

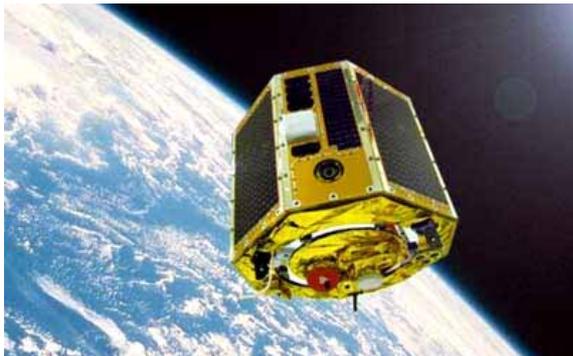
## MICRO LABSAT - Technology Demonstration Microsatellite for Future Missions

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**ABSTRACT:** Micro LabSat is a technology demonstration microsatellite. The important concept is "easy to use". Microsatellites are relatively simple and low-cost, so users can carry out technology demonstration experiments without too much cost and risk. The experiments focusing on on-orbit servicing technologies were planned. The satellite was launched on December 14, 2002 by an H-IIA launch vehicle. All pre-planned experiments were successfully accomplished. Micro LabSat provided many researchers an opportunity to perform several experiments on-orbit, and indicated the merit of microsatellites as a future technology demonstrator.



**Figure 1.** Artist's concept of Micro LabSat

### MOTIVATION OF THE PROJECT

#### *“Deadlock” of R&D for Future Space Technologies*

Recently, research and development activities on space technology in Japan fall into “deadlock” state.

In recent thirty years, space technology of Japan has

made rapid progress. And now we are grown up enough to perform high-tech big projects. Basically this is a good situation. But on the other hand, the damage of failure becomes big. Hence the risk of a space project is getting higher. Consequently, improvement of reliability for projects which has already been authorized becomes the most important task of space industries. Recent failures of big projects accelerate this trend. In such a situation, space development becomes too sensitive to risk.

Accordingly, a pioneering study to create a seed of new mission is reduced. It is getting difficult to get an opportunity to demonstrate new mission concept which has many technical problems to be solved, since it needs too much cost and has too high risk.

On-orbit servicing system is a typical example of such a mission concept. On-orbit servicing is a mission

concept which should be called “classical future mission”, which means realization in near future has been expected for a long time.

On-orbit servicing vehicle is a spacecraft to remove space debris, to inspect and repair satellites, to refuel to geostationary satellites, and to construct the large structure on-orbit. Along with a increasing of the number of satellites, space debris is becoming a significant problem. If the visual inspection of a failed satellite is possible, it will be great help for investigation to specify the cause of the failure.

On-orbit servicing system has substantial needs. But it is difficult to demonstrate it, because it has many technical problems to be solved:

- Onboard autonomy
- Rendezvous sensor for relative navigation
- Image sensor to inspect and monitor the target
- Image processing hardware and software to extract the target from captured image, to recognize the shape, and to estimate the motion of it
- Capturing mechanism of the target
- And so on...

To realize on-orbit servicing, it is necessary to solve all of these technical problems. However, there are too many problems so that it is difficult to establish on-orbit servicing demonstration satellite project which implements full-set of these required technologies at the same time. It costs too much, takes long time to prepare, and also has quite high risk to failure. So researchers cannot repeat the cycle of research and development in short term. This is one of the reasons why on-orbit servicing is not still realized.

Generally, as this example of the on-orbit servicing system, establishment of the new technology demonstration project is getting hard because of cost and risk. Even through each technical problem can be developed separately, a lack of real technology demonstration opportunity has a bad influence upon continuous research of it.

This causes a “dead-lock” on research and development activities in Japan.

### ***Solution - Technology Demonstration Microsatellite for Future Missions***

One practical solution to this “dead-lock” situation is a technology demonstration of technical problems by microsatellites.

Microsatellites can be developed in short-term. Therefore the cycle of research and development can be repeated quickly. Furthermore, microsatellites do not cost much, so researchers can perform challenging experiments with reasonable risk. Hence microsatellites have a potential to contribute efficient research and development activities. It may break the recent "dead-lock" situation.

JAXA developed the microsatellite named "Micro LabSat". This satellite is a technology demonstration microsatellite which can provide researchers an opportunity to perform various experiments of new space technologies. Figure 1 shows the artist's concept of Micro LabSat.

As a example of such a new technology to be demonstrated, we adopted experiments which especially focuses on the technical problems of on-orbit servicing system.

In this paper, overview of Micro LabSat as a technology demonstration microsatellite and the results of on-orbit experiments are described.

## **MICRO LABSAT – SYSTEM OVERVIEW**

### ***Objective of the Project***

Micro LabSat is a technology demonstration microsatellite. This is the first satellite which JAXA (formerly NASDA) intends to make use of the merit of small satellite: low-cost and short-term development.

