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WNISAT - Nanosatellite for north arctic routes and atmosphere monitoring

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ABSTRACT

WNISAT is a 10kg weight nanosatellite of the sun-synchronous low earth orbit, currently being developed by Weathernews Inc. and AXELSPACE, and waiting for the launch with PSLV of India until the year of 2011. Weathernews Inc. is the largest private weather service company headquartered in Japan, which have many sea liners as their customers. Currently, the north arctic ice region reaches the lowest level every year, and sea liners have great interest for this because the north arctic routes means very short distance compare to other routes. Many approaches have been suggested for the monitoring of north arctic routes, and constellation of small satellites is one of the best ways considering efficiency. From this reason, Weathernews Inc, decided to develop small satellites in close collaboration with AXELSPACE. AXELSPACE is a university venture company established in 2008, all engineers have considerable experience in the field of small satellites of nano-class through many projects of their universities. There are two major missions for WNISAT, the first mission is earth observation of commercial use as like explained already. It is challenging to provide with the ice coverage information over high latitude oceans including NIR spectral ranges. And the second mission is atmosphere monitoring for environmental issue, the density of carbon dioxide in atmosphere using a laser application. The bus system of spacecraft and the first mission development are being led by AXELSPACE. The laser application for the second mission is under development by Weathernews Inc. The object of this WNISAT is to show the feasibility of nanosatellite for two major missions, especially the commercial use of small satellites of nano-class. After this WNISAT, several satellites are scheduled for the practical and commercial use within three or five years. At first, this paper will review progress in the development of WNISAT. And, the entire structure of spacecraft and the sub-systems are presented for the review and the detail explanation. After that, it will review the relevance of WNISAT's technology to advanced sensing concepts, reliable and efficient remote sensing and issues of atmospheric carbon dioxide content monitoring. Finally, future schedule after WNISAT is also briefly presented.

1. INTRODUCTION

The Earth shows huge climate changes now, and the changes make remarkable effects in the many places. One of the places is north arctic ocean, its ice region reaches the lowest level every year with the global warming. It has many controversial subjects for the environmentalist, but opens a new route for the sea liners with very short distance. The distance is depends on the route, but the new route could be 5000 to 8000 kilo-meters shorter compared to the traditional route between Asia and Europe. The shorter distance means saving the cost of the delivery time and the fuel consumption. And, its low fuel consumption means low emission of fossil gas, such as CO_2, for the environmental issue also.

On this new route of the north arctic sea, frequent monitoring is essential to the security of vessels. And, many approaches are investigated including satellite services using the big satellite.[1][2] However, there is widespread support for using small satellites to perform remote sensing of the north arctic sea. Small satellites are considered as a solution to perform remote sensing of the Earth with high efficiency because of the low cost. In practice, the performance of one small satellite is strictly limited compared to the big satellite of conventional design. But with the low cost, it is easy to provide constellation service of multiple satellites.[3][4] This constellation service can supports continuous remote sensing information about the target place. Weather news Inc. has many customers of sea liners already, and the customized information of ice region of north arctic sea will be provided through the global ice center of Weather news Inc.

Besides of this first mission, Weathernews Inc. want to provide environmental monitoring service also, especially about the density of CO_2 gas. A laser application is under development by Weathernews Inc. to emit laser pulses with specified frequency. On the ground, the decayed amplitude of the laser is monitored to measure absorbed quantity through the atmosphere. The density of CO2 gas can be calculated from this absorbed laser. This monitoring will be performed by not only Weathernews Inc. but many supporters also as an open project.

To achieve significantly reduced cost, AXELSPACE develops a nano-class satellite of the weight of 10kg. Even the size and weight is small, the performance of satellite is enough to the object of two missions without radical approach to design. Actually, the satellite has typical functions as a satellite with high efficiency. WNISAT will be launched using the piggyback service of PSLV, India. After launching, the satellite is tested about feasibilities for two missions, and the information of this first satellite will be used to the next satellites of the practical and the commercial use.

In the next section, the specification about two missions of WNISAT is introduced including the mission object and the orbit information. On the section 3, the design of satellite is explained with each sub-system. On the section 4, several current control algorithms are explained briefly. Finally, the progress of development is explained on the chapter 5 with conclusion.

2. MISSIONS OF WNISAT

The first mission of WNISAT is monitoring of ice region of north arctic ocean. The target area is different with the season, usually 70 ~ 80 degrees of north will be monitored in the summer season, and 40 ~ 50 degrees of north in the winter season. Not only the visible spectrum of RGB, but the infrared spectrum will be used for the image of monitoring. For the information to the vessels, wide area image is needed, The mission cameras of WNISAT is designed to cover 500km×500km. The ground sample distance is not so critical, about 500m ground sample distance is enough for this mission. The field of view of camera is not narrow with current design, the $56.4^\circ \times 46.4^\circ$ field of view is considered for the each camera of the first mission.

For the security of route, frequent monitoring is required. Considering the size of image and the downlink speed, 10 photos can be acquired for one day. From the shooting to the downlink of the photo, there is some time gap. It is hard to say how much time gap is expected for this satellite because the condition of the path and the downlink condition are different every time. Using rule of thumbs, we expect to gather a photo after half day from the shooting.

