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Advanced System of Micro Satellite for Hyperspectral Remote Sensing Mission

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ABSTRACT

The Space-Science Industries Program has been performing investigations for the Micro-satellite and Hyperspectral remote sensing missions. The Earth Observation Micro-satellite "TAIKI" is a 50 kg satellite which has low-cost and small bus-subsystems for advanced remote sensing missions. This bus-subsystem will be developed as manufactured products. The TAIKI is characterized by a small Hyperspectral sensor "HSC-III" which is targeted at the performances of 30m of ground sampling distance and 61 spectral bands in VNIR (Visible and Near Infrared). The advanced remote sensing data such as Hyperspectral data are large volume, so the downlink uses the laser communication of 100Mbps. The terrestrial laser communication has already been successfully experimented. In addition, HSC-III optics instrument which mainly consists of spectrometer, detector and on-board calibration system has been developed in 2008. This paper reports the small bus-subsystem including the laser communication system for the TAIKI and the Hyperspectral sensor instrument.

INTRODUCTION

The Space-Science Industries Program was started from 2003 in Hokkaido, Japan [1]. The program has a goal which is building some businesses on space. The program is planning to launch Micro-satellite in order to demonstrate the space industries models. The TAIKI is an earth observation micro-satellite and characterized by a spaceborne hyperspectral sensor "HSC-III (Hyper-Spectral-Camera-III)". The TAIKI is the name of a town in Japan, and it means also "big tree" in Japanese.

The program objectives for the TAIKI mission are summarized in the following:

- To provide hyperspectral image for agricultural remote sensing
- To acquire visualization of the effect of climate change on plant distribution.

In general, the hyperspectral sensors are defined as a combination of a spectral radiometer and an area image sensor. The hyperspectral image acquires more spectral information from objects with a high spectral resolution compared with conventional multispectral sensors. Therefore, it enables to distinguish a targeted object with a high accuracy, and give us lots of important information. A typical image generated by the hyperspectral sensors is shown in figure 1. The hyperspectral technology is very attractive not only to the space industries but also academic applications. On the other hand, for utilizing the hyperspectral sensor the satellites need to equip a high speed downlink device and a high-stabilization attitude control system. Furthermore, the HSC-III requires equipping with the high-accuracy spectrometer, inertia reference unit and on-board calibration equipment.

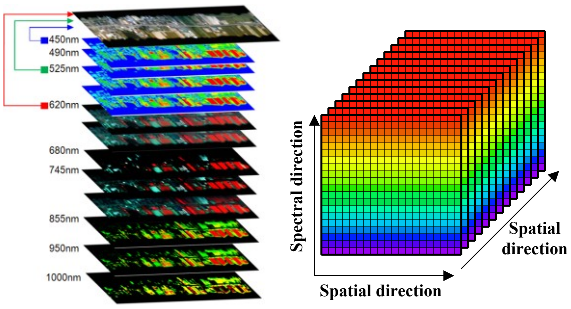

Figure 1: Typical image of the Hyperspectral data

SPACE-SCIENCE INDSTRIES PRGRAM

The program has been performing investigations for the advanced remote sensing missions and developing the Micro-satellites which have low cost and small bus-subsystems in order to demonstrate the space industries models. The bus-subsystem will be developed as manufactured products and keeps a lid on development cost to within 1 M$. The program was preceded by HIT-SAT shown in Figure 2, a CubeSat with a mass of 2.7 kg to demonstrate the new bus technologies. HIT-SAT was successfully launched as a secondary payload to Solar-B (ISAS/JAXA) in 2006 [2]. The TAIKI spacecraft will adopt the proven technologies flown on HIT-SAT.

Data from hyperspectral sensors allow observing a wide variety of parameters from many fields such as agriculture, forestry and geology. The program is planning to provide the hyperspectral image for farmhouse. The conventional methods by using multispectral sensors are used for understanding the soil conditions. According to the research, however, most farmhouses are now in second phase of crop management. To manage lots of crop the hyperspectral images have been shown to be of benefit. This is because the hyperspectral sensors have potential applications such as high-accuracy classification of the kind of crops. Although the HYPERION on EO-1 (Earth Observing-1, NASA, 2000) and CHRIS on PROBA (ESA, 2001) have proven the potential of hyperspectral remote sensing, these sensors were not shown the practical applications with respect to SNR (Signal to Noise Ratio) and spectral accuracy of each band. The Space-Science Industries Program TAIKI has been targeted at the practical use of agriculture. The TAIKI equipped with the HSC-III will provide the high-quality hyperspectral image.

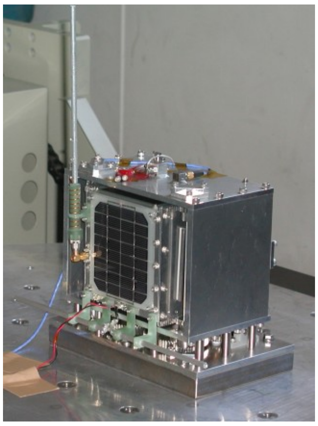

Figure 2: HIT-SAT with the Separation Mechanism

THE TAIKI SPACECRAFT

Spacecraft overview

The TAIKI has missions of Hyperspectral remote sensing Micro-satellite technology demonstration under development at the Space-Science Industries Program. The artist's view of the satellite spacecraft is shown in Figure 3. The satellite is stabilized with the attitude control subsystem providing an attitude accuracy around 3-axis within 2 degrees. Due to the HSC-III equipped with IRU (Inertial Reference Unit), the satellite is required to have mitigated pointing accuracy. The requirements of the satellite bus to accomplish the mission are shown in Table 1.The satellite is developed based on the technology of demonstrated HIT-SAT bus-subsystems which consists of lots of introduction of technologies from COTS (Commercial Off The Shelf) components. To downlink high-volume data from the Hyperspectral sensor the satellite is equipped with a laser communication instrument in addition. A diagram of the satellite bus-subsystem is shown in Figure 4. The components for control of each bus-subsystem have microprocessor or FPGA, so the router between each control processor is placed.