The objective of Micro LabSat project is as follows:

- (1) Develop a low cost microsatellite which enables researchers to demonstrate several challenging technologies in space easily.
- (2) Provide hands-on training for young engineers.

The satellite was launched December 14, 2002, by an H-IIA launch vehicle. It is now almost one and a half

year since the launch. Micro LabSat remains in good condition.

### System Configuration

Figure 2 shows the external view, and Figure 3 shows the internal structure of Micro LabSat. External shape of Micro LabSat is an octagonal prism, and its internal structure is a Y-shaped panel made of aluminum honeycomb core. Gallium-Arsenic solar cells are mounted on the body surface.

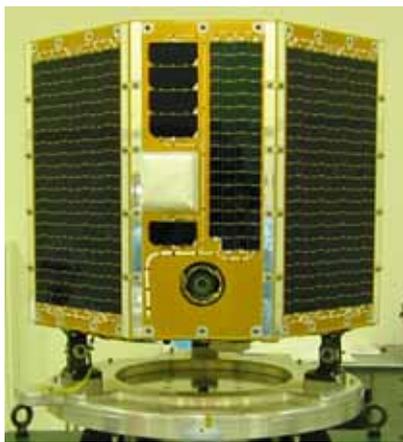


Figure 2. External View of Micro LabSat

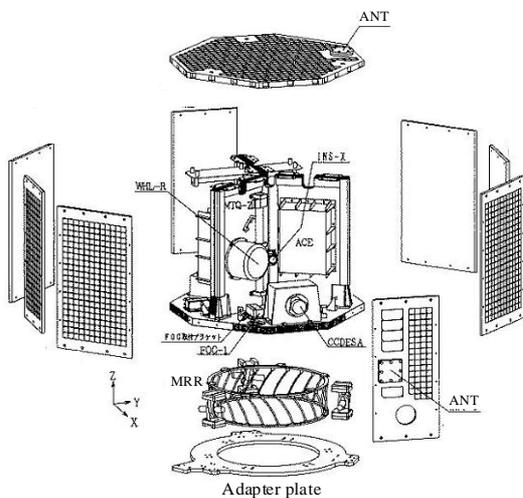


Figure 3. Internal Structure of Micro LabSat

The specifications of Micro Labsat are shown in Table 1. Figure 4 shows the system block diagram, and the acronym list is shown in Table 2.

Table 1. Specifications of Micro LabSat

| Item                        | Characteristics   |
|-----------------------------|---|
| Size                        | 688 × 515[mm]   |
| Shape                       | Octagonal prism   |
| Mass                        | 54[kg]  |
| Generated Power             | Min 55[W]   |
| Attitude Control            | Normal: Spin-stabilization<br>Mission: Three axis stabilization     |
| Communication<br>Up<br>Down | S-band<br>500[bps]<br>HK data: 1024[bps]<br>Mission data: 4096[bps] |
| Orbit                       | Sun Synchronous Orbit<br>Altitude: 800[km]<br>Local Sun Time: 10:30 |
| Launch                      | H-IIA rocket No. 4 (piggyback)<br>December 14, 2002                 |

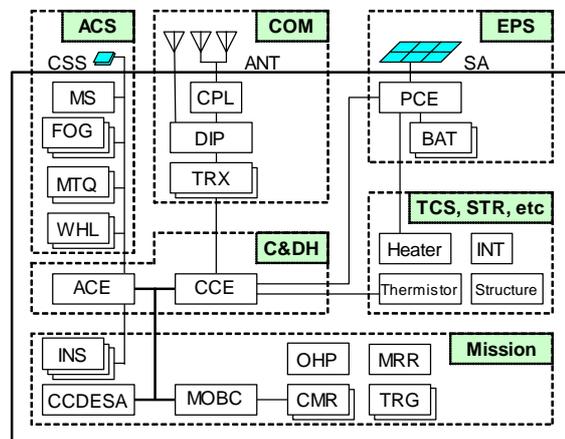


Figure 4. System Block Diagram

Table 2. Acronym List

| Subsystem | Components  |
|-----------|---|
| COM       | Transmitter (TRX), Diplexer (DIP), Coupler (CPL), Antenna (ANT)   |
| C&DH      | Communication Control Electronics (CCE), Attitude Control Electronics (ACE)   |
| EPS       | Power Control Equipment (PCE), Battery (BAT), Solar Array (SA)  |
| ACS       | Coarse Sun Sensor (CSS), Magnetic Sensor (MS), Fiber Optical Gyro (FOG), Magnetic Torquer (MTQ), Wheel (WHL)  |
| MISSION   | CCD Earth Sensor Assembly (CCDESA), Oscillatory Heat Pipe (OHP), CMOS Camera (CMR), Mission Onboard Computer (MOBC), Target (TRG), Target Container (TRGC), Micro LabSat Retain and Release Mechanism (MRR), Inertia Sensor (INS) |

## Command & Data Handling (C&DH) Components using COTS

Micro LabSat has two reliable and highly functional onboard computers (CCE, ACE). CCE and ACE consist of many commercial off-the-shelf (COTS) parts. 32bit CPU, 2.5K FPGA, 4Mbit SRAM and 1Mbit EEPROM are implemented. A multi-task real-time operating system is used. In order to improve radiation hardening, FPGA, SRAM and EEPROM has a voting mechanism.

