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Proceedings

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Center for Environmental Remote Sensing (CEReS)
Chiba University
Symposium Secretariat:
Dr. Luhur Bayuaji
Center for Environmental Remote Sensing, Chiba University
1-33, Yayoi-cho, Inage-ku, Chiba-shi 263-8522 Japan
Telephone: +81(0)43-290-3840; Fax: +81(0)43-290-3857
Email: bayuaji@restaff.chiba-u.jp

Committee:

Steering Committee
Prof. Fumihiko Nishio
Assoc. Prof. Josaphat Tetuko Sri Sumantyo

Local Organizing Committee
Dr. Luhur Bayuaji

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Cover Image:
TerraSAR-X DInSAR image of Tokyo Station, Japan and its surrounding area
TerraSAR-X data provided by PASCO Corp
Analyzed by Josaphat Microwave Remote Sensing Laboratory, CEReS, Chiba University
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DEVELOPMENT OF CIRCULARLY POLARIZED SYNTHETIC APERTURE RADAR ONBOARD UNMANNED AERIAL VEHICLE (CP-SAR UAV)

Josaphat Tetuko Sri Sumantyo

Center for Environmental Remote Sensing, Chiba University, 1-33, Yayoi-cho, Inage-ku, Chiba-shi 263-8522 Japan Tel.+81-43 2903840 Fax +81-43 2903857 (jtetukoss@faculty.chiba-u.jp)

ABSTRACT

Synthetic Aperture Radar (SAR) is well-known as a multi-purpose sensor that can be operated in all-weather and day-night time. The past SAR sensors for Earth observation mission are commonly operated in linear polarization that sensitive to Faraday rotation effect, especially in low frequency. This paper introduce our Circularly Polarized Synthetic Aperture Radar onboard Unmanned Aerial Vehicle (CP-SAR UAV) that is developed to retrieve the physical information of Earth surface for Earth diagnosis mission. The CP-SAR system is considered as small, light in weight and low power consumption system. The CP-SAR sensor is employing elliptical wave propagation and scattering phenomenon by radiating and receiving the elliptically polarized wave, including the special polarization as circular and linear polarizations. This paper introduces the CP-SAR and UAV system, including simulated full polarimetric CP-SAR images.

Index Terms— CP-SAR, Synthetic Aperture Radar, Unmanned Aerial Vehicle (UAV)

1. INTRODUCTION

Synthetic Aperture Radar (SAR) is well-known as a multi-purpose sensor that can be operated in all-weather and day-night time. Past missions of SAR sensors are operated in linear polarization (HH, VV, HV and VH) with high power, sensitive to Faraday rotation effect in low frequency, i.e. L band. In this research, we propose Circularly Polarized Synthetic Aperture Radar onboard microsatellite (CP-SAR μSAT) to retrieve the physical information and land deformation on Earth surface for Earth diagnosis mission [1]. Fig. 1 shows the illustration of CP-SAR μSAT that is being developed in Josaphat Microwave Remote Sensing Laboratory, Center for Environmental Remote Sensing, Chiba University, Japan. Table I shows the specification.

In this research, the CP-SAR sensor is employing the elliptical wave propagation and scattering phenomenon by radiating and receiving the elliptically polarized wave.

![Illustration of Circularly Polarized Synthetic Aperture Radar onboard microsatellite (CP-SAR μSAT)](image)

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### TABLE I. SPECIFICATION OF CP-SAR ONBOARD MICROSATellite

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>500 ~ 700 km</td>
</tr>
<tr>
<td>Inclination angle</td>
<td>97.6 degrees</td>
</tr>
<tr>
<td>Frequency / wavelength</td>
<td>1.27 GHz (L Band) / 24 cm</td>
</tr>
<tr>
<td>Polarization</td>
<td>TX : RHCP+LHCP</td>
</tr>
<tr>
<td></td>
<td>RX : RHCP+LHCP</td>
</tr>
<tr>
<td>Gain / Axial ratio</td>
<td>&gt; 30 dBic / &lt; 3 dB (main beam)</td>
</tr>
<tr>
<td>Off-nadir angle</td>
<td>29 degrees (center)</td>
</tr>
<tr>
<td>Swath width</td>
<td>50 km</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>30 m</td>
</tr>
<tr>
<td>Peak power</td>
<td>90 ~ 300 W (PRF 2000~2500 Hz, Duty 6% : average 5.6 W)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Chirp pulse : 10 MHz</td>
</tr>
<tr>
<td>Platform size</td>
<td>1 m x 1 m x 1 m</td>
</tr>
<tr>
<td>Weight</td>
<td>200 kg</td>
</tr>
<tr>
<td>Antenna size</td>
<td>Elevation 1.0 m x Azimuth 4.0 m x 2 panels for RHCP and LHCP</td>
</tr>
</tbody>
</table>
including the specific polarization as circular and linear polarizations. CP-SAR is as active sensor that could transmit and receive the L band chirp pulses with PRF 2,000 to 2,500 Hz. The sensor is designed as a low cost, light, low power or safe energy, low profile configuration to transmit and receive left-handed circular polarization (LHCP) and right-handed circular polarization (RHCP). Then these circularly polarized waves are employed to generate the axial ratio image (ARI), ellipticity, tilt angle etc. This sensor is considered not depending to the platform posture, and it is available to reduce the effect of Faraday rotation during propagating in Ionosphere. Therefore, the high precision and low noise image is expected to be obtained by the CP-SAR. For this purpose, we are also developing the CP-SAR onboard unmanned aerial vehicle (CP-SAR UAV) for ground testing of this sensor.

2. CP-SAR MISSION

The main mission of our CP-SAR (see Fig. 2) is to hold the basic research on elliptically polarized scattering and its application developments. In the basic research, we will investigate the elliptical (including circular and linear polarizations) scattering wave from the Earth surface, circularly polarized interferometric technique (CP-InSAR), generation of axial ratio image (ARI), ellipticity and tilted angle images etc. We hold the analysis and experiment of circularly polarized wave scattering on vegetation, snow, ice, soil, rock, sand, grass etc to investigate the elliptical scattering wave. In experiment of CP-InSAR, we will hold some experiments to compare the InSAR technique by using circular and linear polarizations. This technique will be implemented to extract the tree trunk height, DEM etc by using the elliptical polarization. The axial ratio image (ARI), ellipticity, tilted angle, polarization and other images will be extracted by using the received RHCP and LHCP wave. The principle of CP-SAR UAV is shown in see Fig.3. This figure shows CP-SAR sensor transmits only one polarization, RHCP or LHCP, then we receive RHCP and LHCP scattering waves simultaneously. Then this image is employed to investigate the relationship between the ARI and physical characteristics of vegetation, soils, snow etc. The image of tilted angle as the response of Earth surface also will be extracted to mapping the physical information of the surface, i.e. geological matters, contour, tree trunk structure and its characteristics, snow-ice classification, vegetation characteristics etc.

In application development, CP-SAR sensor will be implemented for land cover mapping, disaster monitoring, Cryosphere monitoring, oceanographic monitoring etc. Especially, land cover mapping will classify the forest and non-forest area, estimation of tree trunk height, mangrove area monitoring, Arctic and Antarctic environment monitoring etc. In disaster monitoring, CP-SAR sensor will be employed for experiment of CP Differential InSAR in earthquake area, volcano activity etc.
### Table II. CP-SAR UAV Specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>1 to 4 km</td>
</tr>
<tr>
<td>Frequency range</td>
<td>1270 MHz ± 150 MHz</td>
</tr>
<tr>
<td>Baseband range</td>
<td>DC to 150 MHz</td>
</tr>
<tr>
<td>Pulse transmission</td>
<td>50 W, Pulse width 10 µs (max), Duty circle 2% (max)</td>
</tr>
<tr>
<td>Polarization</td>
<td>TX &amp; RX: RHCP+LHCP</td>
</tr>
<tr>
<td>Transmission system gain</td>
<td>+47 dB (min)</td>
</tr>
<tr>
<td>Receiver system gain</td>
<td>+60 dB (min)</td>
</tr>
<tr>
<td>Gain flatness</td>
<td>±1.5 dB (max)</td>
</tr>
<tr>
<td>Receiver noise ratio</td>
<td>3.5 dB (max) @ +25°C</td>
</tr>
<tr>
<td>Modulator</td>
<td>(RX and TX) QPSK</td>
</tr>
<tr>
<td>Output higher harmonic wave</td>
<td>-30 dBC (max)</td>
</tr>
<tr>
<td>Output spurious</td>
<td>-60 dBC (max)</td>
</tr>
<tr>
<td>Transmission system gain tuning</td>
<td>1/2/3/8/16 dB (0 to -31 dB)</td>
</tr>
<tr>
<td>function</td>
<td></td>
</tr>
<tr>
<td>Receiver system gain tuning</td>
<td>1/2/3/8/16 dB x 2 (0 to -62 dB)</td>
</tr>
<tr>
<td>function</td>
<td></td>
</tr>
<tr>
<td>Impedance</td>
<td>50 Ω</td>
</tr>
<tr>
<td>Transmission system output VSWR</td>
<td>1.5 : 1 (typ.)</td>
</tr>
<tr>
<td>Receiver system input VSWR</td>
<td>1.5 : 1 (typ)</td>
</tr>
<tr>
<td>Transmission system antenna</td>
<td>1 µs (typ.) / 2 µs (max)</td>
</tr>
<tr>
<td>switching speed</td>
<td></td>
</tr>
<tr>
<td>Receiver system antenna</td>
<td>1 µs (typ.) / 2 µs (max)</td>
</tr>
<tr>
<td>switching speed</td>
<td></td>
</tr>
<tr>
<td>Transmission system On/Off speed</td>
<td>100 ns (max)</td>
</tr>
<tr>
<td>Receiver system On/Off speed</td>
<td>100 ns (max)</td>
</tr>
<tr>
<td>Power voltage</td>
<td>DC +28 V (DC +25 to +35 V switchable)</td>
</tr>
<tr>
<td>Current consumption</td>
<td>5 A (max)</td>
</tr>
<tr>
<td>Temperature</td>
<td>+5°C to 45°C</td>
</tr>
<tr>
<td>Saving temperature</td>
<td>-20°C to 80°C</td>
</tr>
<tr>
<td>RF connector</td>
<td>SMA-Female</td>
</tr>
<tr>
<td>Power connector</td>
<td>N/MS3102A10SL-3P</td>
</tr>
<tr>
<td>Control connector</td>
<td>D-Sub-37P</td>
</tr>
<tr>
<td>Weight</td>
<td>10 kg (max)</td>
</tr>
<tr>
<td>Size</td>
<td>W250mm x H100mm x D300mm</td>
</tr>
<tr>
<td>Pulse Length</td>
<td>4.33 up to 47.63 µs</td>
</tr>
<tr>
<td>Off Nadir</td>
<td>30° up to 60°</td>
</tr>
<tr>
<td>Resolution</td>
<td>Up to 1 m</td>
</tr>
<tr>
<td>Swath Width</td>
<td>1 km</td>
</tr>
<tr>
<td>Antenna Size</td>
<td>0.75 x 0.2 m (4 panels)</td>
</tr>
<tr>
<td>Axial Ratio</td>
<td>≤3 dB</td>
</tr>
<tr>
<td>Antenna Gain</td>
<td>14.32 dBi</td>
</tr>
</tbody>
</table>

---

Fig. 5. Block diagram of CP-SAR system

Fig. 6. Microstrip antenna for Tx and Rx of CP-SAR [2]

Fig. 7. Images of linear and circular polarization
3. CP-SAR SYSTEM

Fig. 4 shows sub-systems installed in CP-SAR UAV. The system is mainly composed by Flight Control System, Onboard Computer, Telemetry and Command Data Handling, Attitude Controller, and Sensors. Flight Control System is composed by manual and automatic flight module. Onboard computer is employed for controlling all sub-systems in CP-SAR UAV. Telemetry and Command Data Handling subsystems use X-band communications between UAV and ground station. Attitude Controller is composed by Inertial Measurement Unit (IMU) and four GPS units. Sensors are composed by CP-SAR as main mission sensor, and other sensors, including hyper spectral camera and five small cameras. CP-SAR sub-system is composed by Chirp pulse generator module, Transmitter and Receiver (Tx-Rx) module, and Image Signal Processing module.

Fig. 5 shows the circuit block of Tx-Rx module of CP-SAR with specification shown in Table II. Basically, this system is composed by transmitter and receiver sub modules. The input of transmitter is In-phase (I) and Quadrature (Q) signal of chirp pulse generated by pulse generator with baseband range is DC to 150 MHz. Then chirp pulse is modulated by frequency 1,270 MHz, where our Tx-Rx system has frequency range 1270 MHz ± 150 MHz. The transmission system has gain tuning function as 1, 2, 3, 8, 16 dB or 0 to -31 dB, and receiver has gain tuning function as 1, 2, 3, 8 and 16 x 2 or 0 to -62 dB. Power amplifier (PA) is available to control pulse transmission output power 50 W with pulse width maximum 10 μs, and maximum duty circle is 2%. The switching speed of transmission and receiver system antennas (RHCP and LHCP) is typically 1 μs and maximum 2 μs. The antenna is composed by two sets of CP microstrip array antenna (LHCP and RHCP panels) as shown in Fig. 6, totally 4 panels to realize full polarimetric CP-SAR sensor. Size of Tx and Rx unit is W250 mm x H100 mm x D300 mm as one module in our CP-SAR system as shown in Fig. 4.

4. CP-SAR ONBOARD UNMANNED AERIAL VEHICLE (CP-SAR UAV) SYSTEM

In this research, the CP-SAR onboard unmanned aerial vehicle (CP-SAR UAV) as shown in Fig. 2 is developed for ground testing of CP-SAR before installing this sensor on our microsatellite. The platform called Josaphat Laboratory Experimental CP-SAR UAV (JX-1) has 25 kg of payload availability for various microwave sensors (CP-SAR, GPS-SAR, and GPS-Radio Occultation) and optic sensors, i.e. hyper spectral camera. The operation altitude is 1,000 m to 4,000 m. As shown in Table II, the specification of CP-SAR sensor for UAV is center frequency 1,270 MHz, ground resolution up to 1 m, pulse length could be tuned from 4.5 to 48 μs, pulse bandwidth 150 MHz, off nadir angle 30° to 60°, swath width 1 km, antenna size for 4 panels of CP-SAR 1.5 m x 0.4 m, antenna radiation efficiency >80%, PRF 1,000 Hz, and peak power 8.65 W (1 km) to 95 W (4 km). We plan to hold ground experiment with altitude less than 2 km with pulse transmission output power 50 W. The CP-SAR has receiver antenna composed by LHCP and RHCP antenna. The data retrieved by LHCP and RHCP antenna is employed to investigate the characteristics of elliptical polarization, including circular and linear polarizations.

We have simulated circularly polarized waves with full polarization (LL, LR, RL and RR) as shown in Fig. 7 by using ALOS PALSTAR polarimetric mode images. Where L and R is left handed circular polarization and right handed circular polarization, respectively. LR means LHCP transmission and RHCP receiving. This image shows that circularly polarized images show more clear than linear polarized image, and less foreshortening and shadowing effects. It is assumed that the geometrical effect of object (volcano) is strongly affecting to linear polarized images, but less to circularly polarized waves. In the near future, further investigation of characteristics of circular polarization will be done by using our CP-SAR UAV and microsatellite. CP image will be used to retrieve the physical information of Earth surface, i.e. soil moisture, biomass, Cryosphere, agriculture, ocean dynamics, land deformation, disaster monitoring, DEM etc. In the UAV, we also install the linearly polarized SAR (LP-SAR) in same frequency. The LP-SAR data will be compared with CP-SAR data, and employ for some applications.

5. SUMMARY

In this paper, we introduce the circularly polarized Synthetic aperture radar onboard Unmanned Aerial Vehicle (CP-SAR UAV) for ground experiment to investigate performance of CP-SAR sensor. The CP-SAR is designed as the small, light in weight and low power consumption system. The CP-SAR sensor is developed to radiate and receive elliptically polarized wave, including circularly and linearly polarized waves. In the near future, this sensor will be installed in our microsatellite that will be applicable for land cover mapping, disaster monitoring, snow cover and oceanography monitoring etc.

REFERENCES


Activities of AIT for Sustainable Capacity Building in Asia on Space Based Technologies

Lal Samarakoon
Director, Geoinformatics center
Asian Institute of Technology, Thailand

Information
- About 2000 students from 46 countries
- 14,000 alumni from 74 countries
- 22,000 short-term trainees from 71 countries
- 100 faculty from 20 countries
- 30 Board of Trustees members from 25 countries

Established in 1959 as a Post Graduate School Catering for Higher education in Asia

17th CEReS International Symposium, 1st March 2012, Chiba University, Japan
Sustainable approach for Capacity Development

Risk, Hazard, Suitability, Adaptability, Allocation, Relocation ....

GIS System
Integration of Social, Physical & Temporal Data

Storm Surge Model
Drought Model
Flood Model
Landslide Model
Poverty/Development
Healthcare
Modes of Technology Transfer of AIT

1. Higher Education (Graduate & Undergraduate)
   - Long-term planning
   - High and indirect investment
   - Comprehensive and robust

2. Diploma & Certificate (3-6 Months)
   - Target oriented
   - Direct investment

3. Short-term target oriented training (1-4 weeks)
   - Targeted audience
   - Application oriented & Readiness in implementation
   - Conducted locally or at AIT

4. Seminars & Workshops (1-2 Days)
   - Indirect investment
   - Awareness raising
   - Address larger audience, senior officials
Main Services Of GIC/AIT

- Training Programs
- Receiving & Distributing MODIS/NOAA satellite data
- Consulting Works
- Rapid mapping support for Sentinel Asia & IDC
- Conduct Workshops and Conferences
- Applied Research (Disaster, poverty, aquatic ..)
- Publications: journal, reports, manuals, results
- Collaboration (exchange programs, Students, experts ..)

Ongoing and Recent Activities

✓ Completed Mini-Project Training in 8 countries in February 2012 (JAXA)
✓ Completed use of RS/GIS in agriculture for Ministry of Agriculture, Indonesia, December 2011 (Government of Indonesia)
✓ Completed training program for technicians from 8 African countries on remote sensing application on forest fire management, February 2012 (JICA)
✓ Mini-Project Training for 10 countries concluded in February 2010 and start of 8 new projects for 2011 (JAXA)
✓ Phase II of the Poverty Mapping for ASEAN was started on March 2, 2009. Poverty Mapping Workshop in June 11-12 (ASEAN Foundation)
✓ One month Training on MODIS data handling and application for Remote Sensing Center of Mongolia, May 2009 (Mongolian RS Center)
✓ Extreme Flood Event Forecasting – 5 countries in Asia: (2010, United Nations University, Tokyo)
Ongoing and Recent Activities

- Asian Node in Second Administrative Level Boundary data initiative of WHO handling 36 countries, on going
- Capacity Building Project on Space Data for DRR for ADRC in ASEAN countries (2009-2011, Asian Disaster Reduction Center).
- Technical support for Space Application for Environment (SAFE) of JAXA
- Forest Mapping and Database Development for Dept. of Forestry Lao PDR, 2010 - 2011 (JICA)
- Professional Development Training Program on "Project Management, PPP and Good Governance" for Manipur State Officials (09-13 May 2011)
- Professional Development Training cum study visit on "Application of GIS and RS for Ground Water Salinity and NRM" for Bangladeshi Officials (11-15 July 2011)

Terra/Aqua MODIS Receiving, Archiving and Processing Systems in Geoinformatics Center (GIC), AIT

- Operational since May 2001 – present
- More than 20,000 Scenes for Terra/Aqua(day and night)
- Covering 19 countries (South and Southeast Asia)
- Products include: Land, Ocean, Atmosphere and Cryosphere disciplines
- Most products are Standard NASA Products
- Mostly use NASA ATBD (Algorithm Theoretical Basic Documents) for data processing
- Operating System: Linux (only)

Concept of Processing System:
- Automatic
- Near Real-time
- Daily (6-8 image scenes/day)
- Online Product Access for 24 hours
- Easy-to-use Data format Products

17th CERES International Symposium, 1st March 2012, Chiba University, Japan
NTRIP

- "Networked Transport of RTCM via Internet Protocol" (NTRIP) stands for an application-level protocol streaming Global Navigation Satellite System (GNSS) data over the Internet.
  - Eliminate need of Radio Unit for RTK.
  - Coverage is not limited. (compared to radio unit)
  - Easy to use.
  - VRS (Virtual Reference Station) can be used to calculate precise correction.
  - Number of uses per Base station is not limited.
The Quasi-Zenith Satellite System (QZSS), is a proposed three-satellite regional
time transfer system and Satellite Based Augmentation System for the Global
Positioning System,

- QZSS will enhance GPS services in two ways
  - Availability enhancement
  - Performance enhancement
- Transmitting Signals
  - L1C/A signal, L1C signal, L2C signal and L5 sign
  - L1-SAIF and LEX performance enhancement signals (DGPS data)

Applications
- Precise vehicle navigation
- Automated farming
- Precise Point Positioning

Growing NAVIS

The project is coordinated by
Instuto Superiore Mario Boella, Italy.

Targets:
1. Research in Asia on ionospheric condition, algorithm
development, Algorithm enhancement
2. Multi GNSS signal and receivers, signal processing
3. Wireless communication
4. Training, seminars and awareness raising programs

Partners: Italy, Spain, France, Vietnam, Thailand, Malaysia, Australia
JAXA Multi-GNSS Joint Experiment

Effectiveness of QZSS-LEX signal compared to DGPS and IGS PPP data for Thailand

- The project will be done as static and RTK modes. Study area will cover urban and semi urban environments.

- Objective
  - To Quantitatively measure the improvement in positioning due to precise ephemeris and clock from QZSS-LEX, compared to DGPS and PPP calculation from IGS data.
  - Evaluation of GPS positioning improvement techniques.

- Expected results
  - QZSS is expected to give ±10cm positioning accuracy.
  - Comparably high accuracy than IGS real time PPP data.
  - Quantitative evaluation of GPS positioning improve techniques.

Mini-Project Training
(Sponsored by Japan Aerospace Exploration Agency)

Application oriented & Locally Selected projects conducted at GIC-AIT since 2004.