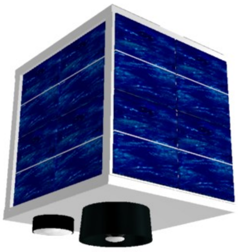

Figure 3: Artist's view of TAIKI spacecraft

Table 1: TAIKI spacecraft parameters

Item	Requirement
Spacecraft mass	50 kg(including sensor instrument)
Size	50cm×50cm×50cm
Orbit	Sun-synchronous orbit Attitude: 500-600 km
EPS (Electrical Power Subsystem)	Body mounted solar sell panels Power generation: = 50W
ACS (Attitude Control Subsystem)	3-axis stabilization Attitude accuracy: ±2.0 deg Attitude stability: 0.03 deg/sec
C&DHS (Command & Data Handling Subsystem)	32bit microprocessor (SH-4) Data recorder: > 30Gbytes
RF-Communication subsystem	Downlink: 10Mbps Uplink: 9.6kbps

Electrical Power Subsystem

EPS (Electrical Power Subsystem) mainly consists of a PCU (Power Control Unit), secondary batteries and solar panels. The basics design has demonstrated by HIT-SAT. EPS employs a body mounted solar array panels which made by triple junction solar cells with conversion efficiency of 26.8%.. The solar array panels are arranged on 5 surfaces without the surface which is equipped with the camera instrument. The secondary battery using Lithium Ion Polymer with capacity of 910mAh are used as 5-parallel sets of 2-series batteries. PCU is a power supply system which performs the PPT (Peak Power Tracking) control by a 16bit microprocessor (H8/3048F) and DC/DC converter. The microprocessor and DC/DC converter shown in Figure 5 employ components that both were demonstrated on orbit by HIT-SAT.

Table 2: EPS parameters

Item	Performance
Solar panel	Body mounted solar panels $GaInP^2$/GaAs/Ge Triple Junction Solar Cells Efficiently: 26.8%
Power generation	Approx. 50-100W
2ndary Battery	Lithium Ion Polymer Nominal voltage: =7.4V (@ 2sereise) Nominal capacity: = 4.55Ah (@ 5 parallels) Predicted cycle life: =20000(@ DOD: 40%)
PCU	16 bit Microprocessor (H8/3048F) Flash memory DC/DC converter (the bus voltage: +5V)