## Electrical Power Subsystem (EPS)

EPS of Micro LabSat has two features; Peak Power Tracking (PPT), and commercial Ni-MH battery cells. Figure 5 shows the diagram of the EPS.

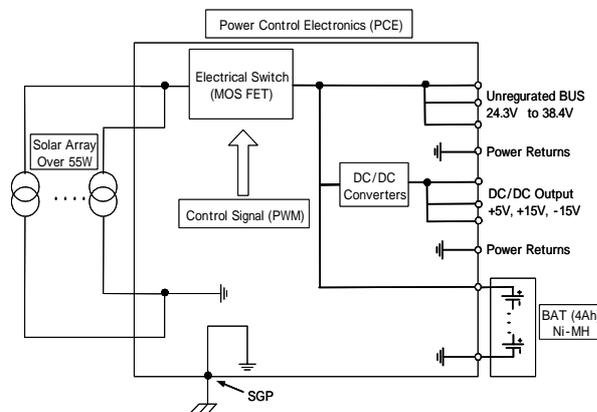


Figure 5. Block Diagram of EPS

The PPT control can extract electric power of solar cells efficiently. And it can also correspond to unexpected high temperature of solar arrays, or radiation degradation. PWM duty control is achieved by on-board software.

Commercial Ni-MH cells are adopted because of its cost and high capacity. In order to apply commercial cells to the satellite, screening was carefully performed.

## Attitude Control Subsystem (ACS)

The basic concept of the Micro LabSat Attitude Control Subsystem (ACS) is as follows.

### (1) Nominal: Spin stabilization

- Passive control technique.
- Simple and highly reliable system.

### (2) Mission: Three-axis stabilization

- Momentum-bias control system
- Safe return to the spin mode by releasing angular momentum of the momentum wheel.

This concept is illustrated in Figure 6.

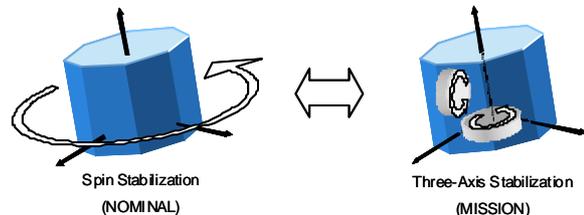


Figure 6. Basic concept of the Micro LabSat ACS

The momentum-bias control method is adopted for three-axis control. The axis of the momentum wheel is parallel to the spin-axis of the satellite.

When the attitude control software detects faults during three-axis control, the satellite can transfer its attitude control immediately to the more reliable spin-stabilization mode by releasing the angular momentum of the momentum wheel.

The Micro LabSat ACS has the following components.

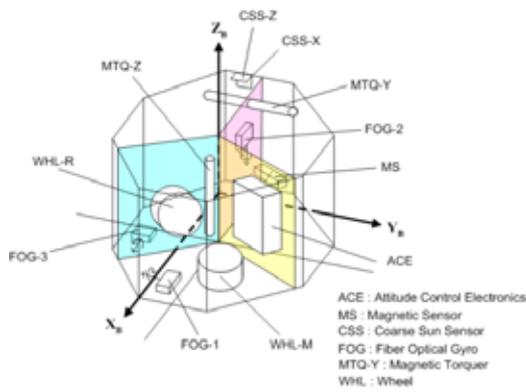
### (1) Sensors

- MS (Magnetic Sensor) : 3 axis
- CSS (Coarse Sun Sensor): 2 axis
- FOG(Fiber Optical Gyro): 3 axis

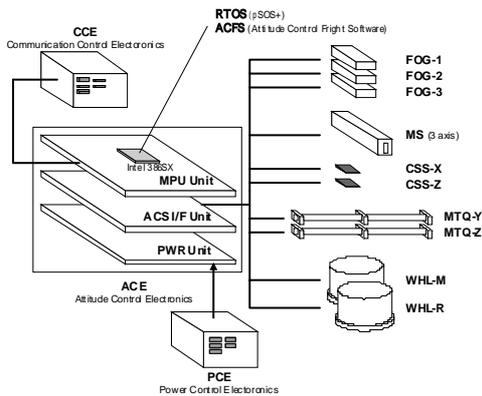
### (2) Actuators

- MTQ (Magnetic Torquer): 2 axis
- WHL (Wheel) : 2 axis

The WHL consists of a momentum wheel (WHL-M) and a reaction wheel (WHL-R). The layout drawing and configuration diagram are depicted in Figure 7 and Figure 8.



