Trans. JSASS Aerospace Tech. Japan
Vol. 12, No. ists29, pp. Tf_27-Tf_31, 2014

Topics

Development and Evaluation of Small Size Whole Sky Observation Camera System for Micro-Satellite

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(Received June 24th, 2013)

Images taken from space are used for various purposes such as Earth observations and disaster monitoring. A new use for such images has emerged—personal amusement. Therefore, we consider whole-sky observations around a satellite using a microsatellite, Rapid International Scientific Experiment Satellite (RISESAT). However, extensive amount of equipment must be installed on microsatellites in a limited amount of space. Therefore, the equipment must be very small. We have developed a data-handling unit capable of processing the data received from more than one camera head, as well as from small camera heads with more than one viewpoint. In this way, we can reduce the number of camera heads installed on a microsatellite. We were therefore able to realize a camera system for a microsatellite installation. Satellite equipment must be able to withstand harsh conditions such as vibrations, high vacuum, and severe temperature changes. In this paper, we conducted environmental tests on the proposed system, and herein we report the development and evaluation results.

Key Words: Camera, Monitoring Camera, Whole Sky Observation, Micro-Satellite RISESAT

1. Introduction

Images taken from space are used for various purposes such as Earth observations, disaster monitoring, and the self-monitoring of satellites. New applications of these images for personal amusement such as Google Earth have recently emerged. These types of amusement applications have the possibility to generate a large demand for such images. Whole-sky observations around a satellite are one of the most possible amusement applications. If the acquired images can be projected onto a spherical screen in a real-time manner and moved by users operating a joystick, the feeling of telexistence, such as flying in orbit, can be achieved. Such an application has the potential to entertain many people. In this paper, we demonstrate this idea using a microsatellite, Rapid International Scientific Experiment Satellite (RISESAT).[1),2)] Because RISESAT is an international scientific microsatellite, it is equipped with multiple equipment within its small structure. For this reason, a compact and lightweight camera system that can be installed on the microsatellite is necessary.

On the other hand, through our laboratory experience in developing a camera system to monitor the deployment of the membrane structure of IKAROS, we were able to confirm the base of camera system. By utilizing this technology,[3),4),5)] we developed a data-handling unit capable of processing data received from more than one camera head, as well as small camera heads with more than one viewpoint. With these developments, we can reduce the number of the camera heads installed on a satellite. Thus, we were able to realize a camera system—Micro Monitoring Camera System (MMC)—that can be installed on a microsatellite.

However, unlike on the ground, space is a vacuum, and is a harsh environment with a large temperature difference between areas illuminated and not illuminated by the sun. The equipment used must meet a predetermined level of performance even under such an environment. In addition, during the launch of the rocket, the equipment will be exposed to severe external vibrations. Therefore, it is necessary to verify whether the structure of this camera system can withstand such vibrations during launch. We conducted environmental tests for verification.

In this paper, we report the development and evaluation results of an engineering model for this proposed camera system.

2. RISESAT

RISESAT is a microsatellite being developed by Tohoku University (Fig. 1), and is the second microsatellite to be developed based on “Hodoyoshi Reliability Engineering.” The size of this satellite is about 500 mm^3, and its weight is about 50 kg. The design life is approximately two years, and it operates at a low-orbit altitude of 900–500 km. Its primary mission is scientific observations using multiple types of scientific equipment selected from foreign institutions.

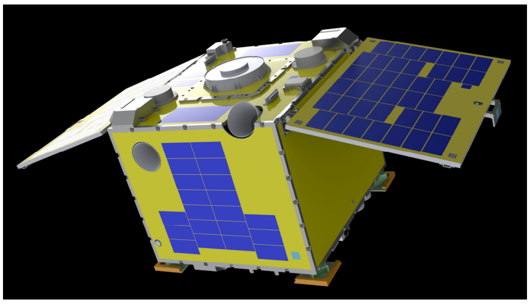

Fig. 1. RISESAT.

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3. Micro Monitoring Camera System

MMC for RISESAT consists of four units: a Data Handling Unit (DHU) and three Camera Head Units (CHU). The system structure is shown in Fig. 2 and an overview is shown in Fig. 3. In this section, we describe the equipment used to configure this camera system.

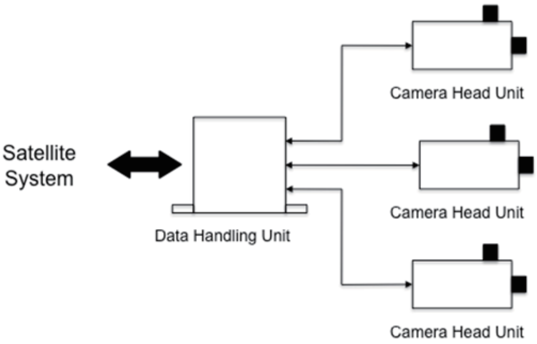

Fig. 2. System structure of MMC.