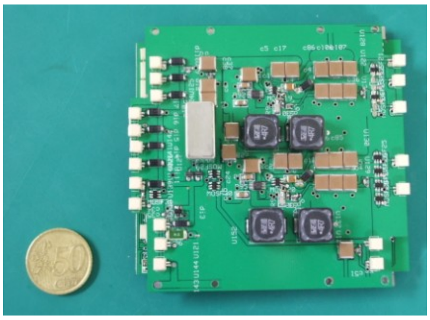

Figure 5: DC/DC converter with latching relay circuits demonstrated by HIT-SAT

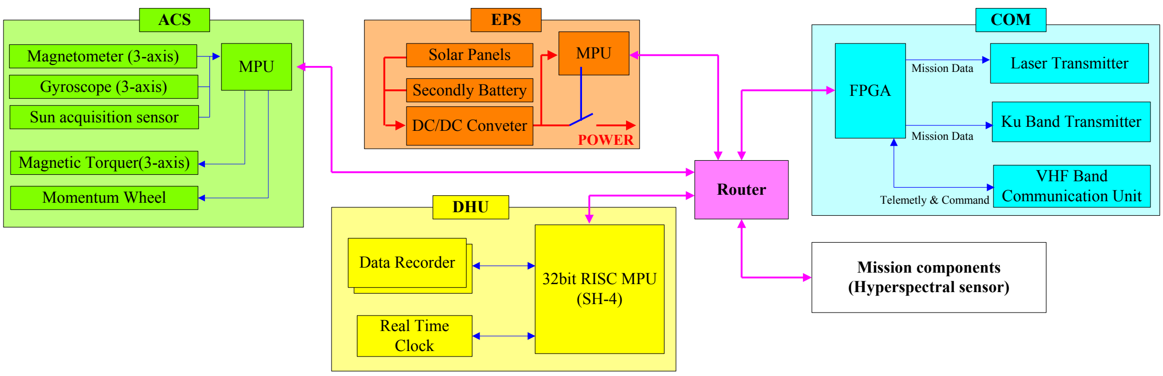

Figure 4: Block diagram of the TAIKI spacecraft bus-subsystems

RF-Communication Subsystem

Communication system for the TAIKI is equipped with RF (Radio Frequency) communication system which consists of Ku-band transmitter, VHF transmitter and receiver, and Laser communication system. The onboard Ku-band transmitter shown in Figure 6 has been developed in Micro LAB, Co., Ltd at Kagoshima in Japan [3]. It employs BPSK (Binary Phase Shift Keying) modulation at 10Mbps, and the output power is 200mW. To downlink high-volume hyperspectral data the satellite is equipped with Ku-band at 10Mbps and Laser transmitter at 100Mbps. The laser can not be used in the bad weather or in the night. Thus, the Ku-band transmitter which is backup transmitter for laser communication will be effectively used under the conditions. VHF transmitter is used for downlink data which consists of H/K status of the satellite, and VHF receiver will receive some commands or up-date of satellite software from a ground station. The data transmission rate is 9.6kbps (command/telemetry). The RF output power of the satellite is 150mW, and the output power of the grand station is 50 W. The both link budget results are summarized in Table 3. The technologies of the components were proven by the HIT-SAT.

Figure 6: Ku-band transmitter, Engineering Model (photo credit: Micro-LAB, Japan)

Table 3: RF-Link budget result (Uplink by VHF, Downlink by Ku-band)

Item	Uplink	Downlink
Frequency	150MHz	20GHz
Band width	16kHz	12MHz
Transmitting Gain	16.15dB	19.6dBi
Receiving Gain	2.15dBi	38.74dB
Transmitting Power	50W	0.2W
Propagation Distance	1000km	
Receiver noise Temperature	23dBK	
G/T	30dBK	
Link Margin	4dB	
C/N	60.515dB	96.862dB

Attitude Control Subsystem

The ACS (Attitude Control Subsystem) is bias-momentum 3-axis stabilized system [4]. The purpose of the ACS is to maintain the attitude of the satellite to the earth within ±2 degrees around 3-axis during earth observation and laser communication. In addition, the attitude stability of 0.03 degrees/seconds is required for realizing the stabilized laser communication. The sensors for attitude control are a spin type sun acquisition sensor (SSAS), 3-axis geomagnetic aspect sensor (GAS) and three 1-axis gyroscopes. The actuators are a momentum wheel and 3-axis magnetic torquers (MTQ). The momentum wheel provides the satellite with bias-momentum of 0.84Nms. Several subcomponents in the ACS such as sensors and actuators shown in Figure 7 have been demonstrated on orbit by the HIT-SAT. 3-axis GAS (HMC2003, Honeywell) and the gyroscope (CRS03-04, Silicon Sensing Systems Japan) are COTS components. The SSAS is original development which is comprised of a 1-dimentional PSD (position sensitive detector) and a pinhole unit. As the estimation of rated specification for MTQ it requires dipole moment of more than 6 Am^2. Dipole moment of the MTQ carried in the HIT-SAT was 0.15 Am^2 which is a little power compared with requirement for control variable of the micro-satellite, though. Therefore, it requires bigger size up. However, the basic experiment has been successful such as Figure 8 which shows the on-orbit result of demonstrated MTQ and 3-axis GAS. The figure shows the time history of measured magnetic field which was removed the effects of MTQ [5]. The attitude control modes of the satellite are an attitude acquisition mode, a normal mode and a safe-hold mode. The control law consists of pitch angle control by the momentum wheel, roll and yaw axes control and angular momentum control by MTQ.

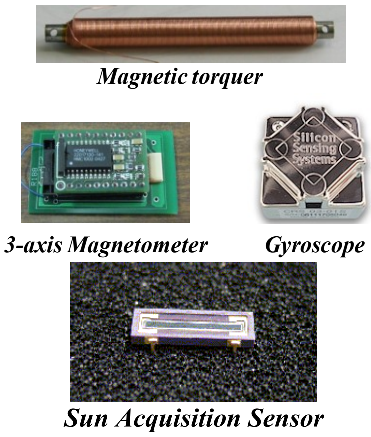

Figure 7: ACS components (demonstrated by HIT-SAT, 2006)

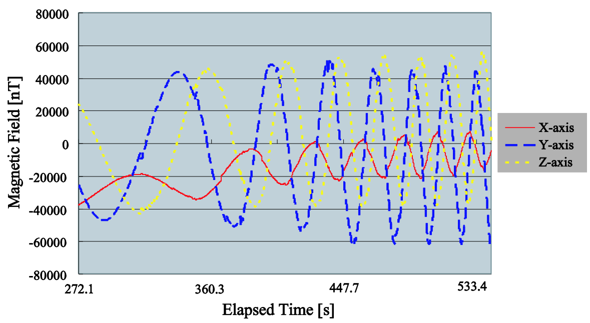

Figure 8: Magnetic Filed removed the effects of Magnetic torquers by HIT-SAT

Data Handling Subsystem

The spacecraft bus and mission components are integrated the DHS (Data Handling Subsystem) based on high speed 32bit RISC processor (Renesas Technology, SH-4, 300MIPS).The processor is selected from commercial component and is not radiation-hardening. The processor has been evaluated under the radiology examination at Takasaki Advanced Radiation Research Institute. As a result, the SEU (Single Event Upset) was 255 times per 110 seconds in case the processor was exposed to Neon (Energy: 4.68MeV). The SEL (Single Event Latch-up) was 3 times per 30 seconds in case the processor was exposed to Krypton (Energy: 33.9MeV). As the analyzed result it estimated that the SEU will be 2.87×10^{-7}/bit/day and the SEL will be 9.81×10^{-5}/device/day. The processor is expected to experience SEU during approximately 3 month in orbit. For self-diagnosis, the DHS equips limit check, verification of the executed commands, device check, and watchdog timer. For autonomous control, the DHS has functions power off and reset of each component. As the result of examining, the CPU from COTS component has enough confidence which is durable under the space radiation environments.