**Figure 7. Layout drawing of ACS**



**Figure 8. Configuration diagram of ACS**

Table 3 shows the component allocation for each function of the ACS.

**Table 3. ACS Functions and Components**

| Function                | MS | CSS | FOG | MTQ | WHL |
|-------------------------|----|-----|-----|-----|-----|
| <b>Spin Control</b>     |    |     |     |     |     |
| Spin Axis Determination |    |     |     |     |     |
| Nutation Dumping        |    |     |     |     |     |
| Spin Rate Control       |    |     |     |     |     |
| Spin Axis Control       |    |     |     |     |     |
| <b>3-Axis Control</b>   |    |     |     |     |     |
| Attitude Determination  |    |     |     |     |     |
| Inertial Frame Fix mode |    |     |     |     |     |
| Earth Tracking mode     |    |     |     |     |     |

The nominal spin-axis is on the plane, including orbit nominal vector and Sun vector. The nominal spin-axis and Sun vector form an angle of 45 deg to achieve maximum power from solar cells. The nominal spin rate is 3 RPM (=18 deg/sec).

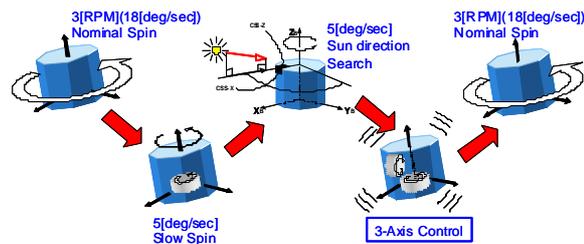
The purpose of the spin-control system is to maintain the spin-axis and spin rate within normal tolerances. It has four functions: spin-axis determination, nutation damping, spin-rate control, and spin-axis control.

Since the Coarse Sun Sensor (CSS) is just a solar cell, its accuracy is poor ( $\pm 10$  deg in the worst case). Therefore, only the three-axis Magnetic Sensor (MS) is used to determine the spin-axis. Telemetry data during one-pass (about 10 minutes), and simulation data by 10th-order IGRF magnetic field model are statistically analyzed to calculate the spin-axis.

The nutation damping control is achieved by driving the MTQ-Z (see Figure 7), based on the Magnetometer output. The spin-rate control is also achieved by driving the MTQ-Y (see Figure 7), based on the Magnetometer output.

The spin-axis control is achieved by driving the MTQ-Z, based on the drive sequence calculated by off-line processing as follows. (1) Consider the direction of torque required to achieve the desired change in spin-axis direction, and search the timing of the MTQ-Z polarity change points. (2) Calculate the suitable drive duty ratio for the MTQ-Z by simulation, in order to obtain desired amount of change in the spin-axis direction.

Micro LabSat temporarily transfers the attitude control mode from the spin-stabilization mode to the three-axis control mode when the satellite has to perform experiments where three-axis control is necessary. Figure 9 illustrates the transition sequence.

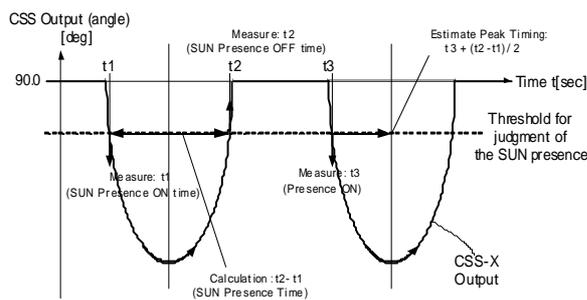


**Figure 9. Three-axis control sequence**

After completion of the experiment, the satellite releases the angular momentum on WHL-M and WHL-R. And it returns to the nominal spin mode.

As mentioned above, the spin-axis can be calculated from the Magnetic Sensor data. However, to know the attitude of the satellite, the angle around the spin-axis should also be determined. Micro LabSat uses the Sun direction to determine this angle.

The CSS-X (see Figure 7) is a solar-cell sensor installed on the side panel surface. In the Sun direction search phase, Micro LabSat monitors the output of the CSS-X and tracks the curve of the trend. Since the satellite is in the slow-spin mode, the curve peaks when CSS-X faces the Sun. The onboard algorithm picks up the timing of the peak, and identifies the direction of the Sun. The poor accuracy of CSS-X does not affect attitude determination because our concern is not the peak signal value, but the peak timing. Figure 10 illustrates the search sequence.