Table 1: Brief specification of the north arctic ocean monitoring mission

Item	Specification	Remark
Spectrum range	NIR, R, G, B	
Monitoring area	500km ×500km	
Ground sample distance	500m	
The number of acquired photos	10photos/day	
Time gap	About the half day	Depends on the condition

Because the required resolution of the image is not so high, it is not necessary to use a radical approach to design. However, at the same time, we must accept that there will be additional engineering constraints on small satellites of nano-class that do not exist on large conventional spacecraft, imposed by the limited resources, such as available electrical power. For these reasons, we are going to use minimum control effort to control attitude of satellite for this arctic sea monitoring.

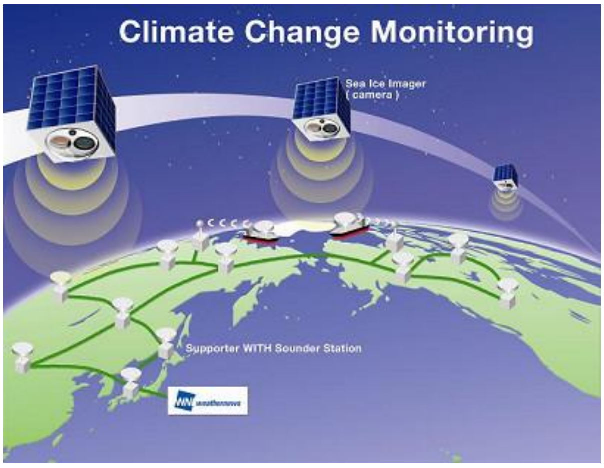

Figure 1: Mission of north arctic sea monitoring

The density of CO2 gas has deep relation with the climate changes. WNISAT provides laser emission to monitor this density of CO2 gas. Emitted laser of specified frequency is decayed in the atmosphere according to the distance and the density of CO2 gas. Considering the absorbing rate and the development efficiency, the laser of wave length about 1.5um is used for this mission. Several projects have been performed already for this purpose. However, those missions are a kind of closed missions of big satellites. This secondary mission aims for an open project for the environmental issue. For this purpose, the emission information is completely opened, and many supporters are going to join this project especially with academic purpose.

Table 2: Specification of the laser emission mission

Item	Specification	Remark
Wavelength of laser	1570nm, CO_2 target 1556nm, reference	
Output power of laser	500W ~ 5kW	Changeable
Pulse frequency(PRF)	500Hz ~ 10kHz	Changeable
Pulse width	1 ~ 999 usec	Changeable

The mission requirements of this laser emission mission differ from the north arctic sea monitoring mission. Perhaps the most obvious difference is requirement about the accuracy of attitude control. Emission angle of the laser is expected with the about 0.5degree. And, the fast speed of satellite makes the very short measurement time about 1.5 seconds. From these aspects, the accuracy of attitude control is required to be better than 0.1deg.

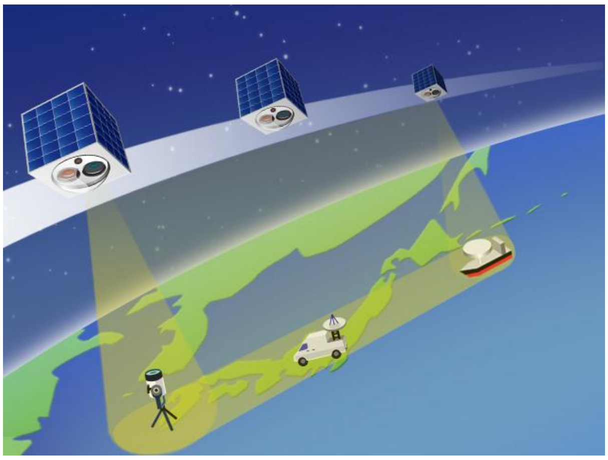

Figure 2: Schematic of the laser emission mission

From these requirements of missions, the orbit condition is determined at first. About the altitude of the orbit, it should be from 600km to 700km. And, shooting time of the north arctic sea monitoring mission and the measurement time of the laser emission mission need that the LTDN(Local Time Descending Node) should be from 9:00 to 15:00.

Like many other small satellites, WNISAT uses piggyback service for the launch not as a main satellite. From this, available orbit is very limited with the time and chance. For this WNISAT, we are going to use PSLV of India. Using the service of PSLV, WNISAT is expected to be launched until the year or 2011. Currently, the expected orbit condition is as like below.

Table 3: Expected orbit condition

Item	Specification	Remark
Type	Sun Synchronous	
Altitude	670km	
LTDN	10:00	

3. SPECIFICATION OF WNISAT

For the attractions of nano-class satellites, AXELSPACE uses following principals to the design of WNISAT.

- Simple architecture
- Aggressive use of COTS(Commercial Off The Shelf) devices
- Practical reliability
- Compact design
- Easy operation

Because of harsh environment of space, conventional design of satellites uses complex design for the enough redundancy. It increases the number of parts dramatically with very high cost on the development of satellites, and sometimes makes it very hard to keep efficient design also. As a small satellite, WNISAT aims for the simple design with small number of parts. With the same reason, we used COTS devices for the design as many as possible, not the specialized parts of space industry. The devices are examined before the design to provide practical reliability of WNISAT. It is also important for us to keep the compact design avoiding waste of resources of satellite. And, WNISAT is a commercial satellite not just academic use, we aims for the design of easy operation considering customers.

