SSC13-IV-7

″Constellation of Earth Observation Micro-satellites with Multi-spectral High-resolution Telescopes″

Toshinori Kuwahara, Kazuya Yoshida, Yuji Sakamoto, Yoshihiro Tomioka, Kazufumi Fukuda, Nobuo Sugimura
Department of Aerospace Engineering, Tohoku University
Aramaki Aza Aoba 6-6-11, Sendai, 980-8579 Japan; +81(0)22-795-6991
kuwahara@astro.mech.tohoku.ac.jp

Junichi Kurihara, Tetsuya Fukuhara, Yukihiro Takahashi
Graduate School of Science, Hokkaido University
Kita 10 Nishi 8, Kita-ku, Sapporo, Hokkaido, 060-0810, Japan; +81(0)11-706-3567
kurihara@mail.sci.hokudai.ac.jp

ABSTRACT

Tohoku University and Hokkaido University have been developing a series of 50kg-class scientific micro-satellites for years. The first micro-satellite was the SPRITE-SAT successfully launched in January 2009 by Japanese H-IIA launcher, which had a mass of about 44 kg and was designed to observe Transient Luminous Events (TLE) in Earth upper atmosphere. SPRITE-SAT was given an operational name of RISING-1 after the launch. Following this satellite, two successor 50kg-class micro-satellites for constellational Earth observation with different types of observation instruments including 5m GSD multi-spectral High-Precision Telescopes (HPT) were initiated. These micro-satellites are namely RISING-2 and RISESAT. The flight model of the RISING-2 is ready for the launch planned in late 2013, and the development of RISESAT will be completed for the launch by the end of Japanese fiscal year of 2013. Both orbits are planned to be sun-synchronous Low Earth Orbit. These micro-satellites will be utilized for constellational Earth observation for planned mission life time of more than two years.

INTRODUCTION

The Space Robotics Laboratory of Tohoku University has been very active in the field of small satellite development for years. Tohoku University has successfully developed, launched, and operated its first scientific micro-satellite SPRITE-SAT (renamed as RISING-1 after the launch), CubeSat RAIKO, and is completing the second microsatellite RISING-2[1-3]. Tohoku University has also started developing a 50kg class international scientific micro-satellite named RISESAT (Rapid International Scientific Experiment Satellite) within the scope of a Japanese FIRST (Funding Program for World-Leading Innovative R&D on Science and Technology) program[4-6].

The characteristic aspect of these successor missions is that the each satellite carries a High-Precision Telescope (HPT) which is a Cassegrain-type telescope combined with Liquid Cristal Tunable Filters. The specifications of each HPT are summarized in Table 1. The focal length of both HPT is 1000m and can achieve 5m pixel resolution on ground in case the orbit altitude is 700km.

PAYLOAD INSTRUMENTS OF RISING-2 AND RISESAT

A picture of the flight model of RISING-2 and the engineering model of RISESAT is shown in Figure 1. The size of both satellites are about 500mm cubic. Black cylindrical instruments on both satellites in the picture are the HPT.

Table 1: Specification of High-Precision Telescope

Parameter	Value
Type of Optics	Cassegrain
Focal Length	1000 mm
Diameter	100 mm
LCTF Filters	RISING-2: 650-1050 nm RISESAT: I: 420-650 nm II: 650-1050 nm
CCD Resolution	5m @ 700 km
FOV	3.3 x 2.5 km
Exposure time	> 1/40000 s
Filter step size	1nm
Wavelength tuning period	10 – 300ms

Figure 1: RISING-2 flight model (left) and RISESAT engineering model (right)