LASER COMMUNICATION SYSTEM

System outline

The laser communication has an advantage of realizing the high speed transmission under the conditions of small size and low electrical power. The high bit rate data transmission device such as the laser communication system is very attractive not only to the space businesses but also academic applications. LCS (Laser Communication System) of the TAIKI is being realized only for the high-rate downlink data transmission [6]. It is comprised of a laser transmitter, an optics instrument, and a pointing control mechanism. The laser transmitter consists of a laser diode array and electrical circuits for the laser driver and TDM (Time Division Multiplexer). A laser power of 1.5 Watts is not available from a single mode. To successfully realize a high power laser transmitter, the LCS employs high-intensity laser diode array which is equipped with thermocoolers for wavelength stability. The laser receiver consists of an APD (Avalanche Photo Diode), amplifier circuits, and demultiplexer. The laser communication method employs the IM/DD (Intensity Modulation / Direct Detection) technique. The laser receiver type is a transimpedance amplifier. The requirements of LCS are summarized in Table 4. The laser acquisition and tracking sequences consist of three parts, the coarse pointing control, the scan control and the tracking control in the following.

1) First, the satellite orbital information and the ground station position information are used for determination of coarse laser pointing angle.

2) Second phase is scan control and searching for the received optical antenna of the ground station. The scan range is ±3 degrees.

3) After the optical acquisition sensor has received the transmitting laser, the ground station transmit feedback signal to the satellite is realized by RF communications. The feedback signal contains the angel error and the received intensity. The feedback signal is used for tracking in position of receiving maximum intensity. When the received intensity is over a threshold value, the data downlink starts using the laser communication.

Table 4: Overview of the LCS requirements

Parameter	Requirement
Laser diode	Wavelength: 830nm Output power: 1.5 W By using Array of Single-mode LD Beam divergence: 1mrad Transmitting diameter: 8mm
Receiver in Ground station	Device: APD (Avalanche photo diode) Amplifier type: Transimpedance amp. Quantum efficiency: 0.75 Multiplication factor: 600 Antenna diameter: 1.0m
Signal format	NRZ (Non-Return Zero) Time Division Multiplex
Modulation	IM/DD (Intensity Modulation/Direct Detection)
Bit rate	100Mbps (BER < 10^{-6})
Transmitter instrument	Instrument mass: 3kg Electrical power consumption: 4W
Tracking accuracy	250μrad(σ)

Terrestrial Laser Communication Experiment

The terrestrial laser communication has been demonstrated in 2003. Figure 9 shows the photo of experimented laser transmitter and laser receiver. The experiment named "*STAR ON THE GROUND*" was successful under the propagation distance of 15 km which was between Sapporo JR tower and Rakuno gakuen University. The overview of the experiment is shown in Figure 10.

Figure 9: Laser transmitter (left), Laser receiver (right)

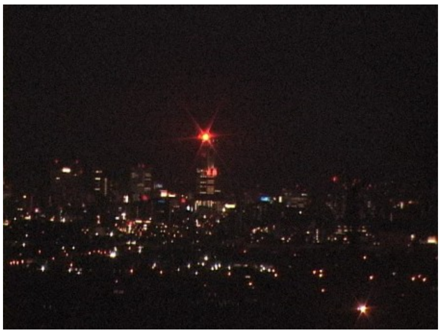

Figure 10: Terrestrial Laser Communication "*STAR ON THE GROUND*"

Pointing control mechanism

The LCS requires high accuracies of pointing control between the satellite and the ground station because of the directional characteristics of the laser beam. This implies a high accuracy pointing control device onboard the spacecraft with a wide range of angular pointing capability. In addition, the device must be of low mass and of low power consumption to fit into a micro-satellite. A 2-axis PCM (Pointing Control Mechanism) device was developed for pointing and tracking control of the laser beam to direct the receiving antenna of the ground station. The PCM device consists of three major components: steering mirror mechanism, angular sensor and electrical unit. The steering mirror mechanism has two coreless DC motors and four rod-end-bearings. The rod-end-bearings are used for mechanism of drive transmission. Thus, the drive transmission of an axial rotation with an angle is possible. The two motors can be placed outside of rotational system. Compared to a general 2-axis azimuth-elevation gimbals configuration, the PCM design offers the advantage of a low internal disturbance, and miniaturization. The angular sensor is equipped with a 2dimensional-PSD (Position Sensitive Detector) and low power laser diode. The pointing angle of the steering mirror is controlled by the input value of the angular sensor. Schematic design is shown in Figure 11.