Fig. 3. CHU (left) and DHU (right).

3.1. Camera head unit

A CHU has two camera heads to reduce the number of camera heads required on a satellite, and consists of three boards: two imager boards that use an OV7950 by OmniVision, and a translator board that uses a PIC by Microchip. The translator board interprets the commands sent by the Universal Asynchronous Receiver/Transmitter (UART) from the DHU. Moreover, the PIC operates the register of the image sensor using an Inter-Integrated Circuit (I^2C). Therefore, the PIC converts communication format between I^2C and UART. Thus, we can adjust the parameters of the image sensor such as the exposure time, white balance, and gain in accordance with the imaging conditions. Moreover, we can independently control the two image sensors using the PIC, and can therefore control the parameters of the image sensor flexibly from the ground. In addition, the translator board is equipped with a regulator that supplies 3.3 V to the image sensor board.

The inside of the CHU is shown in Fig. 4. The sizes of the translator board and two imager boards have been minimized to the maximum extent possible. The height of the enclosure has almost no clearance considering the back focus of the lens. In addition, the enclosure is composed of four parts to facilitate the assembly while maintaining its strength. Thus, we realized a very small enclosure.

There are two types of CHUs installed on the satellite. They are the same in most aspects except for the position of the flange. The CHUs are installed at the positions shown in Fig. 5, and the camera heads are oriented in six orthogonal directions of the satellite. Moreover, the MMC can cover the entire sky with a margin around the satellite using a lens with a 150° diagonal.

The lenses are made of glass and metal, and do not contain any plastic. There is therefore no risk of deterioration such as lens fogging due to the presence of outgas.

The features of the CHU are shown in Table 1.

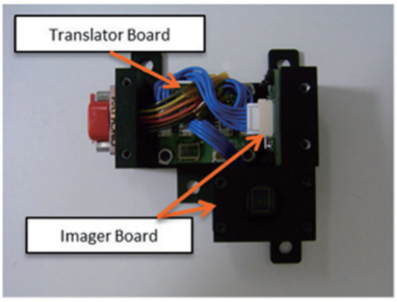

Fig. 4. Internal construction of the CHU.

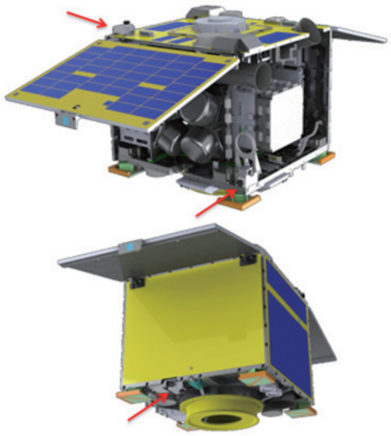

Fig. 5. Installation locations of the CHU.

Table 1. Features of CHU.

Size	55 mm × 50 mm × 24 mm
Weight	100 g
Sensor type	1/4-inch CMOS Color
Resolution	656 × 492
Angle of view	120° × 90°
F number	2.0
Focal length	1.9 mm
Supply voltage	5 V
Power consumption	0.8 W

3.2. Data handling unit

A DHU is equipment that mainly acquires and processes images. The inside of the DHU is shown in Fig. 6. The DHU consists of three boards: an FPGA board (Fig. 7), a decoder board, and an interface board. The interface board is equipped with an ADG608, which is a multiplexer from Analog Devices, Inc. Therefore, the DHU can switch the six analog video signals outputs by the three CHUs. In addition, the DHU communicates with a Science Handling Unit of satellite bus system and three CHUs using UART protocol in RS422 level. Therefore, the DHU is equipped with an RS422 line transceiver. The decoder board is equipped with an ADV7180, which is a First In, First Out (FIFO) analog video decoder from Analog Devices, Inc. The ADV7180 converts an analog video signal output by the ADG608 into digital data. The digital data are then stored temporarily in the FIFO. The ADV7180 has the ability to select one among the six analog video signals. However, using the ADG608, the DHU realizes high-speed switching. The FPGA board is equipped with a Virtex-2Pro from Xilinx, 64 MB of SDRAM, 8 MB of Flash memory, and a Programmable ROM. The Virtex-2Pro has a PowerPC CPU. Therefore, the DHU has high information-processing capability, and can conduct image compression and processing. The DHU can compress an image into a JPEG using an image compression function. Therefore, the DHU can significantly reduce the image size. In addition, the DHU can generate a thumbnail image using an image processing function. The size of the thumbnail image generated is 1/2, 1/4, 1/8, or 1/16 the size of original image. Therefore, we can reduce the time required to transfer one image to the ground, depending upon the situation. In addition, the DHU can temporarily save approximately 80 raw images in the SDRAM.