**Figure 10. Description of CSS-X Peak Search Sequence**

The momentum-bias method was used for three-axis control. Two small wheels are installed on the satellite. One is a momentum wheel (WHL-M), and the other is a reaction wheel (WHL-R).

WHL-M and WHL-R are controlled by the PD controller. Micro LabSat has high stiffness because it is relatively small and has no flexible structures, such as deployable panels. The PD controller is sufficient for Micro LabSat to achieve efficient three-axis control.

Absolute attitude control accuracy is 4.0 deg because the attitude determination basically depends on the accuracy of magnetometer measurement. Short-term attitude stability is 0.3 deg over 1 sec (3sigma), and long-term attitude stability is 0.6 deg over 40 sec (3sigma).

## DEMONSTRATION EXPERIMENTS OF KEY TECHNOLOGIES FOR ON-ORBIT SERVICING

### *Scenario of On-Orbit Servicing Mission*

JAXA, National Institute of Information and Communications Technology (NICT), and University

of Tokyo (UT) jointly performed several experiments as technology demonstration towards the future on-orbit servicing missions.

As mentioned above, on-orbit servicing, such as refueling geo-stationary satellites, monitoring and rescuing failed satellites, and reentering space debris from the orbit, is quite important for future space missions.

One of the most essential technologies to realize on-orbit servicing is capturing non-cooperative target like failed satellites and space debris. Non-cooperative target has no attitude and orbit control capability. And it has no markers for image processing. To perform several services to the target, on-orbit servicing spacecraft is required to have the capability to capture it.

To achieve this, the servicing spacecraft must (1) recognize the target, (2) estimate its shape and motion, and then (3) capture (or dock with) it autonomously.

We planned preliminary experiments to demonstrate solutions for each technical problem of the above sequence. This experiment is divided into three parts, and researchers from different organization conduct each of it separately. Details of each experiment is shown below.

### ***Demonstration of CMOS Camera and a Highly Functional Onboard Computer Used for Image Processing of On-orbit servicing (NICT)***

To recognize the target and estimate its shape and motion autonomously, high grade on-board image processing technologies are required in both hardware and software. So, the high quality inspection camera and the high performance image-processing computer are essential elements of on-orbit servicing technologies.

NICT has developed a camera module based on a commercial CMOS digital still camera (CMR), and a highly functional onboard computer module (MOBC) to perform image processing on-orbit. This system aims to perform various software experiments concerning on-orbit servicing. Figure 11 shows the color CMOS camera module (CMR).



**Figure 11. Color CMOS Camera Module (CMR)**

This camera was developed by modifying the commercial digital still camera. Two cameras are installed on Micro Labsat. This camera consumes less energy than a CCD camera, and the cost is also kept low because the electrical unit within the camera is used with only a slight modification from the commercial one. The specifications of the CMR are summarized in Table 4.

**Table 4 CMR specifications**

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

MOBC is a high performance computer module. 64bit RISC microprocessor is adopted. It is used also in commercial game machines and printers. The performance is about 100 MIPS and 10MFLOPS. It will greatly improve calculation resources. MOBC has a re-programming capability. So users can change program modules flexibly. And they can try new ideas and new technologies even after the launch. Figure 12 shows MOBC and the specifications of it are summarized in Table 5



**Figure 12. On-board image processing microprocessor module (MOBC)**

**Table 5. MOBC specifications**

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

To test the basic functions of the CMR and MOBC, earth images were captured, and compressed in JPEG format on-orbit. Figure 13 shows an example of the captured Earth image.



**Figure 13. Color Image of Earth by CMR**

It is about one and a half year from the launch now, and we can't find a sign of degradations in images by this CMR.

Both CMR and MOBC functions very well on-orbit. This is used as infrastructure of several on-orbit demonstration experiments of Micro LabSat.

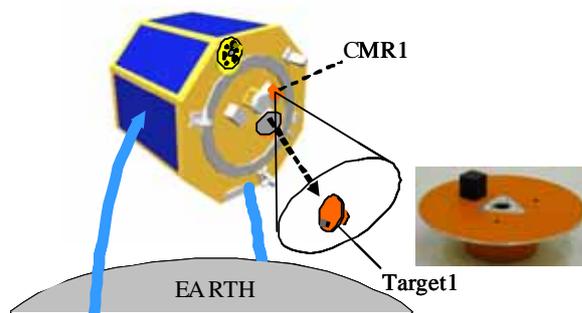
***Demonstration of Image Processing Technology for Autonomous Recognition of the Target (JAXA)***

Future on-orbit servicing missions will require techniques to recognize and extract target objects autonomously from camera images.

It is easy to recognize the target from images with the simple background like black empty space. But it is quite difficult to do it from the images with the bright and complicated background, like the surface of Earth illuminated by strong sunlight.