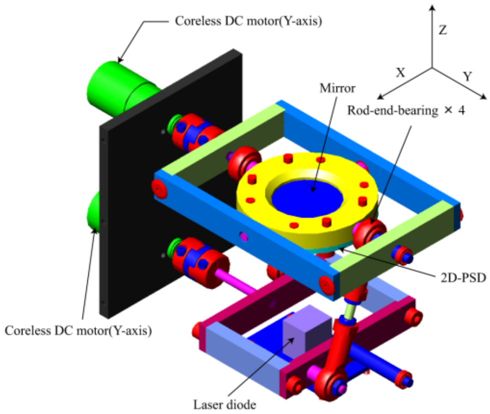

Figure 11: Schematic design of PCM

The LCS including the PCM device is verified by performance evaluation which consists of tracking control sequence and measurement of tracking accuracy in disturbance environment. A schematic block diagram is shown in Figure 12. The PCM is equipped with digital PID controller for a local loop. A CMOS image sensor is used for acquisition of a laser beam. The laser transmitter should be in the far field, but in the experiment, it is in the near field. Thus, the lens unit in front of the sensor has very long focus and narrow-angle because the lens unit is used for changing laser beam to the far field patterns.

The experimental result of tracking sequence which has bias error of 1.5 degrees is shown in Figure13. It can be seen from the result that the time for over all acquisition sequence of LCS was about 10 seconds. There was the open-loop scanning phase during first 5 seconds. The LCS pointed to center position of image sensor by applying close-loop control based on digital PI controller after 5 seconds. The result indicates that the LCS including the PCM successfully fulfilled fast-automatic laser pointing.

The tracking performances in disturbance environment were good. The PCM with the laser transmitter was disturbed by the turn table which generates vibration of 0.03 degrees/seconds as the spacecraft attitude stability.

Figure 14 shows result of tracking accuracy in the environment. The LCS including the PCM achieved the tracking error at less than 250μrad(σ) if the attitude stability of the spacecraft indicates less than 0.03 degrees/sec.

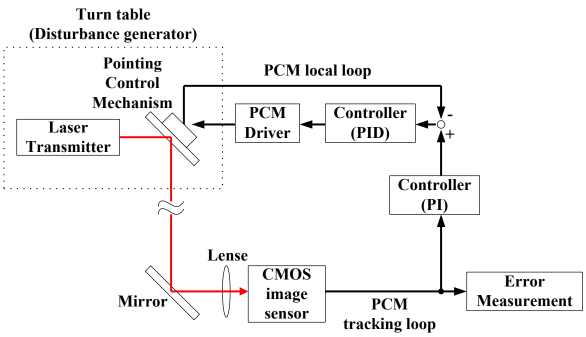

Figure 12: Block diagram of the tacking system including the PCM

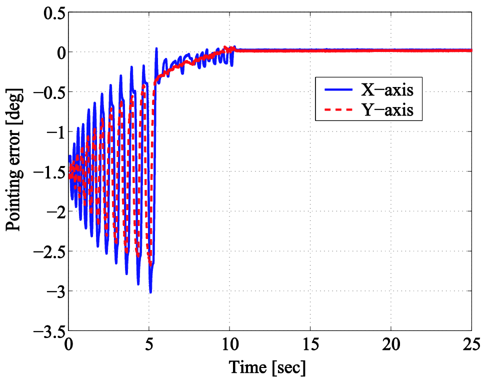

Figure 13: Acquisition sensor error in the tracking sequence

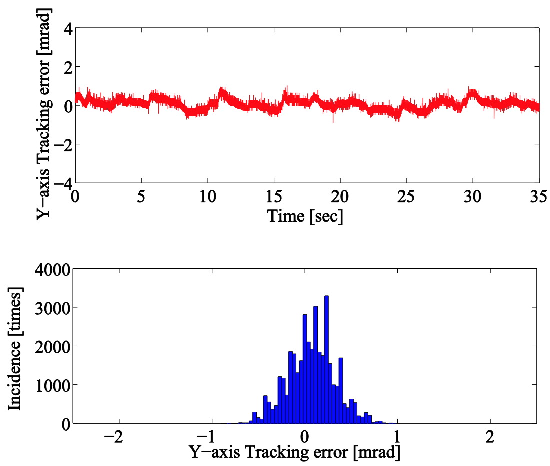

Figure 14: Time response property (above) and histogram (bellow) of tracking error (satellite attitude stability: = 0.03 degrees/sec)

HYPERSPECTRAL SENSOR OUTLINE

The development of the hyperspectral sensor was started from 2003 and manufactured HSC1.0 and HSC1.5 as the laboratory models in the Space-Science Industries Program. The airborne remote sensing experiment was executed by loading HSC1.5 shown in Figure 15 and IRU, and the ground observation experiment using the hyperspectral sensor and the geometric correction of the sensing data were demonstrated. At the next step, we have succeeded to develop a hyperspectral camera as the spin-off product named HSC1700 shown in Figure 16 which installs both the hyperspectral sensor unit and a scanning mechanism inside. The HSC1700 is specified by the spectral range from 400 nm to 800 nm, 81 spectral bands, and image size of 640×480 pixels, radiometric resolution of 8 bits and data transfer rate of 30 frames/seconds. After the release of the spin-off product HSC1700 to the general market, many big companies have been keenly interested in and purchased the products. The hyperspectral camera is gradually creating a new market in many fields such as medical area, foods, manufacturing and inspection, and this success attracts the attention of not only mass media but also government. We are planning to set the HSC-I to the laboratory model, the HSC-II to the airborne sensor and the HSC-III to the spaceborne sensor. At the beginning of 2008, we started to develop a spaceborne small hyperspectral sensor "HSC-III" based on the optical design of the HSC1700.