Procedure:
- a. Applications for New Mini-Projects are called in December each year
- b. Selection is done in March (by GIC and JAXA)
- c. Initial training/procedure development in July-August (1 month in AIT)
- d. Fieldwork is carried out during Sep-December
- e. Analysis and output generation is done in Jan-Feb (1 month in AIT)

More Information: www.geoinfo.ait.ac.th/training/miniproject.php

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Mini-Projects - conducted in 2009-2010

✓ Training and capacity building through real-world projects such as flood, landslides, climate change, mapping etc. (individual)
✓ Involve data/service provider agencies and services/products user agencies, (Institutional/Systematic)
✓ Calibration/validation through field observations

1. Landslide related Risk Analysis – Indonesia (LAPAN)
2. Land use mapping & Monitoring – Cambodia (Ministry of Land)
3. Cyclone Risk Mapping – Bangladesh (LGED)
4. Drought Analysis – Mongolia (Remote Sensing Center)
5. Landslide Mapping – Nepal (Survey Dept.)
6. Wildlife Mapping & Monitoring – Pakistan (WWF)
7. Watershed Management – Thailand (National Parks and Forest)
8. Mangrove Monitoring – Thailand (Chulalongkorn University)
10. Flood Risk Mapping – Vietnam (STI, MONRE)
11. Flood Risk Mapping – Lao PDR (DMC and Hydrology Dept)

Mini-Projects - conducted in 2008-09

1. Landslide related Risk Analysis – Bhutan (Geological Survey)
2. Land use mapping/flood – Cambodia (Ministry of Land)
3. Flood Mitigation – Bangladesh (SPARSSO/LGED/FFWC)
4. Drought Analysis and Global Warming – Philippines (PhilRice)
5. Drought Analysis – Mongolia (Remote Sensing Center)
6. Mangrove/coastal Monitoring – Malaysia (Fishery Dept.)
7. Risk due to Sea Level Rise – Sri Lanka (CCD/Survey Dept.)
8. Flood Risk mapping – Thailand (Irrigation Dept)
9. Forest Fire Risk Analysis – Indonesia (LAPAN)
10. Flood mitigation – Vietnam (STI, MONRE)
11. Flood Mitigation – Lao PDR (DMC and Hydrology Dept)
Capacity building on the use of Space based Technologies in ASEAN

Project:
ADRC-ASEAN Project on Satellite Data for Disaster Risk Reduction under Japan-ASEAN Integrated Fund

Space Applications for Environment (SAFE)

Prototype Implementer
(National User Agency)

Educational Institutes supporting technical aspects

Technical Supporters (International)

Public agencies that have the authority to carry out environment related activities

Data & Application Creator

Space agencies provides satellite data and/or analyzing tools to support environment monitoring.

17th CEReS International Symposium, 1st March 2012, Uppsala University, Japan
## SAFE Prototyping Status

<table>
<thead>
<tr>
<th>Country</th>
<th>Theme</th>
<th>Technical Collaborator</th>
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<tbody>
<tr>
<td>VIETNAM</td>
<td>Forest monitoring</td>
<td>IIS/University of Tokyo</td>
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<tr>
<td>CAMBODIA</td>
<td>Water Cycle and Agricultural Activities</td>
<td>University of Tokyo</td>
</tr>
<tr>
<td>LAO PDR</td>
<td>Forest monitoring and management</td>
<td>IIS/University of Tokyo</td>
</tr>
<tr>
<td>INDONESIA</td>
<td>Potential Drought Monitoring</td>
<td>IIS/University of Tokyo</td>
</tr>
<tr>
<td>SRI LANKA</td>
<td>Risk of Sea Level Rise on Coastal Zone</td>
<td>University of Tokyo</td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>Monitoring Water Cycle Variations &amp; Assessing Climate Change Impacts</td>
<td>IIS/University of Tokyo</td>
</tr>
<tr>
<td>SRI LANKA</td>
<td>Modeling ocean frontal zones using high resolution satellite and float data to locate tune fish aggregations</td>
<td>Fishery Research Agency, Japan</td>
</tr>
<tr>
<td>Thailand</td>
<td>Use of satellite data derived ocean color and SST information for Thailand Fishery</td>
<td>Kyoto University</td>
</tr>
</tbody>
</table>

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### Case Study: Flood Risk Mapping

Irrigation Dept and Survey Dept of Sri Lanka

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17th CEReS International Symposium, 1st March 2012, Chiba University, Japan

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17th CEReS International Symposium, 1st March 2012, Chiba University, Japan

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Flood Risk Mapping - Summary

Data Collection/Data Basing

Hazard Analysis
- Flood Hazard
- Runoff Modeling
- Inundation Modeling

Vulnerability Analysis
- Database
- Social, Physical

Risk Analysis

Web Casting for DRM Workers

Methodology

Flood Vulnerability Analysis based on Household Survey

Household Vulnerability Analysis

Flood Vulnerability analysis

Sensitivity
- Demographic Standing
- Land Characteristics
- Rural Standing
- Water Resources

VULNERABILITY

Adaptive Capacity
- Educational Background
- Economic Strength & Resilience
- Assets
- Previous Flood Events
- Position Relative to River

Exposure

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Results

b. Hazard Analysis

Verification of model result by satellite data

Model

PALSAR

Comparison of the Flood extent derived from HEC-RAS model and Satellite image
Results

Vulnerability Analysis

Flood Vulnerability Map
Corresponding to 100 yr RP Flood Hazard & wrt Population

Vulnerability
- Inulnerable
- Low
- Moderate
- High

"Kalu Ganga" River

Risk Analysis

Buildings (Physical) Risk Analysis

Flood Risk Map
Corresponding to 100 yr RP Flood Hazard & wrt Buildings

Flood Risk
- Risk Free
- Low
- Moderate
- High

"Kalu Ganga" River
Information Sharing


Mini Projects
2007 - 2008

Sponsored by
Japan Aerospace Exploration Agency (JAXA)

Conducted by
Geoinformatics Center
Asian Institute of Technology

Sample

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Collaboration under Sentinel Asia

ADRC Members
JPT Members

Emergency Observation Request
Disaster Information

ADRC

Emergency Observation Request

Data Provider Node
JAXA
ISRO
GISTDA
KARI

Digital Camera Images
Satellite Images & Disaster Information

JAXA Asia Branch
(Bangkok)

Support

Disaster Management Agencies in Asian Countries

Disaster Occurrence

Support

Sentinel Asia System

Data Analysis Node
AIT
ADRC
CRISP

Archive Images
Images by Emergency Observation

Analyzable Data

Support

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Disaster Charter & Sentinel Asia Support

There were about 5000 satellite images from 30 satellites provided for mapping.
Regional Human Network

WELCOME

Japan Aerospace Exploration Agency (JAXA) previously known as National Space Development Agency (NASDA) of Japan has been contributing to capacity building in remote sensing and related space technologies in Asian region with the cooperation of Geoinformatics Center (GIC) previously named as GIS Application Centre (GAC) of Asian Institute of Technology since 1995. The first training course under JAXA sponsorship was launched in 1995 involving twenty participants from Asia to GIC. The idea of this course was PC based GIS Information System, which was appropriate at that time due to very limited awareness of these new technologies.

JAXA supported capacity building and information sharing in the region was carried out in number of initiatives since 1995 namely; Structured Training Programs, Caravan Training Programs, Mini-Projects, and Workshops. Structured training programs were carried out at GIC inviting participants from the region who are working in national agencies. Structured courses were conducted for two weeks at GIC with full sponsorship of JAXA. This activity was continued until year 2003 satisfactorily training more than 400 people. During training at AIT, participants were benefited with access to the library of the institute and opportunities to meet faculty members of AIT to further exchange information and develop future collaborative opportunities.

Another type of training program that is conducted by GIC for JAXA sponsorship is referred to as Caravan Training. These programs are being conducted locally with the collaboration of local agencies. It is expected that this program could offer opportunities to a larger audience to increase awareness in remote sensing, GIS and GPS by conducting locally. Generally, the duration is five days targeting a topic that is relevant to the country concerned. Since 1997, after two years of first structured training program, Caravan type training programs were started and the first training program was conducted in Philippines. Since then, seventeen Caravan training programs were conducted in ten countries.

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Student Internships

Faculty of Geomatics, Sabaragamuwa University of Sri Lanka

"Internship at GIC was a wonderful experience. For me, I had first hand experience with real data and real situation. Selecting the appropriate data for the project, downloading freely available data, accuracy assessment of results. Web GIS and SAR interferometry were another new subject that was able to study in depth with the help from the expert staff at the center. The atmosphere at GIC was very pleasant. The staff was very kind enough to explain any question that I came across. Every day was a new experience learning something new. If you are planning to work in the fields of GIS and Remote Sensing GIC is the place to be in your Internship experience you gain will help you through out your career. Finally, I must thank Dr. Lal and all the staff member at GIC for giving me this wonderful opportunity which I will never forget." -

Aplwat Thongchan

Faculty of Electronic and Telecommunication Engineering, Rajamangala University of Technology (Jan 2009 - Oct 2008)

"I am the Geoinformatics Center helped me to gain a good working experience with Network IP address, Windows server and related technologies. I also learned about field of Geoinformatics such as Digitalizing Map and involved some of training programs. This center was my first international workplace. I had practical and learned English language from working experience. The staff was very friendly and their work style like family. I have good friends and good experiences from GIC that I have never had before."

Koshashi Thanangka Wickramasekara

Faculty of Engineering, University of Moratuwa, Sri Lanka (October 2008 – March 2009)

"I consider the opportunity I got to work as an Intern at the Geoinformatics Center one of the main highlights of my undergraduate period. Apart from the multinational environment it provided, I had the chance to be exposed to the latest technological advances in the field of Remote Sensing and GIS. Not only did I have the privilege of working with the specialists in that area during the training sessions under the industry experts had been an invaluable experience. It will always be indebted to the director and all the staff at GIC for that amazing opportunity and I hope that they will continue their wonderful work of landing a hand to enlighten the young minds with their experience."

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Seminar at Local Institutes

Laos

Sri Lanka

Bangladesh

13th CEReS International Symposium, 1st March 2012, Chiba University, Japan

Lao PDR

Bhutan

Cambodia

Vietnam
Field Work in Philippines

Field Observations in Thailand

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Community Based Survey in Nepal

Community based survey

Mud houses

Brick mortar houses

RCC frame houses

17th CEReS International Symposium, 1st March 2012, Chiba University, Japan

Drought Studies in Philippines

17th CEReS International Symposium, 1st March 2012, Chiba University, Japan
GIC/AIT Working Environment
Summary

1. AIT contributes to capacity building in space based technologies in Asia with various programs,
2. GIC/AIT provides opportunities for joint research works on MODIS and multi-sensor GPS technologies,
3. Truly international institute work without boarders,
4. Knowledge is shared through publications, accepting internships, and through conferences presentations.

Capacity Building and Technological Support
Geoinformatics Center, AIT
www.geoinfo.ait.ac.th
geoinfo@ait.ac.th
Introduction of Advanced small satellite for earth observation

Tomoki TAKEGAI¹ Toshiaki OGAWA¹ Yasuhiro UCHIBORI¹ Koichi KISHI² Tsuyoshi OISHI¹

¹ Space Systems Division, NEC Corporation. 1-10 Nisshin-Cho, Fuchu, Tokyo, 183-8501, Japan
² Satellite Business Development Office, NEC Corp. 3-20-2 Nishi-Shinjuku, Shinjuku, Tokyo, 163-1403, Japan
E-mail: ¹{t-takegai@bu, t-ogawa@dt, y-uchibori@cj, t-ooishi@cj}.jp.nec.com, ²k-kishi@aj.jp.nec.com

Abstract
The Earth observation system by using advanced small satellite bus of "NEXTAR (NEC Next Generation Star)" developed by NEC is introduced in this paper. NEXTAR-300L and NEXTAR-100L are one of NEXTAR series buses, respectively. NEXTAR is designed as standard bus, which we can realize advanced small satellite for earth observation only by combining with high performance sensors.

Keywords: Small Satellite, NEXTAR, ASNARO, SERVIS-3, Earth Observation

1. Introduction
NEC are proceeding to the development of standard advanced small satellite bus based on our technologies which was established at more than 40 years experience on space development with JAXA. This advanced small type satellite bus is called as "NEXTAR". NEXTAR-300L and NEXTAR-100L are one of NEXTAR series buses, respectively. NEXTAR-300L was adopted as "ASNARO" (Advanced Satellite with New system ARchitecture for Observation) and NEXTAR-100L was adopted as "SERVIS-3" (Space Environment Reliability Verification Integrated System 3) project. Both projects are under the contract of Institute for Unmanned Space Experiment Free Flyer (USEF) and Ministry of Economy, Trade and Industry (METI). By using this NEXTAR, we can provide high performance satellite equivalent with a medium or large type satellite at low cost and short duration for development.

1. Overview of NEXTAR System
1.1. Overview
NEXTAR is the spacecraft platform whose purpose is standardization and designed based on the advancing various recent technology innovations. These include the innovative "miniaturization" technology for small scientific satellites. Such advances are helping to provide the "Multi-functionality" and "high performance" of large satellites while maintaining the features of small satellites such as "light weight", "low price" and "short delivery term". Structural/thermal/electrical designs of bus and mission are independent for each other. That means bus design is standardized and can be compatible with several types of mission hardware without any modification of bus design. The concept of NEXTAR bus is shown in Fig 1.

![Fig 1 Concept of NEXTAR standard bus](image)

NEC has several types of NEXTAR bus (including 100L and 300L) as an advanced small satellite for earth observation. The size and weight of NEXTAR -100L is smaller than that of 300L. The line-up of earth observation satellite using NEXTAR series are shown in Fig 2.

The satellite with high resolution optical sensor on NEXTAR-300L is developed as "ASNARO" project (in Section 2) and the satellite with medium optical sensor on NEXTAR-100L is developed as "SERVIS-3" project (in Section 3). And the satellite with X band SAR sensor on NEXTAR-300L is ready for development as ASNARO-2. This satellite has resolution of less than 1m at 10km swath.

Furthermore, a hyper spectrum sensor with many detection band up to 185 bands(with a resolution of 30m at 30km swath) or a multi spectrum sensor for wide area detection (with a resolution of less than 5m at 90km swath) is under development by NEC. Each sensor will be...
integrated onto NEXTAR-500L bus system, which is a larger type standard bus system than NEXTAR-100L/300L.

<table>
<thead>
<tr>
<th>Development Status</th>
<th>Medium resolution optical sensor 1</th>
<th>High resolution optical sensor 2</th>
<th>Hyper sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside of Satellite</td>
<td>Panchromatic/Multi Resolution: 2.5-5m, Swath: 20°-50km</td>
<td>Panchromatic/Multi ( Bands: Resolution: 0.5m, Swath: 10km</td>
<td>HS-38MK, 183 bands Resolution: 0.0m, Swath: 10km</td>
</tr>
<tr>
<td>Sensor performance</td>
<td>Type of Bus: NEXT-100L</td>
<td>NEXT-300L</td>
<td>NEXT-500L</td>
</tr>
<tr>
<td>Development Status</td>
<td>Under development (as &quot;XIMROAD-2&quot; project)</td>
<td>Under development (as &quot;XIMROAD-2&quot; project)</td>
<td>Under development</td>
</tr>
<tr>
<td>Outside of Satellite</td>
<td>Solar sensor</td>
<td>SAR Sensor</td>
<td>Optical sensor for wide area detection</td>
</tr>
<tr>
<td>Sensor performance</td>
<td>Panchromatic/Multi Resolution: &lt;1m, Swath: 10km</td>
<td>X band: Resolution: &lt;1m, Swath: 10km</td>
<td>Multi (4 bands) Resolution: &lt;5m, Swath: 90km</td>
</tr>
<tr>
<td>Type of Bus</td>
<td>Type of Bus: NEXT-100L</td>
<td>NEXT-300L</td>
<td>NEXT-500L</td>
</tr>
</tbody>
</table>

**Fig 2 Line-up of earth observation satellite with NEXTAR-100L/300L/500L bus.**

**1.2. Space Wire Technology**

A technology of SpaceWire RMAP (Remote Memory Access Protocol) is adopted as a one of standardization features of NEXTAR. The CPU boards of computers equipped on traditional satellites as well as other functions such as the data control, attitude control and mission control functions have been developed individually according to the mission requirements of each satellite. With the NEXTAR, this method has been changed to use a standardized computer that implements the functions required of the bus for the entire network (Fig 3).

As a result, the previous method of implementing the data control, attitude control, and mission control using three different computers is now enabled with the use of a small common computer “SpaceCube2” (which was launched on SDS-1 project by JAXA) which contributes significantly to a reduction in the size and price of satellites (Fig 4).

**2. Introduction of ASNARO with NEXTAR-300L**

The satellite which accommodates high resolution optical sensor is now under development as ASNARO (Advanced Satellite with new system Architecture for Observation, which is the first satellite using NEXTAR bus (Fig 5) and will be launched in FY2012. As shown in Table 1, ASNARO introduces new technology including NEXTAR bus technology for a small satellite of about 500kg in order to implement a performance equivalent to that of a satellite weighing a few tones.

**Table 1 Performance comparison with ASNARO**

<table>
<thead>
<tr>
<th>Performance parameter</th>
<th>ASNARO</th>
<th>WorldView-2</th>
<th>GeoEye-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch year: External view</td>
<td>2012 (Scheduled)</td>
<td>2009</td>
<td>2009</td>
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<tr>
<td>Developing country</td>
<td>Japan</td>
<td>U.S.A</td>
<td>U.S.A</td>
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<tr>
<td>Orbit</td>
<td>528km Sun synchronous</td>
<td>778km Sun synchronous</td>
<td>666km Sun synchronous</td>
</tr>
<tr>
<td>Mission Life</td>
<td>3years</td>
<td>7.3years</td>
<td>7years</td>
</tr>
<tr>
<td>Satellite mass</td>
<td>&lt;500kg</td>
<td>2900 kg</td>
<td>2900 kg</td>
</tr>
<tr>
<td>Ground sampling distance (GS)</td>
<td>&lt; 0.5m (Pa)</td>
<td>0.49m (Pa)</td>
<td>0.44m (Pa)</td>
</tr>
<tr>
<td></td>
<td>+2m/Mu</td>
<td>1.44m/Mu</td>
<td>1.44m/Mu</td>
</tr>
<tr>
<td></td>
<td>15m</td>
<td>15.9m</td>
<td>14.4km</td>
</tr>
<tr>
<td>Data rate</td>
<td>833Mbps</td>
<td>800Mbps</td>
<td>740Mbps</td>
</tr>
</tbody>
</table>

**Fig 3 Use of SpaceWire networking technology**

**Fig 4 Compact satellite-born computer in NEXTAR**

**Fig 5 ASNARO Overview**
The features of ASNARO are follows:

(1) Use of the NTSIC Mirror
Optical observation satellites have traditionally used glass as the material for the primary mirror of the camera (telescope), but ASNARO adopts a high-strength, reaction sintered, silicon carbide (NTSIC, developed jointly by NEC Toshiba Space Systems, Ltd. and Toshiba Corporation) as a material of primary mirror. This material is obtained by improving silicon carbide (SiC) and features lighter weight, higher strength, and lower thermal distortion than the glass material (Fig 6). NTSIC features a higher strength than the ordinary SiC material and has a dense and no pores on the surface.

(2) Use of flash memory
The mainstream memory used hitherto in the data recorder for storing the observation data of traditional optical observation satellites has been the SD-RAM that features high-speed processing and high reliability. On the other hand, ASNARO adopts a flash memory that features lower heat dissipation, lower power consumption, lower price, same size and larger capacity than the SD-RAM in order to reduce the size weight and price of the data recorder.

(3) Use of the 16QAM system
Traditionally, optical observation satellites used to use the modulation system called QPSK for transmitting observation data. This system can transmit 2 bits of information per symbol and the rate is limited to around 400 Mbps due to the restriction of the 8GHz frequency band used. Therefore, larger satellites had to have two sets of 400Mbps communication equipment, including antennas, in order to transmit data at 800 Mbps. Currently, ASNARO adopts a 16 QAM system that can transmit 4 bits, which is twice that of the QPSK, per symbol. It can thereby achieve the same 800Mbps transmission as larger satellites using a single set of communication equipment and as a consequence enable reductions in the size, weight, and price of the satellite (Fig 7).

Based on upon features, we can obtain high performance equivalent to that of a satellite weighing a few tones at low cost and short duration for development.

Fig 6 Primary mirror made from NTSIC material

![Fig 7 Configuration of data transmission system]

3. Introduction of SERVIS-3 with NEXSTAR-100L
SERVIS-3 is a satellite to demonstrate NEXSTAR-100L bus with some mission payload using some commercial parts. The specifications of SERVIS-3 are shown in Table 2.

<table>
<thead>
<tr>
<th>Items</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Size</td>
<td>1068 x 1059 x H900 mm (Launch)</td>
</tr>
<tr>
<td></td>
<td>2458 x 1059 x H900 mm (On orbit)</td>
</tr>
<tr>
<td>Mass</td>
<td>&lt; 170 kg (Total)</td>
</tr>
<tr>
<td>Power Generation</td>
<td>&gt; 370W (EOL)</td>
</tr>
<tr>
<td>Power consumption</td>
<td>About 200W (For bus system)</td>
</tr>
<tr>
<td>Communication</td>
<td>S-band 1MBps</td>
</tr>
<tr>
<td>Data Recorder</td>
<td>&gt; 1 Gbyte</td>
</tr>
</tbody>
</table>

The figures of SERVIS-3 are shown in Fig 8 (for Launch and On orbit Configuration).

The system block diagram of SERVIS-3 is shown in Fig 9. SERVIS-3 has three types of reaction control system, Reaction Wheel Assembly (RWA), Magnetic Torque (MTQ), and Thruster system. Because of these system, SERVIS-3
can comply with various system with enough pointing and attitude control performance.

Fig 9 System Block diagram of SERVIS-3.

The features of SERVIS-3 are follows.

(1) Dual Launch
The SERVIS-3 is suitable for dual launch as a sub satellite and has a compatibility with world major satellite. Therefore, the size of SERVIS-3 is very small enough to be launched at lower side of Payload Attachment Mechanism which is the mechanical connection between main satellite and launch rockets. The dual launch configuration is shown in Fig 10. All of the interface (including adapter to maintain enough height for SERVIS-3 under a mechanical interface for main satellite) was already developed.

Fig 10 SERVIS-3 Launch configuration (Dual launch at H2A)

(2) Reduction of Interface Board
In NEXTAR-300L architecture, there are many interface exchange board to accommodate existing/experienced sensors/actuators with Space Wire bus system. That is a reason for NEXTAR-300L to have large compatibility with existing hardware. But in SERVIS-3 configuration, interface boards are deleted by mounting them into inside of each sensor/actuator. Therefore, though SERVIS-3 has limited flexibility with various sensor/actuator, it can achieve smaller size than ASNARO architecture. This means that SERVIS-3 is easier to be integrated as satellite system.

(3) High Mission Installation capability
SERVIS-3 has equivalent or higher mission installation capability than that of other world popular bus system with equivalent size (about 100kg). Table 3 shows a comparison with other world popular bus system (about 100kg).

Table 3 Comparison with other bus (about 100kg)

<table>
<thead>
<tr>
<th></th>
<th>SSTL-150</th>
<th>Myriade</th>
<th>SERVICE 3 NEXSTAR-100L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus System Mass</td>
<td>100kg</td>
<td>About 10kg</td>
<td>About 100kg</td>
</tr>
<tr>
<td>Mission Mass</td>
<td>50kg</td>
<td>&lt;40-90 kg</td>
<td>88kg</td>
</tr>
<tr>
<td>Total Mass</td>
<td>150kg</td>
<td>&lt;140kg</td>
<td>&lt;200kg</td>
</tr>
<tr>
<td>Mass Ratio</td>
<td>33%</td>
<td>53%</td>
<td>&lt;40%</td>
</tr>
<tr>
<td>Satellite Size</td>
<td>730 x 450 x 74 mm</td>
<td>600 x 600 x 800 mm</td>
<td>950 x 950 x 900 mm</td>
</tr>
</tbody>
</table>

4. Summary
NEC is developing advanced standard bus systems of NEXTAR series. The first satellite of NEXTAR-300L was adopted as ASNARO, and the first satellite of NEXTAR-100L was adopted as SERVIS-3. ASNARO has high resolution optical sensor equivalent with the world’s finest optical sensor on orbit. SERVIS-3 has simplified architecture which is suitable for a training of bus development process.