At the first, on the table 4, we introduce main specifications of WNISAT.

Table 4: Main specification of WNISAT

Item	Specification	Remark
Mass	10kg	
Size	27cm×27cm×27cm	Excluding the boom
Expected life time	2 years	
Downlink	UHF, GMSK, 4.8kbps ~ 38.4kbps	

Uplink	UHF, GMSK, 9.6kbps	
Data storage	2Gbytes	
Electrical power generation	About 12.6W	without the attitude control
Battery	Lithium-Ion, 3.8V, 7700mAh	
Attitude control	3 axis attitude control	
Sensors	3 axis magnetometer 3 axis gyroscope 4 sun sensors 2 star trackers(STT) 1 GPS	
Actuators	3 axis magnet torquer 4 reaction wheels	
Accuracy of attitude determination	30arcsec(with STT) 2~3degree(without STT)	
Accuracy of attitude control	Better than 0.1degree (with reaction wheels) 3~5degree (without reaction wheels)	

WNISAT uses integrated architecture for the bus system to simplify the design with reliability. One main OBC(On Board Computer) manages all peripheral instruments including the sensors and the actuators. However, separated mission controller is installed to manage mission system for the both of missions. This architecture provides flexibility to the design of satellites even for the next project.

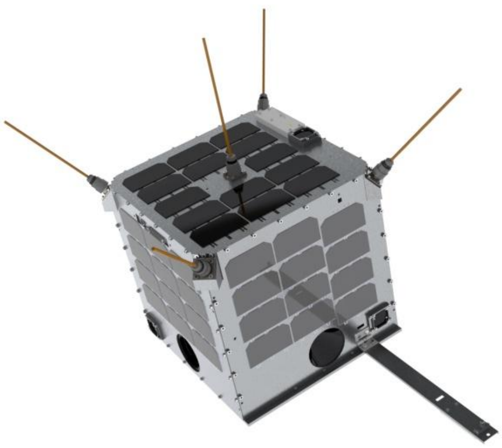

Figure 3: WNISAT

Mission system

There are two missions for the WNISAT. One is the monitoring of north arctic sea about the ice region. The other is laser emission to measure the density of CO2 gas in the atmosphere. These missions are performed with separate control unit from the bus system. Figure 4 shows simplified block diagram of mission system.

The mission system has different power source (battery) also, not just different FPGA device for the control unit. The mission controller manages the two mission cameras and a laser unit following the command from the bus system.

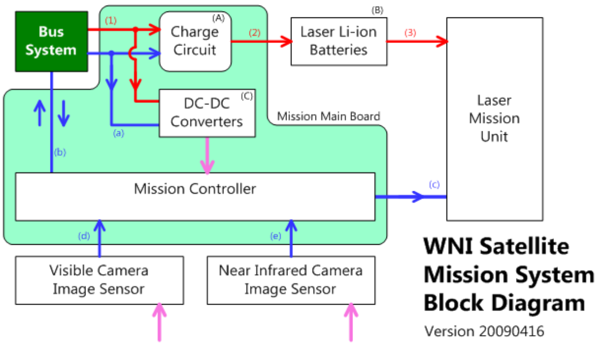

Figure 4: Block diagram of mission system

For the first mission of north arctic sea monitoring, mission controller manages two cameras. One is for the visible light spectrum, another is infrared light spectrum. Both of cameras use the same CMOS image sensor of IBIS5-B-1300. And, the same lenses which have 8mm focal length are used for both cameras. The F number of lens can be adjusted from 1.4 to 16.

Figure 5: M0814-MP Lens for mission cameras

Table 5: Specification of IBIS5-B-1300

Item	Specification	Remark
Pixels	1280×1024	
Pixel size	6.7um×6.7um	
SN ratio	64 dB	
Dark current	7.22 mV/s	
Size	2/3”	
Frame rate	27 fps	

Shutter mode	Snapshot/Rolling	
Power consumption	175 mW	

The figure 6 shows a single laser emission unit. Actually, multiple laser emission units are assembled with amplifier to get enough power.

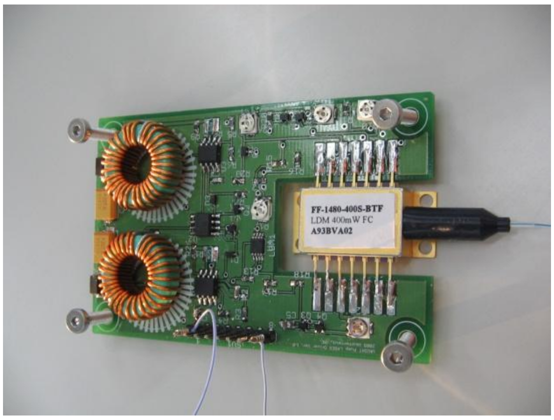

Figure 6: Laser emission unit

C&DH(Command and Data Handling)

The figure 7 shows simplified block diagram of bus system. The main processor uses advanced commercial FPGA(Field Programmable Gate Array). This processor is not radiation hardening, but examined many times internally about the SEU(Single Event Upset) and the SEL(Single Event Latchup). The only satisfied devices for the reliable operation on the low earth orbit are used for the design of satellite. This is same with other electronic devices. Besides these SEU and SEL, every electronic devices are examined about TID(Total Ionizing Dose) to guarantee the life time of two years on the low earth orbit.

