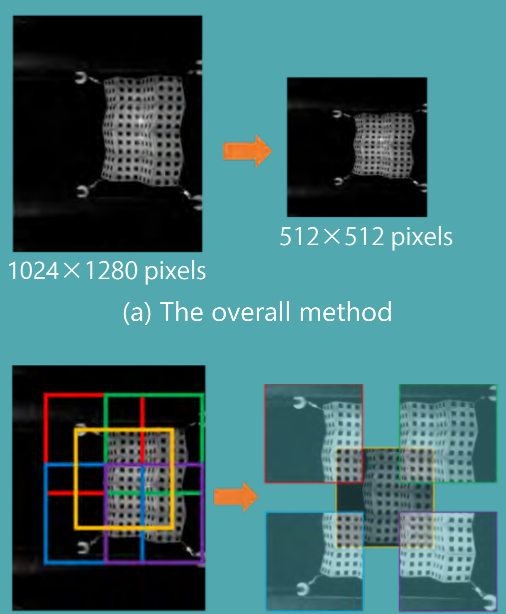
Mission 1: Deployment and shape measurement of the Miura-Ori two-dimensional unfolding structure panel — "Expanding" the future of the large-area structure

In recent years, to perform more advanced missions, satellites are increasingly required to carry large-area structures, such as solar panels, which require high storage capacity due to transportation constraints. As such, it is necessary to measure on-orbit whether the large-area structures meet the shape requirements under the severe space environment. In the "HIROGARI" project, we have been developing the Miura-Ori, using an origami engineering technique to store a two-dimensional open-plate structure and deploy it into space. In addition, an optical surface profile measurement system using a two-dimensional grid has been installed to demonstrate its usefulness. Although there have been applications of Miura-Ori structures in space in the past, this is the world's first demonstration in space from the perspective of origami engineering, where thickness is taken into account.

Achievement 1 — Development and Demonstration of a two-dimensional unfolding structure panel Based on the Miura-Ori

On April 4, 2021, "HIROGARI" confirmed the deployment of the two-dimensional unfolding structure panel (now on referred to as "panel") for the first time. A comparison of dozens of images taken since then confirmed that the paddle, volute spring, and panel gradually expanded and extended. Here, we confirmed two points: the outer edge of the panel was expanding and approaching its original deployment state, and there was no environmental deterioration of the hinge tape or panel material.

Fig. 2: Deployment plate structure panel



(a) The overall method

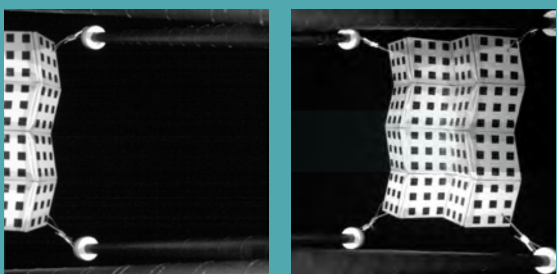
(b) The five-region segmentation method

Achievement 2 — Demonstration of an optical surface profiling system using a two-dimensional grid

After confirming the deployment of the panel on orbit using two camera images, we analyzed the images using a method based on an optical shape measurement method called Granting Projection Method. To evaluate the practicality in operation, during analysis we compared the measurement results from a method that compresses the entire image and sends it at once (Fig. 2(a)), and a method that divides the shooting area into five and sends multiple images while maintaining a high resolution (Fig. 2(b)).