By using this NEXTAR, we can provide high performance satellite equivalent with medium or large type satellite at low cost and short duration for development.

Reference


Development of Micro-satellite Technology at the Indonesian National Institute of Aeronautics and Space (LAPAN)

Robertus Heru Triharjanto
Center For Satellite Technology, LAPAN
jl. Cagak Satelit km.4 Rancabungur, Bogor 16310, Indonesia
rtriharjanto@yahoo.com

ABSTRACT

The evolution of design of LAPAN’s micro-satellite will be presented in here. Micro satellite systems have been chosen for space technology development in Indonesia due to the cost effectiveness. Starting in 2003, LAPAN has implemented LAPAN-TUBSAT micro-satellite program, which has successfully carried its mission as experimental Earth observation satellite and capacity building tools. The satellite is currently serving its 5th year of operation. Since 2008, LAPAN is preparing two satellites; named LAPAN-ORARI and LAPAN-IPB. The mission for LAPAN-ORARI is Earth observation using RGB camera, maritime traffic monitoring using AIS, and amateur radio communication (text & voice). The satellite will be launched as auxiliary payloads for ASTROSAT mission which has orbit of be 650 km circular at inclination of 80, expectedly before the end of 2012. The purpose of the project is to develop capability to design, Assembly, Integration and Test (AIT) process of micro-satellite in Indonesia. LAPAN-IPB will carry an experimental 4-bands multispectral imager, as well as AIS and communication for Amateur Radio Community, and to be flown by PSLV SSO mission expectedly before the end of 2013. The three projects shows LAPAN’s micro-satellite bus development, that grow in complexity to accomodate more complex mission. The knowledge advancement is expected to prepare the Center for developing operational satellite for supporting the food security program in Indonesia.

I. Introduction

Indonesia is located approximately 5,150 km along the length of the equator (or about 1/8th of earth circumference), and the widest breadth is around 1,750 km, with more than 220 million population. With the extensive region with diverse geographical problem, the utilization of satellites is important for Indonesia to address solutions to the problems of the nation.

Despite the extensive of satellite technology use since 1970s, Indonesian satellite communication system is still purchased from other countries. The same with the remote sensing satellite system, which have been extensively used since 1980s. It is known that during the Aceh tsunami, the disaster management support is heavily dependent on foreign satellite services. Economically, in the long term, the technology dependency created great loss for Indonesia. In addition to that, the dependency made Indonesia prone to political pressure from technology supplier countries.

The development of micro-satellites has become an opportunity for LAPAN in developing its satellite program. The development of such satellites requires only limited budget and facilities, compared to the development of big satellites. Meanwhile, the
capability to develop micro-satellite will brings LAPAN to the readiness state to implement a future space program that will have measureable economic impact, and therefore contribute to the country's sustainable development effort.

II. LAPAN-A1 Satellite

The development of LAPAN-A1, Indonesian 1st microsatellite which is also named LAPAN-TUBSAT, was started in 2003. Its Assembly Integration and Test was done in 2004-2005 in Technical University of Berlin, Germany. The satellite payload is a COTS video camera with 1000 mm lens, resulting into nadir resolution of 5 m and nadir swath of 3.5 km from 650 km altitude. In addition to that the satellite carries another video camera with 50 mm lens, resulting into 200 m resolution video image with swath of 80 km at nadir. The uplink and downlink for telemetry, tracking and command (TTC) is done in UHF and downlink for video is done in S-band analog. The satellite is successfully launched to SSO of 635 km as auxiliary payload in Polar Satellite Launch Vehicle (PSLV) C7 from Sriharikota, India on January 10th, 2007, and now has entered its fifth year of operation and still in good condition.

![Image](image_url)

Figure 1. 3-roda cement factory, West Java (taken by LAPAN-TUBSAT 25 May 2010)

III. LAPAN-A2 Satellite
Gaining experience in developing, launching, and operating micro-satellite as well as in developing and operating satellite’s ground station, LAPAN continue in developing its 2nd satellite, named LAPAN-A2. The mission for LAPAN-A2 is Earth observation using RGB digital camera, maritime traffic monitoring, and amateur radio communication.

Since Indonesian territory is spread along the equator, LAPAN study the operation of satellite at low inclination orbit, so that the satellite may pass Indonesia as much as SSO orbit pass the North/South pole (14 times in 24 hours at 600 km orbit). The study shows that in order to be able to cover the entire Indonesia with surveillance camera oriented at nadir, the inclination needed is 10°. Therefore, when ISRO announce that it would launch ASTROSAT mission which has orbit of be 650 km circular at inclination of 8°, LAPAN decided to put the satellite as auxiliary payloads for the mission. With frequent pass over Indonesia, the missions are expected to be more useful.

The objective of LAPAN-A2 satellite project is to achieve the design, integration and operation of micro satellite in Indonesia. LAPAN-A2 main mission is Earth Observation using digital RGB camera (5 m resolution). In addition to that the satellite carry AIS (Automatic Identification System) receiver to monitor maritime traffic, a reaction wheel made by LAPAN for space proofing, and an amateur radio Automatic Packet Reporting System (APRS), as well as amateur radio voice repeater, for Indonesian Amateur Radio Organization (ORARI). Due to this cooperation, LAPAN-A2 is called LAPAN-ORARI.

Figure 2. AIS payload test result, Surabaya, East Java, 2010

LAPAN-A2 satellite is planned to has two picture operation modes: automatic target pointing and interactive operation. The 1st mode will employ close loop process between Star Sensor, GPS, and the attitude control actuator. The 2nd mode is the same as the
operation of LAPAN-TUBSAT, in which the video camera mode will be used to find the target, before the high resolution picture is taken.

IV. LAPAN-A3 Satellite

The objective of LAPAN-A3 satellite project is to support the national food sustainability program. Therefore the payload requirement is defined by Institut Pertanian Bogor (IPB). IPB in an academic institution that specialized in agricultural science and technology, which is awarded as national academic reference for Indonenesian food sustainability program. Based on such cooperation, the satellite is also named LAPAN-IPB satellite. The multi-spectral imager will serve the data acquisition related to crop growth/yield estimation as well as coastal environment monitoring, which are important for the food security management. The satellite is planned to be launched to SSO altitude 650 km by PSLV expectedly mid 2013.

The main payload of the satellite is a 4-band multi-spectral imaging line imager (using 4 Kodak 8023 sensor with spectral filter on 450 - 520 nm, 520-600 nm, 630-690 nm, and 760-900 nm) with 1000 mm Nikor Lens, to produce spatial resolution of 18 m, swath width of 110 km. The satellite will also carry digital camera similar to LAPAN-A2 with 1,6 m lens, so that it may provide image with 3,5 m resilution. In addition to that, the satellite will carry AIS and APRS to support global maritime monitoring mission and worldwide radio amateur community.
V. Upgrade on satellite bus

Table 1. Advancement in LAPAN's satellite bus

<table>
<thead>
<tr>
<th></th>
<th>LAPAN-TUBSAT</th>
<th>LAPAN-ORARI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generation</td>
<td>4 Silicium solar panels (432x243 mm). Each panel has 34 cells in series, provide 14 W max power</td>
<td>4 GaAs Solar panels (465x262 mm). Each panel has 30 cells in series, provide 32 W max Power</td>
</tr>
<tr>
<td>Power storage</td>
<td>5 NiH2 batteries, configured in series. The batteries would provide nominal voltage of 12.5 V, 8 Ah capacity</td>
<td>3 Lithium-Ion batteries in paralel, 4 Cells per pack in series, 15 V Nominal Voltage, 17 Ah total capacity</td>
</tr>
<tr>
<td>Attitude sensor</td>
<td>1 CMOS star sensor</td>
<td>1 CMOS star sensor + 1 CCD star sensor</td>
</tr>
<tr>
<td></td>
<td>4 solar panel + 2 solar cell sun sensor</td>
<td>6 solar cell sun sensor</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Orbit determination</td>
<td>None</td>
<td>GPS</td>
</tr>
<tr>
<td>ACS mode</td>
<td>MANUAL DRIVE MODE &amp; SUPPORT ANTI-SUN CAMERA POINTING MODE (CLOSE LOOP MAIN COMPUTER, -Z SOLAR PANEL, AND WHEEL DRIVE ELECTRONICS)</td>
<td>SUPPORT AUTOMATIC ORIENTATION OF THE CAMERA TO CAPTURE SPECIFIC TARGET LOCATION (CLOSE LOOP STAR SENSOR, GPS, MAIN COMPUTER AND WHEEL DRIVE ELECTRONICS)</td>
</tr>
<tr>
<td>Payload data support</td>
<td>Analog data switch</td>
<td>SOLID STATE MEMORY &amp; MULTI- Payne load data handling system</td>
</tr>
<tr>
<td>Payload data transmission system</td>
<td>S-band analog</td>
<td>LAPAN-A2 : S-band analog &amp; digital (6 Mbps)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LAPAN-A3 : X-band digital (100 Mbps)</td>
</tr>
</tbody>
</table>

Table 1 shows that the capacity of LAPAN’s satellite bus increases from its 1st generation to the next. LAPAN’s 1st satellite weights around 55 kg, its 2nd generation weight around 70 kg. Structural layout of each satellite is as follows.

![LAPAN-TUBSAT layout](image)

Figure 4. LAPAN-TUBSAT layout
Figure 5. LAPAN-ORARI & LAPAN-IPB layout

The commonality in LAPAN's satellite buses are the mechanical packaging, i.e using the 2-shelves base, and star-configuration type computing system. Extrapolating the capacity of the Center for Satellite Technology for the next 5 years, LAPAN would be capable to develop 100 kg class satellite. Such satellite bus would be able to support battery capacity 34 Ah (at 15 V) and charging capacity 120 W, which will be able to serve more power demanding mission.
VI. Conclusions

From the facts above, it can be seen that LAPAN's satellite program is technology is growing, from simple satellite for capacity building purposes to more complex satellite designed to serve more complex mission.

In developing its satellite program, LAPAN always involve partnership with other institution interested in satellite technology. LAPAN will always looking for new partner, as well as maintain its current partner, to work together on its next satellite program.

VII. References

2. Hardhienata, S; Triharjanto, R.H. (Editors); LAPAN-TUBSAT : From Concept to Early Operation; Lembaga Penerbangan dan Antariksa Nasional; 2007
5. Triharjanto, R.H.; Mukhayadi, M; LAPAN-TUBSAT Attitude Control : Operational Implementation of Angular Momentum Bias on SSO Satellite; 6th Regional Conference on Aerospace Science, Technology and Industry; Bandung, June 2007
9. www.lapantubsat.org
Future perspectives of SAR polarimetry with applications to multi-parameter fully polarimetric pol-sar remote sensing & geophysical stress-change monitoring with implementation to natural disaster assessment and monitoring within the “Pacific Ring of Fire” by implementation of polar & equatorially orbiting satellite sensors

Wolfgang-Martin Boerner\(^1\)*

In coordination with

Yoshio Yamaguchi\(^2\), Akinobu Sato\(^2\), Roichi Sato\(^2\), Hiro Yoshi Yamada\(^2\); Alberto Moreira\(^3\), Gerhard Krieger\(^3\), Andreas Reigber\(^3\), Irena Hajnsek\(^3\); Kostas Papathanassiou\(^3\); Katsumi Hattori\(^4\), Josaphat Tetuko Siri Sumantyo\(^4\), Kun-Shan Chen\(^5\), Chih-Yuan Chu\(^5\), Chih-Tien Wang\(^5\), Jong-Sen Lee\(^5\); Enrico Paringit\(^6\); Roberto Heru Triharjanto\(^7\), Mahmud Raimadoya\(^7\)

1 University of Illinois at Chicago, UIC-ECE/CSN, Chicago, IL/USA
2 Niigata University, Electronic Information Engineering, Ikarashi, Niigata, Japan
3 DLR-HR, Oberpfaffenhofen, Bavaria, Germany
4 Chiba University, Earthquake Research Center & CEReS, Chiba, Japan
5 National Central University, NCU-CSRSR/MRSL, Jhongli, Taoyuan, Taiwan ROC
6 UPD-GE, Diliman, Quezon City, Metro-Manila, Philippines
7 LAPAN, Jakarta; BAC-CREE/RAWG, Jalan Meranti Dramaga Campus, Bogor, Java, Indonesia

Exploitation of fully polarimetric Satellite POLSAR modes for natural hazard detection and subsequent disaster reduction of SE-Asian/Pacific earthquakes, volcano eruptions and tsunamis – Japan, Taiwan, Philippines and Indonesia

Abstract: The outstanding performance capabilities of the three Satellite POLSAR sensors are well established; and in this exposition the exploitation of the fully polarimetric ALOS-PAL=PPL=SAR mode is demonstrated by implementing the NIIGATA-UNIVERSITY four-scatterer SAR image decomposition with coherency-matrix rotation proving the superior imaging capabilities of the fully polarimetric SAR modes not only for the ALOS-POLSAR L-Band and similarly to the S-Band, C-Band and X-Band. The novel fully polarimetric POL-SAR image processing techniques are then applied to natural hazard detection and subsequent disaster reduction of tsunamis with landslides, volcano eruptions with plume aftereffects & landslides, and of earthquakes with drop-slips experienced within the SE-Asian/Pacific Ring-of-Fire including next to Japan in Taiwan, the Philippines and Indonesia, promoting equatorially orbiting Single and TanDEM L-/S-/X-Band POLSAR sensor deployment.
The terrestrial tectonology: Alfred Wegener’s tectonic plate theory and the two major seismic belts
TUB-LAPAN-ORARI ORBIT PROFILE
(14 pass per 24 hr / orbit time 100 minutes and stay above horizon at about 10 minutes)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PALSAR</th>
<th>RADARSAT-2</th>
<th>TerraSAR-X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit: LEO, circular</td>
<td>Sun-synchronous</td>
<td>Sun-synchronous</td>
<td>Sun-synchronous</td>
</tr>
<tr>
<td>Repeat Period (days)</td>
<td>46</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td>Equatorial Crossing time (hrs)</td>
<td>22:30 (ascending)</td>
<td>18:00 (ascending)</td>
<td>18:00 (ascending)</td>
</tr>
<tr>
<td>Inclination (degrees)</td>
<td>98.16</td>
<td>98.6</td>
<td>97.44</td>
</tr>
<tr>
<td>Equatorial Altitude (km)</td>
<td>692</td>
<td>798</td>
<td>515</td>
</tr>
<tr>
<td>Wavelength (Band)</td>
<td>23 cm (L)</td>
<td>5.6 cm (C)</td>
<td>3 cm (X)</td>
</tr>
<tr>
<td>Fully polarimetric mode</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1. Comparison of High-Level Parameters
ALOS is one of the largest Earth observing satellites ever developed, at 3850 kg. It is in a near-exact 45-day repeat sun-synchronous orbit, 690 km altitude above the equator. The active phased array SAR antenna is obliquely Earth-lacing, aligned with the spacecraft velocity vector. The solar array is arranged at right angles to the orbit plane, consistent with the near-mid-day orbit phasing. The X-band down-link must be shared with optical instruments, which constrains SAR operation times.

<table>
<thead>
<tr>
<th>Mode (selected)</th>
<th>Resolution (m)</th>
<th>Swath (km)</th>
<th>Looks</th>
<th>Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard, stripmap</td>
<td>20 x 10</td>
<td>70</td>
<td>2</td>
<td>HH or VV</td>
</tr>
<tr>
<td>Fine</td>
<td>10</td>
<td>70</td>
<td>1</td>
<td>HH or VV</td>
</tr>
<tr>
<td>ScanSAR (5-beam)</td>
<td>100</td>
<td>350</td>
<td>8</td>
<td>HH or VV</td>
</tr>
<tr>
<td>Dual polarization</td>
<td>(as above)</td>
<td>(as above)</td>
<td>(as above)</td>
<td>(HH, HV, VV, VH)</td>
</tr>
<tr>
<td>Quad-pod</td>
<td>30 x 10</td>
<td>30</td>
<td>2</td>
<td>Full polarization</td>
</tr>
</tbody>
</table>
The four-component decomposition of scattering powers $P_s$, $P_d$, $P_v$, and $P_c$.

4-component scattering power decomposition algorithm using rotated coherency matrix.

Radar line of sight

Deorientation

Rotation of image
Scattering power decomposition

Pauli-basis
Taiwan
23.703N
120.875E
2009/5/1
PASL110000501142420097020002
©METI, ERSDAC

The destruction along the Cheleng-Pu fault caused by the Chi-Chi earthquake of 1999 September 21
Mt. Mayon – The pearl of the Orient

Philippines

13.498N
123.561E

2010/1/15

Data no.
ALPSRP211880260

©METI, JAXA

Scattering power
Decomposition

Decomposed image (Ps, Pd, Pv) with rotation 2*12 window
South-East Asia

ALOS-PALSAR Polarimteric Mode

Ascending

Indonesia

2007/3/10
Data no.
ALPSRP059887030
ALPSRP059887040

2009/3/15
Data no.
ALPSRP167247030
ALPSRP167247040

Yoshio Yamaguchi

©JAXA, METI
TUB-LAPAN-ORARI ORBIT PROFILE
(14 pass per 24 hr / orbit time 100 minutes and stay above horizon at about 10 minutes)

WIDEBAND INTERFEROMETRIC SENSING AND IMAGING POLARIMETRY
Mount Semeru puffs steam behind a cloud of sulphur gas from Mount Bromo in the Tengger caldera on Java.
A flurry of ruptures have occurred since 2000
Next major eruption within 20 years
Off-Tohoku M9 Seaquake & Tsunami 110311

Friday, March 11, 2011 at 05:46:23 UTC
Friday, March 11, 2011 at 02:46:23 PM at epicenter
Epicenter
38.322°N, 142.369°E

110311-Tsunami
OFF-TOHOKU-COASTAL-DISASTER
Map-book, 2011 March/April

Clearly interpreting the Japanese

Expression Tsu-nami 津波 = Harbor-wave

Note that every harbor along the affected Eastern Off-Tohoku coastal corridor was severely damaged by the incoming and outgoing tsunami water-walls
Off-Tohoku 9.0 Earthquake with Super-Tsunami
Destruction of City and Harbor of Ishinomaki by 110311 Tsu-nami (Harbor-Wave)
Off-Tohoku M9 Seaquake & Tsunami 110311

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WIDEBAND INTERFEROMETRIC SENSING AND IMAGING POLARIMETRY
Global Monitoring of Bio-, Geo-, Cryo- and Hydrosphere processes with high temporal and spatial resolution.
(Prof. A. Moreira – POLINSAR09)

Radar Interferometry

TerraSAR – X (1 & 2) (2010)
Pol – InSAR Sensors
TanDEM-X
TandemSAR-L (Destiny): JPL & DLR

WIDEBAND INTERFEROMETRIC SENSING AND IMAGING POLARIMETRY

TUB-LAPAN-ORARI ORBIT PROFILE
(14 pass per 24 hr / orbit time 100 minutes and stay above horizon at about 10 minutes)
Major Paradigm for Remote Sensing from Air and Space of the Terrestrial Covers:

“Natural hazards are inevitable! Natural disasters are not & how can we reduce aftereffects?”

Accomplished with the aid of fully Polarmetric POLInSAR Sensors at Very High Resolution and all pertinent bands:

---

ACQUISITION OF NEW BANDS FOR PASSIVE & ACTIVE SENSING

- Deep earth sounding
  - ULF - LF
- Ground penetrating radar
  - LF - VHF
- Mineral resource exploration
  - HF - UHF
- Biomass and vegetative cover estimation
  - HF – EHF (P/L/C-Band)
- Man made surface structure monitoring
  - HF – EHF (C/X/K-Band)
- Atmospheric passive remote sensing
  - cm – sub-mm

◊ We need to put our act together as the global remote sensing community and request from ITU/WMO the protection of the “fundamental natural resource: the e-m spectrum”, and for providing the spectral bands for us to fulfill our professional duties as


---
Table - EESS (active) Frequency Bands between P-band and Ka-band (Huneycutt)

<table>
<thead>
<tr>
<th>IEEE Band Designation</th>
<th>Frequency Band (MHz)</th>
<th>Bandwidth (MHz)</th>
<th>Allocation Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-band</td>
<td>432-438</td>
<td>6</td>
<td>Secondary (WRC‘03)</td>
</tr>
<tr>
<td>L-band</td>
<td>1215-1300</td>
<td>85</td>
<td>Primary (WRC‘97)</td>
</tr>
<tr>
<td>S-band</td>
<td>3100-3300</td>
<td>200</td>
<td>Secondary (WRC‘97)</td>
</tr>
<tr>
<td>C-band</td>
<td>5250-5570</td>
<td>320</td>
<td>Primary (WRC‘97)</td>
</tr>
<tr>
<td>X-band</td>
<td>8550-8650</td>
<td>100</td>
<td>Primary (WRC‘97)</td>
</tr>
<tr>
<td>X-band</td>
<td>9300-9900</td>
<td>600</td>
<td>Primary (WRC‘97, WRC‘07)</td>
</tr>
<tr>
<td>Ku-band</td>
<td>13250-13750</td>
<td>500</td>
<td>Primary (WRC‘97)</td>
</tr>
<tr>
<td>Ku-band</td>
<td>17200-17300</td>
<td>100</td>
<td>Primary (WRC‘97)</td>
</tr>
<tr>
<td>K-band</td>
<td>24050-24250</td>
<td>200</td>
<td>Secondary (WRC‘97)</td>
</tr>
<tr>
<td>Ka-band</td>
<td>35500-36000</td>
<td>500</td>
<td>Primary (WRC‘97)</td>
</tr>
</tbody>
</table>

---

F-SAR technical characteristics (Reigber)

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>C</th>
<th>S</th>
<th>L</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF [GHz]</td>
<td>9.6</td>
<td>5.3</td>
<td>3.25</td>
<td>1.325</td>
<td>0.35/0.45</td>
</tr>
<tr>
<td>Bw [MHz]</td>
<td>760</td>
<td>400</td>
<td>300</td>
<td>150</td>
<td>100/50</td>
</tr>
<tr>
<td>PRF [kHz]</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>PT [kW]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Rg res. [m] Az res. [m]</td>
<td>2.5</td>
<td>2.2</td>
<td>2.2</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Rg cov. [km] Sampling Channels Data rate</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>12.5 (at max. bandwidth)</td>
<td>8 bit real, 1000MHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>247 MByte/s (per channel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---
FOUNDATIONS AND RELEVANCE OF MODERN EARTH REMOTE SENSING & ITS APPLICATIONS BY IMPLEMENTING SPACE-BORNE POL-IN-SAR

Conclusions:

The Electromagnetic Vector (Polarization) Wave Spectrum: 
A Natural Global Treasure

Terrestrial Remote Sensing with POLinSAR for
The Diagnostics of the Health of the Earth
**MMU UAVSAR: A Miniature C-band Synthetic Aperture Radar for Remote Sensing**

Koo Voon Chet

1 Multimedia University, Faculty of Engineering and Technology, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia, vckoo@mmu.edu.my

**Abstract**

A new miniature C-band SAR onboard an unmanned aerial vehicle (UAV) has been developed at the Multimedia University (MMU), Malaysia. Its major components include a microstrip antenna, a C-band RF transceiver, an onboard SAR recording and processing unit, and an embedded motion sensing system. The overall dimension of the system is approximately 1 ft³, with total weight of 12 kg, thus suitable for a small UAV operation. This paper highlights the design, development and field measurement of the UAVSAR system.

