Utilizing Commercial DSLR for High Resolution Earth Observation Satellite

Nobutada Sako
Canon Electronics Inc.
3-5-10, Shibakoen, Minato-ku, Tokyo 105-0011, Japan; +81-3-6910-1105
sako.nobutada@canon-elec.co.jp

ABSTRACT

CE-SAT-I, the first technology demonstration satellite from Canon Electronics Inc. has been launched on June 23, 2017 from India by PSLV-C38. Canon is to enter small satellite industry to exercise its precision manufacturing, image processing and mass production capabilities as a new business sector. In this study, commercial DSLR camera, Canon EOS 5D Mark III has been proposed as a detector of the satellite with 40cm aperture, 3720mm focal length telescope aiming to capture 0.9m GSD from LEO. The satellite size is 50 x 50 x 80cm and 65kg in weight. Advantage of area sensor by applying commercial DSLR camera brings full HD and full color video, standardization and cost deduction capabilities. The sensor resolution is 5760 x 3840 pixels and the physical size of the sensor is 36 x 24mm. Point-and-shoot camera, PowerShot S110 is also equipped as wide angle camera as a finder of main telescope. Systems of CE-SAT-I has been developed based on commercial product of Canon. For instance, OBC has been developed based on same technology of multi-function printer. During initial operation, satellite health has been fully confirmed and optical calibration has been done with resolution test chart on the ground. Focus calibration has been performed with temperature control and physically adjusted by hyper-sonic actuator equipped on secondary mirror. Advanced missions are performed including video capturing, HDR, super-resolution and reprograming of OBC after initial operation. Ground stations has been developed and operated by Canon Electronics. The antennas are located around Tokyo and remotely operated. With the heritage of CE-SAT-I, Canon electronics is aiming to build a constellation of over 100 satellites with 8K low light real time video broadcasting with laser communication.

BACKGROUND

Canon Electronics Inc. (CEI) started business in space industry. CEI is a subsidiary company of Canon Inc. and manufacturing products such as copier, camera, lens, handheld terminal, magnetic sensor and so on[1]. In order to expand its business, CEI is seeking opportunities of business from satellite components, satellite system sales to data analysis and professional service. Precision machining, image process and mass production technic are key technologies of us to catch up with preceding companies in small satellite field.

Study about Satellite and Ground System

This is the first time for CEI to be involved in space activities, 50kg class micro satellite, which has the similar size as common company products, was chosen for technical demonstration. Earth observation is selected as a mission since imaging is DNA of Canon. Canon have commercial digital camera, movie camera, security camera and recently acquired X-ray, CT, MRI are also imaging of human body. This time we aimed to take images of the Earth. The satellite is named "CE-SAT-I" and ground segment is also the target of in-house development.

Today there are many knowledge, products and personnel related to small satellites compared to twenty year ago when nano and pico satellite rose in the world. CEI established Satellite Systems Laboratory in 2012 (Space Technology Laboratory at this time) to start CE-SAT-I project. Members are selected from in-house designer and craftsman and specialists are invited from outside of the company such as a satellite systems engineer who developed CubeSat first in the world, astronomer of gravitation wave detector, software, semiconductor, radio engineers and so on. At the same time, Hodoyoshi project directed by Professor Nakasuka, the University of Tokyo, started to supply flight proven made in Japan and ITAR free micro satellite components[2]. CE-SAT-I adopted common bus components from this Hodoyoshi products to focus on mission and critical bus parts.

ABOUT CE-SAT-I

Objectives

CEI set project objectives as following.

- Cultivation of new business using developed CE-SAT-I and acquired images from the satellite.
- Development of human resource by experiencing the entire project.
- Foster company motivation.

CE-SAT-I is the first outcome of space business domain and expected to be the symbol of the company.

Missions

Considering the background of CEI, missions are set as

- Verification of micro satellite and ground segment technology.

- Taking a "good" image of the Earth which resolution is better than 1m GSD, based on Canon group imaging and machining technology.

CE-SAT-I is a technical demonstration satellite and because of micro satellite, we set challenging goal as for imaging.

Bus Specification

An appearance of CE-SAT-I flight model and its inside are shown in Figure 1, Figure 2 and general specifications are shown in Table 1.