Under such background or lighting conditions, detection of targets and estimation of their motion are difficult by using only the brightness information of the image. By using the color information of captured images, performance of the automatic recognition software will considerably be improved.

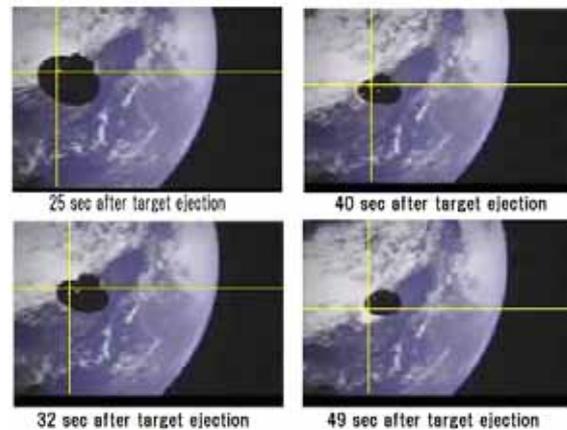
JAXA developed the software for automatic target recognition using color information of captured image. And we conducted on-orbit experiments of this target recognition software using color images of "target" released from Micro LabSat. Figure 14 shows the overview of this experiment.



**Figure 14. Autonomous Recognition Experiment**

The orange target 1 mounted on Micro-LabSat is released toward the Earth. CMR takes images of the

target 1 continuously. And the software installed in MOBC extracts the target from images with the Earth background. Figures 15 shows the result of this experiment.



**Figure 15. Images of the target released from Micro LabSat.**

The target seems black in images because it was in the shadow of Micro Labsat. But the target was illuminated by very dim light. This light was the albedo of Earth reflected by the surface of Micro LabSat. Because of this slight illumination, a part of the target where slight color information remained was extracted. The crosshairs in Figure 15 is the position of the extracted target. It indicates that the autonomous recognition was performed successfully.

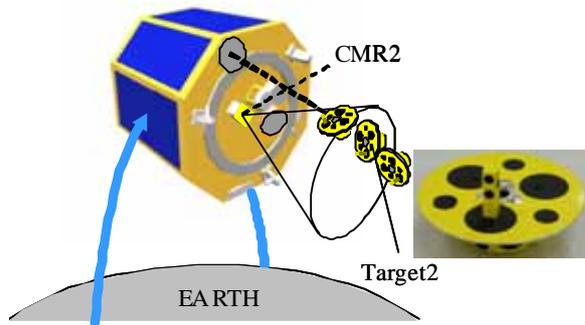
Considering that most satellites are covered with the distinctive color of multi-layer insulation, this autonomous recognition software will be useful for on-orbit servicing spacecraft to detect space debris or failed satellites.

***Motion Estimation and Visual Tracking Experiment (University of Tokyo and JAXA)***

Capturing of tumbling objects in space will be one of the important techniques for on-orbit servicing missions. Before capturing, it is necessary to estimate the motion of the target object. And visual tracking control, which means the attitude of the on-orbit servicing spacecraft is controlled to aim and keep the line of sight of its camera towards a certain direction, is another important technology for capturing phase.

University of Tokyo performed the motion estimation

and visual feedback control experiment on the released target using captured images by CMR. Figure 16 shows the overview of this experiment.



**Figure 16. Motion Estimation and Visual Tracking Experiment**

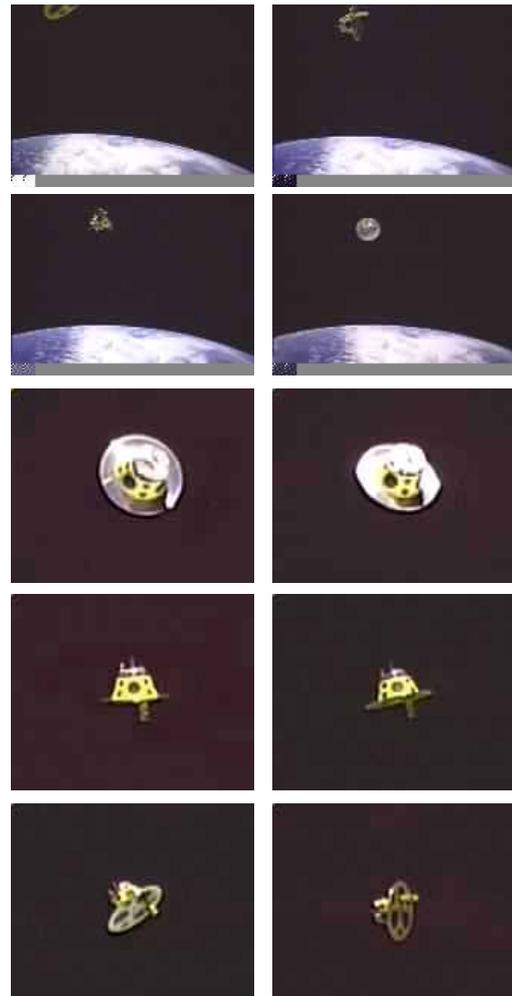
A target, 10 cm diameter small object with some visual markers on the surface was released from the bottom of the Micro LabSat.