**Keywords**: Synthetic Aperture Radar, Unmanned Aerial Vehicle, SAR processing

1. **Introduction**

Radar is a common tool used in many applications such as imaging, missile guidance, remote sensing and global positioning [1]. The Synthetic Aperture Radar (SAR) was first proposed by Carl Wiley in 1951 [2] which described the use of Doppler frequency analysis to improve radar image resolution. SAR has been proven to be very useful over wide ranges of applications, including high resolution geological and topological mapping, snow monitoring, military surveillance, and classification of earth terrain [3]-[4].

An Unmanned Aerial Vehicle (UAV) is an aircraft that is capable of operating without the presence of pilot or crew in the aircraft’s cabin. It can be found extensively in the area of reconnaissance and surveillance as well as military purposes [5]. In recent years, UAV has become an alternative platform for Synthetic Aperture Radar (SAR). As compared to conventional airborne or space-borne SAR systems, UAV-based SAR system has lower operation cost, lower risk, and suitable for in-situ measurement where frequent revisit is required. The potential of UAVSAR in a diverse range of applications has led to the development of a number of UAVSAR systems [6]-[12].

In 2010, an experimental UAVSAR had been developed by the Multimedia University (MMU), under the collaboration with the Malaysian Remote Sensing Agency (ARSM) [13]. The platform used is a small UAV with allowable payload less than 25 kg and working space less than 1 ft³.

2. **System Overview**

The specifications of the MMU UAVSAR system are summarized in Table 1. This SAR sensor operates at 5.3 GHz with moderate chirp bandwidth of 80 MHz. VV-polarization is chosen since it is sensitive to the vegetation's vertical canopy structure, and thus allowing crop type and growth stage discrimination. The backscattering data is collected in stripmap mode with nominal incidence angle of 30 degree. It can produce SAR imagery of all classes of terrain with backscattering coefficient between 0 and −30dB. The nominal speed and altitude of the UAV is 30 m/s and 1000 m, respectively.

Due to the limited payload capacity of the UAV, the SAR sensor must be very compact and small in size. Most of the subsystems are custom-built since there is no room to mount standard instruments such as signal generator and workstation onto the UAV platform. Figure 1 shows the overall arrangement of various subsystems housed in a three-layer chassis. Its total weight is approximately 12 kg.

<table>
<thead>
<tr>
<th>System Parameters</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of Operation</td>
<td>Stripmap</td>
</tr>
<tr>
<td>Operating Frequency</td>
<td>5.3 GHz (C-band)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>80 MHz</td>
</tr>
<tr>
<td>Polarization</td>
<td>Single, VV</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>3 m × 3 m</td>
</tr>
<tr>
<td>Nominal Platform Speed</td>
<td>30 m/s</td>
</tr>
<tr>
<td>Nominal Platform Height</td>
<td>1000 m</td>
</tr>
<tr>
<td>Payload Weight</td>
<td>&lt; 25 kg</td>
</tr>
<tr>
<td>Allowable Working Space</td>
<td>12” (L) × 9” (W) × 12” (H)</td>
</tr>
</tbody>
</table>

**Fig.1 The MMU UAVSAR Sensor**
3. Subsystem Design

3.1. Antenna Design

Based on the specifications above, a lightweight, small size, linearly polarised microstrip array antenna panel is required. The centre frequency for the antenna array is set at 5.3 GHz, with SWR less than 2. The directive gain of the panel is more than 25dBi for good detection in the presence of noise. Fig. 2 shows the typical slant range geometry of the UAVSAR.

![Fig.2 Slant Range Geometry](image)

The azimuth array is designed with 16 elements spaced 44 mm apart [14]. The 3 dB beamwidth is about 4°. No amplitude variation is planned in the azimuth plane, thus power will be uniformly fed resulting in a sharp pencil beam. The final antenna prototype is shown in Fig.3 and the three-dimensional radiation pattern of the array is given in Fig.4.

![Fig.3 The UAVSAR Antenna Prototype](image)

![Fig.4 The 3D Radiation Pattern of the SAR Antenna](image)

3.2. RF Subsystem Design

As shown in Fig.5, the RF subsystem consists of a transmitter and a receiver. The main functions of the RF transmitter are to up-convert and amplify the incoming baseband IQ signals to an appropriate level suitable for long distance transmission. The desired chirp signals (IQ) are generated using FPGA-based DDS architecture [15]. These signals are fed into the RF subsystem. Dual antenna system is employed in this design to provide high isolation between the transmitter and the receiver. The received echoes are further amplified and down-converted to baseband IQ signals, which will then be fed to a dual-channel high speed ADC.

![Fig.5 RF Transceiver Design](image)

3.3. Embedded UAVSAR Recording and Processing Unit

Fig. 6 shows the general flow of the embedded UAVSAR data recording and processing unit. The raw data is acquired using a high speed 12-bit dual channel analog-to-digital converter (ADC) with data rate of 7.5 Mbps. The digitized raw data are stored in a solid-state drive and a copy of it will be sent to the onboard SAR processor. The onboard SAR processor is implemented using an embedded high performance computer [16]. Range-doppler algorithm is employed for real-time imaging, while omega-k algorithm is used for high-resolution image formation.

![Fig.6 Overview of the UAVSAR Recording and Processing](image)

3.4. Embedded Motion Sensing Unit

The embedded motion sensing unit consists of two main components namely the Inertial Measurement unit (IMU) and the Global Positioning System (GPS) receiver. The integrated IMU-GPS system provides all the necessary motion data (such as platform speed, acceleration, yaw-pitch-roll angles) in real-time for precise motion sensing. Fig.7 shows the embedded motion sensing unit with built-in
IMU and GPS receiver. A 8-bit microcontroller is used to read and transfer both the IMU and GPS data to a single board computer for recording and further processing.

![Fig.7 The Embedded Motion Sensing Unit](image)

**4. SAR Experiments and Preliminary Flight Tests**

In order to verify the performance of the SAR system before the UAV flight mission, a series of ground experiments has been conducted. Fig.8 shows the measurement setup where the SAR system was mounted onto a truck. The truck was then travelled at a constant speed for approximately 1 km to perform SAR imaging. The processed SAR image is shown in Fig.9. It is clearly shown that multiple strong targets are observed at distance more than 1.2 km.

![Fig.8 Ground-based SAR Experiment](image)

**Fig.9** SAR Image of a Ground Test Site

Finally, the SAR sensor was installed into a small UAV for flight test. As shown in Fig.10, the allowable working space is a small opening of approximately 12” (L) × 9”(W) × 12” (H). The SAR antenna was mounted underneath the UAV’s fuselage as illustrated in Fig.11.

![Fig.10 Installing SAR Sensor into UAV](image)

**Fig.11** SAR Antenna Mounted Underneath the Fuselage

A sample of the SAR images captured on December 2010 is presented in Fig.12, with comparison to the Google Earth map of the same site. Clear signatures of river, roads, urban and vegetated areas are observed.

![Fig.12 A Sample of SAR Image Taken at Mersing Test Site, Johor, Malaysia on December 2010](image)
5. Summary
A new miniature C-band SAR onboard an unmanned aerial vehicle (UAV) has been successfully developed at the Multimedia University (MMU), Malaysia. It will be used for remote sensing and surveillance applications in near future.

Acknowledgements
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References
Polarimetric Synthetic Aperture Radar: Theory and Applications

Yoshio Yamaguchi
Dept. of Information Eng., Niigata University, 950-2181 Japan, yamaguch@ie.niigata-u.ac.jp

Abstract
Scattering power decomposition theory and some images of fully polarimetric synthetic aperture radar data are presented for disaster monitoring. Utilization of fully polarimetric data can derive full color images with red–green–blue color coding, red for the double-bounce power, green for the volume scattering power, and blue for the surface scattering power, for which each color brightness corresponds to the magnitude. Since disaster causes the change of each scattering power, it becomes easy for everyone to recognize the change by color in the decomposition image when time series data sets are available. By applying the four-component scattering power decomposition to fully polarimetric data acquired with Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR), we present several images for natural disaster monitoring on volcano activity, snow accumulation, land slide and tsunami effect caused by great earthquake. It is seen in the polarimetric decomposition images that most disaster areas show increasing surface scattering power compared to those in normal situations.

Keywords: Polarimetric Synthetic Aperture Radar, Scattering power decomposition

I. Introduction
Since the launch of ALOS-PALSAR in 2006, a large number of fully polarimetric (Quad-pol) data sets have been acquired from space [1]-[2]. Although the fully polarimetric mode is hitherto an experimental one, it has provided us with precious data sets of various places spread over the planet earth. The total number of scenes exceeds more than 274,000.

There are various image analysis methods for fully polarimetric data sets [3]-[8]. The representative and fundamental methods are based on incoherent analysis dealing with ensemble averaging of several pixels retaining the second order statistics of polarimetric information. The most frequently used method is the H-Alpha-Anisotropy developed by Cloude and Pottier [3]-[5] based on the eigenvalues of coherency matrix. The second one is the scattering power decomposition method [6]-[8] based on physical scattering models, which was first developed by A. Freeman and S. Durden [6]. The current paper describes the four-component decomposition with rotation of the coherency matrix for more accurate polarimetric synthetic aperture radar (POLSAR) image decomposition and scatterer classification.

The scattering power decomposition scheme divides polarimetric data of the imaging pixel area into surface scattering, double bounce scattering, volume scattering, and helix scattering components. These scattering powers are calculated very easily, and are used to compose full color images with RGB color-coding. They have been successfully applied to POLSAR image analysis since color-coded images are easier to understand, and since each color represents a specific scattering mechanism.

II. Scattering Power Decomposition
If scattering matrix data set of the imaging pixel area is acquired, the corresponding coherency matrix can be created, which retains the second order statistics of polarimetric information. The ensemble average of the coherency matrix is given as

\[
\langle [T] \rangle = \langle k_s k_s^\dagger \rangle, \quad \text{with} \quad k_s = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix},
\]

where \(\dagger\) denotes complex conjugation and transposition, \(\langle \rangle\) denotes ensemble average.

Then the measured coherency matrix is rotated by the angle

\[
2\theta = \frac{1}{2} \tan^{-1} \left( \frac{2 \Re \{T_{35}\} - T_{22} - T_{33}}{2 T_{25}} \right)
\]

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so as to minimize the T33 term in (1) using
\[
\langle [T(\theta)] \rangle = [R_p(\theta)] \langle [T] \rangle [R_p(\theta)]^T, \quad \text{with} \quad [R_p(\theta)] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & \sin \theta \\ 0 & -\sin \theta & \cos \theta \end{bmatrix}
\]  
(3)

Then the rotated coherency matrix (measured) is expanded into four sub-matrices which correspond to surface scattering, double bounce scattering, volume scattering, and helix scattering mechanisms

\[
\langle [T(\theta)] \rangle = f_s \langle [T] \rangle_{\text{surface}} + f_d \langle [T] \rangle_{\text{double}} + f_v \langle [T] \rangle_{\text{vol}} + f_c \langle [T] \rangle_{\text{helix}}
\]  
(4)

where \(f_s, f_d, f_v, \text{ and } f_c\) are the expansion coefficients to be determined. These four terms have been derived based on the physical scattering models as shown in Fig. 1. The derivation of scattering power is provided in [8]. The algorithm for the four-component scattering power is shown in Fig. 2.

III. Decomposition Results for Disaster Monitoring

A great earthquake with magnitude 9.0 hit East Japan on March 11, 2011. This disaster was accompanied by a huge tsunami which attacked the eastern seashore of Tohoku area in Japan. ALOS-PALSAR had acquired fully polarimetric data over Ishinomaki area before and after the earthquake on 20101121 and 20110408, respectively. The area was heavily destroyed not only by the earthquake by also by the tsunami. The major part of Ishinomaki-city and neighboring Onagawa-cho were completely destroyed and washed out by the tsunami. Fig. 3 shows the corresponding ALOS-PALSAR polarimetric images of Ishinomaki-city before and after the earthquake together with ground truth data. Although the second data take (April 8) was 28 days after the earthquake (March 11), it is possible to confirm several changes: red color (man-made) area turned into blue color (surface scattering due to completely washed out area by tsunami) near by seashore in Fig. 3 (a) and (b). The ground truth was carried out by Association of Japanese Geographers and Geospatial Information Authority of Japan. Fig. 3 (c) shows the extent of disaster area with blue indicating destroyed by tsunami and with orange indicating flooded by tsunami. The legend color “orange” in Fig. 3 (c) denotes the flooded area where the tsunami hit. But there still remain some buildings/houses and man-made structures after the tsunami. The “blue” color in Fig. 3 (c) denotes the area where almost all buildings/houses and man-made structures were collapsed/destroyed and washed by the tsunami, leaving bare surface on the ground. We can see fairly well correspondence in Fig. 3 (b) and (c).

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Rotational deorientation matrix

\[
\langle [T] \rangle = \begin{bmatrix}
T_{11} & T_{12} & T_{13} \\
T_{21} & T_{22} & T_{23} \\
T_{31} & T_{32} & T_{33}
\end{bmatrix} = \frac{1}{n} \sum k_r k_r^\dagger \\
\theta = \frac{1}{4} \tan^{-1} \left( \frac{2 \Re \{ T_{23} \}}{T_{22} \cdot T_{33}} \right)
\]

\[
\langle [T] \rangle = [R(\theta)] \langle [T] \rangle [R(\theta)]^\dagger \\
[R(\theta)] = \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos 2\theta & \sin 2\theta \\
0 & -\sin 2\theta & \cos 2\theta
\end{bmatrix}
\]

Four-component decoherence

\[
P_e = 2 \, \text{Im} \langle T_{23} \rangle
\]

Helix scattering power

\[
10 \log \left( \frac{T_{11} + T_{22} - 2 \Re \{ T_{12} \}}{T_{11} + T_{22} + 2 \Re \{ T_{12} \}} \right)
\]

Volume scattering power

\[
P_s = \frac{15}{4} T_{33} - \frac{15}{8} P_c
\]

\[
P_s = 4 T_{33} - 2 P_c
\]

\[
P_s = \frac{15}{4} T_{33} - \frac{15}{8} P_c
\]

if \( P_s < 0 \), then \( P_s = 0 \) (remove helix scattering)

\[
S = T_{11} - \frac{1}{2} P_r
\]

\[
D = T_{22} - \frac{7}{30} P_r - \frac{1}{2} P_c
\]

\[
C = T_{12} - \frac{1}{6} P_r
\]

\[
S = T_{11} - \frac{1}{2} P_r
\]

\[
D = T_{22} - T_{33}
\]

\[
C = T_{12}
\]

\[
S = T_{11} - \frac{1}{2} P_r
\]

\[
D = T_{22} - \frac{7}{30} P_r - \frac{1}{2} P_c
\]

\[
C = T_{12} + \frac{1}{6} P_r
\]

\[
TP = T_{11} + T_{22} + T_{33}
\]

\[P_s, P_d, T_P > TP\]

no

\[
P_s = S + \frac{|C|^2}{S}
\]

\[
P_d = D - \frac{|C|^2}{S}
\]

Surface scattering

\[C_s > 0\]

no

Double bounce scattering

\[C_s > 0\]

\[
P_s = D + \frac{|C|^2}{D}
\]

\[
P_d = S - \frac{|C|^2}{D}
\]

if \( P_s > 0, P_d > 0\)

\( P_s > 0, P_d < 0\)

\( P_s < 0, P_d > 0\)

Decomposed power

\[
T_P = P_s + P_d + P_e + P_c
\]

\[
P_s = TP - P_c, P_d = 0
\]

\[
P_s = TP - P_c, P_d = 0
\]

\[
P_e = TP - P_c
\]

Four comp.

Three comp.

Three comp.

Two comp.

Fig. 2 Four-component scattering power decomposition algorithm using rotated coherency matrix
IV. Concluding remarks

It is seen in the polarimetric decomposition images that most disaster areas show increasing surface scattering power compared to those in normal situations.

References
Synthetic Aperture Radar Interferometry: techniques and applications

Daniele Perissin
daniele.perissin@cuhk.edu.hk

ISEIS, CUHK, Hong Kong

Foreword

The Speaker

2002 Master in Telecommunication Engineering, Politecnico di Milano, Italy
2006 PhD degree in Information Technology, Politecnico di Milano, Italy
Till 2009 Assistant researcher in Politecnico di Milano, Italy

Since 2nd October 2009, Research Assistant Prof., ISEIS, CUHK
Techniques (1)

Synthetic Aperture Radar Interferometry
InSAR

Vertical ground displacement with centimeter precision

Interferogram

Colour map of the variation of the sensor-target distance as fractions of the wavelength

\[
\frac{2\Delta r}{\lambda}
\]

Each fringe indicates

\[
\Delta r = \frac{\lambda}{2} \approx 2.8\text{cm}
\]

of displacement

Bam (IRAN)  Earthquake, Dec. '03

CERES, Chiba University  Daniele Perissin  ISEIS-CUHK

Techniques (2)

The Permanent Scatterers (PS) Technique

CERES, Chiba University  Daniele Perissin  ISEIS-CUHK  6/37
InSAR Permanent Scatterers (PS)

Scatterers that do not change their electromagnetic behavior (Houses, manmade constructions, exposed rocks)

Many repeated images (>20) are needed!

PSInSAR

The Permanent Scatterers (PS) technique

We can estimate the height between P and O only if P and O are permanent targets

\[ \Delta h_{PO} = \arg \max \left\{ \frac{1}{N} \sum_{i=1}^{N} e^{j\phi_i} \cdot e^{-jK_\lambda \Delta h_{PO} B_{ij}} \right\} \]

Non-linear problem, can be solved through a periodogram

CERES, Chiba University  Daniele Perissin  ISEIS-CUHK  8/37
The Height of PS's in Hong Kong

TSX data

PSInSAR technique to monitor ground deformation

CUHK

2cm/year

1cm/year

Subsiding areas

TSX data
Hong Kong with TerraSAR-X data

ID: 169765
Ellipsoidal Height (WGS84) [m]: 33
Res. Height [m]: 15.8
Velocity [mm/year]: -14.1
Displ. to Temp. Ratio [mm/degC]: 0.04
Temporal Coherence: 0.83
Sample: 9667, Linx: 4932

by SARPROZ (c)
Directions: To here - From here

Cosmo SkyMed, Shanghai

~1.5 Million PS's

CERES, Chiba University  Daneile Perissin  ISEIS-CUHK  12/37
Techniques (3)

The ADVANCED Permanent Scatterers analysis
What are PS's?

Many repeated acquisitions taken at different times, with different geometries, polarizations, ...

Point targets extraction

Estimation of RCS, size, resonance, height, ...

Characterization and classification

Multi-platform PS's

Trihedral

Different attitudes, Different incidence angles

Parallel orbits

Dihedral

Ascending

Descending

Pole

CERES, Chiba University Daniele Perissin ISEIS-CUHK 15/37

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Details of PS density from 3 tracks

ERS data in Milan

Parallel tracks combination, ERS + Envisat

Seasonal displacement time series of a DIHEDRAL PS in Milan
Techniques (4)

The Quasi-PS technique
On mountains or in vegetated areas, there are no PS's

The Quasi-PS analysis

The core concept

Coherent connections

SAR sampling grid
The Quasi-PS analysis

The basic idea

Model used in the PS analysis for estimating PS height and velocity

\[ \sum_{(i,k)} \gamma_{ik} \exp \left( \frac{i}{\Delta \phi_{pq}^{ik} - \Delta \phi_{Model}^{ik}} \right) \]

Processing weights

Images Graph

PSC Graph


Quasi-PS: an example

Estimating the height of the terrain with ERS data in Rome, Italy

Permanent Scatterers

Quasi-Permanent Scatterers
Techniques (5)

Change Detection and “Temporary” PS analysis

Tibet Railway stability monitoring

Monitoring the displacement of corner reflectors with Envisat
Case study: Hong Kong Government project

Hy(S)Q/007/2011 - Research on SRRST in Ground Settlement Monitoring

Hong Kong with TerraSAR data: study and test of CR's

Cheap, light, easy to carry, easy to mount, resistant to HK weather, ...
...and: temporary.

CERES, Chiba University
Daniele Perissin
ISEIS-CUHK
Techniques (5)

Non-linear movements estimation
**PSInSAR applications**

Vertical-horizontal motion decomposition

Regular sampling required for non-linear motion reconstruction !!!

Radarsat data

---

**All these techniques (PS, A-PS, Q-PS, T-PS, ...) are implemented in a sw:**

**SARPROZ**

The SAR processing tool by PeriZ

http://ihome.cuhk.edu.hk/~b122066/index_files/download.htm
Main characteristics of SARPROZ:

- **User friendly Graphical Interface:** no other language knowledge is required for standard uses

- **Based on Matlab:** advanced users can very easily develop their own software extensions. Data and parameters are very easily imported/exported using Matlab.

- It can be compiled and it runs independently from Matlab on any platform (Unix, PC, Mac).

- **Completely parallelized:** SARPROZ can run on multiple CPU cores or computer clusters automatically.

http://ihome.cuhk.edu.hk/~b122066/index_files/download.htm
Multi-temporal InSAR processing: techniques and applications

Conclusions

Multi-temporal InSAR processing is a complex task involving different techniques depending on available data and aim of the analysis.

To be able to solve all cases, high expertise and powerful software tools are needed.

Multi-temporal InSAR has a wide range of applications, here we saw monitoring urban and extra/urban phenomena, like subsidence and settlement due to excavations/land reclamation.

Collaborations are very welcome: daniele.perissin@cuhk.edu.hk
Chemistry of stratosphere and mesosphere revealed by ISS/JEM/SMILES for Earth Diagnosis.