The DHU must be adequately compact to be installed on a microsatellite. Therefore, the three boards are stacked together. Each board is in an octagonal shape to fit into the case well. In this way, we can fit the DHU into a very small case 80 mm × 60 mm × 45 mm in size. Moreover, the stacked boards are resistant to vibrations by being suspended from the upper lid.

The DHU adopts Linux as the operating system. Therefore, using an existing free library such as the JPEG compression library, we can shorten the development time.

The features of the DHU are shown in Table 2. A block diagram of this camera system is shown in Fig. 8.

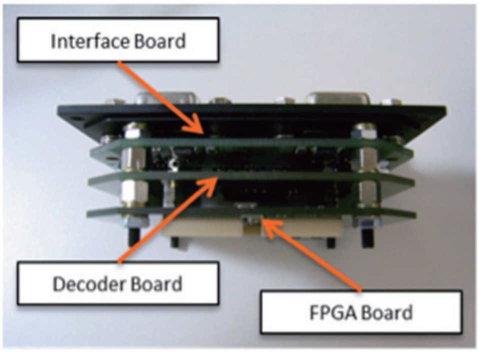

Fig. 6. Internal construction of the DHU.

Fig. 7. FPGA board.

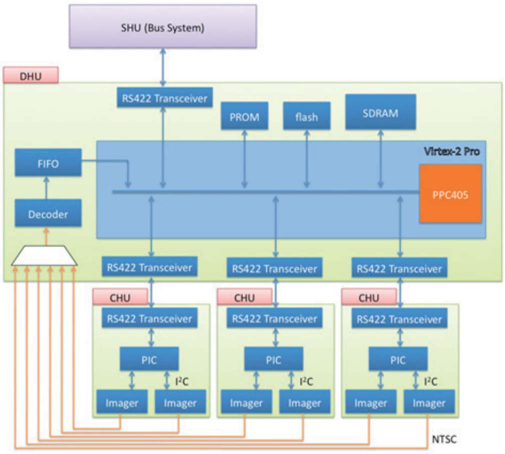

Fig. 8. Block diagram of an MMC.

Table 2. Features of DHU.

Size	80 mm × 60 mm × 45 mm
Weight	260 g
CPU	PowerPC405
RAM	64 MB
OS	uClinux (Linux kernel 2.4)
Type of image	RAW/JPEG
Supply voltage	5 V
Power consumption	1.0 W

4. Evaluation Test

Space is a harsh environment with high vacuum, strong radiation, and severe temperature changes. In addition, rockets incur severe vibrations during launch. Equipment installed on a satellite must not fail even under such harsh conditions. Therefore, we conducted vibration tests and thermal vacuum tests for verification. In addition, we conducted a test to confirm that the proposed camera system can capture the entire sky in its field of view. In this section, we describe these tests and their results.

4.1. Vibration test

We conducted vibration tests at Kyushu Institute of Technology (Fig. 9). The vibration levels used are the Acceptance Test and Qualification Test levels of H-IIA rocket. The vibration type is a sine and random wave for each axis. In addition, we conducted a burst wave test on the z-axis.

For an integrity check, we confirmed the existence of problems such as electrical abnormalities, shifts in focus, and deviations of the optical axis between the lens and image sensor caused by vibrations. There are two check items: a visual check of the image, and a communication check between the CHU and DHU. The communication was confirmed by reading the value of the specific address of the image sensor from the DHU. The visual check of the JPEG images generated by the image acquisition and compression on the DHU was conducted.

From the results, there were no electrical abnormalities caused by the vibrations. In addition, when we compared the acquired images visually before and after the vibration test, no effects on the optical system were observed. Moreover, no structural damage was observed. From above, we were able to confirm that the proposed camera system can withstand the vibrations of a rocket launch sufficiently.

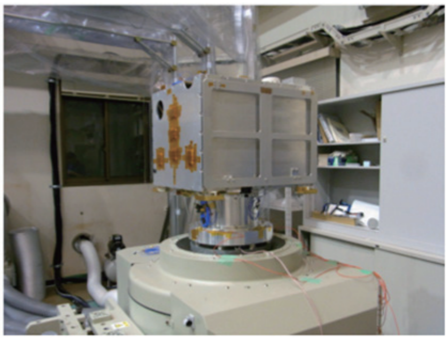

Fig. 9. Vibration test equipment.