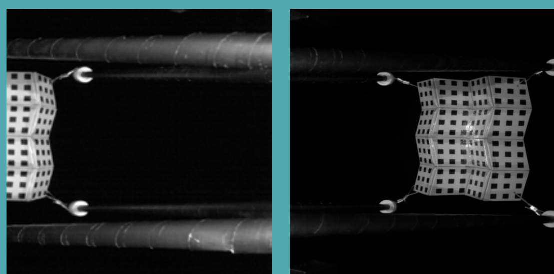
The images are shown in Figs. 3 and 4, and the results of surface profile measurement are shown in Figs. 5 and 6. The front images in Figs. 5 and 6 are looking at the surfaces shown in Figs. 3 and 4, respectively, and the side images are looking at the right side of the panel from Figs. 3 and 4. In Figs. 3(a) and 4(a), we can see that the +Y side camera does not show a portion of the panel due to an incomplete deployment of the paddle. Therefore, we were not able to measure the entire panel, but we were able to measure the colored area in Figs. 5 and 6 (presumably the first row of panels from the right), and the folds of the panel were confirmed in both methods. In addition, when comparing the side views, Figure 5 shows less variation in shape and the crease is clearly captured. In conclusion, we have confirmed that our measurement method is effective in space by using images taken by this five-region segmentation method. In addition, by measuring the distance in the image as a supplementary measure and estimating the deployment angle of the paddle and panel on which the measurement camera is mounted, we were able to confirm an increase in the deployment angle over time (Fig. 7 and Fig. 8).

Fig. 3: Images captured with the five-region segmentation method



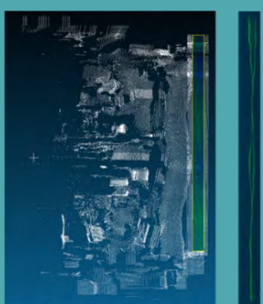
(a) Shot from +Y side (b) Shot from -Y side

Fig. 4: Images taken with the overall method



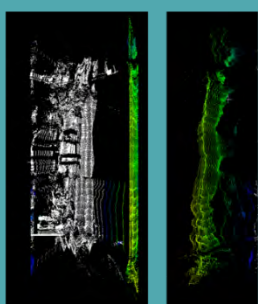
(a) Shot from +Y side (b) Shot from -Y side

Fig. 5: Image analysis results of the five-region segmentation method (1)



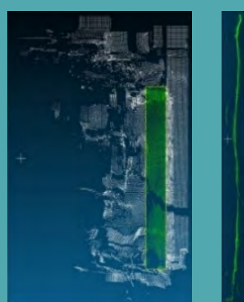
Front Side

Fig. 6: Image analysis results of the overall method



Front Side

Fig. 7: Image analysis results of the five-region segmentation method (2)



Front Side

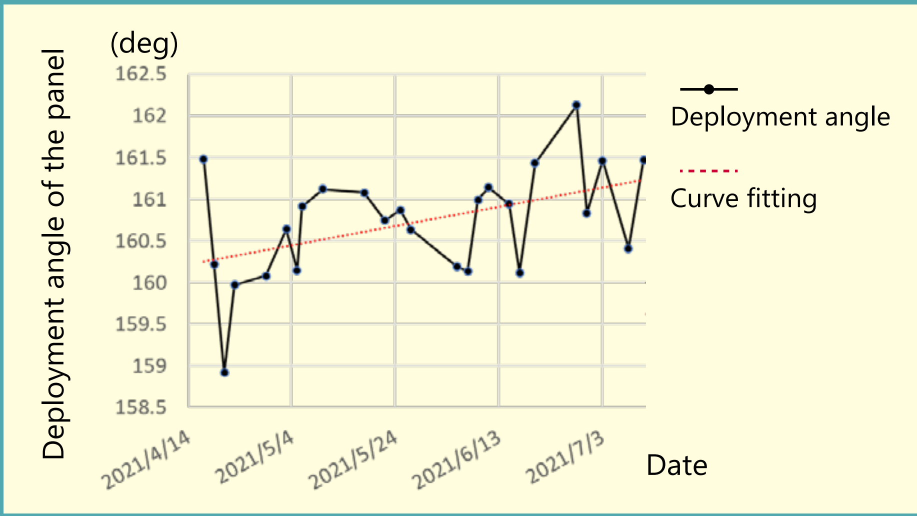


Fig. 8: Estimated panel expansion angle based on in-image distance measurement

Mission 2: High-speed data communication on the amateur radio band — "Expanding" the range of the amateur radio frequency

In the past, many amateur radio satellites used communication speeds of 1.2kbps and 9.6kbps on UHF and VHF. In addition, they mainly use AX.25, which requires a retransmission request from a station on earth in case of packet loss, which increases the cost of operating a satellite. Therefore, "HIROGARI" adopted the faster 13.6 kbps GMSK and 19.2 kbps 4FSK, as well as a protocol using Reed-Solomon codes with error correction capability (now on referred to as "RS") and a protocol combining Reed-Solomon codes with convolutional codes (now on referred to as "RS+ convolutional"). We have demonstrated the usefulness of these communication technologies and aim to achieve a higher efficiency.