Makoto SUZUKI1, Naohiro Manago1
(JAXA/ISAS, Chiba U./CeRES)
Naohiro Manago1, Chihito MITSUDA2, Koji IMAY, Hischau AKIYOSHI3, Takashi SANO4, Yoko NAITO5, D. KININWARD6, and Masato SHIOKANI7
1Institute of Space and Astronautical Science, JAXA
2Fujitsu Ltd, Tokyo R&D Inc.
3National Institute for Environmental Studies
4Department of Geophysics, Kyoto University
5NCAR
6Research Institute for Sustainable Humanosphere, Kyoto University

Passive microwave remote sensing in Japan

- AMSR, AMSR-E have shown excellent performance for remote sensing of SST, sea ice, etc.
- AQUA/AMSR-E had stopped operation last year, but AMSR-2 instrument and GCOM-W satellite is now waiting for launch (it was delayed from Feb. 2012, by the delay of another satellite provider).
- A sub-mm chemistry mission, SMILES had been conducted jointly by JAXA and NICT. It proposed around 1987 originally, and it finally onboard ISS on Sep. 18, 2009. It worked only 6 months, but it demonstrated breakthrough performance at 625, 650 GHz region, Tsys = 340K, using 4 K cooled SIS detector.
  - This is the my 3rd instruments that worked only 6 months.
    • ADEOS-I/ILAS, ADEOS-II/ILAS-II, ISS/JEM/SMILES (this talk)
    • And suffered another satellite failure, not entering Venus orbit, on Dec. 9, 2010, but it failed. Venus Climate Orbiter, Akatsuki, is now wandering around 0.6-0.7 AU to reach Venus again around 2015/16.
JEM/SMILES Payload

- Dimension: 1.66 m x 1.7 m x 0.8 m
- Weight: < 500 kg
- Mission Life: 1 year

The SMILES was carried by the H-IIIB with the H-II Transfer Vehicle (HTV) (Sep. 11); the HTV was attached to the ISS (Sep. 18); the SMILES was attached to the JEM (Sep. 25) (All dates in JST)
JEM/SMILES Mission

(JEM/SMILES: Superconducting Submillimeter-Wave Limb-Emission Sounder designed to be aboard the Japanese Experiment Module on ISS; Collaboration project of JAXA - Japan Aerospace Exploration Agency - and NICT - National Institute of Information and Communications Technology -)

1. Demonstration of superconductive mixer and 4-K mechanical cooler for the submillimeter limb-emission sounding in space

   [Mechanical Cooler] Two-stage Stirling and J-T;
   20mW @4K, 200mW @20K, 1000mW @100K;
   Power Consumption: <300 W; Mass: 90 kg

   [SIS Mixer]
   RF: 640 GHz, IF: 11-13 GHz; Junction: Nb/AlOx/ Ni; ~7 kA/cm²;
   Fabricated at Nobeyama RC

2. Observation on atmospheric minor constituents in the middle atmosphere

   [Standard Products]
   - 1 scan: O₃, HCl, ClO, CH₃CN, O₃ isotopes, HOCl, HNO₃
   - Multi-scan: HO₂, BrO

   [Research Products] UTH, Cirrus Clouds, volcanic SO₂, H₂O₂

SMILES Instrument

625, 650 GHz region, SSB system
4 K cooled, Tsys = 340 K
Two 1.2 GHz bandwidth spectrometers
0.8 MHz spectral resolution.
Comparable or even better than best laboratory instruments.
Scientific targets of SMILES

1. Inorganic Chlorine chemistry
   • ClO to HCl ratio
     (O_3 trend in the US)
   • HOCl production
     (O_3 trend in the LS)
   • Global ClO
     (background ClO)
2. Bromine budget
   (very short-lived source gas issue)
3. HO_3 budget
   etc.

Simulated SMILES observation performance

Error estimation for the mid-latitude case based on the single scan measurement

Overview of JEM/SMILES Instruments: SIS Device

**SIS Junction**: Nb/AlOx/Nb  
**Junction Area**: ~1 x 1 mm^2  
**Current Density**: 6-7 kA/cm^2  
Fabricated at Nobeyama Radio Observatory, JAPAN
Two Bands among Band A, B, C can be observed.

Band A

Frequency, GHz: 629.2, 629.4, 629.6, 630.0, 630.2, 630.4, 630.6

Band B

Frequency, GHz: 629.2, 629.4, 629.6, 630.0, 630.2, 630.4, 630.6

Band C

Frequency, GHz: 629.2, 629.4, 629.6, 630.0, 630.2, 630.4, 630.6

Frequency region has been selected by engineering interest, as high as possible, but 625-626 GHz region is the only frequency to measure HCl below 1 THz.

At 600 GHz troposphere is opaque in limb.

Teys ~ 350 K and Noise floor is ~0.4 K, given by

\[ NEΔT = \frac{T + T_{\text{rms}}}{\sqrt{N^*T}} \]

ISS Orbit plane rotates in ~90 days, 45 days for diurnal coverage. It will be good platform for diurnal variation study and solar occultation, such as ISS/SAGE-III (2015?)


ISS orbit
- Low altitude: 500 km
- Moderate Inclination: 53.2°
Comparison of SMILES ClO v2.0 with MLS 3.3
MLS coincidence, DSZA < 2°, SMILES ver.2 release candidate.

Coincidence event on Oct. 12, 2009
SMILES, MLS at 50.4°N 130.7°E (the first coincidence in current criteria).
SZA= 59.6°

Coincidence Statistics 30S-40S, 161 SMILES vs. 301 MLS profiles, most coincidence cases in current criteria. < 10% agreement with MLS 3.3 between 22-48 km

Daytime ClO comparison with NCAR WACCM
Other latitude slightly worth than these examples.

coincidences 0-10N, Oct. - Feb.,
SMILES vs. WACCM

coincidences 30-40N, Oct. - Feb.,
SMILES vs. WACCM
Detection limit of SMILES CIO, 15 ppt at 25 km in single shot, negative bias at 22 km in nighttime. Detection limit changes with pressure.

**Daytime (noon) and Nighttime (midnight) difference at 10N-10S**

Theoretical detection limit and standard variation of nighttime. Below 35 km, it should be detection limit.

---

SMILES (+ MIPAS) can provide knowledge of chlorine partitioning at the background atmosphere based upon observations. 2010/10/12, local solar noon (53N-60N) and midnight (233-335), CIONO₂ - MIPAS IMK, day 53N-57N, night 50N-54N

**Daytime profiles**

**Nighttime profiles**

2011.9.20
Fig. 1 HCl (left), ClO (center), and O₃ (right) distribution on Jan. 23, 2010 at the 22 km altitude in the northern hemisphere.

HCl is about 1.6 ppb at outside polar vortex and it is almost entirely converted to the ClO (1.6 to 2.0 ppb). O₃ destruction has occurred as much as 20% (from 4 ppmv to 3.2 ppmv) after 3 weeks of heterogeneous chemical process.

Fig. 2 (a) shows trajectory of observation points of SMILES (large circles) from 15:23UT to 15:47 in Jan. 23, 2009, and CALIPSO observation points which passed north of Europe. Fig. 2(b) shows SMILES ClO vertical section.

(c) SMILES ClO vertical section interpolated.

(d) SD-WACCM ClO vertical section.
Checking CIO more thoroughly, Jan 23 at different orbits. (left) SMILES interpolated, (right) WCCAM interpolated.
SMILES can measure same location at different local times. Jan. 23rd measurements showed, nighttime CLO decline generally agreed well with WACCM calculation. This suggest current knowledge of (CIO)₂ formation rate is acceptable.
SMILES $O_3$(Left-Upper), Locations (Right-Upper), CIO (Left-Lower), HCl (Right-Lower)

SMILES O3(LeftUpper), CIO(LD), Locations(RU). CALIPSO (RD)

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Diurnal variation of O3 in the mesosphere observed by SMILES

- mesospheric O3 shows strong diurnal variation, but it was not observed clearly from ground and space.
- Daytime O3 and HO2, etc have relations to H2O, which is now under evaluation. (Clancy et al, JGR 1994)

\[
\text{O}_3 = (k_5-k_4)/(k_7+J_3)(k_9+10)^{(1/2)}(\text{H}_2\text{O})^{1/2} \tag{1}
\]

\[
\text{HO}_2 = (k_5-k_4)/(k_7+J_3)(k_9+10)^{(1/2)}(\text{H}_2\text{O})^{1/2} \tag{2}
\]

SMILES and a model calculation (Vaughan, Nature, 1984)
Kovalenko et al. (2007) have questioned the reaction rate of ClO + HO₂ → HOCl + O₂ (JPL206/2011), and it proposed to be near the value reported by Stimpfle (1979). von Clarmann et al. (2009) also supported this claim from MIPAS-B balloon measurements. This could affect total ozone loss at the lower stratosphere significantly. We checked the reaction rate by using steady state relations around [HOCl] at the 30-45 km.

Zonal mean temperature = 249K.

- **k₁ (nominal)**
  \[ k₁ = 2.7 \times 10^{-12} \exp\left(\frac{220}{T}\right) \text{ cm³/molecule/s} \ (JPL2006) \]
- **k₁ (upper limit)**
  \[ 9.66 \times 10^{-12} \text{ cm³/molecule/s} \]
- **k₁ (lower limit)**
  \[ 4.41 \times 10^{-12} \text{ cm³/molecule/s} \]

Kovalenko et al. (2007) [Balloon and Model] showed better agreement with k₁ by Stimpfle et al. (1979). von Clarmann et al. (2009) also reported same results using ENVISAT/MIPAS.

\[
\begin{align*}
  k₁ & = 3 \times 10^{-12} \exp\left(\frac{850}{T}\right) \times 4.5 \times 10^{-12} \text{ cm³/molecule/s} \\
  & = 3.44479 \times 10^{-12} \text{ cm³/molecule/s (Stimpfle)}
\end{align*}
\]

---

**ClO + HO₂ → HOCl + O₂ (k₁)**

At the middle atmosphere 40-50 km, chlorine species are distributed among HCl, HOCl, and ClO. The chemical balance among these species is controlled by the following chemical reactions;

\[
\begin{align*}
  \text{ClO} + \text{HO₂} & \rightarrow \text{HOCl} + \text{O₂} \quad k₁ \\
  \text{HOCl} + \text{OH} & \rightarrow \text{H₂O} + \text{Cl} \quad k₂ \\
  \text{HOCl} + \text{hv} & \rightarrow \text{OH} + \text{Cl} \quad j₁
\end{align*}
\]

The daytime chemical equilibrium [ClO]/[HOCl] can be simplified at 40-50 km, where [OH] is small, as follows.

\[
\frac{[\text{ClO}]}{[\text{HOCl}]} = \frac{j₁}{k₁}
\]

- **SMILES ver. 2.0a, [ClO], [HO2], [HOCl]**
- **GEOS-5 meteorological data**
- **j₁: HOCl photolysis is calculated, from cross-section JPL2006, multiple scattering calculation using MODTRANS (DISORT, 16 streams).**

---

**SMILES観測[ver. 2.0a]に基づくk₁の計算は30, 35, 40 kmにおいてJPL2006を支持している。**

Oct. 12, 2009, 57.111.8°N, SZA=64.811.6°
Stratospheric ClO, HO2, and HOCl measurements by SMILES can estimate $k$ ($d_{34}$): ClO + HO2 $\rightarrow$ HOCl + O2

JPL2011 value: $A = 2.7E-12$, $R/E = 220$

$$d_{34} = [\text{HOCl}] / [\text{ClO}] / [\text{HO2}] \times [\text{HOCl} + d_{34}[\text{OH}] + f35[O]]$$

SMILES data fit (left), was not successful but agree with JPL2011 at 250 K.
If we look at only the yellow circle region $T<250$ K ($1/T > 0.004$), it may agree with JPL2011.

Summary

- SMILES observed chemistry of 2009-10 Arctic winter with higher sensitivity (~0.015 ppb precision for ClO, better than Aura/MLS ~0.1 ppb), it should make description of chemistry much easy and clear.
- Spatial and temporal features agreed quite well between SMILES and SD-WACCM, in general.
- (ClO), formation was tentatively checked through ClO decay during nighttime by comparison with SD-WACCM results, and it looks current knowledge of chemical kinetics is acceptable.
- Chlorine partitioning inside polar vortex can be studied with ClONO2 and other data (from other sensor or model calculations).
- SMILES L2 data (currently ver. 2.1) will be kept updating (to ver. 2.2, 2.3, ...), and ver. 2.1 will be open to general public soon.
Simulation of direct and indirect effects of aerosol on ground radiative fluxes in Chiba City region

Gerry Bagtasa1,2, Naohiro Manago1, Naoko Saitoh1, Hiroaki Kuze1
1Center for Environmental Remote Sensing, Chiba University,
Chiba Inage-ku Yayoi-cho 1-33, 263-8522 Chiba Japan
2Institute of Environmental Science & Meteorology/Natural Sciences Research Institute,
University of the Philippines, Diliman Quezon City, 1004 Philippines
E-mail: gerrybagtasa@gmail.com

Abstract
There is growing evidence that aerosols have profound effects on radiative and thermodynamic systems of the atmosphere. In this study, the effects (direct, semi-direct and indirect) of aerosols are simulated over Chiba city region using WRF-Chem for the year 2011. Results show that the indirect effect supersedes the direct radiative effects of aerosols. Ground-based shortwave (SW) downward flux measurement (SKYNET) shows substantial decrease in SW flux during summer due to increased cloud coverage as compared to an aerosol-free atmosphere. Increased cloud coverage also affects the outgoing longwave radiation during summer, however, it does not seem to have considerable effect on the longwave downward flux. On its effect on near-ground temperature, aerosols in the fine and coarse modes tend to increase and decrease near-ground temperature, respectively.

Keywords: aerosols, direct and indirect effect, radiative flux, simulation, WRF-Chem

1. Introduction
Atmospheric effects of aerosols are one of the major uncertainties in our current understanding of Earth’s climate system (IPCC, 2007). Aerosol radiative forcing remains at an uncertainty of -0.5 +/- 0.4 Wm⁻² while radiative forcing due to greenhouse gases is at 2.63 +/- 0.26 Wm⁻² (Forster et al., 2007). Recently, there is growing evidence that aerosols have profound effects on radiative and thermodynamic systems of the atmosphere (IPCC, 2007). These effects include reduction in solar radiation (direct effect), changes in near surface temperature as well as planetary boundary layer height (semi-direct effect), reduction in cloud droplet size and an increase in cloud droplet number concentration that can lead to changes in cloud albedo and lifetimes (indirect effect) (Isaakzen et al., 2009).

While most aerosol simulation studies focus on past air pollution episodes, only a few deal with the feedback effects of aerosols. For instance, Chapman et al. (2009) investigated the influence of elevated aerosol sources on summertime aerosol forcing and cloud and aerosol interaction in northeastern America. Zhang et al. (2010) simulated aerosol-climate feedback effects over the continental USA for January and July of 2001. Goto et al. (2012) analyzed the effect of aerosol loading on the relationship between SW downward flux, atmospheric optical thickness and single scattering albedo. In this study, we used an online-coupled chemical transport and radiation model (WRF-Chem) to investigate the monthly variation of aerosol direct, semi-direct and indirect effects for the year 2011 in Chiba City region.

2. WRF-Chem Model
Weather Research and Forecast (WRF) (http://www.wrf-model.org) is a mesoscale numerical weather system designed for both operational forecasting and atmospheric research applications with horizontal resolutions ranging from meters to thousands of kilometers. It is a non-hydrostatic model, with several dynamic cores including a fully mass and scalar conserving coordinate version that is widely used in air quality prediction applications. WRF also includes various choices for physical parameterizations to represent atmospheric processes (i.e. microphysics, cloud, radiation, etc.).

The chemistry component of the WRF-Chem (Grell et al., 2005) is a regional air quality modeling system, which is being continually developed by NOAA (National Oceanic and Atmospheric Administration of USA) and several other research institutes.
The model treats the processes of transport (advective, convective and diffusive), wet and dry deposition, chemical transformation, emission, photolysis, aerosol chemistry and dynamics, etc. Detailed description of the model is found elsewhere (Grell et al., 2005). In the past, chemical transport models treated the meteorological and chemical processes separately. Typically the meteorological model was first considered, after which a chemical model is supplied. WRF-Chem is fully consistent with the meteorological component, having the same transport scheme, same time steps, same horizontal and vertical grids and same physical schemes for sub-grid scale transport. This enables users to see the feedback mechanisms between chemistry, radiation, cloud and climate.

3. Method

In this study, we simulated the atmosphere over Chiba City area with and without the existence of aerosols. The effects of these 2 conditions on the overall state of the atmosphere are analyzed and contrasted. Moreover, some observed radiative and meteorological parameters are compared to the simulated atmosphere. These parameters include the shortwave SW and longwave LW downward flux observations, outgoing longwave radiation (OLR), cloud cover and near-surface temperature.

3.1 Observational data

To assess the radiative effects of aerosol, SW and LW downward flux observations by SKYNET (http://atmos.cr.chiba-u.ac.jp/index.html) in Chiba was used. The observation sites of SKYNET are located mainly in East Asia from Mongolia to Thailand as well as in Japan. Observation sites include such instruments as sky radiometer, pyranometer, pygeometer, etc. The data observed at each site are collected into a site server and then transferred using an internet for super sites and sent by off-line transportation for other sites. These data are archived into a SKYNET server in Chiba University and then open to the public. Suspended particulate matter (SPM) concentrations are collected from the Atmospheric Environmental Regional Observation System (AEROS) which covers the whole of Japan (http://soramame.taiki.go.jp/). AEROS has 124 sites all over Chiba prefecture and data can be freely downloaded from their website. Meteorological observations used in this study are from the Japan Meteorological Agency’s (JMA) Automated Meteorological Data Acquisition System (AMeDAS). AMeDAS is a surface observation network used for gathering regional weather data throughout Japan.

3.2 Domain configuration and Initial and boundary condition

The simulation domain for this study extends from 29.45°N to 46.18°N and 126.52°E to 148.48°E, covering the main islands of Japan (i.e. Honshu, Kyushu, Hokkaido and Shikoku; excluding Okinawa). The model run has a horizontal grid spacing resolution of 22 km. The meteorological initial and boundary conditions are from the National Center for Environmental Prediction (NCEP) Final Operational Model Global Tropospheric Analyses (FNL) data, available every 6 hours at 1°x1° grid spacing resolution (http://dss.ucar.edu/datasets/ds083.2/). Anthropogenic emissions for gaseous species and aerosols were from the global emission inventory data for the year 2005 compiled and distributed by the Database for Global Atmospheric Research (EDGAR) system (http://www.mnp.nl/edgar) and Reanalysis of tropospheric chemical composition (RETRO) (http://retro.enes.org/index.shtml).

3.3 WRF-Chem Model Configuration

Table 1 summarizes the configuration used in the simulation.

<table>
<thead>
<tr>
<th>Process</th>
<th>WRF-Chem Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microphysics scheme</td>
<td>Lin et. al.</td>
</tr>
<tr>
<td>Longwave radiation</td>
<td>RRTM scheme</td>
</tr>
<tr>
<td>Shortwave radiation</td>
<td>Goddard</td>
</tr>
<tr>
<td>Surface layer</td>
<td>Monin-Obukhov</td>
</tr>
<tr>
<td>Land surface</td>
<td>Noah Land Surface Model</td>
</tr>
<tr>
<td>Boundary layer</td>
<td>Yonsei University scheme</td>
</tr>
<tr>
<td>Cumulus parameterizations</td>
<td>Grell 3D</td>
</tr>
<tr>
<td>Aerosol chemistry</td>
<td>MADE/SORGAM (Trimodal)</td>
</tr>
</tbody>
</table>

Table 1: WRF-Chem configuration options
4. Results and Discussion

Atmosphere over the Chiba City area was simulated with the following conditions: (1) aerosol-free atmosphere hereon denoted by "noChem" and (2) aerosol including gas chemistry, referred to as "wChem", as calculated using the global emission inventories RETRO and EDGAR, including sea-salt, DMS and dust aerosols. Fig. 1 shows the daily-averaged downward SW Flux from January 1 to December 31 of 2011.

Fig. 1 Observed and simulated daily downward SW Flux variation for the year 2011.

Fig. 2 Observed and simulated monthly-averaged downward SW Flux for the year 2011.

Figure 2 shows the monthly-averaged downward SW Flux for the year 2011. The graph shows a consistent over-estimation bias of the WRF-Chem model in estimating ground SW flux as compared to observations of SKYNET. However, for the months of August and September, there was an apparent difference between noChem and wChem simulations, where aerosol-free condition simulation shows larger calculated values of downward SW flux. This apparent difference is not seen in fig. 3, which is the monthly-averaged downward LW flux for the same year.

Figure 4 shows the simulated monthly cloud cover over Chiba city area. Here, it is apparent that simulated cloud cover for the aerosol-loaded (wChem) atmosphere is more than two times higher than the aerosol-free (noChem) simulation. This resulted to a lower SW flux for the aerosol-free atmospheric simulation. However, the underestimation of the aerosol-free condition has no apparent effect on the downward LW flux as seen in Fig. 3.

Although SKYNET has no OLR, simulated OLR for aerosol-free and aerosol-loaded atmosphere as shown in fig. 5 also shows differences in their values for the months of August and September. This time, simulated OLR is higher for the noChem run. This is still due to the higher cloud cover for the 2 summer months resulting from the existence of aerosols in the atmosphere.
Fig. 5 Simulated monthly-averaged outgoing longwave radiation (OLR).

Fig. 6 shows the average observation and simulation of near-surface temperature from AMeDAS. The WRF has an apparent underestimation bias in estimating near-ground temperatures except for the months of August and September. For the wChem simulation run, however, temperature tends to be higher, and closer to actual observation, than the noChem run. Aerosols tend to increase near-ground temperature but was compensated with higher cloud cover during the months of August and September.

Fig. 6 Observed and simulated monthly-averaged near surface temperature in Chiba City.

5. Conclusion

Simulation of aerosol-free (noChem) and aerosol-loaded (wChem) atmospheres over Chiba City area was done to quantify the effects (direct and indirect) of atmospheric aerosols. Comparison between observed and simulated SW flux showed large deviation for the aerosol-free condition particularly for the months of August and September. This is also the case for the OLR. This can be attributed to the underestimation of cloud cover for an aerosol-free atmosphere. Moreover, existence of aerosols tends to increase near-surface temperature as shown by the simulation, though there is not much difference in terms of near-surface temperature for the months of August and September due to the higher cloud cover that compensated supposed increase of temperature from the wChem simulation run. Separate wChem simulations with only fine aerosols and fine plus coarse aerosols showed that coarse aerosols slightly reduce near ground temperature.

Acknowledgements

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References


Direct sunlight-DOAS measurement of aerosol and NO₂ using a non-scanning fiber sensor
Ilham Alimuddin,¹ Tomoaki Tanaka,² Hiroshi Hara,² Yusaku Mabuchi,¹ Naohiro Manago,¹ Tatsuya Yokota,² and Hiroaki Kuzu¹

¹Centre for Environmental Remote Sensing (CEReS), Chiba University,
²National Institute for Environmental Studies
E-mail: ilimuddin@graduate.chiba-u.jp

Abstract
The technique called Differential Optical Absorption Spectroscopy (DOAS) is useful for optical remote sensing, enabling measurement of atmospheric trace species over a long distance of a few kilometers [1]. The DOAS method based on a intense light source such as a xenon lamp emitting visible radiation is quite suitable for urban air pollution studies, since both nitrogen dioxide (NO₂) and aerosol, the most important pollutants originated from human activities, can be directly measured using a near horizontal light path in the lower troposphere. In contrast to such active DOAS approach, the use of direct solar radiation can possibly be used for the retrieval of the same air pollution species. In this study, we describe a non-scanning, fiber-based sensor for monitoring the sunlight. Three independent optical fibers are directed toward slightly different azimuthal directions along the ecliptic, receiving the sunlight during several hours around noon. The ends of the fibers are bundled together at the surface of a diffuser plate. The scattered light from the plate is collected with a lens, and coupled to another fiber that, in turn, is connected to a high resolution spectrometer (USB 2000+). This spectrometer can transmit the data in every 100 ms to a PC for implementing the spectral analysis.