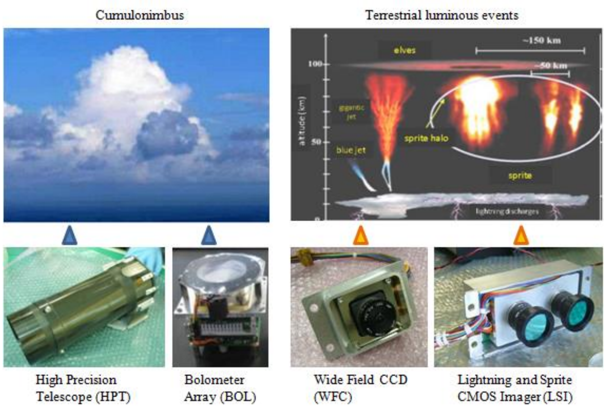

Figure 2: Payload instruments of RISING-2

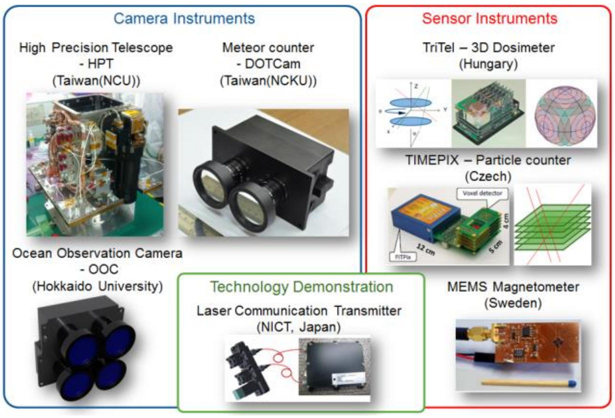

Figure 3: Payload instruments of RISESAT

RISING-2 Mission

RISING-2 carries an HPT with red, green, blue, and multi-spectral (LCTF) CCD sensors with 5m GSD, a bolometer array with 1km GSD, Lightning and Sprite CMOS Imagers (LSI), a Wide Field CCD Camera (WFC), and a VLF antenna. The HPT is equipped with a Liquid Crystal Tunable Filter (LCTF) with wavelength range of 650-1050 nm for the multi-spectral channel. By combining these instruments, scientific Earth observations such as stereoscopic observation of cumulonimbus clouds and TLE observation are planned.

RISESAT Mission

The development of the RISESAT was started in 2010, and the engineering model is under verification at the time of writing. RISESAT is an international scientific micro-satellite as a joint project of several Japanese and foreign institutions in Taiwan, Sweden, Hungary, and Czech Republic. RISESAT carries an improved version of HPT with 5m GSD, an Ocean Observation Camera (OOC) with 100m GSD in four wavelengths, a Dual-band Optical Transient Camera (DOTCam), a three-dimensional space dosimeter sensor TriTel, a particle counter TIMEPIX, and a magnetic field sensor μMAG. The HPT of the RISESAT has two LCTFs in 420-650 nm and 650-1050 nm. The specification of the above mentioned optical payload instruments are summarized in Table 2. The mechanical structure of each satellite, as well as their specifications are summarized in Figure 4 and Figure 5, Table 3 and Table 4, respectively. Both RISING-2 and RISESAT carry about 10 kg of payload instruments each which is about the 20% of the satellite total mass.

Table 2: Specifications of optical payload instruments of RISING-2 and RISESAT

Instrument	Satellite	Spectral Range	FOV (deg)	GSD@700km (m)
HPT (High-Precision Telescope)	RISING-2	RGB and NIR	0.27 x 0.20	5
	RISESAT	VIS and NIR		
BOL (Bolometer Array)	RISING-2	IR	48 x 36	900
WFC (Wide Field Camera)	RISING-2	Panchromatic	180 x 134	6700
LSI (Lightning and Sprite Imager)	RISING-2	765-830, 762 nm	29 x 29	700
OOC (Ocean Observation Camera)	RISESAT	405, 490, 555, 869 nm	5.6 x 4.2	100
DOTCam (Dual-band Optical Transient Camera)	RISESAT	623-750, 560 nm	22 x 16.5	400