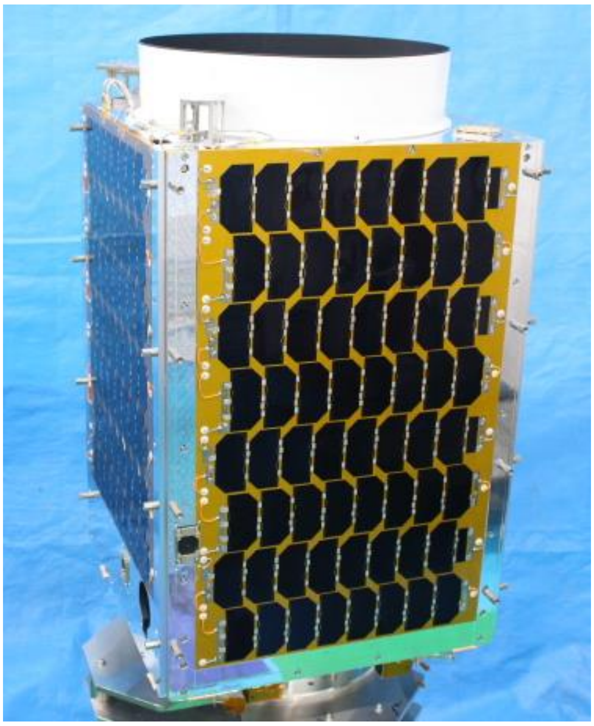

Figure 1: CE-SAT-I

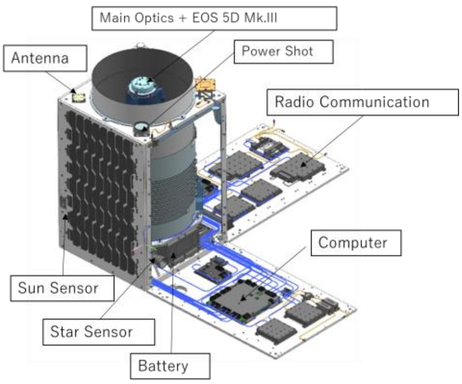

Figure 2: Components Layout

Table 1: General Specification of CE-SAT-I

Item	Specifications
Size	500*500*850[mm]
Mass	65[kg]
OBC	CPU: SH2A (300[MIPS]) Storage:2[GB]
Power	Average generation: 80[W] Peak power tracking Bus voltage: 18[V] Liion secondary battery
Communication	Up: 32[kbps] in S band Down: 2/0.2[Mbps] in Xband
AOCS	Three axis zero momentum Pointing: 0.19[deg] Stability: 2.8E-5 [deg]/ 0.01[sec] Agility: 40[deg]/40[sec]
Mission	Main camera: 1[mGSD] Sub camera: 100 [mGSD]

Internal space of the satellite is mostly occupied by a main telescope described in the next session. Bus components are thinly arranged on panels.

A tree type information architecture is adopted in CE-SAT-I (Figure 3). A DJM is an intelligent repeater attached on each panel and it gather information from components on the panel and send commands and distribute power to them. This system makes harness in the satellite less.

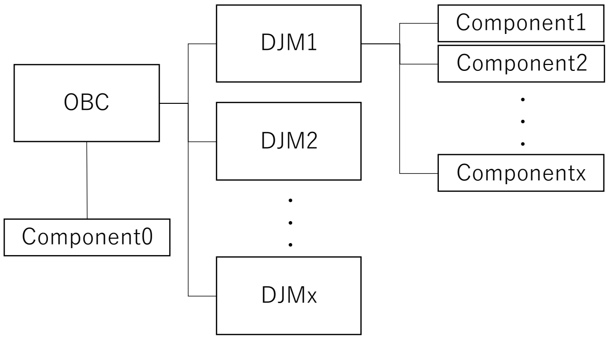

Figure 3: Information Architecture

OBC, power, communication subsystem is equipped with backup unit to achieve simple redundancy. AOCS has functional redundancy by combining several different actuators and sensors. Computers and power control units mutual monitor each other to reset in case of SEL is occurred.

Mission Specifications

Two cameras are installed in CE-SAT-I. The main camera is a telescope which can take 0.9[m] GSD image from 500[km] height. Its optics are designed and integrated by CEI for this mission. Canon DSLR EOS 5D Mark III (EOS) is used as a detector. This EOS is slightly modified for space-use and controlled from OBC via USB interface. You can use EOS as you use it on the ground. Basic image process is done by EOS.

Sub camera is PowerShot S110. Intentionally no modification was made on this camera and installed on the top of CE-SAT-I as it is. Therefore, every time the camera is turned on, its lenses are mechanically moved to prepare shooting.

Since both cameras have area sensors, the satellite nominally points to a target while taking images in any exposure time. In other way, pseudo push broom can be performed by using short exposure time while the satellite points to the Earth center.

Camera specifications are shown in the following.

