Micro/nano-satellite Research, Technologies and Applications - Japanese Development History and Future Vision -

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University of Tokyo
Japanese Space Development by JAXA

H-IIA Rocket (11 ton to LEO)

ISS participation
- JEM
- HTV

Many Satellites
Contents

• Japanese University’s History of Micro/nano /pico-satellite development

• Recent stepping-up from education to practical use

• New program for micro/nano-satellite development and utilization with “reasonably reliable systems (Hodoyoshi)” concept

• Future vision: How micro/nano-satellites can be used for business, Earth monitoring, or human welfare, etc.
Emerge of Nano/pico-Satellites in Japan

Success of CubeSat (1 kg) by Univ. Tokyo and Titech (2003.6.30)
- University level budget (30K$)
- Development within 2 years
- Surviving in space for 8 years
- Ground operations, frequency acquisitions, launch opportunity search processed by ourselves

1 ~ 50kg (Micro/Nano/pico-sat): Starting from education but higher level satellites appears
Starting Point: CanSat (since 1999)
Educational Significances of Micro/Nano/Pico-Satellite Projects

- **Practical Training of Whole Cycle of Space Project**
  - Mission conceptualization, satellite design, fabrication, ground test, modification, launch and operation
  - Know what is important and what is not.

- **Importance for Engineering Education**
  - Synthesis (not Analysis) of an really working system
  - Feedbacks from the real world to evaluate design, test, etc.
  - Learning from failures (while project cost is small)

- **Education of Project Management**
  - Four Managements: “Time, human resource, cost and risk”
  - Team work, conflict resolution, discussion, documentation
  - International cooperation, negotiation, mutual understanding

- **Also contributions to other technology areas!**
University of Tokyo’s History of Nano/pico-satellite Developments

2003
11 12

CubeSat XI-IV
(ROCKOT) 2003/6

Education, camera test

2004

CubeSat XI-V
(COSMOS) 2005/10

Education, CIGS solar cells

2005

PRISM
(H-IIA) 2009/1

2006

20m GSD Remote Sensing

2007

Astrometry (top-science)

2008

2009

NANO-JASMINE
(CYCLONE-4) 2011

5m GSD Remote Sensing

2010

2012

HODOYOSHI-1

Development

launch
# CubeSat “XI-IV (Sai Four)”

**Mission:** Pico-bus technology demonstration in space, Camera experiment  
**Developer:** University of Tokyo  
**Launch:** ROCKOT (June 30, 2003) in Multiple Payload Piggyback Launch

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>10x10x10[cm] CubeSat</td>
</tr>
<tr>
<td>Weight</td>
<td>1 [kg]</td>
</tr>
<tr>
<td>Attitude control</td>
<td>Passive stabilization with permanent magnet and damper</td>
</tr>
<tr>
<td>OBC</td>
<td>PIC16F877 x 3</td>
</tr>
<tr>
<td>Communication</td>
<td>VHF/UHF (max 1200bps) amateur frequency band</td>
</tr>
<tr>
<td>Power</td>
<td>Si solar cells for 1.1 W</td>
</tr>
<tr>
<td>Camera</td>
<td>640 x 480 CMOS</td>
</tr>
<tr>
<td>Mission life</td>
<td>more than 8 years</td>
</tr>
</tbody>
</table>

Captured Earth Images and Distribution to Mobile Phones
**CubeSat “XI-V (Sai Five)”**

**Mission:** CIGS solar cell demonstration, Advanced camera experiment  
**Developer:** University of Tokyo  
**Launch:** COSMOS (October 27, 2005) deployed from “SSETI-EXPRESS”

<table>
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<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td><strong>Size</strong></td>
<td>10x10x10[cm] CubeSat</td>
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<tr>
<td><strong>Weight</strong></td>
<td>1 [kg]</td>
</tr>
<tr>
<td><strong>Attitude control</strong></td>
<td>Passive stabilization with permanent magnet and damper</td>
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<tr>
<td><strong>OBC</strong></td>
<td>PIC16F877 x 3</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>VHF/UHF (max 1200bps) amateur frequency band</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Si, GaAs, CIGS cells</td>
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<tr>
<td><strong>Camera</strong></td>
<td>640 x 480 CMOS</td>
</tr>
<tr>
<td><strong>Mission life</strong></td>
<td>&gt; 5 years</td>
</tr>
</tbody>
</table>

![image](image.png)
PRISM "Hitomi"

Mission: Earth Remote Sensing (20 m GSD, RGB) with Deployable Boom
Developer: University of Tokyo
Launch: H-IIA (Jan 23, 2009) Piggyback with GOSAT (CO₂ monitoring sat)

Size
20x20x40[cm] in rocket
20x20x80[cm] in space

Weight
8.5 [kg]