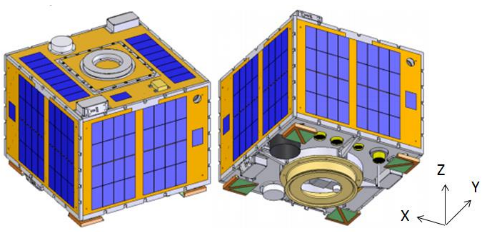

Figure 4: RISING-2 artist impression

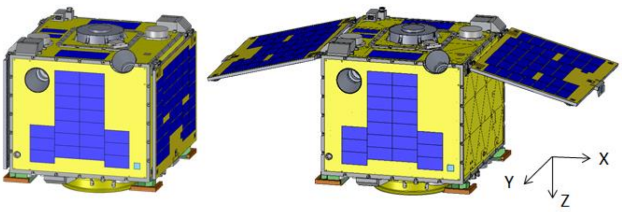

Figure 5: RISESAT artist impression

Table 3: RISING-2 system specification

Size and Weight at Launch	
size	W 500 x D 500 x H 500 mm
weight	41 kg
Orbit	
type	Sun Synchronous Orbit (SSO)
localtime	*undecided*
altitude	about 700-km circle (98-min period)
inclination	98 deg
Attitude Determination and Control	
type	3-axis active control by reaction wheels (no deployable mast)
sensors	star sensors, gyro sensors, sun sensors, magnetometers, GPS receiver
actuators	3 reaction wheels 3 magnetic torquers
Power	
solar cells	GaAs multijunction cell (24% efficiency) 8 series x 4 parallels x 4 panels (side) 8 series x 2 parallels x 1 panels (top)
batteries	9-cell NiMH (total 3.7AH, 10.8V)
power	42.0 W (avg. in 62-min sunshine per period)
power	28.4 W (at observation mode)
comsumption	7.8 W (at typical mode, no observation) 5.8 W (at power save mode)
Communication	
uplink	UHF, 1200bps at Sendai station, Japan
downlink	S-BAND, 0.1W, 38400bps max main: Sendai station, Japan sub: Kiruna station, Sweden sub: Thai station, Thai

Table 4: RISESAT system specification

Size and weight	
size	Smaller than W 500 x D 500 x H 500 mm
weight	Max. 60. Typ. less than 55 kg
Orbit	
type	Sun Synchronous Orbit
local time	9:00-15:00 (Default LTDN 11:00)
altitute	between 500 – 900 km
inclination	approx. 98 deg
Attitude determination and control	
method	3-axis stabilization
pointing accuracy	< 0.1° (3σ) (Reqs.), < 0.04° (3σ) (Objectives)
pointing stability	6"/s for 200ms
sensors	star sensor (2), FOG (3-axes), magnetometer (3-axes), GPS receiver (1), course and accurate sun sensors(4π)
actuators	reaction wheels (4) magnetic torquers (3-axes)
Power supply	
solar cells	GaAs multijunction cell 10 series x 5 parallel x 3 panels (Deployanble panels and one body panel) 10 series x 1 parallel + 10 series x 2 parallel
battery unit	9 series x 2 parallel NiMH (3.7Ah, 18V)
max. power generation	> 100 W
max. power consumption	> 50 W
Communication	
command uplink	UHF, 2400bps at Sendai station, Japan
HK downlink	S-Band, 0.1W, 38400pbs – max. 500Kbps main: Sendai station, Japan sub: Fukui Univ. of Tech. station, Japan sub: Kiruna station, Sweden
Mission Data downlink	X-band, max. 2.45Mbps main: Fukui Univ. of Tech. station, Japan sub: Sendai station, Japan

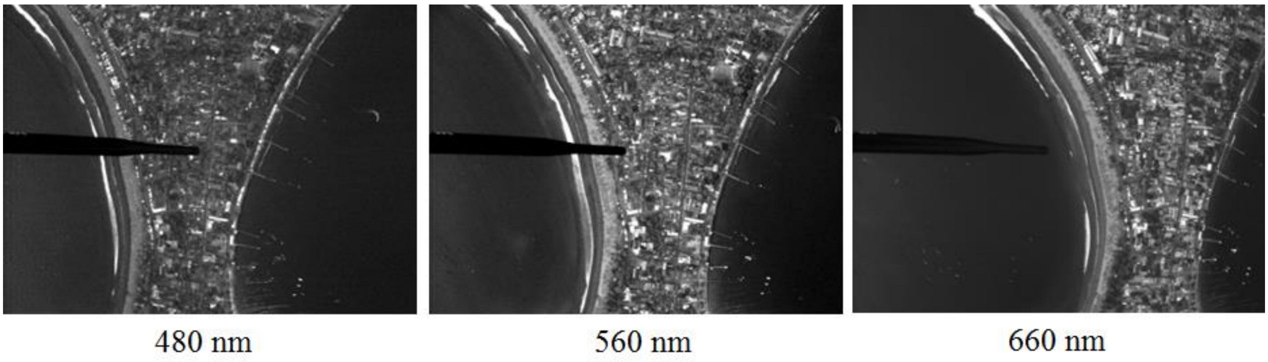

Figure 6: Sample images taken with LCTF and the same CCD sensor in indicated three different wavelengths, taken by an UAV. A ground pixel resolution of 5m is reproduced by post image processing.