The measurement was carried out on three, nearly cloud-free days on 11-13 January 2012. The spectral features in the wavelength range between 400 and 700 nm can be used for the aerosol retrieval, whereas that between 400 and 450 nm for the DOAS measurement of NO₂. The resulting column values are compared with the simultaneous data taken with a collocated sunphotometer and CEReS DOAS spectrometer [1]. Also, the data obtained from nearby ground sampling stations are taken from AEROS database.

Keywords: MAX DOAS, fiber sensor, aerosol, NO₂

1. Introduction
In recent years, the atmospheric pollution in Japan has been improved as a whole, as compared with situations a couple of decades ago. Nevertheless, occurrence of air pollution exceeding the environmental standards is still seen in places such as urban roadside and factory areas. Therefore, efforts are required for monitoring anthropogenic air pollution, especially the combustion products such as nitrogen oxides and aerosol particles, also known as suspended particulate matter (SPM). The determination of total (column) amount of such air pollutants can be implemented via optical measurement, in which the spectral intensity is compared before and after the extinction (i.e. the sum of scattering absorption) (1). In this study, we experiment the DOAS method to measure this.

2. Data and Methodology
Raw data is basically retrieved from the spectrum capturing devices such as spectrometer. The design of the spectrometer and how it is supported by other devices in capturing the signal that differentiate DOAS method one from another. In terms of light source there 2 types of DOAS, active is when the light source is an artificial light such as Xenon lamp, while passive DOAS only relies the source from the direct and scattered spectrum of the sun. Pulsed or Long Path DOAS is an example of active DOAS and Multi Axis DOAS is passive, Fig. 1. The direct sun-light DOAS is also categorized as passive and considered low cost as it only uses 400um optical fibers. In our laboratory we experiment all these types of DOAS with the path shown in Figure 1.
Figure 1. Types of DOAS used in Chiba University measurement. A. LP DOAS B. MAX DOAS

Figure 2. The direct sunlight DOAS configuration with USB2000+ Spectrometer.

The Direct Sunlight DOAS method is similar to MAX DOAS technique (2). It uses three independent optical fibers are directed toward slightly different azimuthal directions along the ecliptic, receiving the sunlight during several hours around noon. The ends of the fibers are bundled together at the surface of a diffuser plate. The scattered light from the plate is collected with a lens, and coupled to another fiber that, in turn, is connected to a high resolution spectrometer (USB 2000+).

The analysis of the DOAS spectra is based on the Beer–Lambert’s law expressed as:

\[ I(\lambda) = kI_0(\lambda)e^{-\sigma(\lambda)n} \]  

where \( I(\lambda) \) is the measured intensity, \( k \) is the system constant, \( I_0(\lambda) \) is the unattenuated reference intensity, \( L \) is the path length, \( \sigma(\lambda) \) the wavelength-dependent absorption cross section, and \( n \) is the number density of the species averaged over the path length. The dimensionless quantity \( L\sigma(\lambda)n \) represents the optical thickness, denoted as \( \tau \). Below we describe the algorithm developed for the retrieval of NO2 concentration and the aerosol optical thickness. After the background subtraction, the observed light intensity \( I_{obs}(\lambda) \) can be expressed as:

\[ I(\lambda) = kI_{ref}(\lambda)Tg(\lambda)Tm(\lambda)Ta(\lambda) \]  

where

\[ I(\lambda)\]: the observed spectrum  
\[ k \]: Apparatus constant  
\[ I_{ref}(\lambda) \]: reference spectrum  
\[ Tg(\lambda) \]: NO2 Transmittance  
\[ Tm(\lambda) \]: molecule transmittance  
\[ Ta(\lambda) \]: aerosol transmittance

From the formula above we can derive equations,

\[ \tau_m = 0.00535\lambda^{-0.66+0.071} (\lambda \text{ in } \mu m) \]  

\[ \tau_a = B\lambda^4 (\lambda \text{ in } \mu m) \]  

\[ T = \exp(-\tau) \]  

\[ I'(\lambda) = I(\lambda)/I_{ref}(\lambda)Tm(\lambda) = kTg(\lambda)Ta(\lambda) \]  

\[ I_0'(\lambda) = kTg(\lambda) \]  

\[ Tg(\lambda) = I'(\lambda)/I_0'(\lambda) \]  

\[ \tau_g = -\ln[I'(\lambda)/I_0'(\lambda)] = \ln[I_0'(\lambda)/I'(\lambda)] \]  

\[ \tau_g = \sigma(\lambda)NL \]  

with this equation we can obtain the gas column density (3).
Data was acquired in 3 consecutive days on January 11-13, 2012 at the period of 11.00-14.30 time of observation. The dates were chosen for a cloud free condition to maximize the probability of having the NO₂ and Aerosol detected. Sun spectrum was captured using a self-made program, DANDOAS, with an integration time of every 100 ms and interval of every 60 second data. The fibers were facing the directions from 180-185 degrees.

Below is the graph showing the raw data taken on 3 different dates, Fig 3. And data taken on 2012-01-11-11.00 compared with the spectrum of the sun at the Top of Atmosphere (TOA) from 400-1000 nm wavelength and the standard air mass, AM 1.5.

![Raw Data](image)

Fig. 3. Raw data measured at 3 different dates at the same acquisition time

The observation intensity data of 400-450 nm after being normalized were compared with the spectrum of TOA at the same wavelength to obtain the transmittance value. The differential optical thickness (Δτ) can be obtained from the difference of the transmittance value and the value of slope of the wavelength and the transmittance. Finally the (Δτ) normalized to match with the differential absorption cross section of NO₂ (Δσ) from the laboratory experiment.

3. Result and Discussions

Below are the graph created from analysis.

![Graph](image)

Fig. 5. The slope created from the transmittance value for each observed wavelength 400-450 nm.

On the graph it is noted that the transmittance value for 428-435 nm wavelength are missing due to the inconsistencies of the measurement after the spectral matching, Figure 6.

![Graph](image)

Fig. 6. Spectral matching of the Δτ and Δσ.

![Graph](image)

Fig. 7. Scatter plot of Δτ and Δσ.
From the differential optical thickness (\( \Delta \tau \)) normalized value and the differential absorption cross section (\( \Delta \sigma \)) normalized value, a scatter plot was created to obtain the value of the NO\(_2\) gas column density, Fig 6. Of the scatter plot, the slope is \( y = 0.0491x + 0.0142 \) indicates strong linear relationship while the R\(^2\) value is less than 0.5 indicates the relative column density is weak (4).

We also compare the result with other measurement conducted within local area of DOAS system and ground measurement of AEROS soname data.

![Fig. 8. Measurement of local DOAS system.](image)

When compared to that observed by DOAS and Chiba University (DOAS Chiba univ.), there is a high value on the average degree of 5ppbv which is better results of DOAS measurement in Samukawa Elementary School Ground Station (3). It is obvious changes were seen at high concentrations of NO\(_2\) in the summer becomes low in concentration compared to the winter season.

4. Conclusion and Further works
DOAS technique has been proven to be reliable in retrieving trace gas concentration and particulate matter and for preliminary result, using DOAS technique direct to sunlight without scanning devices enable the efficiency and low cost devices in measuring pollutant concentration in the certain atmospheric column in any given condition.

Further work will be carried out in analyzing the data and compared with other measurement result.

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References


Monitoring Land Subsidence of The City of Makassar using JERS-1 SAR data

Ilham Alimuddin\textsuperscript{1,2}, Luhur Bayuaji\textsuperscript{1}, Josaphat Tetuko Sri Sumantyo\textsuperscript{1} Hiroaki Kuze\textsuperscript{1}
\textsuperscript{1Centre for Environmental Remote Sensing (CEReS), Chiba University,}
\textsuperscript{2Department of Geology, Faculty of Engineering, Hasanuddin University, Indonesia}
E-mail: ilimuddin@graduate.chiba-u.jp

Abstract
Most of the land subsidence events in large cities are associated with the withdrawal of large amounts of groundwater from an aquifer. Such events have occurred in a number of cities in the world due to the groundwater extraction required for development and modernization. Cities in Indonesia have experienced the same phenomena because of the excessive use of groundwater, resulting in the subsidence of the watertable. Study on land subsidence in Jakarta, the capital of Indonesia, was initiated in 1970s using various methods including the latest method based on ground positioning system (GPS) and differential interferometric synthetic aperture radar (DInSAR). Other cities such as Semarang, Surabaya, and Bandung have also been investigated using similar approaches.

The target area of the present study is the city of Makassar, the capital city of South Sulawesi province. The population of the city has increased to 1.2 million in 2010 from the value of 0.94 million in 1990, causing the increased use of both land surface and ground water. Here the DInSAR analysis is conducted on the JERS-1 SAR data acquired during a six year period of 1993-1998. For field recognition, we make use of the QuickBird high resolution optical data, as well as the observation result from a recent field campaign performed in 2009.

The result has indicated that the western part of Makassar has subsided by 10-15 cm during the period of JERS-1 SAR data acquisition. It is known that this part of the city used to be coastal areas and has been reclaimed after around the year 2000. Other than the ground water extraction, the land on the northern part of the city has also subsided due presumably to the load of warehouse and housing constructions. The DInSAR result is in line with the field observation where some houses were levelled down from the initial surrounding and load of construction was clearly observed on some sites.

Keywords : Land subsidence, DInSAR, JERS-1 SAR, Quickbird, Makassar

1. Introduction
The earliest study on city subsidence in Indonesia is the city of Jakarta [1,2], capital of Indonesia has been initiated since 1970s using various method of measurement with the latest method using this differential interferometric synthetic aperture radar (DInSAR). Other cities have been investigated using this technique as well including Semarang [3], Surabaya and the latest one Bandung [4]. Other big cities are waiting for further research with this technique such as Makassar, Medan and Denpasar. This paper describes the development of measuring the dimension of land subsidence phenomena that has occurred in the city of Makassar.

The city of Makassar as the capital of South Sulawesi Province is the 4th largest city in Indonesia, considered to be the gateway of Indonesia from the eastern part. Situated at the southwest part of Sulawesi Island, Makassar city covers an area of 175.77 km\textsuperscript{2} divided into 14 sub districts. Makassar city lies on the geographic coordinate of 119°18'27.97"-119°32'31.03" East Longitude and 5°00'30.18" -5°14'46.69" South Latitude. The landform is relatively flat, classified as alluvial plain and topography level from 0-21 meter above the sea level, Figure 1. Geologically, the city is covered by 3 types of formation, Camba Volcanic Formation, Baturape Volcanic formation which mainly consist of fine sediment clastic of volcanic eruptive rocks but mostly eroded and alluvium formation deposit as recent weathered material. In general, we can find 3 types of rock units, tuff, breccia and ash which derived from the volcanic origins and sediment deposit like fine to coarse sand. The population of the city has increased to 1.2 million in 2010 from the figure of 0.94 million in 1990, causing the increased use of both land surface and ground water. The rapid urbanization has made Makassar as center for economic development in eastern part of Indonesia.

Based on the statistic data of Makassar City, population has been increasing due to the development and
modernisations that create urbanisation. Makassar as the capital city of the South Sulawesi Province is the target of urbanization. Hence the situation will continuously grow alongside the needs for the people for development to have a better life. As the number of population increase, industries has been triggered to provide new open areas for business, construction and this situation demand spaces. When the government is not able to be pushed in the rural area, the spaces in the city will eventually decrease for particular landuse creating land degradation and could generate land subsidence in the future due to the extraction of water well in the surrounding areas. This has been suspected as the cause of the subsidence of the city land phenomena.

![Figure 1](image1.png)

**Figure 1.** Study area of Makassar City Land Subsidence with the 14 subdistricts.

2. Data and Methodology

This research utilized 8 scenes of JERS-1 SAR images of level 0 covers a swath area of 75 km² in descending modes with 35.5 degree of incident angle, but the area focused for the subsidence study is only 175.77 km². The subsidence analysis is also supported with optical image data, SPOT 4 acquired 2007 and ALOS AVNIR 2 acquired on June 21 2008. Field campaign was conducted in September 2009 and January 2011 with each measurement was taken by handheld Global Positioning System (GPS). For site validation other than the field check we also used high resolution of IKONOS images acquired in 2009 and for ground sampling validation of Quickbird acquired on May 6, 2007. All supporting data are georeferenced UTM and WGS 1984 GIS platform.

![Figure 2](image2.png)

**Figure 2.** Quickbird and AVNIR2 image of the coverage area.

![Figure 3](image3.png)

**Figure 3.** DInSAR Processing images of Makassar City. A. Coherence image of 1995/1996. B. DInSAR Image pair of 1995/1996 images C. SAR, real image D. Deformation Image.

Differential Interferometric Synthetic Aperture Radar (DInSAR) were performed using SIGMASAR software developed by JAXA (Dr. Shimada) combined with ENVI and ARC GIS in creating the GIS analysis. The DInSAR processing uses 2 pass interferometry with 2 pairs of SLC images were processed to create interferogram. The differential interferogram furtherly flattened and unwrapped to obtain the deformation map of the subsidence area.
3. Result and Discussions

We have shown that the application of DInSAR technique using JERS-1 data can reveal subsidence conditions in the study area. Mostly the subsidence occurred in the northern part of Makassar city during the time interval studied here, though the population density in northern part is lowest among the entire city regions. Industrial district, reclamation area, trading center area, international airport and the seaport are built in this region. The center of the subsidence with the subsidence-affected coverage area can also be estimated easily. It has been found that the subsidence occurred in separated regions with different land usage. Nevertheless, the ground survey has indicated that high human activity exists in every point of subsidence.

Various human activities such as ground water pumping and construction working should have affected the local subsidence phenomena in Makassar, as in the case of other large-scale cities [5]. The main cause of subsidence in Makassar has not been revealed because of the complex feature of the phenomena. However, the result of the present study strongly suggests that the human activity and land use alteration are influencing the geomorphological changes in this city.

Figure 5. Focus on deformation image of Tamalate and surrounding overlaid with Quickbird image acquired on 20070506. The yellow circle line indicates subsidence. Field campaign conducted in September 2009 revealed some locations that indicate the incidence of land subsidence and the fact that some parts of the city are having load of building construction that make the city experience of slight movement of its earth surface.

New building construction of warehouses can be seen in picture P1 taken in the area of Tallo, New housing and modern apartment as well as community business complex in P2. Evidence of subsidence can be seen from P4 in Pootere, P5 in Panakkakak, P6 in Mariso and P7 in Tamalate. On of the main road, the soil load can be a thickness of 15-20 centimeters.

Figure 6. Field survey indicates a subsidence.

4. Conclusion

DInSAR method is used to estimate subsidence phenomena which has been derived and applied in this study. Continuous information of subsidence area will be useful for urban maintenance and urban development field, as one important factor for planning and construction works. So far, only few subsidence-related studies have been carried out using SAR data over urban area. We have tried to apply JERS-1 SAR although not all pairs can give good coherence due to the baseline and atmospheric aspects.

Makassar City has been experiencing land subsidence in certain areas as well land piling specially in the area where new building construction complex. We have successfully implemented the DInSAR processing technique in measuring the dimension of the land subsidence. The incidences in some areas show evidence of from 10-15 cm of subsidence. Shown by field observation conforming the DInSAR images.

References

UAVSAR Processing System with Virtex-6 FPGA Board

Kazuteru Namba¹, Takuma Kusama¹, Koshi Oishi¹, Kei Iizuka¹, Hideo Ito¹, Josaphat Tetuko Sri Sumantyo²

¹Graduate School of Advanced Integration Science Chiba University, namba@ieee.org
²Center for Environmental Remote Sensing (CEReS) Chiba University, jetukoss@faculty.chiba-u.jp
1-33 Yayoi-cho Image-ku Chiba-shi Chiba, 263-8522 Japan

Abstract
Synthetic Aperture Radar (SAR) is a class of multipurpose sensors, which can operate in all-weather and day-night time. Circular Polarization SAR (CP-SAR) is less subject to the ionosphere of the earth, and thus it is expected to improve accuracy of observation. We are requested to reduce the size of SAR image data by making on-board SAR image processing on a flight platform. From such a viewpoint, an on-board SAR image processing system is developed for the unmanned aerial vehicle (UAV) with the CP-SAR.

This paper shows an on-board SAR image processing system on an UAV. This radar system is required semi-real-time observation. The proposed system is composed of two FPGA evaluation boards and a PC. One board makes SAR image processing using Range-Doppler-Algorithm (RDA). The other board and the PC has Intel Atom processor and a Solid State Drive (SSD) are used to store data. The proposed system processes a SAR image in 32 seconds or less at a guess. This indicates that the proposed system is applicable to an on-board SAR image processing system on an UAV making semi-real-time observation.

Keywords: CP-SAR, SAR image processing, on-board processing, FPGA

1. Introduction
Synthetic Aperture Radar (SAR) is a class of multipurpose sensors that can operate in all-weather and day-night time. The SAR is available for various purposes such as observing real-time information of ocean waves and monitoring the area of forest [1]. Data observed by radar on aerial platforms such as satellites and aircrafts are processed and delivered to the earth. To use it for disaster management, we have to process and deliver them at high speed. By processing observed raw data at an on-board SAR image processing system, we can reduce the size of data. As a result, we can reduce the communication time between the platforms and the ground, and the required size of storage system in the platforms.

Circular Polarization SAR [2] (CP-SAR: Circularly Polarized SAR) is the world's first SAR that utilizes the circularly polarization. The CP-SAR is less subject to the ionosphere of the earth compared to the traditional radar using horizontal and vertically polarized waves, and thus it is expected to improve accuracy of observation. From this, the Center for Environmental Remote Sensing (CEReS) is developing a micro-satellite carrying CP-SAR. For a preparatory experiment, the CEReS plans to fly Unmanned Aerial Vehicles (UAVs) equipped with CP-SAR. This paper presents an on-board SAR image processing system on UAV for the preparatory experiment. The proposed system is composed of two FPGA evaluation boards and a PC. One board processes SAR image. This board contains a Xilinx Virtex-6 FPGA (XC6VLX240T-1FFG1156) and a 2 GB DDR3 DRAM. The proposed image processing system has only one 2 GB DRAM, though it processes SAR image data with the size of 6,144 x 19,904 pixels. This fact enables us to process SAR image with only one evaluation board and thus it makes the construction cost for the proposed system low.

The other board contains Xilinx Spartan-6 FPGA (XC6SLX45TFFG484), and the PC has Intel Atom processor and a Solid State Drive (SSD). They are used to store data processed by Virtex-6 FPGA.

2. Preliminary
2.1 UAV
Figure 1 shows a picture of the UAV that the CEReS will use the preparatory experiment. This UAV is of 4.75 m length and with 6.00 m wingspan. It is 0.51 m tall. The flight altitude is 3 – 4 km in plan. The main apparatus carried on UAV is CP-SAR antennas, an antenna control system, a flight control system, and SAR image processing system described in this paper. The UAV has no image data downlink system and has a SSD storing the processed pictures. The stored data will be observed after landing.
2.2 SAR image processing

Raw image data obtained from CP-SAR requires two-dimensional data processing, range compression for range direction (direction of the microwave radiation) and azimuth compression for azimuth direction (traveling direction of the platform), just like data from traditional SARs. To process image data, the proposed system uses Range-Doppler-Algorithm (RDA), shown in Figure 2 [3]. This algorithm uses two reference data, range and azimuth reference data, obtained beforehand and processed with FFT. We can obtain the processed image from the raw image performing the following operations: First, the raw data are processed with FFT in the range direction, and it is converted from the time domain into the frequency range. Subsequently, in range compression, data are convoluted with (multiplied by) the range reference data. Next, it is processed with FFT in the azimuth direction. To prevent image resolution reducing, the Secondary Range Compression (SRC) is performed. After SRC, data are processed with IFFT in the range direction. Next, we perform Range Cell Migration Correction (RCMC), which corrects errors caused by migration of the UAV. Next, data are convoluted with the azimuth reference data. Finally, we process data with IFFT in the azimuth direction, and then we obtain the processed SAR image.

3. Proposed SAR image processing system

Figure 3 illustrates the outline of the proposed SAR image processing system. The proposed system contains a Xilinx ML605 evaluation board with Xilinx Virtex-6 FPGA. All operations for SAR image processing shown in the previous section (Figure 1) are performed on this board. In the proposed system, processed data are stored in SSD and they will be observed after landing of UAV. Unlike traditional hard disk drive (HDD), SSD features high shock resistance and thus is available for the preparation experiment on UAV. To transfer processed data from the ML605 board to the SSD at a low cost, we use a Xilinx SP605 evaluation board with Xilinx Spartan-6 FPGA and a Windows 7 PC with Intel Atom processor. First, processed data are sent to SP605 via Rocket IO [4], and next, they are sent to PC through PCI-Express bus. Finally, the PC stores the data into SSD.
Figure 2, the algorithm contains six times of FFT processing. However, to implement this algorithm in one ML605 board, the proposed system has only two FFT circuits, 8,192-point FFT and 32,768-point FFT circuits. The 8,192 (32,768) point FFT circuit makes both FFT and IFFT processing in the range (azimuth) direction for both the processed SAR image and the reference data. The other calculations, i.e. range and azimuth compression, SRC and RCMC, are made in the calculation block. The range and azimuth compressors have SRAM for storing reference data. The proposed system has one 2 GB DDR3 DRAM controlled by the DRAM controller on the FPGA. The DRAM can keep only one SAR image data with the size of 8,192 x 32,768. In the DRAM, SAR image data are ordered along the range direction. To utilize DDR3 DRAM at high speed, we have to sequentially access data of 32 bytes with consecutive addresses. In other words, we cannot access image data in the azimuth direction at high-speed. To access at high-speed, the proposed system contains the corner turn block. The corner turn block contains an SRAM which can store image data with the size of 32 x 32,768. By using this SRAM, we can change the order of data between the range and azimuth directions, i.e. we can make a corner turn. The proposed system processes the SAR image as follows:

I. Process raw data in the range direction with the range FFT.

II. Convolute the data with the range reference data in the range compressor.

III. Send the data into the SRAM of the corner turn block and make a corner turn.

IV. Store the data in the azimuth direction into the DDR3 DRAM through the DRAM controller.

V. Load the data from the DRAM, and process it with the azimuth FFT.

VI. Process the data with the SRC.

VII. Copy the data into the SRAM in the corner turn block.

VIII. Store data in the range direction into the DRAM.

IX. Load the data from the DRAM, and process it with the range IFFT.

X. Process the data with the RCMC.

XI. Copy the data into the corner turn block, and store the data in the azimuth direction into the DRAM.

XII. Load the data along the azimuth direction into the azimuth compressor, and then convolute the data with the azimuth reference data.