Attitude control
3-axis stabilization with Sun, Magnet sensor, MEMS gyro magnetic torquers

OBC
SH2, H8 x 2, PIC x 2

Communication
VHF/UHF (max 9600bps)

Mission life
> 2.5 years

Captured images
Mexico Seashore  US Desert  Kita-Kyushu (Japan)  Wide Angle Camera
The Nile River

WAC (Wide Angle Camera)

NAC (Narrow Angle Camera)
Nano-JASMINE

Mission: Astrometry (Getting precise 3D map of stars and their movements)

Developer: University of Tokyo, National Astronomical Observatory of Japan, Shinshu University, Kyoto University

Launch: Cyclone-4 (planned within 2013) from Alcantara Launch Site

Size: 50 [cm-cubic]
Weight: 33 [kg]
Attitude control: 3-axis stabilization with Star, Sun, Magnet sensor, FOG, RW, Magnetic torquers

OBC: FPGA
Communication: S-band 100 [kbps]
Mission life: 2 [year]

Special features:
-Attitude Stability: 0.8 arcsec for 8.8 sec
-Thermal Stability: < 0.1K (at -50 degree)
-Map Accuracy: Compatible with “Hipparcos” Satellite (‘89)
-Telescope: two CCDs with TDI
**WNISAT-1**

**Missions:** Iceberg observation in Arctic Ocean, Atmospheric Observation (CO₂)

**Developer:** AXELSPACE, Weathernews Inc.

**Launch:** DNEPR (2012) (planned)

<table>
<thead>
<tr>
<th>Size</th>
<th>27x27x27[cm]</th>
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<tbody>
<tr>
<td>Weight</td>
<td>15 [kg]</td>
</tr>
<tr>
<td>Attitude control</td>
<td>3-axis stabilization with STT, SAS, Magnetometer, Gyros RW, magnetic torquers</td>
</tr>
<tr>
<td>OBC</td>
<td>FPGA</td>
</tr>
<tr>
<td>Communication</td>
<td>UHF (max 38.4 kbps)</td>
</tr>
<tr>
<td>Camera</td>
<td>Visible &amp; NIR, GSD 500m</td>
</tr>
<tr>
<td>Laser</td>
<td>CO₂ absorbed (1.55µm)</td>
</tr>
<tr>
<td>Mission life</td>
<td>2 years</td>
</tr>
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</table>

**Please visit:**
http://www.axelspace.com

**Components by AXELSPACE**

- Star Sensor (AxelStar)
- Coarse Sun Sensor (AxelSun)

More info available at our website!

Global Iceberg Monitoring

Experiment of CO₂ density measurement
UNISEC (UNIversity Space Engineering Consortium)

- Founded in 2002, became NPO in 2003
- 56 laboratories from 36 universities: > 500 students
- 220 individual and company supporting members
- **UNISEC Missions:**
  - Education and human resource training for space development/utilization
  - Innovative space technology “seeds” development
- **Activities to be Supported:**
  - Joint experiment, joint development, joint education, etc.
  - Workshop, symposium, technology exchange, etc.
  - Consultation on legal matters (frequency, export law, etc.)
  - Finding “rivals” within the community!

http://www.unisec.jp
UNISEC Satellites Development

The University of Tokyo XI–IV
Tokyo Institute of Technology Cute–I

The University of Tokyo

2003 June
2005 Nov.
2006 Feb.
2006 July
2006 Sept.
2008 Apr.
2009 Apr.
2010 May

Nihon University SEEDS (FM1)

Hokkaido Institute of Technology HITSAT

Nihon University SEEDS (FM2)

Cute–1.7 +APD
Tokyo Institute of Technology

The University of Tokyo

UNITEC–1 UNISEC

KSAT Kagoshima University

PRISM

The University of Tokyo

WASEDA–SAT2 Waseda University

Negai☆ Soka University

Kagawa University

KKS–1
Tokyo Metropolitan College of Industrial Technology

STARS

Tohoku University SPRITE–SAT
From Education to Practical Use

• Satellite development process should be changed
  – Workload concentrated (trial-and-error) style => Systematic development style
  – University competition => university collaboration, including more small/medium industries
  – Establish “technology pool” for all the components
  – From “educational reliability” to “customer reliability”
  – Establish an environment where universities pursue technology innovation while industry pursue non-advanced technology conservation

• Aiming at all-Japan consortium where each university or company participates with its strength

• Mission creation is essential
Governmental “First” Program selected as one of 30 science and technology research projects in Japan (2010-2014)


Project Leader
Shinichi Nakasuka
School of Engineering, University of Tokyo
Problem of mid-large Satellites

Trend towards larger satellites
- Enormous cost >100M$
- Development period >5-10 years
- Conservative design
- Almost governmental use
- No new users and utilization ideas
- Low speed of innovation

GEO
OTHERS


Weight (ton)
“Hodoyoshi” Micro/Nano-sat Project Overview

Mid-large satellite based space development and utilization
- Many fundamental drawbacks

Paradigm Shift by Micro/Nano-sat
- Low cost / fast development time
- New users / new utilization areas

Research Themes
1. Theoretical research on “Reasonably Reliable” Systems Engineering
   - Hodoyoshi aims at not ultimate performance and reliability but some reliability is still needed

2. Innovation of component technologies to solve the “size” problems
   - Novel ideas / concepts using new physics/electronics/dynamics, etc.