When it comes into the view of the CMR, the target image was obtained with about two-second interval.

Motions of visual markers on the surface were tracked with a certain image processing algorithm. And using the position information of these markers in the image, the target attitude and attitude rate as well as moment of inertia ratio were estimated using Kalman filter.

When the target image became too small to be used for attitude motion estimation, the visual tracking experiment was initiated. Micro LabSat controlled its attitude so that the target came to a certain point of the captured image. The control algorithm is called Switching Time Search Controller (SWSC). It is specially designed to deal with the unique feature of the Micro LabSat that only two wheels can be used to control the attitude.

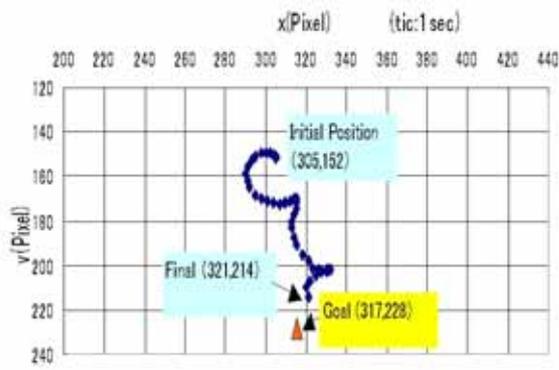
Figure 17 shows the images during the motion estimation experiment.



**Figure 17. Images of Flying Target during Motion Estimation Experiment**

After target recognition was successfully made, the target images were extracted from the whole images. And then high-resolution zoomed-in images were downlinked (the lower six images in Figure 17). The onboard software analyzed them to extract the positions of characteristic points (black marker on the target) which were downlinked together with the images. The Kalman filtering operation was performed on-ground in near real-time fashion using these downlinked data to obtain the target motion parameters. Relative position and velocity of C.G.(Center of Gravity), relative quaternions, angular velocity, positions of the characteristic points in the target body frame, and moment of inertia ratio were all estimated simultaneously.

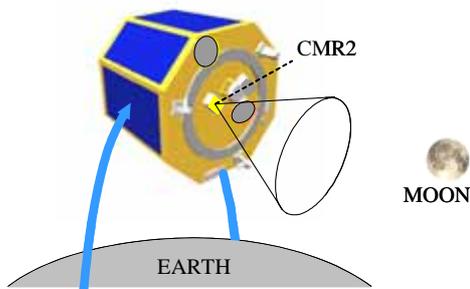
Figure 18 shows the result of the visual tracking experiment.



**Figure 18. Target Trajectory on Camera Image during Visual Tracking Experiment**

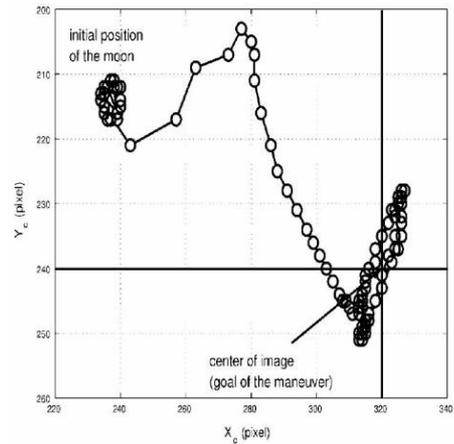
After 44 seconds from the start of the visual tracking control, the algorithm completed the control. And the target on the camera image reached at the final point which is quite near from the goal position.

After the experiment using flying targets was conducted, an extra visual tracking experiment using another control algorithm was planned by JAXA. This is an advanced mission. In this case, Moon is used as a target in place of the target released from Micro LabSat. Figure 19 shows the concept of this experiment.



**Figure 19. Concept of Visual Tracking Experiment Using Moon as Target**

The control algorithm is sliding mode controller. It is designed to control the attitude by using only two wheels. Figure 20 shows the result of this experiment.



**Figure 20. Target Trajectory on Camera Image during Visual Tracking Experiment Using Moon**

The attitude was controlled so that the position of the Moon in the image goes to the desirable point in 100 sec. It can be seen the limit cycle after the convergence.