For the safety, additional small processor of PIC is installed separately. The PIC processors have been used as a main processor in the many previous projects. It shows enough reliability against the harsh environment of low earth orbit, especially about the radiation. This PIC processor monitors periodically the status of main processor of FPGA, and the information from the receiver is shared with FPGA using multiplexer. From these, PIC processor resets the FPGA when the critical fault is occurred in the main OBC. The reset can be performed automatically or manually according to the situation.

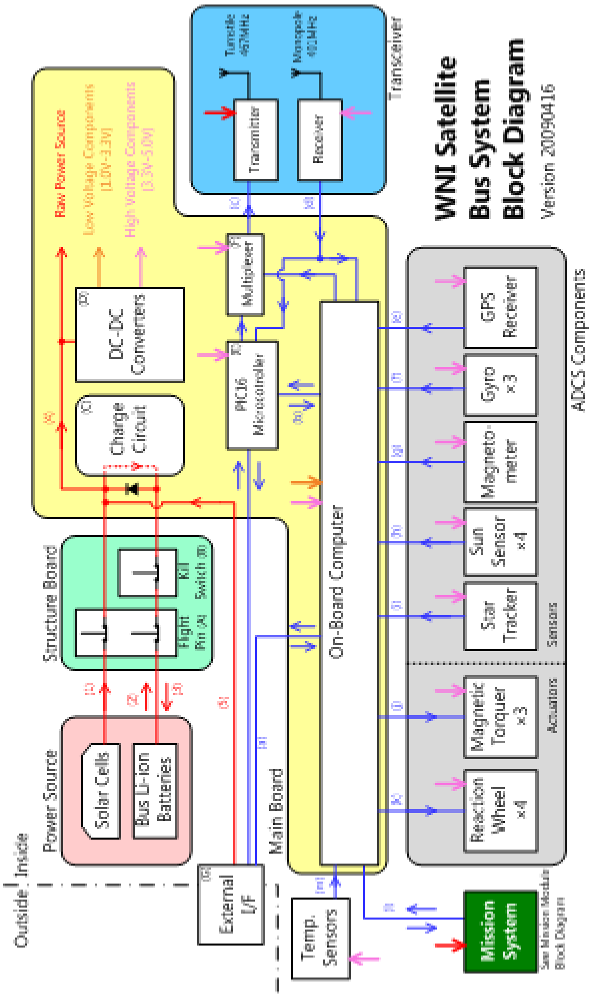

Figure 7: Block diagram of bus system

Power

Solar cells of five surfaces of satellite and lithium-ion batteries are used for the power system. The two types of solar cells are used for the electrical power generation. On is improved triple junction cell with conversion efficiency of 26.8%, the other is ultra triple junction cell with conversion efficiency of 28.3%. Because of the limited budget, ultra triple junction cells are used on the –Z surface only. The other surfaces are covered with improved triple junction cells excluding +Z surface. When the attitude control works properly, this +Z surface looks the earth with nadir. The power to be generated is about 12.6W in sunshine without attitude control. The lithium-ion batteries with capacity of 7700mAh are used as 10-parallel sets of 1-series cells. DOD(Depth Of Discharge) is expected to be 17.9%. The charging circuit is a circuit of constant current/constant voltage charging. The unregulated voltage are converted using DC/DC converter to the regulated +5V, +3.3V. Against the single event latchup, each power lines have the fuse to protect the circuit from the overcurrent.

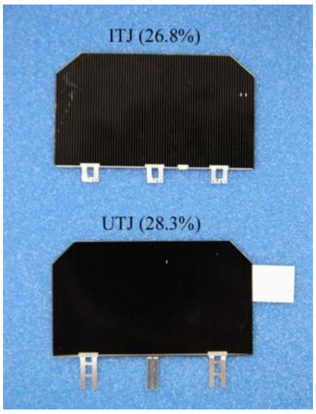

Figure 8: Solar cells

Communication

Simple and inexpensive devices are used for the communication subsystem of WNISAT. The frequency of communications is UHF. There are 5 antennas for the communication. 4 antennas around the –Z surface are for the transmission from the satellite, and 1 antenna is for the receive function from the ground station to the satellite. This design of antenna provides the stable communications even the attitude control does not work properly, and minimizes the shadow effect to the solar cells. Main ground station will be operated by Weathernews Inc. at the Makuhari. Also, AXELSPACE supports the operation using different ground station.

Table 6: Specifications of communication system

Item	Uplink	Downlink
Frequency	UHF	UHF
Type	GMSK	GMSK
Speed	9.6kbps	4.9/9.6/19.2/38.4kbps
Power consumption	N/A	3W(Max)