APPLICATIONS

Micro-satellites are potentially suitable for constellational observation, because they can be built in shorter periods with lower costs compared to larger satellites. Though micro-satellites have limitations in available size, mass, power, data transmission rate, attitude control capability, etc. recent technological advance enables improvements in spectral, spatial, temporal, and radiometric resolutions of observation data. Especially, constellational Earth observation can achieve higher global coverage with higher temporal resolution. In usual cases, constellational satellites have the same on-board instruments. The RISING-2 and RISESAT, however, forms a constellation by utilizing different kinds of multiple on-board instruments to complement spatial resolution and spectral range of particular areas of interest on Earth. Characteristics of each optical instrument are elaborated in following sections. The application fields of RISING-2 and RISESAT payload instruments are summarized in Figure 7.

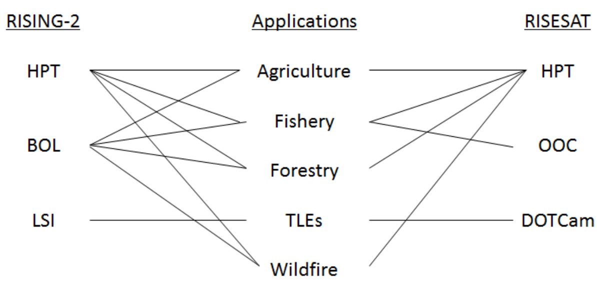

Figure 7: Application fields of RISING-2 and RISESAT payload instruments.

High Precision Telescope

HPT (High Precision Telescope) is a multi-purpose optical instrument utilized for a wide variety of Earth and astronomical observations. HPTs installed on both satellites have similar spatial resolutions but different spectral ranges. Both HPT use a Cassegrain telescope with 10-cm diameter and 1-m focal length and can observe the Earth surface with 5-m GSD. HPT on RISING-2 has four sensitive CCDs as detectors, and three of them are allocated to Red/Green/Blue bands to make color images. The other CCD is for multispectral observations in the near-infrared region (650-1050 nm) using a Liquid Crystal Tunable Filter (LCTF). On the other hand, HPT on RISESAT has two CCDs with two LCTFs for the visible (420-650 nm) and near-infrared (650-1050 nm) regions. LCTF can electrically change the center wavelength to transmit the light in a unit of 1 nm. This means LCTFs have 230 and 400 bands for visible and near-infrared regions, respectively. Multispectral observation with LCTF is comparable to hyperspectral observation in the number of spectral bands and more suitable for microsatellites on many aspects. LCTF makes it easy to downsize an optical instrument and reduce the data amount by selecting necessary spectral bands for imaging. Color images of an area of interest obtained by HPT on RISING-2 can be more spectrally resolved in visible region by HPT on RISESAT.

Bolometer Array

BOL (Bolometer Array) on RISING-2 is an uncooled bolometer array camera, which can detect the light of 8-14 μm in thermal infrared region. Thermal distribution measured by BOL is useful for monitoring the surface temperature of land and ocean, especially for wildfire detection from space. A suspected area of wildfire detected by BOL on RISING-2 can be identified with high spatial resolution in visible region by HPT on RISESAT. The detailed information on the wildfire location allows firefighters to rush immediately into the area in a large forest. The coordinated observation by HPT on RISESAT has another advantage to complement relatively high power consumption of 8.4 W by BOL on RISING-2.