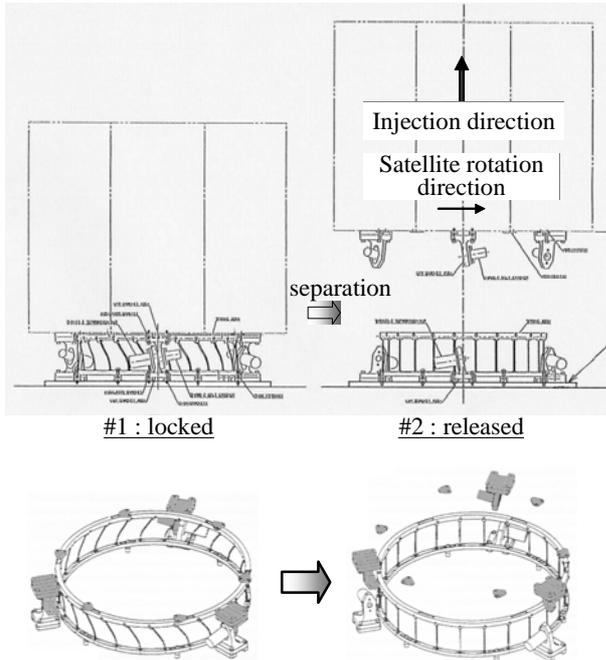
As mentioned above, these three experiments about on-orbit servicing were accomplished successfully. Researchers could demonstrate their ideas easily. The methods used in these experiments are expected to be improved. And it will help on-orbit servicing spacecraft to capture the non-cooperative target.

### OTHER EXPERIMENTS

Micro LabSat performed not only experiments concerning on-orbit servicing but also several other technology demonstrations of advanced space components.

#### *Small Satellite Separation Mechanism*

Figure 21 shows a small satellite separation mechanism.



**Figure 21. Small Satellite Separation Mechanism**

This mechanism can provide the satellite spin motion when it separates from the rocket. It is helpful for the satellite to establish attitude stabilization immediately after separation.

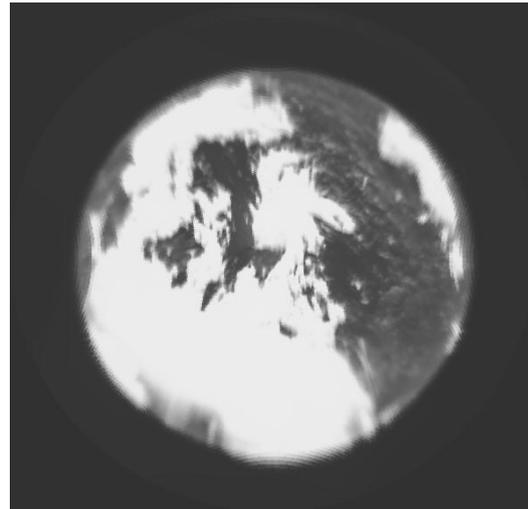
This mechanism is demonstrated by Micro LabSat. And Japanese lunar explorer SELENE adopted this mechanism as a separation mechanism of its child satellite.

#### **CCD Earth Sensor**

Figure 22 shows the CCD Earth Sensor Assembly (CCDESA) and Figure 23 shows the captured image.



**Figure 22. CCD Earth Sensor Assembly (CCDESA)**



**Figure 23. Captured Image of Earth by CCDESA**

Usually, Earth Sensor (ESA) uses infrared devices such as pyroelectric devices to detect the edge of the Earth. On the other hand, CCDESA uses a Charge Coupled Device (CCD), which detects the visible rays to take the Earth pictures. This sensor calculates the center of the Earth from the pictures. And also it estimates the attitude of spacecrafts.

In the future, this sensor can be used not only as the Earth sensor but also as the main attitude sensor in the Moon or other planets where CO<sub>2</sub> can hardly be detected. This sensor is installed on Micro LabSat as a mission component. Its feasibility and performance are demonstrated.

#### **Space class - Earth Image Streaming for Space Education**

Educational activities utilizing Micro LabSat is also performed. In this "space class" program, a classroom is connected to the satellite operation room via internet. And children can experience the operation of Micro LabSat from their classroom. Children send a command to capture image from their classroom, and they can see the obtained pictures from Micro LabSat in almost real-time. Figure 24 shows a classroom during space class.



**Figure 24. Space Class - Educational Program**

Space class has been held at various places in Japan. Over one thousand children, have joined this program. Through this program, children can feel that space is close to them, and have interest about it. Such a program is suitable to small satellites because of its flexibility of the operation.

## CONCLUSION

Micro LabSat is a technology demonstration microsatellite developed by JAXA.

Micro LabSat has been in good condition since the launch (December 14, 2002). All preplanned experiments, especially the on-orbit servicing technology demonstration, were accomplished successfully. Micro LabSat succeeded to provide many researchers an opportunity to perform experiments on-orbit, without too much cost and risk.

Now operation is in the advanced stage. Several additional advanced missions have been proposed. With further operation, future technical achievements can be expected.

On the next project, more rapid and low-cost development of microsatellites will be tried by utilizing the technology of Micro LabSat.

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