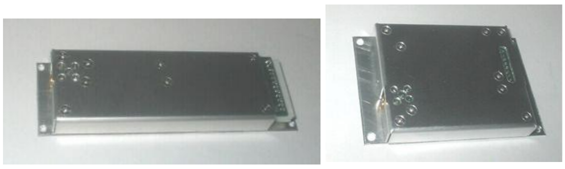

Figure 9: Transmitter and Receiver

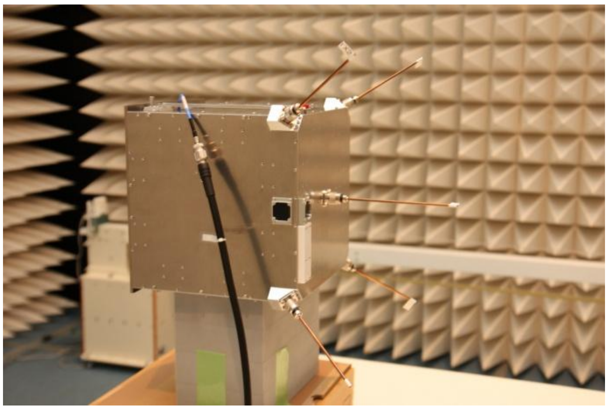

Figure 10: The antenna pattern test

Structure

The structure uses aluminum for the main material. The installment design of each device is very compact, and every device uses optical measurement device to calibrate the install angle. Especially main sensors are installed with error angles below 0.1 degree. About the thermal control design, active method is not used to solve thermal control problem. However several devices and surfaces are treated with specified paints following heat transfer simulation. Entire satellite structure is examined about the vibration condition required from the rocket.

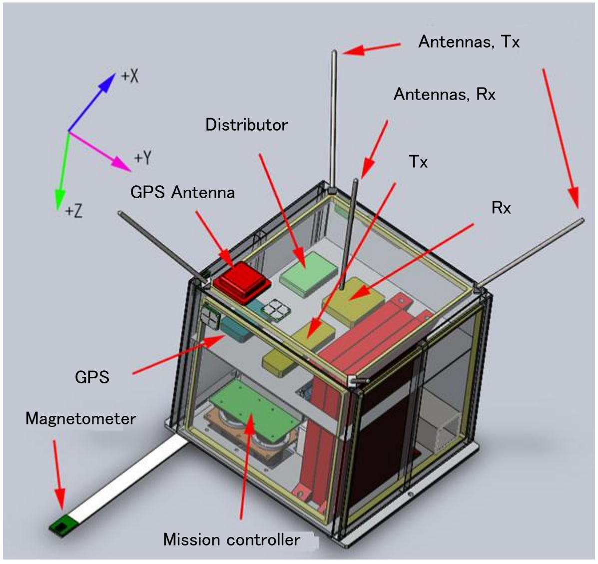

Figure 11: Simplified structure diagram

Attitude determination and control system

The attitude control system of WNISAT is zero momentum three axis control system. This attitude control system can achieves better than 0.1 degree for the maximum accuracy of attitude pointing. The sensors for attitude control are four sun sensors, two star trackers, three axis magnetometer, three axis gyroscope, and GPS. For the actuators, three magnetic torquers and four reaction wheels are used.

- Sun sensors

Two dimensional position sensitive detector(PSD) is used for the sun sensor. Each sun sensor has thin plate with small hole for the screen on the sensor. The field of view is ±45 degree.

- Star trackers

The star tracker used for this WNISAT is developed by AXELSPACE. It has light weight for small satellites, below 0.5kg. The star trackers detect stars brighter than magnitude six, and compute the attitude compared with the data of star catalogue. When multiple star trackers are used for a satellite, Star trackers are operated as like master-slave, and master star tracker compute averaging quaternion automatically with the data of slave star trackers. This averaging quaternion satisfies Whaba's condition as the optimal attitude determination. There are two types of star trackers because of mechanical constraints. The only difference is mechanical hood which blocks the disturbance light. The star tracker of short hood has very compact size, but it is easy to disturbed by sunlight or other external light such as albedo. The long hood has much better optical characteristics, but it has longer size and slightly heavier than short hood. Currently, the star tracker is developed for the WNISAT, and it is provided as the commercial products with low price also, name of AXELSTAR. The performance of AXELSTAR is under enhancement including various interface protocols.

Table 7: Specification of AXELSTAR

Item	Specification
Mass	0.41kg(Short hood), 0.47kg(Long hood)
Supply voltage	5V
Power consumption	Idle mode : 50mW Waiting mode : 0.8W Shooting mode : below 1.8W
Interface protocol	3.3V SPI
Data update	1 Hz
Output data	Quaternion, Direction cosine matrix Error covariance matrix
	Star information(Tangent values of Azimuth and Elevation, Hipparcos ID) Image of black and white (1024×1024)
Operational temperature range	-20℃ ~ 50℃
Field of view	8° × 8°
Magnitude of stars	Above 6
Sun angle of disturbance	80° (Short hood) 35° (Long hood)
Maximum error	30 arcsec, 3σ (Y, Z axis) 0.2°, 3σ (X axis)

Figure 12: Star trackers developed by AXELSPACE

- Magnetometer

The earth magnetic field is very useful information especially for the satellite on the low earth orbit. WNISAT uses HMC1001/1002 magnetic sensor of Honeywell corporation for the three axis magnetometer. Avoiding residual magnetic field of the satellite, this magnetometer will be deployed by the boom on the orbit. The distance between the satellite and the magnetometer is 0.22m, which is enough to measure earth magnetic field without consideration of residual magnetic field of satellite.