LSI and DOTCam

LSI (Lightning and Sprite Imager) on RISING-2 and DOTCam (Dual-band Optical Transient Camera) on RISESAT are specialized for observations of Transient Luminous Events (TLEs), such as sprites and elves above thunderclouds. LSI on RISING-2 consists of two cameras with different optical filters, narrow (762 nm) and broad (765-830 nm) band pass. The camera equipped with the narrow filter is designed to detect high-altitude TLE emissions by minimizing contamination from low-altitude lightning emissions, while the other camera with the broadband filter is able to measure both emissions. These cameras are directed to the nadir from the satellite and take images from straight above a thundercloud. DOTCam on RISESAT also has two cameras with different band pass filters, narrow (560 nm) and broad (623-750 nm). Unlike LSI on RISING-2, these filters are designed only to measure high-altitude TLE emissions of different atmospheric species and hence the two cameras need to view the Earth’s limb direction. A combination of the nadir viewing by LSI on RISING-2 and the limb viewing by DOTCam on RISESAT provides valuable information on the three-dimensional structure of TLEs that is important for understanding the spatial and temporal evolutions of lightning and TLEs.

Ocean Observation Camera

OOC (Ocean Observation Camera) on RISESAT is developed to conduct high spatial resolution observations of CDOM (Colored Dissolved Organic Matter), which has a significant impact on aquaculture in coastal sea area. The four spectral bands (405, 490, 555, and 869 nm) are selected for CDOM observations by OOC. The observation by the four bands makes it possible to derive important parameters such as chlorophyll-a and suspended materials other than CDOM. If the distribution of the sea surface temperature in a target sea area is measured by BOL on RISING-2, the observation result of OOC can extend applications more generally to aquaculture and coastal environment analyses.

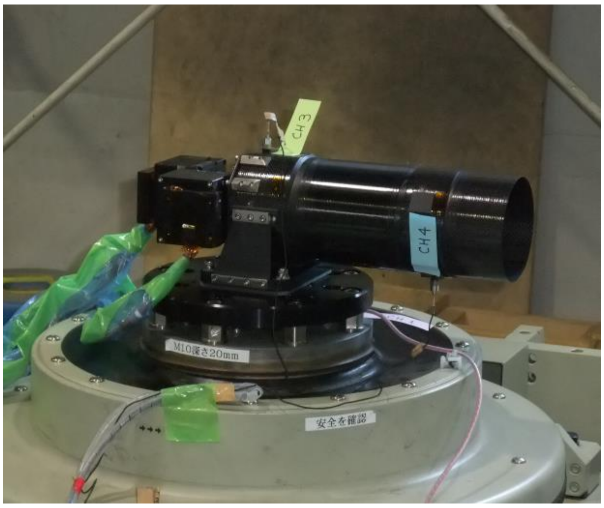

Figure 8: Qualification vibration test of HPT.

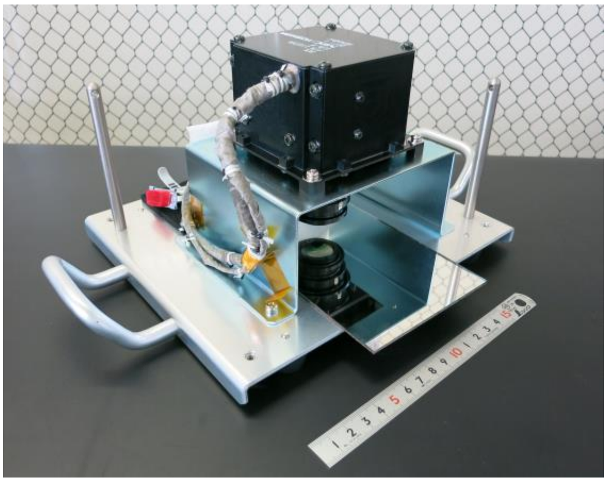

Figure 9: Flight model of Bolometer Array.

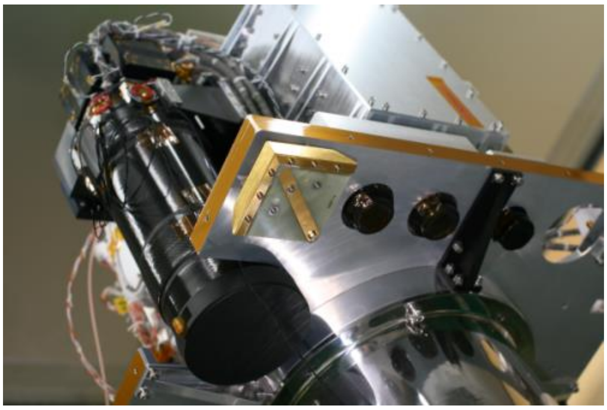

Figure 10: Flight model of RISING-2: camera heads of HPT, LSI, and WFC from the left to right.

