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Preliminary Experiments on Image Processing for Satellite Orbital Maintenance

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Abstract

Rescuing a satellite once it has been launched is very difficult. Because we can only obtain information about a satellite by telemetry from the satellite itself, we cannot obtain any more information once a satellite has failed. Furthermore, space debris reentering the atmosphere is becoming a significant problem because the number of satellites is increasing. Therefore, we are currently studying the technologies needed to create an orbital maintenance system (OMS) for a rescue satellite to inspect satellites, to remove unneeded satellites, and to repair failed ones. As an actual on-orbit experiment, the Micro-OLIVe is a mission for testing the image-processing computer and inspection-monitoring camera, which are essential elements in creating the OMS. In this paper, we describe an experiment system and the quick results of the first part of our Micro-OLIVe experiments.

1. Introduction

Image processing technologies such as target recognition and target ranging using images are essential in achieving space servicing. Space servicing vehicles need to not only recognize a target but also to avoid corrosion autonomously. To create autonomous on-board image processing, developing high-performance processors and software technologies is essential.

The Communications Research Laboratory has been studying an on-orbit satellite maintenance system. Rescuing a satellite once it has been launched is very difficult. Because we can only obtain information about a satellite by telemetry from the satellite itself, we cannot obtain any more information about a satellite once it has failed. Furthermore, space debris reentering the atmosphere is becoming a significant problem because the number of satellites is increasing. Therefore, we are currently studying the technologies needed to create an orbital maintenance system (OMS) [1]-[5] for a rescue satellite to inspect satellites, to remove unneeded satellites, and to repair failed ones.

Recently, due to an increase in the number to telecommunications and broadcasting satellite operations, there has been growing interest in preventing satellite failures, in maintaining the orbital environment, and in reducing the amount of space debris. Amidst these conditions, the space communication market should continue to grow in the future. Also, many communication and broadcasting satellites are being planned for launch well into the first decade of the 21st century. Therefore, to guarantee growth in space communication, we must contain space debris and maintain a favorable space environment. Thus, technology must be developed as soon as possible to provide in-orbit services for communication and broadcasting satellites. We need to begin work on the development, experiments, and testing of inspection technology.

As an actual on-orbit experiment, the Micro-OLIVe is a mission to test an image-processing computer and inspection-monitoring camera, which are essential elements to create an OMS. This mission was conducted in cooperation with NASDA, the Aerospace Technology Laboratory, and the University of Tokyo on the Micro-LabSat launched in 2002, in conjunction with the environment observation technology satellite ADEOS-II.

In this paper, we are going to describe an experiment system and quick results for the first part of the Micro-OLIVe experiments.

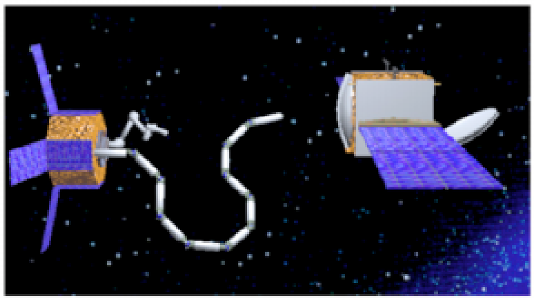

Fig. 1 OMS Image

Fig. 2 Micro-LabSat (Photo by NASDA)

2. Equipment

2.1 MOBC (Processor for Images and Robotic Applications)

Microprocessors have been vastly improved in ground systems, especially for the game and amusement markets. However, the microprocessors for space use have not been greatly improved because they need to work in a severe space environment and must also be extremely reliable. However, if the microprocessors that are popularly used on the ground could be used in space and demonstrate a high performance, costs would be greatly decreased.

CRL and Toshiba have developed a microprocessor multi-chip module to control the OMS, including its robotic system and image processing. The module is multi chip module (MCM) and includes a 64-bit RISC processor that is conventionally used in games and printers. (Fig. 3) The processor performance is about 100 MIPS and 10 MFLOPS, which will greatly improve the calculation resources. For the program and tentative data area, 2 Mb memory is equipped with automatic error correction, and 4 Mb of additional memory is equipped for a work area in image processing.

During the micro-OLIVe mission, the microprocessor's performance was determined in the space environment. This developed microprocessor can not only be utilized in the OLIVe mission and the OMS but also in other space programs.

As for the software structure, a real-time multitask operational system was adopted for flexible operation. Users can easily equip their programs using the 'support of the C complier and source level debugger. The program module could exchange uplink communication flexibly after the satellite launched. The specifications of the MOBC are summarized in Table 1.