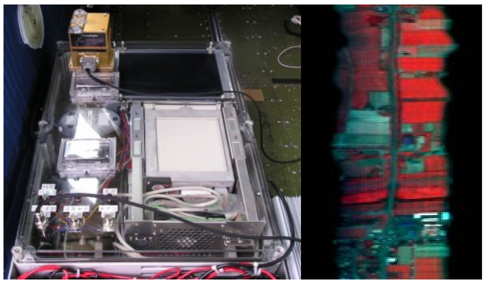

Figure 15: Airborne hyperspectral sensor HSC 1.5

Figure 16: Spin-off product model HSC1700

THE HSC-III INSTRUMENT

Outline of HSC-III

The key requirements of the HSC-III call for a GSD (Ground Sampling Distance) of 30 m, spectral range of 400-1000nm (VNIR: Visible and Near Infrared only) containing 61 bands of 10 nm resolution, SNR (Signal to Noise Ratio) of > 300, and an instrument mass of 10 kg [7]. The HSC-III employs push-bloom type image sensor with 20.6 km swath width. The HSC-III consists of the telescope, the spectrometer, and the mission data handling system, the on-orbital calibration equipment and IRU.

Table 5: HSC-III instrument capabilities

Item	Performance
Instrument mass	10 kg
Power consumption	10 W
Imaging type	Push-bloom method
Ground sampling distance	30 m
Swath width	20.6km
Field of view	1.8degrees
Telescope aperture	20cm
Wavelength range	400-1000nm (61 bands)
Spectral resolution	10 nm
Spectral calibration stability	< 0.25nm
Maximum input	Albedo 70%
SNR	> 300@620nm > 200@400-1000nm (Conditions: Albedo 30%)
MTF	> 0.2 @ Nyquist
Digitization	10bit
Mass memory	30 GB

Optics instrument

The telescope has a pupil diameter of 0.2 m, and has two mirror configuration of Ritchey-Chretien type. The spectrometer has the transmitting grating with the entrance slit and relay-lens unit, and array sensor using back-illuminated CMOS image sensor. The entrance light from the slit is dispersed by the grating onto the array sensor. A transmitting grating based spectrometer has capabilities of the design flexibility and miniaturization for the instrument. And it enables dispersion of entrance light into spectra of constant angle, so each spectral band width will become constant. The equipped transmitting grating is 50 mm long by 50 mm wide, 300 lines/mm grating frequency and approximately 75 % maximum efficiency, and the grating made of B270 glass. The entrance slit is 50mm long by 30μm. The schematic layout of the optics instrument, including the telescope and the spectrometer is shown in figure 17. For miniaturization the spectrometer is equipped with two folding mirrors.

A back illuminated CMOS image sensor based detector with quantum efficiency (QE) 85% (at 650 nm) is selected from INTEVAC. The detector is a commercial component, but has the advantage including 100 % fill factor, high-QE, low-read noise, low-dark charge, flexible ROI settings, and high-frame rate (230fps by using ROI).

A SNR performance was calculated for establishing the system design. The numerical model includes solar radiance model consists of a gray body at temperature of 5900K, zenith angle of 23 degrees and Kurucz model (2003) [8], and the sensor model. The data presented in Figure 18 are results of predicted SNR performance which is targeted at vegetation (grasses), soil (Alfisol) and albedo 30 %. From the numerical result, we can conclude that the peak SNR is higher than 300 at the critical wavelength range around 700 to 800nm for vegetation monitoring.

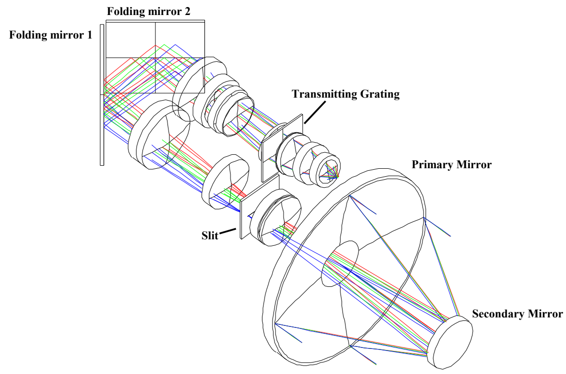

Figure 17: Optical layout for the HSC-III

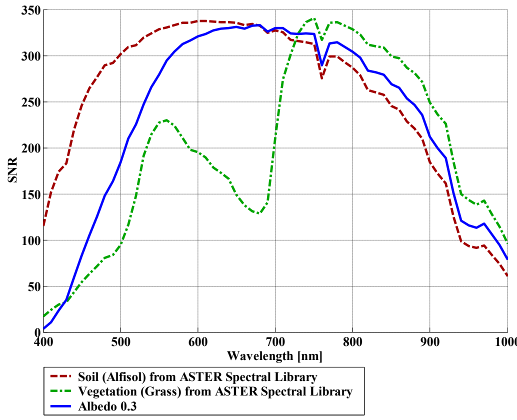

Figure 18: Predicted SNR performance

Breadboard model of the spectrometer

A BBM (Breadboard model) of the HSC-III spectrometer instrument based on the HSC1700 have been developed in 2008 founded by NEDO (New Energy Development Organization, Japan). The spectrometer is specified by the wavelength range from 400 nm to 1000 nm, 61 spectral bands and radiometric resolution of 10 bits. It is equipped with a CCD image sensor which has low-QE compared with the back-illuminated CMOS image sensor. The several spectral performances are summarized in Table 6 and Figure 20. The out-of-band power is defined as a ratio which is out-of-band radiance divided by input radiance, and the requirement is less than 20 %. The result of wavelength from 400nm to 800nm indicates sufficient performance. The performances of more than the wavelength of 800nm were not good. This is because the QE of the CCD image sensor and the spectral radiance of the halogen which was used for light source are reduced from approximately 800nm. The spectral band width is defined as FWHM (Full Width at Half Maximum), and requirement is 10 nm±1.5nm. The result for the spectral band width as function of wavelength is plotted in Figure 21. The result showed that the spectral band which has an average of 9.3nm was not significantly changed by the wavelength.