4.2. Thermal vacuum test

We conducted a thermal vacuum test at Kyushu Institute of Technology. The test was conducted between -10°C and 50°C in a high vacuum state. In addition, we attached a thermocouple to the DHU and three CHUs to measure the temperature of each piece of equipment. For an integrity check, we confirmed whether electrical errors occurred during the test. For this, we confirmed three items: measurement of the power consumption, a communication check between the DHU and CHUs, and image acquisition.

From the results, it was noted that we were able to communicate between the DHU and CHUs. Furthermore, we were able to perform a successful image acquisition. However, the power consumption increased in a high temperature state (Fig. 10). It is considered that the image sensor increased the power consumption under bright conditions during the test due to the heaters inside the vacuum chamber, which were used to heat up the temperature. In addition, there were no noises or disturbances in the acquired images. From the test described above, we were able to confirm that this camera system can operate stably at high and low temperatures and in the vacuum condition of space.

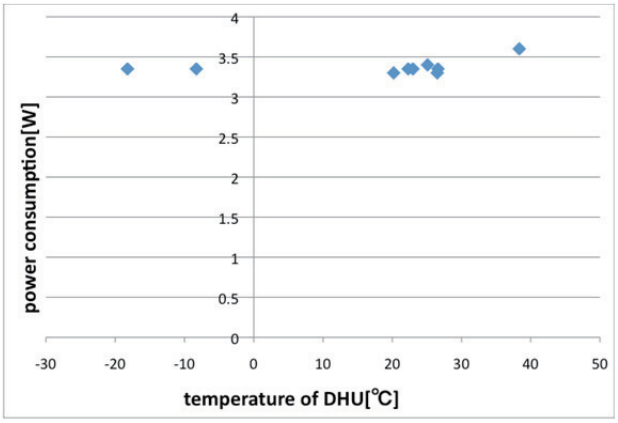

Fig. 10. Relationship between temperature and power consumption.

4.3. Field verification experiment

The primary purpose of this camera system is to obtain images of the whole sky as seen from a satellite. For this purpose, the proposed camera system must have the whole sky in its field of view. We conducted a field verification experiment to verify this. The field of view of each CHU is shown in Fig. 11, where the location with the most demanding condition is circled in red. This condition is identified considering the barrel distortion of the wide-angle lens. At the position of the red circle, a portion of field of view of each camera head shall overlap with each other, so that we can conclude that this camera system has a field of view of the whole sky. For this experiment, we assembled the proposed camera system onto the satellite, and acquired images from each camera. While doing so, we turned a penlight toward the satellite from the direction of the red circle. In this way, we could confirm the existence of overlapping when the light of the penlight appeared in the images acquired by each camera.

The results are shown in the right side of Fig. 11. It can be seen that the light from the penlight does appear in the images acquired by each camera, and we can therefore confirm that this camera system can capture the whole sky in its field of view.

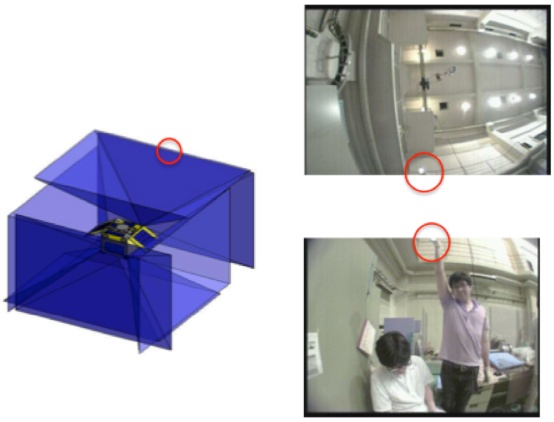

Fig. 11. Images and their field of view.

5. Conclusion

In this paper, we reported the evaluation results and development status of a whole sky observational camera system for a microsatellite. The engineering model of this camera system is already complete. Moreover, the results of an environmental test indicate that this camera system can withstand harsh conditions such as vibrations, severe thermal differences, and a strong vacuum. In the future, we will develop a flight model for the proposed system. Moreover, we aim to develop an application for providing users with a feeling of telexistence - flying in orbit.

Acknowledgments

This research was granted by the Japan Society for the Promotion of Science (JSPS) through the "Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program)," initiated by the Council for Science and Technology Policy (CSTP). RISESAT project is also partly supported by Grant-in-Aid for Scientific Research on Innovative Areas KAKENHI:24760658 from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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