Three organizations utilized the MOBC in different experiments during the Micro-OLIVe mission. Thus, we adopted an operating system structure in which the system performed tasks according to start up parameters, which were pre-set. Because the operation system overrode telemetry formats, command structures, active tasks, and all program resources based on these start up parameters, the programmers got almost the full performance in each application.

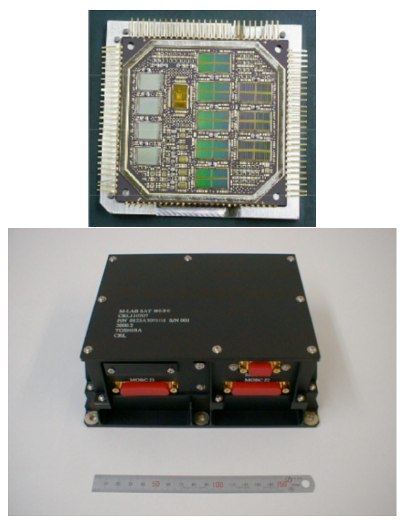

Fig. 3 Image processing computer used in Micro-OLIVe Mission

Size	205×160×80mm
Weight	1.4kg
Power Consumption	4.0W (Stand-by Mode) 5.3W (Peek)
On-board Lifetime	3 month
MPU Performance	64bint RISC Processor 96MIPS, 10MFLOPS
Memory	EEPROM 512Kbyte RAM 2Mbyte (Automatic Error Correction) VRAM 8Mbyte (4Mbyte×2 Double Buffering)
Misc.	ARCNET Interface Serial Interface × 2 (for CMR) Lossy and Lossless JPEG On-board Reprogramming

Table 1 MOBC Specifications

2.2 CMR (Color C-MOS Camera Module)

Energy consumption is one of the most important concerns in a space system. The C-MOS imaging unit is advantageous in that it has low energy consumption. Based on our design, the C-MOS imaging unit consumes only about one-tenth the energy of the CCD imaging unit. However, the C-MOS unit has not been widely used in space systems.

CRL developed camera units that use a conventional C-MOS digital still camera. They consume much less energy than a CCD camera, and the cost is also kept low because the units within the camera are used with only a slight modification. (Fig. 4) During the micro-OLIVe mission, the two C-MOS cameras modules, which were developed by modifying the conventional digital still camera, were also tested in space, and their feasibility for space application was demonstrated. The specifications of the CMR are summarized in Table 2.

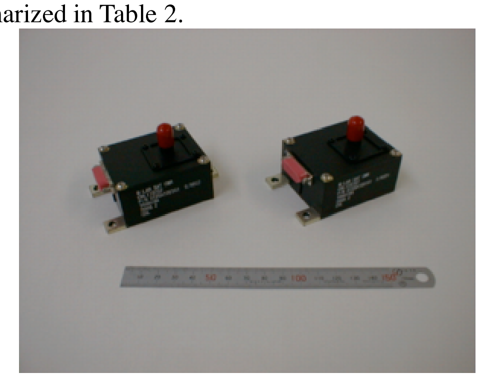

Fig. 4 CMOS Cameras used in Micro-OLIVe Mission

Size	50×60×30mm
Weight	140g/unit
Power Consumption	1.4W/unit
On-board Lifetime	3 month
Performance	VGA Resolution (640×480pixel) YC 4:2:2 Read-out
Sensitivity	1000～145000LUX
Interface	Serial 614.4KHz NTSC Composite (Not used in micro-OLIVe mission)

Table 2 CMR Specifications

3. Results

3.1 Image Capturing Experiments

To test the basic functions of the CMR and MOBC, earth images were captured, compressed in JPEG format, and downlinked.Figure5showsexamples of the captured earth images.

The images can be captured in three modes, single shot, continuous capturing, and batch capturing. In continuous capturing mode, the MOBC captures and compresses at about 3 frames per second. In batch capturing mode, 8 images can be acquired at a maximum of 1 frame per second. More than 30 images were captured successfully, and no trouble occurred. We will continue testing as long as possible to ensure there are no long-term degradations.