〈Result〉 Demonstration of high-speed data communication technology

We conducted communication experiments to compare the performance of six communication methods, including conventional ones and were able to establish communication using all of them. In the experiment, the communication conditions were divided into four categories, day and night, and high and low elevation, while calculating the effective speed - how much mission data can be downlinked per unit of time. The effective speed at low elevation angles is shown in Table 1. A high elevation angle is advantageous for communication conditions because the distance between the satellite and the ground station is closer, but for the "HIROGARI" mission, even at a low elevation angle, which is relatively unfavorable for communication, the effective speed of GMSK 13.6kbps AX.25 and GMSK 13.6kbps RS exceeded that of the conventional communication system. As a result, we were able to demonstrate the high-speed data communication technology.

Table 1: Effective speed of each communication method at a low elevation angle

Communication method	Effective day speed [kbps]	Effective night speed [kbps]
GMSK 9.6kbps AX.25 (conventional)	4.2	4.7
GMSK 13.6kbps AX.25	5.22	5.59
GMSK 13.6kbps RS+convolutional	3.86	4.13
4FSK 19.2kbps RS+ convolutional	3.20	3.57
GMSK 13.6kbps RS	7.51	7.92
4FSK 19.2kbps RS	1.81	2.82

Mission 3: Message Box Service — "Expanding" the interaction with amateur radio

We are currently providing a message box service using amateur radio and "spread" the interaction among not only amateur radio operators but also those who don't use amateur radio. We are inviting messages from all over the world and sending selected messages to "HIROGARI" to be sent out to the world. We are also receiving comments from amateur radio operators who received the messages and publish them on the Internet. For more information about the service, please visit the Amateur Radio Mission Site

URL: https://www.sssrc.aero.osakafu-u.ac.jp/hrg_amateur_mission/

About the Small Spacecraft System Research Center at Osaka Prefecture University

This is a center where students play a central role in the development of spacecraft such as nano-satellites and small rockets. Students from freshman to graduate level cooperate and work together. They create curricula, and the experienced teach newcomers the skills necessary for spacecraft development, as well as conduct outreach activities to bring space closer to the local community. Currently, the institute is affiliated with the Research Center for the 21th Century at Organization for Research Promotion.

About the Muroran Institute of Technology Aerospace Plane System Research Center

The Aerospace Plane System Research Center provides local industries with opportunities to develop advanced system technologies related to aerospace aircraft and engages in research and development with the aim of commercializing advanced systems on a small scale. They also provide an educational environment that motivates a student's desire for research and encourages their spontaneity by conducting specific "manufacturing research". The research and development of a small unmanned supersonic aircraft that can be used for practical purposes and the nano-satellite "HIROGARI" are typical examples.

Reference URLs, etc.

Osaka Prefecture University Website https://www.osakafu-u.ac.jp/en/

OPU Small Spacecraft System Research Center Website http://www.sssrc.aero.osakafu-u.ac.jp/

OPU PERSEUS Website http://www.perseus.21c.osakafu-u.ac.jp/

OPU Tsubasa Fund Website http://www.kikin.osakafu-u.ac.jp/

Muroran Institute of Technology Website https://muroran-it.ac.jp/en/

MuroranIT "HIROGARI" Mission Website https://u.muroran-it.ac.jp/sslab/HIROGARI.html

MuroranIT Aerospace Plane System Research Center Website http://www.muroran-it.ac.jp/aprec/index.html

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