XIII. Process the data with the azimuth IFFT.

XIV. Copy the data into the corner turn block.

XV. Output the data to the SSD in the range direction.

4. Evaluation

For every SAR image with the size of 6,144 x 19,904, the SAR image processing time required for our near-real-time observation system is 60 seconds [3]. This evaluation shows that the proposed system satisfies this requirement. Table 1 shows the evaluation result. In the evaluation, the operation clock frequencies of the FPGA and DDR3 DRAM are 200 and 800 MHz, respectively. The FFT calculation time was
4.74 second. The time for the other calculation was not measured because some calculations used on our UAV were not fixed. However, it was estimated at shorter than the FFT calculation time. The communication time between ML605 and SP605 was 5.70 second, and that between SP605 and SSD was 16.20 second. These operations are made in a sequential fashion. In sum, the total operation time is 31.38 second or shorter for every SAR image, which satisfies the requirement. The table 2 shows the comparison result with the existing SAR image processing systems [4,5]. The operation time of the existing system [4] is longer than that of the proposed system because it uses five older FPGA boards with Virtex-5, which brings about long communication time between FPGA boards. The operation time of [4] is much longer, because its operation differs from those of the proposed system and the existing one [4]. In fact, the system [5] makes some corrections which are not made in the proposed system and [4]. Thus, we cannot make a simple comparison with [5] using the table 2.

Table 1. Operation time for proposed system

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time (second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR image processing</td>
<td>4.74</td>
</tr>
<tr>
<td>ML605 to SP605</td>
<td>5.70</td>
</tr>
<tr>
<td>SP605 to SSD</td>
<td>16.20</td>
</tr>
<tr>
<td>Total</td>
<td>31.38 or shorter</td>
</tr>
</tbody>
</table>

Table 2. Comparison with existing systems

<table>
<thead>
<tr>
<th>Total time (second)</th>
<th>[4]</th>
<th>[5]</th>
<th>Proposed system</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>180 or shorter</td>
<td>31.38 or shorter</td>
<td></td>
</tr>
</tbody>
</table>

4. Conclusion

This paper presented a low-cost UAV on-board SAR image processing system, which uses FPGA evaluation boards ML605, SP605, and a PC with an SSD. The operation time of the proposed system is shorter than 31.38 second, which satisfies the requirement for near-real-time observation systems. In this work, some parts of the proposed system have not been completed while major parts have already been implemented. Future works include the development and evaluation of the completed system.

References
Measurement of trace gases in the lower troposphere using visible and near-infrared light sources

Kenji Kuriyama, Hayato Saito, Yusaku Mabuchi, Naohiro Manago, Ippei Harada, Hiroaki Kuze
CEReS, Chiba University, tskmasu@graduate.chiba-u.jp

Abstract
We have developed spectroscopic methods for continuous monitoring of trace species in the lower atmosphere. Such kind of approach based on in-situ, long path length measurement is complementary to the conventional methods based on air sampling. First, differential optical absorption spectroscopy (DOAS) has been applied to simultaneously monitor aerosol and nitrogen dioxide, both being the most important air pollutants in the urban atmosphere. A pulsed xenon lamp equipped on a tall smokestack has been exploited as a light source of the DOAS measurement with an optical path length of 5.5 km. By analyzing the DOAS data with ancillary data from ground sampling, sunphotometer as well as weather data, aerosol behavior characteristic of the Chiba area has been revealed in relation to the regional wind system. Second, the long-path measurement using infrared light sources has demonstrated the capability of measuring atmospheric concentration of carbon dioxide, one of the most important greenhouse gases.

Keywords: Differential Optical Absorption Spectroscopy (DOAS), Air pollution, Aerosol, Molecular absorption, Trace gas species

1. Introduction
The air pollution in Chiba city, which is located along the coast of the Tokyo Bay, exhibits complicated behavior influenced by both local sources such as heavy traffic and industrial complexes and advection from the larger Tokyo metropolitan area. The dominance of southwesterly winds in summer generally causes high humidity from the bay area, whereas that of north to northwesterly winds in winter results in high level air pollution in conjunction with the formation of nocturnal inversion layer [1]. Here we employ the long-term differential optical absorption spectroscopy (DOAS) data taken with an optical path of 5.5 km that connects the observation setup at CEReS and a 130 m tall smokestack of a garbage incinerator operated by the city government. Also the data provided from a collateral sunphotometer and nearby ground sampling stations are employed to elucidate the behavior of major pollution species, aerosol (suspended particulate matter, SPM) and NO2. Since the DOAS data can be obtained every 5 min, it provides much higher temporal resolution than the ground sampling data, which are produced on hourly basis.

The analysis has indicated that both coarse particles (such as sea salt) and fine particles (such as sulfates) are transported by sea breeze from the southwestern part of the city, where industrial complexes are located along the Tokyo Bay. Since our observation path is severely affected by traffic exhaust from major highways, a significant level of air pollution sometimes takes place depending on the sea/land wind conditions and the development of inversion layer. It has been observed that especially in winter, radiative cooling and weak wind conditions often result in considerable accumulation of pollutants.

Similar long-path optical absorption can also be applied to the monitoring of carbon dioxide (CO2), the most important greenhouse gases of anthropogenic origins. As a countermeasure for increasing CO2 concentrations, reliable and less costly approach that enables the in-situ measurement of CO2 and other greenhouse gases are becoming more and more important. The Greenhouse gases Observing SATellite (GOSAT) was launched on January 23, 2009 by JAXA and NIES (http://www.jaxa.jp/projects/sat/gosat/index). The data for CO2 column amount retrieved by a ground-based Fourier transform spectrometer (FTS) are useful for the validation of satellite data (Bosch et al., 2006). A network of FTS’s has been established by NES on a global scale (Total Carbon Observing Network: TCCON, https://TCCON-wiki.caltech.edu/) [3]. The column amounts of both CO2 and CH4 (XCO2 and XCH4) from TCCON are calibrated to the concentration scale of WHO with the help of airborne sampling data of these trace gas species [4]. In our approach, on the other
hand, the absorption spectra of both CO$_2$ and water vapor have been measured along an optical path length of 6.2 km by means of DOAS approach using a halogen lamp and a super luminescent diode (SLD). Conventionally the CO$_2$ concentration measurement has been undertaken using sampling methods, giving precise but very local concentration of this greenhouse gas species. In contrast, the present method is able to provide data averaged over a long path length, thus better representing the regional concentration. Although the present effective resolution of approximately 8 nm is still insufficient for resolving each rovibrational transition in the 1.6 μm band, further improvement of the detection system will enable the concentration measurement with the accuracy of a few ppm.

2. Instruments

Pulsed flashlights equipped at tall constructions, called aviation obstruction lights, have successfully employed as light sources for the DOAS measurements of NO$_2$, the most important air pollution species in urban areas [5]. Also, this approach makes it possible to monitor the quantity of aerosol, or suspended particulate matter (SPM). Conventionally aerosol measurements have been carried out by means or ground sampling or sunphotometer, giving data that represent local atmosphere or column amount, or aerosol optical thickness (AOT), toward the solar direction. Thus, the DOAS measurement based on nearly horizontal light path near the ground level provides complementary information as compared with these existing approaches. Both the DOAS and sunphotometer measurements can yield the information on the wavelength dependence of aerosol scattering or extinction, in the form of Angstrom exponent. Here we make interpretation of the DOAS data in comparison with the data from ground sampling and sunphotometer measurements, as well as meteorological data such as wind speed and wind direction. The DOAS instrument, located at CEReS with a height of about 25 m above ground (45 m ASL), is composed of an astronomical telescope and a compact CCD spectrometer connected to a PC. The light source at the top of a 130-m tall incinerator stack (160 m ASL) is a xenon flashlight, giving short (0.5 ms), intense (2 × 10$^5$ cd) pulses every 1.5 s. Both NO$_2$ and aerosol quantities are obtained along the 5.5 km light path.

For CO$_2$ measurement, we employ both a halogen lamp (Usbio, JCS1000WBGX) and a super luminescent diode (DenseLight, CSS403A) as light sources. A 10-cm diameter telescope is used to collimate the light beam from either of these sources. The detection is attained with an InGaAs photodiode array (Hamamatsu, C9914GB) with a nominal resolution of 8 nm. In order to increase the resolution, and hence the sensitivity of the CO$_2$ detection, we have also constructed a home-made high-resolution spectrometer for the detection of CO$_2$ absorption band at 1.6 μm wavelength. Briefly, the spectrometer is equipped with a reflective, blazed grating for the use in the near-infrared region, and two cylindrical lenses are employed for coupling the diffracted light onto the array detector (Hamamatsu, G10768-1024D), resulting in a better resolution of 0.1-0.3 nm/pixel.

3. Results and discussion

3.1 Continuous monitoring of air pollution using DOAS

Here we describe the DOAS data in winter, since higher level of air pollution often takes place during the cold season because of the stable and dry weather conditions. Figure 1 shows the DOAS NO$_2$ data between 9-10 December 2009 observed at CEReS in comparison with the nearly collateral ground sampling data observed at the Miyanoji station. Since the xenon flashlight is operated only during the daytime, only the sampling data are shown during the nighttime. On 9 December, northwestern wind (land breeze) around 1 m/s speed was observed, while during the subsequent night, wind was nearly nonexistent. Consequently, relatively high concentration of NO$_2$ (30-40 ppb) was observed until the morning of 10 December, presumably ascribable to the traffic exhaust. After 6 JST, the increase of both the atmospheric boundary height and wind speed (up to 3 m/s) resulted in the reduced concentration of NO$_2$ (ca. 15 ppb), representing the diffusion of the pollutants.

Figure 2 shows the aerosol parameters (extinction coefficient, AOT, and Angstrom exponent) in relation to the wind data on 22 February 2009. Relatively smaller values of the Angstrom exponent ($\tau_{\text{ang}}$) indicate the dominance of coarse particles, mostly due to sea salt particles from the Tokyo Bay. Relatively larger values, on the other hand, suggest that aerosol is from land sources composed of fine particles originating from NO$_2$ and H$_2$SO$_4$. After around 15 JST on 22 February 2001, strong wind from the WSW direction was observed, and as a result, the advection of sea salt particles resulted in the decreased value of $\tau_{\text{ang}}$.

3.2 Near-infrared, long-path monitoring of CO$_2$ concentration

Figure 3 shows the absorption spectra of CO$_2$ and water vapor observed over the atmospheric path length of 6.2 km (30 July 2009). Broad water band are seen in the wavelength regions of 1250-1550 nm and 1750-1975 nm, whereas two CO$_2$ bands are observed around 1600 nm and 2000 nm. Figure 4
Fig. 1 Temporal change of NO$_2$ concentration comparison between the DOAS and ground observation results, and temperature and wind speed changes during 9-10 December 2009.

shows the band in 1950-2050 nm in an expanded scale. Since it is known that the spectrum of the halogen lamp is relatively smooth, the laboratory observed spectrum can be used as a reference ($I_0$) with appropriate scaling. The transmittance after the absorption ($T = I / I_0$) can be calculated in this way. As illustrated in Fig. 5, the fitting between the observed (blue) and simulation (red) curves yields the CO$_2$ concentration of 350 ppm. Here, the simulation has been performed with the MODTRAN radiative transfer code, with an optical resolution of 7.0 nm.

The atmospheric measurement has indicated that a better resolution of the detection system is needed in order to attain better accuracy in CO$_2$ concentration values from the optical long-path measurement. For this purpose, we have conducted a laboratory experiment in which a superluminescent diode (SLD) and an InGaAs photodiode array. With a homemade grating spectrometer, the absorption has been obtained in the wavelength region of 1570-1590 nm (Fig. 6). Here the CO$_2$ absorption is observed with a 1.5-m long cell filled with 1 atm CO$_2$ gas. For comparison, laser lines emitted from a narrow-band external cavity diode laser (ECDL) are also shown with a simulated curve based on the HITRAN molecular absorption database. Although very similar absorption features are observed in Fig. 6, the observed absorbance indicates that the effective resolution attained with the experiment has been less than 0.5 nm. Further improvement of the spectrometer is undertaken for realizing better resolution, and hence better detection sensitivity of CO$_2$ in the real atmospheric experiment.

4. Summary
Since the DOAS data can be obtained in every 5 min, the resultant temporal resolution is much higher than that obtained from the ground sampling that provides air pollution data based on accumulation period of 1 h. We have considered the mechanism of the severe air pollution that often takes place in association with the development of the nocturnal boundary layer by combining the DOAS,
Fig. 3 Molecular absorption spectra observed in the atmospheric measurement over a path length of 6.2 km.

Fig. 4 Determination of CO$_2$ concentration: comparison of the laboratory and atmospheric spectra.

Sunsphotometer, and meteorological data.

Conventionally the CO$_2$ concentration in the atmosphere has been measured as a column amount from in-situ sampling based on ground and/or airborne measurements. In the present paper, we have demonstrated that the capability of the atmospheric long-path measurement for monitoring the concentration of CO$_2$ and water vapor by utilizing infrared light propagation over a distance of 6.2 km. Such an approach will be useful for carbon fixation studies related to agriculture and forestry, as well as monitoring CO$_2$ emissions from factories, power plants, and other types of emission sources.

References
Determination of Dielectric Constants using Reflection Coefficient Measurement and its Application to Snow and Ice Monitoring

Kohei Osa¹, Josaphat Tetuko Sri Sumantyo², Fumihiko Nishio³
¹Weathernews Inc.,
1-3Nakase Mihama-ku chiba-shi (Japan), k-osaw@wn.com,
²Center for Environmental Remote Sensing, Chiba University,
1-33 Yayoi-cho Inage-ku chiba-shi (Japan), (jtetukoss, fnishio@faculty.chiba-u.jp

Abstract
The purpose of our research is to investigate and clarify the microwave response from snow and ice on a flat surface and to develop the measurement methods based on these results. The authors attempt to apply those methods to development of microwave sensor for road-surface condition monitoring of winter road maintenance operation, and to ground truth of SAR observations on a sea ice and a snow field. In this paper, a determination method of dielectric constants using reflection coefficients measurement with oblique incidence is introduced. This method is based on free space technique which is often used for determination of dielectric constants of various materials. The authors have conducted experiments and tried to apply the method to determining dielectric constants of snow and ice. And some results of those experiments are introduced here.

Keywords: Microwave remote sensing, Winter road maintenance, Dielectric measurement of snow and ice

1. Introduction
Every material has a unique set of electrical characteristics that depends on its dielectric properties. Complex dielectric constant defined by $\varepsilon_r (=\varepsilon' - j\varepsilon'')$ is one of the important parameters which expresses electric properties of dielectric media. Snow and Ice are also dielectric media in microwave range. Dielectric properties of snow have been reported with many experiments so far, and the empirical models for dry snow and wet snow have been proposed. For example, dielectric constant can be expressed as a function of the physical parameters of snow, density, liquid water content, etc. Based on the results of measurement of the dielectric constants, the physical parameters of snow can be estimated by using those relations and the condition of snow can be estimated consequently. Therefore, it is very important for microwave remote sensing research on snow and ice to investigate the dielectric properties and accurate measurements of dielectric constants are required.

The purpose of our research is to investigate and clarify the microwave response from snow and ice on a flat surface and to develop the measurement methods based on these results. The authors attempt to apply those methods to development of microwave sensor for road-surface condition monitoring of winter road maintenance operation, and to ground truth method on dielectric properties of a sea ice and a snow field.

In this paper, a determination method of dielectric constants using reflection coefficients measurement with oblique incidence is introduced. This method is based on free space technique which is often used for determination of dielectric constants of various materials. The authors have conducted experiments and tried to apply the method to determining dielectric constants of snow and ice. And some results of those experiments are introduced here.

2. Dielectric properties of snow and ice
Snow and Ice are dielectric media in microwave range. Complex dielectric constant defined by $\varepsilon_r (=\varepsilon' - j\varepsilon'')$ is a important parameter which expresses electric properties of dielectric media.

It is well known that the real part value of ice is around three and the imaginary is $10^3$ at microwave ranges [1]. Snow is a mixture of ice particles and air voids. Dielectric properties of snow have been reported with many experiments so far. Hallikainen and Ulaby et al proposed the empirical models for dry snow and wet snow [2][3]. Dielectric constant $\varepsilon_r$ can be expressed as a function of the physical parameters of snow, i.e. density and liquid water content. Based on the results of measurement of $\varepsilon_r$ the physical parameters of snow can be estimated by using those relations and the condition of snow can be estimated consequently.
Dielectric constant of snow (empirical model):

Dry Snow [3]:
\[ \varepsilon_r = \varepsilon_r' = 1.0 + 1.9 \rho_w \quad (\rho_w \leq 0.5 \text{[g/cm}^3]\text{]} \] (1a)

\[ \varepsilon_r = \varepsilon_r'' = 0.51 + 2.88 \rho_w \quad (\rho_w \geq 0.5 \text{[g/cm}^3]\text{]} \] (1b)

where, \( \rho_w \) is density of dry snow.

Wet Snow [3]:
\[ \varepsilon_r' = 1.0 + 1.83 \rho_r + 0.02 m_v^{0.19} + 0.073 m_v^{0.31} \frac{1+(f/f_o)^2}{1+(f/f_o)^2} \] (2a)

\[ \varepsilon_r'' = 0.073 (f/f_o)^{0.31} \frac{1+(f/f_o)^2}{1+(f/f_o)^2} \] (2b)

where \( \rho_r \) is density of dry snow, \( m_v \) is liquid water content of snow, \( f \) is a frequency of incident wave and \( f_o \) is the relaxation frequency of water.

3. Methodology

The measurement processes are 1) a measurement of reflection responses from specimens, 2) a calculation of reflection coefficients and 3) an estimation of dielectric constants. The outline of the processes is shown in Fig.1.

3.1. Measurement of reflection responses

Magnitude and phase of reflection responses from a specimen are measured with a vector network analyzer (VNA). These measured responses are expressed in S-parameters \( S_{11}(\omega) \) in frequency domain. A continuous wave of angular frequency \( \omega \) is generated with VNA and radiated from an antenna system. The reflected wave from the specimen is received by the antenna and measured as reflection response with the VNA.

3.2. Calibration of reflection coefficients

Because of reflections due to connectors, horn antenna and lens and losses due to cables and so on, the measured S-parameters includes these responses and is different from the actual reflection response of the specimen as following equation. Therefore, it is necessary to remove the residual responses and calibrate the measured values.

3.3. Estimation of dielectric constants

3.3.1. Inverse problem on dielectric constants

Reflection of incident wave occurs at the surface of dielectric medium because of electromagnetic discontinuity. \( R_i \), the reflection coefficient at the boundary, is expressed by \( Z_0 \), \( Z_i \), impedances of air and the medium.

\[ R_i = \frac{Z_i - Z_0}{Z_i + Z_0} = 1 - \sqrt{\varepsilon_i} \quad (3) \]

In case of a dielectric medium, which has planar surface and infinite depth (Fig.2), \( R_i \) can be determined by \( \Gamma \), a ratio of electric field of the incident wave and reflected wave.

\[ \Gamma(\omega) = \frac{E_{\text{incident}}}{E_{\text{reflection}}} = R_i = \frac{1 - \sqrt{\varepsilon_i}}{1 + \sqrt{\varepsilon_i}} \quad (4) \]

Based on the results of measurement of \( \Gamma, \varepsilon_i \) can be estimated by solving the inverse problem.

3.3.2. Layered dielectric medium model (oblique incidence)

Assuming that snow and/or ice on a road surface and road itself compose layered dielectric medium, which has two layers of different media, we measure the dielectric constants of those media. The illustration of the layered dielectric medium model is shown in Fig.3, where \( \theta_0 \) is an incident angle. Using a continuous wave of angular frequency \( \omega = 2\pi f \), or frequency \( f \), incident obliquely on the surface of the medium, microwave measurements are made and reflection coefficient \( \Gamma(\omega) \) at the surface of the model is expressed by Eq.(5).

\[ \Gamma(\omega) = R_1 + \frac{R_2 e^{j\gamma_1 \theta_0}}{1 - R_1 R_2 e^{j\gamma_1 \theta_0}} \left( 1 + (-R_2) \right) \]

\[ \gamma_1 = \frac{\omega}{c} \sqrt{\varepsilon_i - \sin^2 \theta_0} \]

(5)

where \( \gamma_1 \) is a propagation constant in layer 1 perpendicular to boundary 1. \( c \) is light speed. \( \theta_0 \) is incidence angle. \( \gamma_1 \) is expressed by Eq.(6). \( R_1, R_2 \) are reflection coefficients at boundary 1 and 2 respectively, which are expressed by Eq.(7a), (7b) for TE wave, by Eq.(8a), (8b) for TM wave.

\[ R_{1,T} = \frac{\cos \theta_0 - \sqrt{\varepsilon_i - \sin^2 \theta_0}}{\cos \theta_0 + \sqrt{\varepsilon_i - \sin^2 \theta_0}} \]

(7a)

\[ R_{2,T} = \frac{\sqrt{\varepsilon_i - \sin^2 \theta_0} - \sqrt{\varepsilon_i - \sin^2 \theta_0}}{\sqrt{\varepsilon_i - \sin^2 \theta_0} + \sqrt{\varepsilon_i - \sin^2 \theta_0}} \]

(7b)

for TE wave (H polarization):

\[ R_{1,T} = \frac{\sqrt{\varepsilon_i - \sin^2 \theta_0} - \varepsilon_i \cos \theta_0}{\sqrt{\varepsilon_i - \sin^2 \theta_0} + \varepsilon_i \cos \theta_0} \]

(8a)

\[ R_{2,T} = \frac{\varepsilon_i \sqrt{\varepsilon_i - \sin^2 \theta_0} - \varepsilon_i \sqrt{\varepsilon_i - \sin^2 \theta_0}}{\varepsilon_i \sqrt{\varepsilon_i - \sin^2 \theta_0} + \varepsilon_i \sqrt{\varepsilon_i - \sin^2 \theta_0}} \]

(8b)

for TM wave (V polarization):

4. Experiments

4.1. Measurement System

An illustration of the measurement system is shown in Fig.4. This system consists of a compact VNA, Anritsu MS2036A, and an antenna system. The antenna system consists of horn antennas and dielectric lenses, which are
set up on a movable frame. Continuous waves generated with the VNA are radiated from the antenna system and incident oblique on the surface of a specimen. Reflected waves are received with the antenna system at the opposite side, and the reflection responses are measured with the VNA.

4.2. Measurement result of artificial snow

i) Specimen: To investigate the microwave response to snow, dielectric measurements for artificial snow were conducted on 20th thru 23rd July 2010 at the Snow and Ice Research Center (Shinjo, Yamagata), NIED. The measurements of artificial dry snow were made in the 4 to 6 GHz range with the incident angles of every 10 degree from 40 to 70 degree. The physical parameters of the specimens are shown in Table 1.