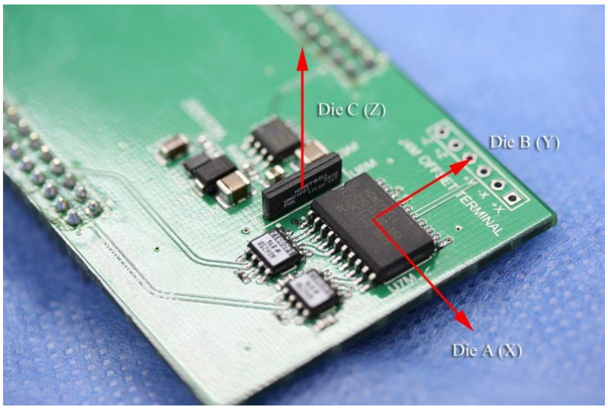

Figure 13: Magnetometer

➢ Gyroscope

WNISAT uses three gyroscopes for the measurements of angular velocity. Originally, we had many candidates, and have performed examination of accuracy, bias stability, and reliability about radiation. After examination, CRS09-12 of Silicon Sensing company is selected for WNISAT. Three gyroscopes are used for each axis of XYZ.

Table 8: Specification of gyroscope

Item	Specification	Remark
Static noise	0.03 degree/sec	
Stability of bias	3.0 degree/hour	
Random work	0.1deg/hour^0.5	
Output type	Analog	
Size/Mass	63×63×19mm 60g	

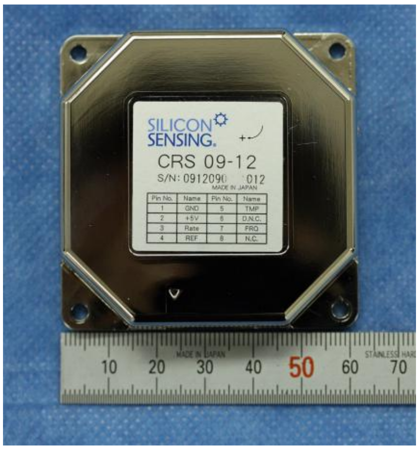

Figure 14: Gyroscope

➢ GPS

Exact position information on the orbit is very important for the attitude determination and mission system. WNISAT uses a GPS(Global Positioning System) for this purpose. This GPS was used for the space project of INDEX already. ISAS(Institute of Space and Astronautical Science) supported the modification of this GPS for the space environment at the previous project, and it showed enough reliability and performance on the orbit. Actually, this is one of few specialized devices of space industry which used for WNISAT.

Table 9: Specification of GPS

Item	Specification	Remark
Time for the cold start	Within 30 minutes	
Accuracy, measurement error	0.9m	
Accuracy, position information	17m	
Power consumption	5V, 160mA	
Receiving signal	L1, C/A code	
Sensitivity	Below -132dBm	
Number of channel	8	
Size	11×36×56mm	Excluding antenna
Mass	39g	Excluding antenna
Temperature of operation	-30℃~ 70℃	
Radiation hardness	20krad	

Figure 15: GPS with antenna

➢ Magnetic torquer

Magnetic torques is very attractive actuator on the low earth orbit. It produces mechanical torque combined with the earth magnetic field. Because of this, the most difficult point of this magnetic torquer is the available torque is limited on the normal surface with the earth magnetic field. It makes very hard to get desired torque when the satellite needs the specific torque along the earth magnetic field vector. However, it needs relatively small electrical power, and has very high reliability without moving parts. WNISAT uses three magnetic torquers. To avoid nonlinearity of hysteresis, coreless type torquers are selected even the torque has limitation. These magnetic torquers are main actuators for the initial detumbling control and the usual attitude control with minimum control efforts, especially for the electrical powr consumption. When the reaction wheels are operated for the accurate attitude control of laser mission, these magnetic torquers can be used for momentum dumping also. The maximum magnetic moment is 0.8 Am^2. Usually, the residual magnetic moment acts like disturbance torque, and the magnetic moment of torquers must be larger than the residual magnetic moment. We keep the residual magnetic moment within the 10% from the magnetic moment of magnetic torquer.

➢ Reaction wheel

The magnetic torquers are used for the main actuators, however it is very difficult to get high accuracy of attitude control with only magnetic torquers. WNISAT needs the attitude pointing accuracy better than 0.1degree for the laser emission mission. For this accurate attitude control, WNISAT uses reaction wheels of Astro und Feinwerktechnik to acquire torques of any axes whenever the torque is required. The four reaction wheels have skew symmetry assembly structure to provide redundancy without zero-cross problem also.

Table 10: Specification of RW1

Item	Specification	Remark
Nominal rotation speed	8000 rpm	
Maximum rotation speed	16380 rpm	
Angular momentum	5.8×10^-4Nms @8000rpm	
Resolution of speed measurement	0.25 rpm	
Nominal torque	23 uNm	
Torque deviation	< 2.2 uNm	
Mass of wheel	24g	
Mass of conrol board	45g	
Moment of inertia	694.5×10^-9 kgm^2	
Supply voltage	5V	
Maximum power consumption	About 1.74 W	

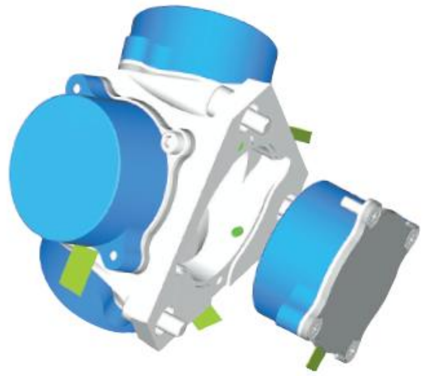

Figure 16: Reaction wheels

4. OUTLINE OF SOFTWARE

In this section, we are going to introduce software of WNISAT, mainly the operation mode and the ADCS(Attitude Determination and Control System) briefly. The operation modes on the orbit will be introduced at first. Every mode has specified object, and available devices are different depends on the mode.