INSTRUMENT QUALIFICATIONS

The flight models of the payload instruments of RISING-2 were qualified for the planned launch by Japanese launch vehicle H-IIA in 2013. The satellite flight model is now under final acceptance tests at the time of writing. Some pictures of these are illustrated in Figure 8, Figure 9, and Figure 10. The RISESAT engineering model is now under qualification tests, and the flight model will be manufactured by the end of March 2014, by taking the results of engineering model qualification tests into account. The flight model of RISESAT will become ready for launch in 2014. The detailed launch opportunity for RISESAT is still under arrangement.

SATELLITE OPERATION

The operation of these satellites will be conducted at the Tohoku University's ground station in Sendai, Japan as the main commanding station, together with supporting receiving ground stations in Fukui in Japan, and Kiruna in Sweden. Data downlink of RISING-2 is done via S-band frequency, and that of RISESAT is done in S-band, X-band, and also laser data-downlink channel.

CONCLUSION AND OUTLOOK

This paper described the scientific payload instruments aboard the micro-satellites RISING-2 and RISESAT, as well as the mission objectives of constellational Earth observation especially by means of their optical payload instruments. Detailed information about the specifications of the satellite systems and payload instruments were provided. RISING-2 and RISESAT are both planned to be launched in low Earth sun-synchronous orbits and aim to conduct constellational Earth observations in the fields of agriculture, fishery, forestry, wildfire, planetary physics, and possibly more. Combinational use of different types of on-board instruments will be utilized to complement spatial resolution and spectral range of particular areas of interest on Earth to provide valuable data set for scientific Earth observations and technical investigations. Instruments for RISING-2 were fully qualified, and those for RISESAT are arranged as international collaborative missions, which will be qualified and whose flight models are manufactured in Japanese fiscal year of 2013. The obtained payload data is planned to be partly opened to scientific communities.

ACKNOWLEDGMENTS

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

REFERENCES

1. Y, Takahashi, K, Yoshida, Y, Sakamoto, and T, Sakanoi, "SPRITE-SAT: A university small satellite for observation of high-altitude luminous events," Small Satellite Missions for Earth Observation: New Development and Trends, Springer, Feb. 2010, pp.197-206.
2. T. Kuwahara, Y, Sakamoto, K, Yoshida, Y, Takahashi, T, Fukuhara, and J, Kurihara, "Mission and system of the Earth observation microsatellite RISING-2," Proceedings of 8th Symposium on Small Satellites for Earth Observation, Berlin, April 2011, pp.512-519.
3. K. Fukuda, T. Nakano, Y. Sakamoto, T. Kuwahara, K, Yoshida, and Y, Takahashi, "Attitude control system of micro satellite RISING-2," Proceedings of 8th Symposium on Small Satellites for Earth Observation, Berlin, April 2011, pp.206-213.
4. K, Yoshida, Y, Sakamoto, T, Kuwahara, and Y, Takahashi, "A series of 50kg-class micro-satellites for advanced science missions," Proceedings of 8th Symposium on Small Satellites for Earth Observation, Berlin, April 2011, pp.99-106.
5. T. Kuwahara, K. Yoshida, Y. Sakamoto, Y. Tomioka, and K. Fukuda, "Satellite System Integration based on Space Plug and Play Avionics," System Integration (SII), 2011 IEEE/SICE International Symposium, 2011, pp. 896-901.
6. T. Kuwahara, K. Yoshida, Y. Sakamoto, Y. Tomioka, K. Fukuda, M. Fukuyama, Y. Shibuya, "International Scientific Micro-satellite RISESAT based on Space Plug and Play Avionics," Proceedings of 26th Annual AIAA/USU Conference on Small Satellite, Logan, Utah, USA, August, 2012.