Table 2: Main Camera Specifications

Item	Specifications
Main mirror diameter	400[mm]
Focal length	3,720[mm]
Telescope type	Catadioptric: Cassegrain + correction lens
Detector + Image processor	EOS 5D Mark III base CMOS sensor RGB Bayer pattern IR cut filter
Shutter	Mechanical and/or electrical
Focus	Adjustable
Resolution	0.87[m] GSD at 500[km] height
Wave length	400- 700[nm]
Image foot print	6 * 4 [km]
Output	Still: 5760 * 3840 pixels in RAW and JPEG format with 6 frame/sec continuous shooting Motion: Full HD (30p)
Thermal control	Segmented heaters

Table 3: Sub Camera Specifications

Item	Specifications
Main lens diameter	16[mm]
Focal length	26.0 (Tele) - 5.2(Wide) [mm]
Telescope type	Refracting
Detector + Image process	PowerShot S110 CMOS sensor RGB Bayer pattern

	IR cut filter
Focus	Adjustable
Resolution	30 (Tele) - 200 (Wide) [m] Variable using zoom mechanism
Wave length	400 - 700[nm]
Image foot print	150*110(tele) – 900*700(wide) [km]

Ground Segment

Ground stations development are supported by Tokai University. The antennas are (Figure 4) set up on the CEI factor site located at north of Tokyo and main control center is set in Tokyo headquarter. Both segments are connected via network. Ground stations site is now preparing for multi-satellite operation. CE-SAT-I is operated by members of Satellite Systems Laboratory, CEI.

Figure 4: Receive Antenna

Table 4: Antenna Specifications

Item	Specifications
Dish Diameter	2.4[m]
Motion	XY type
G/T	24[dB/K]

Launcher

CE-SAT-I was launched by Indian PSLV C-38 together with Cartosat-2D and 30 piggyback satellites on June 23rd, 2017 from SDSC. The orbit insertion was normal, and it was 505km SSO and LTDN was 9:30.

Figure 5: Launch Campaign with Rocket Team

CE-SAT-I OPERATION RESULTS

Initial Operation Phase

The first five months are initial operation phase to examine the following items.

- C&DH
  - Command, telemetry and data storage verification
  - Re-programing of OBC and components.
- Power
  - Balance of power generation and consumption
  - Peak power tracking with optimal attitude toward the Sun.
- Communication
  - Performance of the satellite and ground.
  - Interference measurement with other satellite.
- AOCS
  - Attitude control performance
- Mathematical thermal model correlation.
- First light of main and sub camera.
- Operation system verification and optimization of procedure.

With some struggles, bus and ground parts were verified to satisfy the design requirements. The sub camera was used from the early stage (Figure 6). The main camera was carefully activated and took the first light as shown in Figure 7 before making any adjustment. Soon after that, focus was mechanically tuned and optics temperature was adjusted to the expected proper setting (Figure 8).