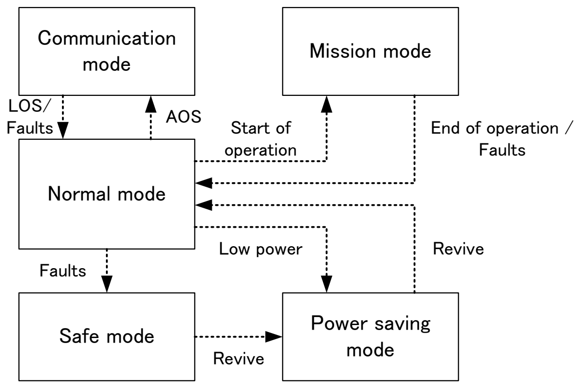

Figure 17: Operation modes

➢ Normal mode

When the satellite is not under execution of mission activity or communication with the ground station, the satellite is under normal mode. The status of satellite is monitored periodically. If electric power become low, the operation mode is changed to the Power saving mode, and if some faults are occurred, the satellite changes operation mode to the Safe mode as soon as possible. Mission system is power off completely in this normal mode. And other devices such as sensors and actuators are operated minimally to acquire the house keeping data.

- Communication mode

If the satellite comes to the visible position from the ground station, the acquisition of signal is started with the communication mode. The downlink of the house keeping data and the mission data is performed following the uplink command from the ground station. Reed-Solomon code is used for the error detection and correction to improve the efficiency of communication. And, the status of satellite is updated by the uplinks also. After lost of signal, the operation mode changes to the normal mode again. Or, if some faults are occurred during this communication mode, the operation mode is changed to the normal mode immediately.

- Mission mode

Following the command registered in the memory of bus system or the direct command of uplink, the mission mode is performed by the mission controller. After power on, the mission system operates the mission activities following the instruction. If the operation is finished or some faults are occurred during this mode, the operation mode is changed to the normal mode.

The three axis attitude control algorithm is executed in this mission mode. All sensors and actuators are operated with full power for the laser emission mission. However, the reaction wheels are operated minimally, and only one stat tracker is turned on for the north arctic sea monitoring mission.

- Safe mode

When the satellite has faults, and the normal mode is failed to handle the faults, operation mode changes to the safe mode as soon as possible. Almost every device is power down in this safe mode, and keep this status until the operation mode is changed to the power saving mode by the uplink command.

- Power saving mode

The satellite changes operation mode to this power saving mode when the electrical power become low, or uplink command changes operation mode from the safe mode to the power saving mode. After electrical power satisfies the normal condition, operation mode changes to the normal mode automatically.

Attitude determination and control

As like every other satellite, WNISAT has to deal with initial attitude acquisition, in which large rotations and high angular rates must be dealt with. The most popular control law for spacecraft detumbling and initial attitude acquisition is the famous b-dot algorithm.[5] After the satellite is separated from the rocket, the magnetometer is deployed with the boom. Deployed magnetometer estimates the rates of the magnetic field in the satellite body frame, $\dot{b}$, and the attitude controller calculates the required magnetic moments of torquers. The b-dot control law is given by

$$m = -K\dot{b}$$

where K is a positive definet gain matrix. The magnetic moments of torquers are depends on the current linearly. With this initial attitude acquisition, the kinetic energy of satellite is reduced using only magnetic sensors and actuators. And the satellite is ready to start the 3 axis attitude control.

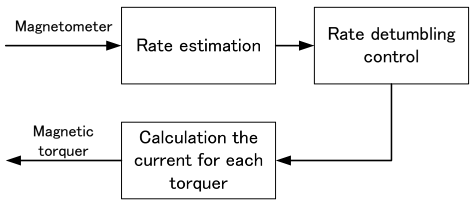

Figure 18: Schematics of initial attitude acquisition

The three axis attitude control algorithm is based on the compact control law of a linear feed-back of attitude error and rotation rate.[6] The attitude is acquired by two methods, one is from the star trackers directly, and another is from the estimation algorithm of ESOQ2(Second Estimator of the Optimal Quaternion).[7] For the ESOQ2 algorithm, the data of magnetometer and the data of sun sensors are used with the reference data of the inertia frame with the orbit information. The orbit information is acquired from the GPS and the orbit model of SGP4(Simplified General Perturbations Satellite Orbit Model 4). For the SGP4 orbit model, the TLE(Two Line Elements) data of NORAD should be updated by uplink. IGRF(International Geomagnetic Reference Field) model is used for the reference data of earth magnetic field. For the sun model, simple model of the Astronomical Almanac is used.[8]

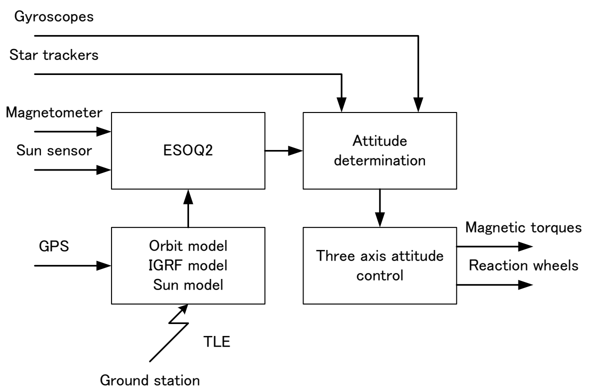

Figure 19: The three axis attitude control configuration

The control input is computed in the case of full state feedback, attitude and rate, as like following equation.