Figure 19: BBM of the HSC-III spectrometer equipped with CCD image sensor which has low-QE

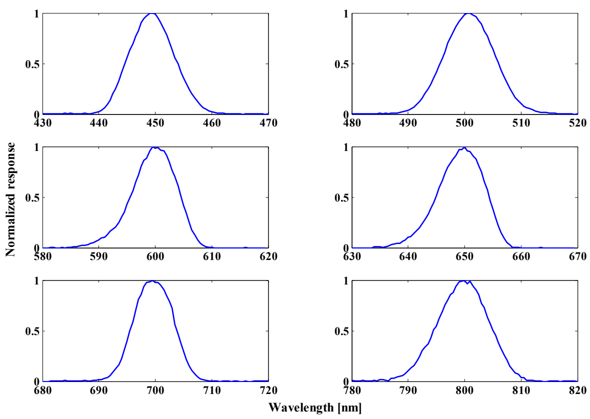

Figure 20: Normalized response of each band

Table 6: Spectral performances

Wavelength	Band width	Central error	Out of band power
400 nm	7.30 nm	+ 0.85 nm	7.38 %
450 nm	9.65 nm	-0.38nm	12.83 %
500 nm	9.40 nm	+0.40 nm	11.66 %
550 nm	9.35 nm	+0.85 nm	11.94 %
600 nm	9.10 nm	+0.15 nm	11.37 %
650 nm	9.10 nm	+0.65 nm	13.49 %
700 nm	9.25 nm	-0.38 nm	12.34 %
750 nm	9.70 nm	+0.05 nm	15.97 %
800 nm	8.90 nm	+0.75 nm	9.98 %
850 nm	10.95 nm	-0.63 nm	22.73 %
900 nm	12.40 nm	-0.40 nm	28.0 %

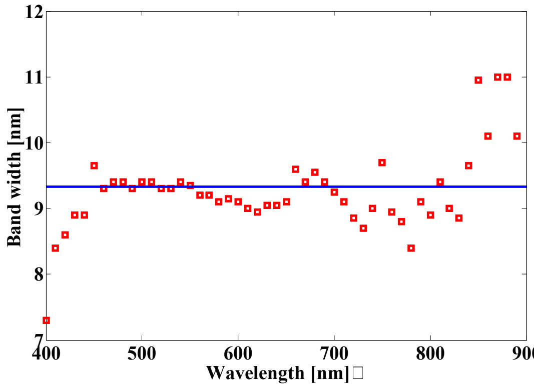

Figure 21: Spectral band width as function of wavelength

Mission Data Handling System

The block diagram of Mission Data Handling System (MDHS) is shown in Figure 22. MDHS mainly consists of two FPGA. The Space-Science Industries Program is suggesting that other satellites (including the TAIKI) carry the HSC-III. The interface between the sensor and the spacecraft requires high-flexibility. One of the FPGA is used for link to the spacecraft. The communication standard employs Space Wire which is being widely used on the space missions by ESA, NASA and JAXA. And, one of the FPGA is used for frame grabber board including the SDRAM of 896Mbytes.The frame rate needs constant speed to get the constant GSD because hyperspectral imaging method employs push-bloom technique. HSC-III has 30 m GSD, so it requires 235 frame rates. And data volume is 384Kbytes/image, required bit rate is 90Mbytes/seconds. Thus, the communication interface between detector and MDHU employs the Camera Link Standard. The Camera Link Standard uses 28bits to represent up to 24 bits of pixel data and 3 bits for video synchronous signals. The data transmission rates of the Camera Link up to 2.38Gbits/seconds support the required transfer speeds of hyperspectral data.