3. Innovation of Micro/Nano-satellite architecture considering standardization, modularity and Hodoyoshi development process
   - Adequate and sufficient process to obtain so-so performance should be searched

4. All Japan micro/nano-satellite consortium establishment to combine Japanese universities’ and small business’ competences, also creating user communities
Innovation in Component Technologies and Process

① Advanced technologies in all areas
- component pools in Japan
- high performance/size

② Novel concepts
- new idea for each function
- new satellite architecture

③ Process Innovation
- standardization to reduce cost/development time
- test process innovation
- software re-use

Optical subsystem: in-orbit compensation, etc to aim for 2.5m (final) to 5m (initial) ground resolution

Communication subsystem: high performance RF to optical link

Deployable system: concept/ideas

Attitude control subsystem: 1 arcmin control accuracy

Structure/Thermal subsystem: easy to develop and analyze

C&DH subsystem: radiation tolerant high performance processor and data link
Tentative Image of Project Target

• Practical (but not maximum)-quality satellite with low cost and short development time ex. ) ground resolution: 5m (initial) → 2.5m (final)

• Develop and make available all the required micro/nano-sat components within Japan
  – World wide Bench-marking of all the component technologies have been made and we aim at top level quality in terms of “performance/size”

• Satellite bus cost < 3M€
  development time < 1.5 year
  – Process and component innovation required
Missions Creation for Hodoyoshi Program

• Low-cost and small size realize satellite constellation
  – More frequent (ex. semi-daily) observation of the same areas

• Formation flight
  – Many scientific applications such as inter-ferometer, multi-site observation, stereo vision

• “Personal Satellite” “My Satellite”
  – Novel ways of utilization including entertainment, education, contents, etc
  – Just like “PC and internet” innovation which has changed the world
Even nano-satellites can do lots of tasks in space. Possibility of missions which have never been created for large cost satellites.

- Education companies (space contents)
- Local government (good for young generation science education. Comm. link at disaster time)
- Equipment manufacturers (advertisement by space demo.)
- Amateur astronomers (Space telescope they can use freely)
- Weather forecast company (Own information) (→WNI-sat)
- Space organization/companies (quick In-orbit test bench) (→XI-V solar cell test)
- Space scientists (test of sensors, real space science)
The Mission Idea Contest has been established since 2010 for aerospace engineers, college students, consultants, and anybody interested in innovative space development from all over the world. Regional Coordinators are working in each region.

The objective of the contest is to encourage innovative exploitation of nano-satellites to provide useful and sustainable capabilities, services or data. The 2nd contest will be held in Nagoya in October 10, 2012.

http://www.spacemic.net
Satellite Development Plan (5 sats within 4 years)

#1: 5m GSD for personal use
- Data is open to private users so that they can test their utilizations
  (developed by AXELSPACE)

#2: Foreign space science mission
- Mission selection is under way from 14 candidates
  (developed by Tohoku University)

#3: Constellation of 2 or 3 satellites
- Data sales, business trial, etc.
- Conceptual design is just started
  (developed by Univ. Tokyo and NESTRA)

To be launched in 2012

Searching for co-launch (4 x 50kg) opportunity in 2013 4Q - 2014 1Q
**HODOYOSHI-1**

**Mission:** Earth Remote Sensing (5m GSD, 4 bands: RGB & NIR)  
**Developer:** AXELSPACE, University of Tokyo, NESTRA  
**Launch:** Foreign Rocket in 2012