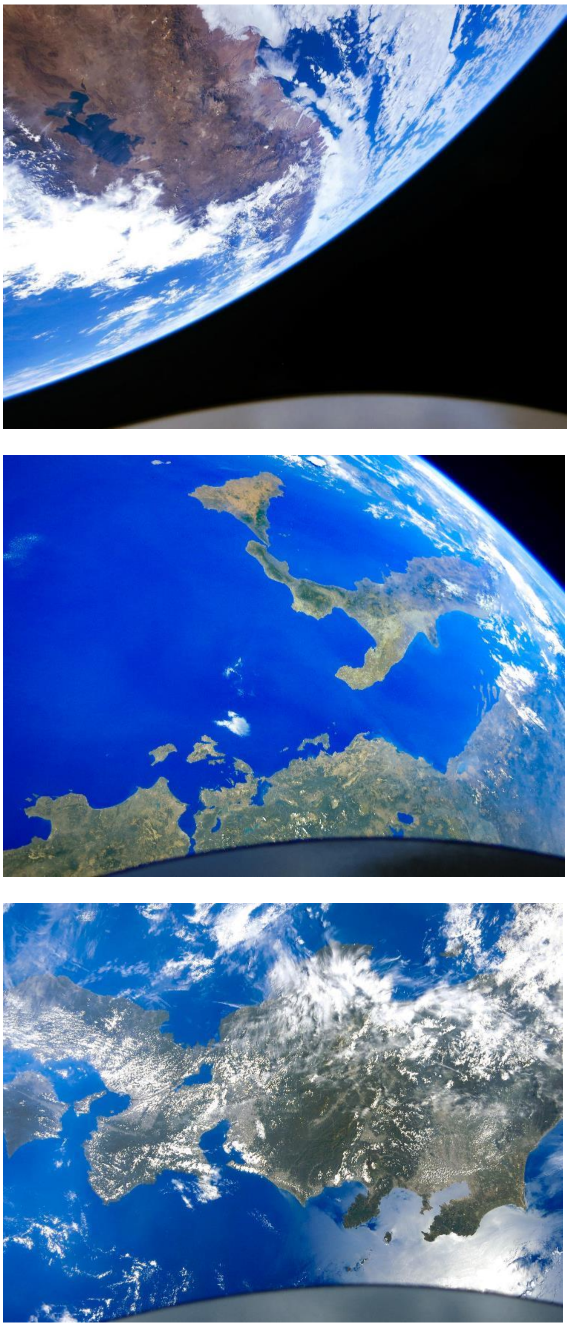

Figure 6: Sub Camera Images

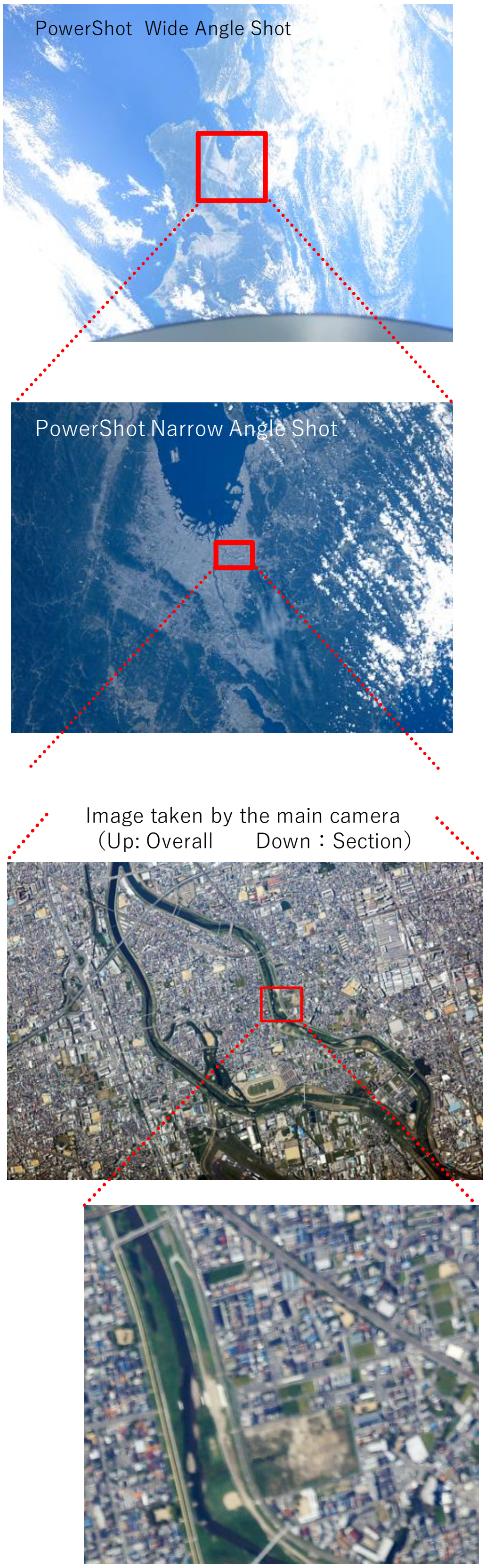

Figure 7: Main Camera First Light

Figure 8: Main Camera Image Sample

Nominal Operation Phase

In view of CE-SAT-I and its operation is stable, the phase is currently moved to nominal phase which is aimed to take the best image by CE-SAT-I.

Shootable duty ratio on the orbit was up to 90% by optimizing power generation, heater usage and wheel unloading.

The main optics aberration is calculated by taking pictures of large test pattern or color charts on the ground. Aberration estimation using normal images are also performed in collaboration with Meisei University[3]. Based on the calculation, segmented heaters around optics are driven to minimize the aberration.

Advanced imaging including super resolution using multiple images, high dynamic range image synthesis, imaging of night area is under examined.

Satellite bus performance improvement and labor saving of operation and analysis are usual theme. Long term trends are monitored to improve next satellite design.

FUTURE PLANS

Image Analysis

Information extraction from taken images is one major important task CEI should take.

Future Project

Following on the first satellite project, CEI could proceed satellite development in any direction at this stage. Therefore, considering CEI mass production capability, a constellation consists of more than hundred satellites which take 8K video image and stream it in real time using a laser terminal is a reasonable target.

CONCLUSION

CEI has joined small satellite industry with micro satellite CE-SAT-I which can take 1[m] GSD images based on Canon group technologies. CE-SAT-I is now doing bus tests and taking still and motion images to verify its quality and practicality. Also next satellite projects are also in progress to accelerate to achieve our goals.

References

1. Canon Electronic Inc. web page, https://www.canon-elec.co.jp/english/index.html
2. Shinichi Nakasuka and Ryu Funase, "Small and Micro/Nano - Satellite Possibilities in Space Science and Exploration – Examples from Japan", Small Satellite Conference, 2016.
3. Norihide Miyamura, "Image-based Adaptive Optics for Remote Sensing Satellite", International Symposium on Space Technology and Science, 2013-f-23, 2013.