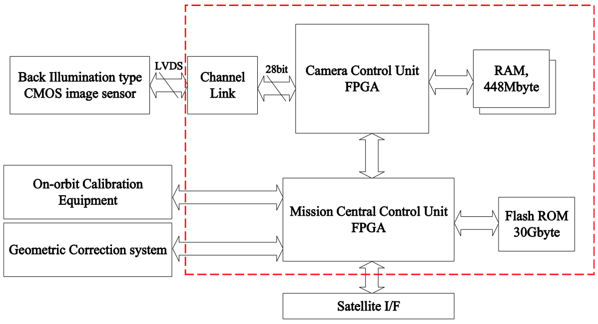

Figure 22: Block diagram of MDHS

On-orbit Calibration Equipment

It is crucial to consider the on-orbit spectral calibration technique of hyperspectral sensor as suggested previous work [9]. Hyperion and CHRIS have been calibrated by solar spectrum and atmosphere absorption bands [10]. On the other hand, these calibration processes are not enough accuracy that is required for hyperspectral sensor. To ensure high standard hyperspectral sensor should have subsystem for on-orbit calibration. The OCE (On-orbit Calibration Equipment) which is characterized by LED array has been proposed by our research. HSC-III will be equipped with the on-board OCE shown in Figure 23. For spectral and relative radiometric calibration provides visible LEDs, near-infrared LEDs and diffused panel in front of the entrance slit. The diffused panel provides three positions for observation, radiometric calibration, spectral calibration, inner calibration. In addition the locking mechanism is necessary in order to inhibit vibration by rocket. The OCE is also equipped with monitoring photodiodes for radiometric calibration of each LED. The wavelength shift of the especially near-infrared LED is approximately 0.2nm/K. In addition the required spectral accuracy is less than 0.25nm. As a consequence the absolute temperature of the LED array must be kept within ±0.5K. The LED array will be equipped with TEC (Thermocooler) unit which included thermo resistor and thermoelectric cooler (such as Peltier device) in order to spectral calibration stability.

This year the breadboard model of the OCE which mainly consists LED array and diffused panel was developed. It features six high-intensity visible LEDs and a near-infrared LED. In addition the OCE is equipped with a high intensity white LED for radiometric calibration. To diffuse the calibration light source the Spectralon panel is used.

The calibration accuracy by using OCE-BBM has been evaluated. The equipment layout is shown in Figure 24. By using OCE calibrated spectrum of the HSC-III spectrometer instrument (BBM). First of spectral calibration step calculates the relation between central wavelength of each LED and pixel number of targeted spectrometer by using Centroid method. And by the least-square method calculates cubic polynomial which is spectral calibration curve. The center wavelength of each LED was measured by other spectrometer which features spectral resolution of 0.1nm and wavelength range of 350 to 1150nm. For comparing spectral accuracy used mercury lamp and xenon lamp (Spectral line: 404.66nm, 435.84nm, 546.07nm, 579.07nm and 883.79nm). The OCE-BBM to central pixel of spatial direction can be calibrated with sufficient accuracy as can be seen from Figure 25. The each spectral residuals less than 0.03nm was depicted in the figure.

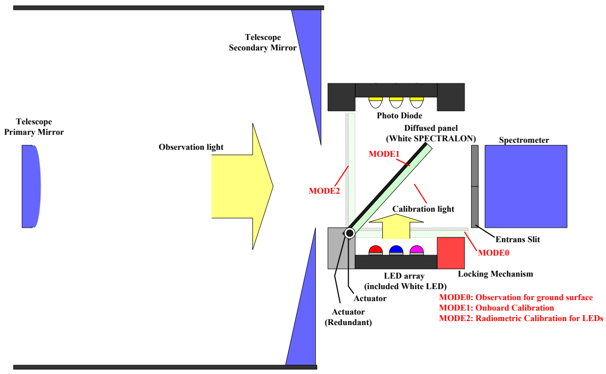

Figure 23: Schematic layout of the OCE

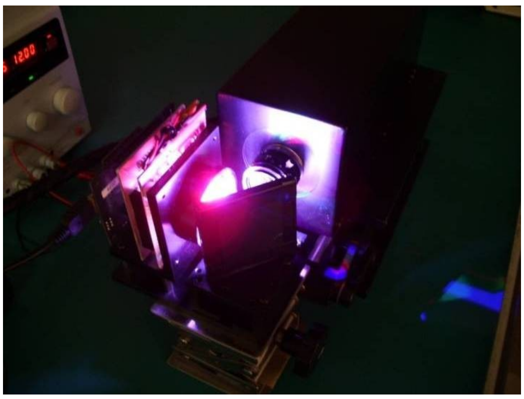

Figure 24: Overview of the spectral calibration by OCE for HSC-III spectrometer

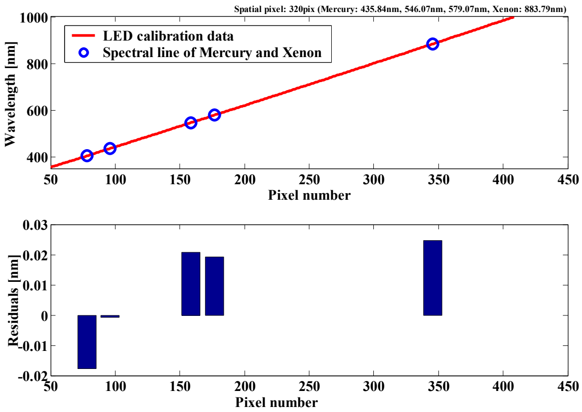

Figure 25: Residual compared with each spectral line (Central pixel of spatial direction)

CONCLUSION

This paper presented the TAIKI for demonstration of the Hyperspectral remote sensing micro-satellite. The satellite is developed based on the technology of in-orbit demonstrated bus-subsystems which consists of lots of introduction of technologies from COTS components. The attitude control is bias-momentum 3-axis stabilized system. To downlink high-volume data from the Hyperspectral sensor the satellite is equipped with a laser communication instrument in addition. The hyperspectral sensor HSC-III is targeted at 30m GSD, VNIR wavelength range and 300 SNR. We also have successfully developed breadboard model of the HSC-III spectrometer instrument, mission data handling unit and on-orbit calibration equipment. The Space-Science Industries Program is currently planning to initiate the Engineering Model (EM) Phase in 2009.

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