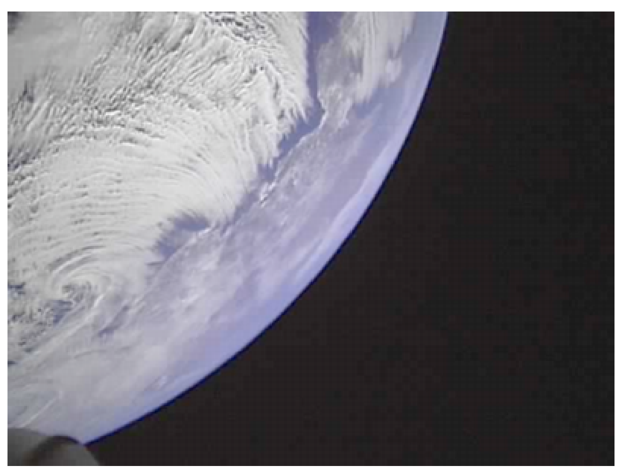

Fig. 5 Examples of captured images

3.2 Test of Re-programming Function

If we can update on-board programs and install new program modules flexibly, we can try new ideas and new technologies even after a satellite launches. We can try a lot of possible image processing methods using the same equipment. This kind of flexible operation will expand the possibilities in experiments.

To update an on-board program flexibly, we developed a method to change part of the program module after the satellite launched. (Fig. 6) When programmers compile an on-board program, a static memory unit called a partition and the position of the program modules are determined. When we want to update on-board program, we can safely exchange on-board programs in units of partitions. The updated program modules check their possible bit errors using the CRC code before they are placed on the program memory area. In the newer version, the programmer utilizes all the program modules determined in the original version, without any special notice. The utilization is done because the memory addresses for all the program modules in the original version are the same as those in the newer version.

Using small update program modules, we performed an experiment to check the re-programming function. We found that the on-board program responds to the same command differently after the on-board program was updated.

Utilizing this function, we will not only improve the on-board image processing function but also test new image processing technologies.

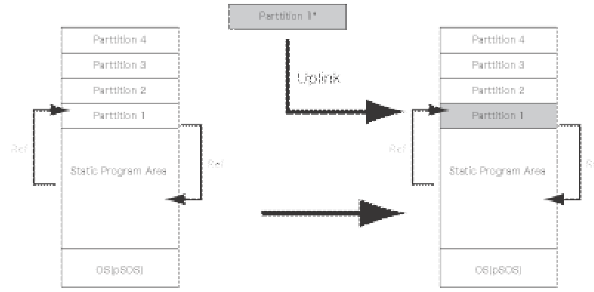

Fig. 6 Re-programming Function

3.3 Remote Operation Experiments

When we want to perform experiments on remote operation techniques, we need to acquire a real-time downlink. Fortunately, we had a good opportunity to get a real-time downlink from Micro-LabSat, owing to the cooperative efforts of NASDA. The real-time mission telemetry transmission system is called a quick look system. Figure 7 shows the outline of the system. A 4-kbps mission downlink acquired in the ground station of NASDA was transmitted to the operation room by an ISDN communication line in real time. These mission downlinks and telemetry data can be delivered to several terminals in the same network using a TCP/IP protocol and displayed in different ways.

Using the quick look system, we performed experiments to test some human-machine interface methods. Three telemetry data display systems were compared by response time, eye movement (recorded by an eye mark recorder), and operator feeling. The operators were requested to capture the earth images while the satellite was spinning. The time delay between the command and image transmission was about 8 sec during a round trip. As for the display of the downlink images, we also utilized automatic prediction of the earth direction, and tested their qualities.

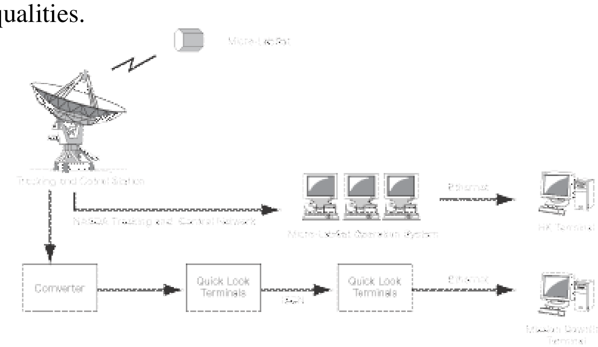

Fig. 7 Quick Lock Experiment System

Fig. 8 Remote Operation Experiment

4. Conclusion and Future Plans

In this paper, we introduced the overview of the preliminary experiments on image processing for satellite orbital maintenance, called the Micro-OLIVe Mission. The basic functions of the processor for image processing, the robotic applications, and the color C-MOS camera module were successful in testing. The first remote operation experiment using real-time downlink analysis and displays of images also succeeded and was utilized for an experiment on human machine interface.

Using the equipment, whose basic functions in these experiments were tested, we will perform experiments on image processing technologies, such as target recognizing and tracking using targets that will be ejected from a satellite, the hardware test will also continue to analyze long-term degradation and single event profiles.

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