$$T = -(k_p \underline{q} + k_v I\omega)$$

At this equation, the k_p is the gain for the attitude error, and k_v is the gain for the angular rate. I is inertia matrix of the satellite. When the only magnetic actuators are used for the attitude control, the desired torque is hard to be acquired from the magnetic torquers because the torque of magnetic torquers is only on the normal surface from the earth magnetic field. Usually, the famous cross product law is used for the calculation of magnetic moment of torquers for the desired torque, T.

$$m = \frac{k}{|b|^2}(b \times T)$$

This cross product law is based on the assumption the magnetic moment is normal to the earth magnetic field, however the assumption is not satisfied actually, and the calculated magnetic moment is not exact. For the accurate attitude control of laser emission mission, it is need to compensate to the torques of magnetic torquers for the desired toques using the torques of reaction wheels, T_{RW}.

$$T = T_{RW} + T_{MTQ}$$

$$T_{MTQ} = m \times b$$

Actually, the torque of reaction wheels is used for one axis while other two axes are controlled by the magnet torquers depends on the earth magnetic field vector in the body frame. If the torque of z axis in the body frame is controlled by reaction wheel, the magnetic moments of torquers about x and y axis are calculated with following equations.[9]

$$\begin{bmatrix} T_x \\ T_y \end{bmatrix} = B_{m2} \begin{bmatrix} m_x \\ m_y \\ m_z \end{bmatrix}$$

$$B_{m2} = \begin{bmatrix} 0 & B_z & -B_y \\ -B_z & 0 & B_x \end{bmatrix}$$

$$B_{m2}^{+} = B_{m2}^{t}(B_{m2}B_{m2}^{t})^{-1}$$

$$\therefore \begin{bmatrix} m_x \\ m_y \\ m_z \end{bmatrix} = B_{m2}^{+} \begin{bmatrix} T_x \\ T_y \end{bmatrix}$$

Simulations are repeated to verify these algorithms and the parameters under various conditions. Figure 20 shows one of the results.

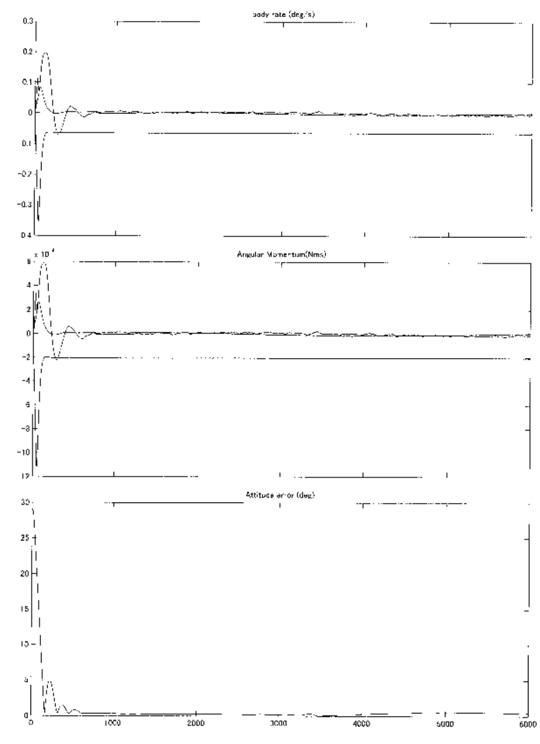

Figure 20: Simulation result for the attitude control

5. CONCLUSION

This paper describes outline of the remote sensing satellite of WNISAT for the monitoring of north arctic ocean and the CO2 gas density monitoring. WNISAT will be launched until the year of 2011 by PSLV of India. The satellite is under the development process between the engineering model and the flight model now. Although WNISAT is very small satellite of nano-class, the performance is enough for the two missions of commercial purpose with the simple and proved control algorithm. Typical functions of the spacecraft are supported with each sub-system, and several devices are newly developed to satisfy the object of small satellite, high performance with low cost.

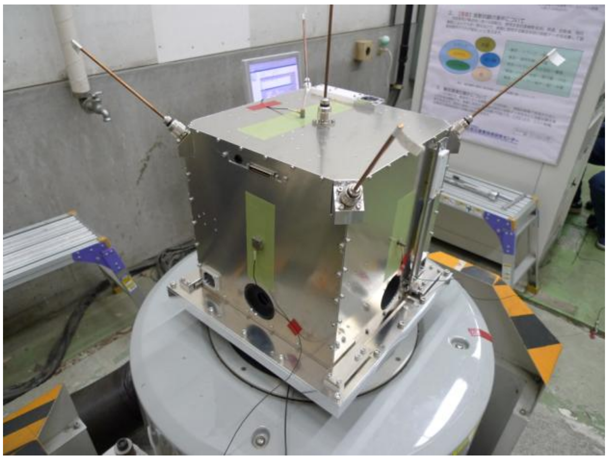

Figure 21: Vibration test of engineering model

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