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tr>
<td>Size</td>
<td>50 [cm-cubic]</td>
</tr>
<tr>
<td>Weight</td>
<td>50 [kg]</td>
</tr>
<tr>
<td>OBC</td>
<td>FPGA</td>
</tr>
<tr>
<td>Communication</td>
<td>UHF, X (max 20 Mbps)</td>
</tr>
<tr>
<td>Mission life</td>
<td>2 [year]</td>
</tr>
<tr>
<td>Attitude control</td>
<td>3-axis stabilization with</td>
</tr>
<tr>
<td></td>
<td>STT, SAS, Magnetometer, Gyros, RW, Magnetic</td>
</tr>
<tr>
<td></td>
<td>- stability 0.1 deg/sec</td>
</tr>
<tr>
<td></td>
<td>- pointing accuracy 5 arcmin</td>
</tr>
<tr>
<td></td>
<td>- determination 10 arcsec</td>
</tr>
<tr>
<td>Optical sensor</td>
<td>15kg, 5m GSD (500km alt.)</td>
</tr>
<tr>
<td></td>
<td>- Focal length 740mm (F# 7)</td>
</tr>
<tr>
<td></td>
<td>- IFOV 24.3 x 16.2 km (500km alt.)</td>
</tr>
<tr>
<td></td>
<td>- Bands(SNR) B(103), G(119), R(84), NIR(63)</td>
</tr>
<tr>
<td></td>
<td>- Onboard storage 8GB (~100 compressed images)</td>
</tr>
</tbody>
</table>

Mission instruments developed by Genesia Corporation
<table>
<thead>
<tr>
<th></th>
<th>LEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>LEO</td>
</tr>
<tr>
<td>GSD</td>
<td>5 m (at 500km alt.)</td>
</tr>
<tr>
<td>Focal length</td>
<td>740mm (designed for above GSD)</td>
</tr>
<tr>
<td>Fno</td>
<td>7</td>
</tr>
<tr>
<td>IFOV</td>
<td>24.3km × 16.2km per image</td>
</tr>
<tr>
<td>Maximum Captured Area</td>
<td>24.3km × 240km (by 16 consecutive images along track)</td>
</tr>
<tr>
<td>Wavelength bands</td>
<td>Blue: 0.45um - 0.52um, Green: 0.52um - 0.60um, Red: 0.63um - 0.69um, NIR: 0.76um - 0.90um</td>
</tr>
<tr>
<td>SNR</td>
<td>Blue: 77 / 103, Green: 89 / 119, Red: 62 / 84, NIR: 46 / 63</td>
</tr>
<tr>
<td>Mass</td>
<td>&lt; 15kg for the sensor</td>
</tr>
<tr>
<td>Temperature range for optimal imaging performance</td>
<td>Tc±10K (or broader: based on optical athermalization technology. Tc is designed to be +20 degree for this optics)</td>
</tr>
<tr>
<td>Advanced functionality</td>
<td>* TDI (Time Delay Integration) for improved SNR</td>
</tr>
<tr>
<td></td>
<td>* Internal calibrator of radiance levels.</td>
</tr>
</tbody>
</table>
Example:
Rapid Eye
6mGSD
Example of Footprints

Swath: 24.3km

e.g., 81km with five images
(maximum 16 images)

Kanto plain in Japan (c) 2010 Google
Capacity Building Support Program
UNIFORM (UNiversity International FOrmation Mission)

- Each country develops one micro-satellite (< 50kg)
  - To be operated in constellation manner
  - Standardization of bus/component
  - Training of satellite development is supported by Japanese Universities
  - Equipment cost partially supported by Japanese government (in negotiation)

- Ground Station Network
  - Low-cost GS is developed to realize one GS in each country (S/X-band)

- Missions
  - Common mission + individual mission
  - Common mission will be determined by discussions within community

Possibility: one or two 50kg satellites launch in every two years since 2013
## UNIFORM Satellite Specification

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
<td>50 kg</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>50 x 50 x 50 cm</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>S-band DL/UL (HK)</td>
</tr>
<tr>
<td></td>
<td>X-band DL (Mission)</td>
</tr>
<tr>
<td><strong>Power Generation</strong></td>
<td>100 W + (tentative)</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>Li-ion 5.1 Ah (tentative)</td>
</tr>
<tr>
<td><strong>Attitude Control Sensors</strong></td>
<td>3 Sun Sensors</td>
</tr>
<tr>
<td></td>
<td>Star Tracker</td>
</tr>
<tr>
<td></td>
<td>Fiber Optics Gyroscope</td>
</tr>
<tr>
<td></td>
<td>Magnetometer</td>
</tr>
<tr>
<td><strong>Attitude Control Actuators</strong></td>
<td>3-axis magnetic torque</td>
</tr>
<tr>
<td></td>
<td>rods</td>
</tr>
<tr>
<td></td>
<td>4-axis reaction wheels</td>
</tr>
<tr>
<td><strong>Mission Payloads</strong></td>
<td>Microbolometer Camera</td>
</tr>
<tr>
<td></td>
<td>Visible Light Camera</td>
</tr>
</tbody>
</table>
Summary

• Japanese universities’ progress from education to practical use
  – From CanSat, CubeSat to space science, remote sensing, technology demonstration

• New program to seek for paradigm shift by micro/nano-satellites
  – Development process innovation to assure low-cost and quick development
  – Importance of creation of missions suitable for micro/nano-satellites

• Micro/nano-satellites will change the space development/utilizations with their strength