<table>
<thead>
<tr>
<th>No</th>
<th>Material of specimen</th>
<th>density [g/cm^3]</th>
<th>thickness [mm]</th>
<th>Temp [deg C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>Layer 2</td>
<td>Layer 1</td>
<td>Layer 1</td>
<td>Layer 1</td>
</tr>
<tr>
<td>1</td>
<td>Snow (EPS)</td>
<td>0.34</td>
<td>50</td>
<td>-2.4</td>
</tr>
<tr>
<td>2</td>
<td>Snow (EPS)</td>
<td>0.34</td>
<td>20</td>
<td>-2.4</td>
</tr>
</tbody>
</table>

(EPS: expanded polystyrene foam)

ii) Measurement result: The measurement results of frequency variation of magnitude of reflection coefficients are shown in Fig.5. And estimation results for each specimen are shown in Table 2. Dielectric constants of dry snow can be calculated by the empirical model (Eq.(1)). Substituting the density of the specimen 0.34 g/cm^3, we get the dielectric constant, 1.646. The measurement value of 1.67 and 1.61 agrees well with this value.

<table>
<thead>
<tr>
<th>No</th>
<th>Material of specimen</th>
<th>Dielectric constant (real part)</th>
<th>Thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>Layer 2</td>
<td>Layer 1</td>
<td>Layer 2</td>
</tr>
<tr>
<td>1</td>
<td>Snow (EPS)</td>
<td>1.67</td>
<td>(1)</td>
</tr>
<tr>
<td>2</td>
<td>Snow (EPS)</td>
<td>1.61</td>
<td>(1)</td>
</tr>
</tbody>
</table>

(EPS: expanded polystyrene foam)

iii) Angular variations of reflection coefficients: The angular variations of the magnitudes of $\Gamma$ of V-pol. And H-pol. at 5GHz are shown in Fig.6 7 for specimen No.1 respectively. Furthermore the ratios of $\Gamma$ of V-pol. by H-pol. at 5GHz are shown in Fig.8 for specimen No.1. From the angular variations of $\Gamma$ of V-pol., the Brewster angles $\theta_B$ described by Eq.(9) can be read. But also the angular variations of the $\Gamma'$ ratio can show the angle more clearly.

$$\tan \theta_B = \sqrt{\varepsilon_i}$$  \hspace{1cm} (9)

5. Conclusion

The microwave measurement method of dielectric constants in order to detect snow and ice on a road surface were presented. Some examples of measurements for artificial snow using free space method were introduced. The results show reasonable estimations of the dielectric constants, and they indicate that the method could be utilized for detecting snow and ice on a road surface. Furthermore angular variations of reflection coefficients are shown and the Brewster angles can be read from them. These results indicate that the angular variations of reflection coefficients with the Brewster angles can be used to estimate dielectric constants.

However, it cannot be said that we have enough data to develop the sensor system, various cases should be examined. The authors continue to conduct measurements in order to investigate efficiency of the method and grasp the problem for practical use.

Acknowledgements

This research is supported by the Weathernews Inc. donation research program at Chiba University. Experimental measurements for artificial snow were conducted by joint research program with the Snow and Ice Research Center (Shinjo, Yamagata), NIED.

Reference

Fig. 1 Measurement process.

Fig. 2 Reflection at surface of a dielectric medium.

Fig. 3 Theoretical model.

Fig. 4 Measurement system.

Fig. 5 Measurement result: frequency variation of magnitude of reflection coefficients (d1=50[mm]).

Fig. 6 Angular variation of magnitude of reflection coefficients at 5GHz of V-pol. (d1=50[mm]).

Fig. 7 Angular variation of magnitude of reflection coefficients at 5GHz of H-pol. (d1=50[mm]).

Fig. 8 Angular variation of reflection coefficients ratio of V-pol. by H-pol. at 5GHz. (d1=50[mm]).
Tsunami Inundation Hazard Map and Evacuation Route Assessment as Disaster Mitigation Using Remote Sensing and Geographic Information System Application in Parangtritis Coastal Area, Indonesia

Ratih Fitria Putri1, Josaphat Tetuko Sri Sumantyo2

1Microwave Remote Sensing Laboratory, Center for Environmental Remote Sensing Chiba University, 1-33, Yayoi-cho, Inage-ku, Chiba-shi, 263-8522 Japan, ratih_nabila@yahoo.co.id
2Center for Environmental Remote Sensing Chiba University, 1-33, Yayoi-cho, Inage-ku, Chiba-shi, 263-8522 Japan, jtutkoss@faculty.chiba-u.jp

Abstract

Parangtritis is located on the coastal area of Bantul District, Yogyakarta Province, Indonesia. This area is considered as high vulnerable area due to tsunami. The coastal area of Parangtritis has multi-land use purposes, as tourism, residential, and agricultural areas which leading to the vulnerable area to tsunami hazard. This research is aimed at analyzing the tsunami hazard impact and making risk disaster mitigation of this hazard. This research uses four scenarios of direction, i.e. wave from west, south-west south, and south east. This research also uses 6 scenarios of run-up, i.e. 5 m, 10 m, 15 m, 20 m, 25 m, and 30 m. The superimposed technique between hazard model, agricultural and non agricultural land use map will be carried out to have the understanding of the potential impact of tsunami to agricultural land production. The research revealed that the coastal area of Bantul is very vulnerable to tsunami hazard. Tsunami is a natural phenomenon which cannot be prevented; however, this does not imply that no one should live in coastal areas. It is very important to maximize the mitigation effort in order to minimize the negative impact from the natural disaster. A remotely sensed approach in combination with the Geographic Information System (GIS) might be more useful for establishing the spatial extent of potential hazard inundation. Digital Image Processing methods used to produce hill shade, slope, minimum and maximum curvature maps based on SRTM DEM contribute to the detection of morphologic traces. These maps combined with Landsat ETM and seismo-tectonic data in a GIS database allow the delineation of coastal regions can be useful for Tsunami analysis. This paper reports the results of an assessment of the impact of tsunami inundation for a coastal segment of Parangtritis. This study has been undertaken for three reasons: (1) the Parangtritis coastal area is one of the most vulnerable areas due to tsunami and has been identified as an area at risk from future tsunami occurrence; (2) this research will predict and make tsunami inundation hazard scenario simulation in research area; (3) Furthermore, to our knowledge, coastal land-use planning in general fail to considered the potential role of the extreme hazard facing on the coastal area. Bantul Local government cooperation with Yogyakarta Central Government has been install siren systems in Parangtritis area where the vulnerable area of tsunami. An emergency evacuation place on the way to a hill top is effective for saving lives. In case of tsunami at midnight, it will be much more dangerous for the villagers to evacuate, because of the complete darkness without electricity, so indications to let them know the evacuation route should be considered. For successful evacuation, therefore higher evacuation places than the expected tsunami should be set in and/or near residential areas.

Keywords: Tsunami Inundation Hazard Scenario, Evacuation Route, Disaster Mitigation, Remote Sensing, Geographic Information System.

1. Introduction

Human lives in present day are very vulnerable faced with natural disaster. The disaster happen because of the natural processes both of endogenic (earthquake, volcanic eruption, tsunami) and exogenic processes (flood, landslide, drought, or meteoric). Increasing number of people and the unpredictable disaster has made higher risk in term of losses. Nowadays the development in Remote Sensing and Geographic Information System can use for reducing and monitoring the disaster. For this reason, well prepared of the disaster risk management are requires in order to minimize disaster impact to human life. Indonesia is one of the most vulnerable areas due to natural disaster, because it is closed to the collision area of the three main tectonic plates in the
world. As the result, this area is very susceptible to the endogen activity and others natural disaster risk.

Table 1 described tsunami record in Indonesia. Tsunami Aceh occurred in 2004 that caused by big earthquake (9.1 in Scale Richter) and recorded as the biggest earthquake since 1900[1]. In the year of 2006, the tsunami happens in the southern part of West Java which shifted to the east. The effect is all the southern part of coastal zone in Java was affected by tsunami.

Table 1. Tsunami Record in Indonesia

<table>
<thead>
<tr>
<th>Year</th>
<th>Magnitude</th>
<th>Victims (Dead/Injured)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1883</td>
<td>7.5</td>
<td>36000</td>
<td>Krakatau</td>
</tr>
<tr>
<td>1961</td>
<td>-</td>
<td>26</td>
<td>NTT, Flores Tengah</td>
</tr>
<tr>
<td>1964</td>
<td>-</td>
<td>110479</td>
<td>Sumatera</td>
</tr>
<tr>
<td>1965</td>
<td>7.5</td>
<td>71 Dead, 71 Injured</td>
<td>Mualua, South Sumata</td>
</tr>
<tr>
<td>1967</td>
<td>5.8</td>
<td>56/108</td>
<td>Tumambang (South Sulawesi)</td>
</tr>
<tr>
<td>1968</td>
<td>7.4</td>
<td>392 Dead</td>
<td>Tambo (Center Sulawesi)</td>
</tr>
<tr>
<td>1969</td>
<td>6.9</td>
<td>6497</td>
<td>Magane (South Sulawesi)</td>
</tr>
<tr>
<td>1977</td>
<td>-</td>
<td>316 Dead, 316 Injured</td>
<td>NTB dan P. Sumbawa</td>
</tr>
<tr>
<td>1977</td>
<td>8</td>
<td>225</td>
<td>NTT, Flores, and P. Amur</td>
</tr>
<tr>
<td>1979</td>
<td>-</td>
<td>27/200</td>
<td>NTB, Sumbawa, Bali, and Lombok</td>
</tr>
<tr>
<td>1982</td>
<td>-</td>
<td>13400</td>
<td>NTT, Lamintuwa</td>
</tr>
<tr>
<td>1987</td>
<td>-</td>
<td>83/108</td>
<td>NTT, East Flores, and P. Pantar</td>
</tr>
<tr>
<td>1989</td>
<td>-</td>
<td>7 Dead</td>
<td>NTT and P. Alok</td>
</tr>
<tr>
<td>1992</td>
<td>7.5</td>
<td>15922/126</td>
<td>NTT, Flores, P. Babi</td>
</tr>
<tr>
<td>1994</td>
<td>7.8</td>
<td>38400</td>
<td>Bangkoang (East Java)</td>
</tr>
<tr>
<td>1996</td>
<td>8</td>
<td>363</td>
<td>Pali (Center Sulawesi)</td>
</tr>
<tr>
<td>1996</td>
<td>8</td>
<td>107 Dead, 107 Injured</td>
<td>P. Bai (Iran Jaya)</td>
</tr>
<tr>
<td>1998</td>
<td>-</td>
<td>34 Dead</td>
<td>Tabora Malabu (Malabu)</td>
</tr>
<tr>
<td>2000</td>
<td>-</td>
<td>4 Dead</td>
<td>Bangga, Center Sulawesi</td>
</tr>
<tr>
<td>2004</td>
<td>9.1</td>
<td>&gt;200000</td>
<td>NAD and Nort Sumatra</td>
</tr>
<tr>
<td>2005</td>
<td>-</td>
<td>-</td>
<td>P. Nas</td>
</tr>
<tr>
<td>2006</td>
<td>7.7</td>
<td>665</td>
<td>South Java</td>
</tr>
</tbody>
</table>

*Source: Diposaptono & Budiman, 2006[1]*

Java Island due to tectonic setting is very vulnerable occurred by Tsunami disaster. According to the catalogue for tsunamis in the Indian Ocean, which includes about tsunamis, 80% of the tsunamis are from Sunda arc region, where on an average, tsunamis are generated once in three years with different scale events[3]. Figure 1 shows the study area. Parangtritis have highly vulnerable of tsunami hazard, it caused many buildings in the coastal area of only a few meters from the coastline and the area is relatively flat. Parangtritis area located on the South Coast of Java subduction zone directly facing the Indo-Australian Plate and Eurasian Plate.

Fig. 1. Study Area

A remotely sensed approach in combination with the Geographic Information System (GIS) might be more useful for establishing the spatial extent of potential hazard inundation as well as to calculate the spatial agricultural damage over large areas[4]. Remote Sensing Approaches for coastal morphology were developing rapidly in the last 2 years. Based on the Landsat ETM and DEM data derived by SRTM of the coastal area produced spatial information in order to represent the coastal morphology.

2. Methods

The inundation zone due to tsunami would be determined using the predicted water depth scenario. This study intends to identify the inundation zone of the hypothetical water depth scenario and quantify the impact of the inundation to agricultural land and non agricultural land. Unfortunately, we exclude the physical mechanisms or hydrodynamic characteristics of tsunami during generation, propagation, or inundation. The formulation of Tsunami inundation wave simulation as below:

The relationship between the height of the tsunami, the coefficient of roughness, and distance towards land was formulated as follows:

\[
x_{\text{max}} = \frac{0.06 H_0^{1/2}}{n}
\]

Where:
- \(x_{\text{max}}\) = Maximum distance the tsunami on land from the shoreline;
- \(H_0\) = Height of waves at the shoreline;
- \(n\) = Roughness coefficient (0.015 to 0.07)

To follow the condition of the surface which has a surface height variation, equation 2 is modified by entering a determining factor as to lose altitude slopes of the tsunami as shown in the following equation formulated by
Berryman\textsuperscript{[5]}.

\[ H_{\text{loss}} = \left( \frac{16.7 \cdot a^2}{H_0^2} \right) + 0.5 \cdot \sin S \]

Where:
- \( H_{\text{loss}} \) = Losing altitude for the 1 m distance tsunami propagation
- \( N \) = Roughness coefficient
- \( H_0 \) = Initial height of the tsunami on the coastline
- \( S \) = Slope Surface
- \( S \) = Slope surface Z

\[ u = \sqrt{2g \cdot h} \]

Where:
- \( u \) = Wave Velocity
- \( g \) = Gravitation Velocity
- \( h \) = Depth

Equation 3 shows that the velocity is proportional to the height of the tsunami inundation. Tsunami on Parangtritis area is simulated by made model with few scenarios; 5 m, 10 m, 15 m, 20 m, 25 m and 30 m with different direction wave (West, South and South-West wave direction). Those variations were to represent the scenarios that possible happen on south coast of Java, on field measurement reported that along the south coast of Java between Batukaras and Baron the measured run up heights (RU) ranged from less than 1 m to 15, 7 m. Modelling of inundation areas are based on surface roughness coefficient, wave direction, wave height variation, and slope (slope) area of research. The parameters are then used to calculate the landward inundation. Propagation calculations per pixel that passes through the use of certain land and a certain slope, the reduction in height of the tsunami can be detected. Figure 4 shows flowchart research design.

3. Results and Discussion

Tsunami Inundation Hazard Scenario Simulation Map

Based on inundation simulation results of the tsunami on the mainland can be seen that the direction of arrival of waves in the stagnant area of influence. At the height of the waves 30 meters inundated the most extensive area occurs when the wave coming from the southwest or an angle almost perpendicular to the coastline with inundation area is 419,144 hectares. Area inundated by the smallest occur if the direction of incoming waves from the southeast scenario. If the waves coming from the south it will inundate an area of 3,038 hectares of rice fields. The most extensive inundation occurs when the wave came from the southwest that is 18,209 hectares. When the tsunami came with run up scenario 5 meters then the whole model shows that there are no fields are flooded. Spatial distribution on a variety of tsunami wave height and direction is presented in Figure 5a, 5b, 5c and 5d shows tsunami inundation hazard map. Tsunami inundation zone for 20 meters scenario has 129,250 hectares (west wave direction); 337,960 hectares (southwest wave direction); 319,125 hectares (south wave direction); and 197,976 hectares (southeast wave direction).

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Fig. 4. Flowchart Research Design

Fig. 5a. Tsunami Inundation Hazard Map with west direction Wave Simulation

Fig. 5b. Tsunami Inundation Hazard Map with Southwest direction Wave Simulation
Evacuation Route as Tsunami Disaster Mitigation

An emergency evacuation place on the way to a hill top is effective for saving lives. There are two alternative paths disaster evacuation for this area, evacuation path to the Yogyakarta city and evacuation path to the mountain area on the east side of area which is the more save zone from the tsunami disaster. The city area can be reach by the road way. Meanwhile the mountain side can be reach by road way and the footpath which is well known by local people. Figure 6 shows evacuation route of tsunami inundation.

Tsunami inundation impact of Parangtiritis coastal area will be needed special safety handling and supervising for holiday and special events due to the high tourist visitors come, can be in thousands visitors on these days. Every visitor has difference preference on the place along the beach but based on this research, area that within around SAR post, this area more density than others. For hazard zone tsunami can be concluded that only when the height 10 m the very danger situation came that threat all the houses and population on that area.

4. Summary

Tsunami is a natural phenomenon which cannot be prevented; however, this does not imply that no one should live in coastal areas. It’s very important to maximize the mitigation effort in order to minimize the negative impact from the natural disaster. Both government and local people have to sit together, discussing one thing how the standard operation procedure when if the tsunami happen, and how it could be done or government could provide nearest evacuation zone. The result of our study may have important implications for many different stakeholders to make coastal zone in Parangtiritis coastal area.

Acknowledgement

The authors would like to thank Center for Environmental Remote Sensing Chiba University and Faculty of Geography Gadjah Mada University

References

Continuous investigation of Metropolitan city land deformation by DInSAR technique on L, C and X-band SAR data, case study: Jakarta city, Indonesia

Luhur Bayuaji¹, Bambang Setiadi¹ and Josaphat Tetuko Sri Sumantyo¹

¹Center for Environmental Remote Sensing, Chiba University 1-33 Yayoi-cho, Inage-ku, Chiba, 263-8522 Japan.

[bayuaji@restaff., bambang@, jtetukoss@faculty.jchiba-u.jp]

Abstract

Jakarta, the capital city of Indonesia, has been suffered from land deformation that causes of the damage of properties, public facilities and flood during rainy season. The geological structure in Jakarta Area is mostly Alluvial in the northern part. The enormous use of ground water is estimated as the cause of the land deformation. In this study, we apply DInSAR technique on L, C and X-band SAR data to monitor land deformation between 2007 and 2011, continuously. This study exposed the ability of L, C and X-band to analyze land deformation in urban area. The result showed the deformation occurred on several places in northern part of Jakarta.

Keywords: InSAR, DInSAR, Subsidence, Jakarta

1. Introduction

Differential synthetic aperture radar interferometry (DInSAR) is a technique useful for accurately detecting the ground displacement or land deformation in the antenna line-of-sight (slant-range) direction using synthetic aperture radar (SAR) data taken at two separate acquisition times [1, 2]. The D-InSAR method is complementary to ground-based methods such as levelling and global positioning system (GPS) measurements, yielding information in a wide coverage area even when the area is inaccessible [3].

The area studied in the present work is Jakarta, the capital city of Indonesia. The interferograms, from L, C and X-Band, were used to investigate the land deformation on the study area during 2007 and 2011. Some data from L and C-Band was overlapped in time line. This study will highlight the specific characteristic of each frequency band in term of accuracy, error noise and decolleration that assure considering different sensor characteristic usage.

2. Study Area

Jakarta is located between 106°33’00"-107°00’00"E longitude and 5°48’30"-6°24’00"S latitude, in the northern part of West Java province. The area is relatively flat: in the northern and central part, topographical slopes range between 0°-2° and in the southern part, they are up to 5°. The altitude of the southernmost area is about 50 m above sea level and the other areas are lower (Figure 1A).

Figure 1B shows the geological information of the study area, which is mostly dominated by alluvial deposit. There are 13 natural and artificial (for supplying public water) rivers flowing through the city. It has humid tropical climate with annual rainfall varying between 1500-2500 mm and is influenced by the monsoons. The nighttime population is around 8 million, which increases to 11 million during business hours since many people commute from satellite cities of Jakarta. The population (residence) density in the five districts was between 9,600-23,000 people km-² as of the year 2000, while the most recent statistics in 2009 indicates that the values are between 12,000-19,000 people km-² [4].

The occurrence of land subsidence in Jakarta was recognized by a Dutch surveyor as early as 1926 [5]. Scientific investigations started in 1978,
and continuous investigation using leveling measurement was conducted during 1982-1999 [6]. The measurement using GPS was also undertaken during 1997-2005 [7]; however, its extension to a long-time and wide-area measurement would impose considerable effort and cost.

In this study we would like to investigate land subsidence by applying DInSAR technique on three different wavelength satellite data between 2007 and 2011.

3. L, C and X-Band SAR data set

3.1. L-Band Interferometry: ALOS

The L-Band ALOS PALSAR instrument has been applied to many subsidence studies [8, 9]. In this study, ALOS has the longest wavelength (23.6 cm) and has the advantage of deeper penetration of vegetated areas that contribute to reduce the temporal decorrelation.

We analyzed the subsidence using four images between 2007 and 2009, that constructed into three pairs. All the images have been acquired from ascending orbits. The topographic-phase component was removed using 90-m DEM obtained from the Shuttle Radar Topography Mission (SRTM) version 4.1 that has been processed with hole-filled algorithm.

3.2. C-Band Interferometry: Envisat

The C-Band Envisat Advanced SAR (ASAR) sensor has been on operation mode since 2002 and has been used in many subsidence analysis [10, 11]. The wavelength is about 5.6 cm that give a temporal decorrelation over vegetation area compared to L-Band data of ALOS PALSAR. We exploited five images between 2007 and 2009 with ascending orbit. Four pairs have been constructed and have overlapped with ALOS PALSAR data interferometry.

3.3. X-Band Interferometry: TERRASAR-X

The ability of TERRASAR-X data to analyze subsidence in urban area has been proved in [12]. In this study, even though the TERRASAR-X has the shortest wavelength (3.1 cm), it has the highest spatial resolution compared to other data and become its advantage.

The TERRASAR-X data is the only data that has
descending orbit in this study. We processed one pair of TERRASAR-X data between 2010 and 2011. This is the newest available data in this study. The timeline of obtained SAR for all satellites can be found in figure 2, while in Table 1, we report their pair, spatial baseline and temporal baseline.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Pair Number</th>
<th>Pair Combination</th>
<th>Perpendicular Baseline (m)</th>
<th>Temporal Baseline (week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS</td>
<td>1</td>
<td>20070131 20080203</td>
<td>220</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20080203 20081105</td>
<td>840</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20081105 20090205</td>
<td>380</td>
<td>13</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>1</td>
<td>20070210 20080719</td>
<td>124</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20080719 20080927</td>
<td>154</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20080927 20081206</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>20081206 20090912</td>
<td>188</td>
<td>40</td>
</tr>
<tr>
<td>TERRASAR-X</td>
<td>1</td>
<td>20100809 20110613</td>
<td>110</td>
<td>44</td>
</tr>
</tbody>
</table>

4. Result and Discussion

Figure 3 shows the result of DInSAR processing for every data pairs. At a glance, each pair result has less similarity compared to one another. Some of them gives good and clear fringes, some has a result with a lot of noise and some of them come with some many fringes that may come up from atmospheric disturbance. This result can be accepted since the data set of this study is particularly inhomogeneous in terms of wavelength, spatial resolution, three different acquisition geometries and temporal decorrelation.

Giving a side of less similarity result, the subsidence on the northern part of Jakarta can be easily recognized. The subsidence occurrence in this area can be expected since this area formed on alluvial geological structure as seen in Figure 1B.

5. Result and Discussion

Figure 3 shows the result of DInSAR processing for every data pairs. At a glance, each pair result has less similarity compared to one another. Some of them gives good and clear fringes, some has a result with a lot of noise and some of them come with some many fringes that may come up from atmospheric disturbance. This result can be accepted since the data set of this study is particularly inhomogeneous in terms of wavelength, spatial resolution, three different acquisition geometries and temporal decorrelation.
Figure 3. DInSAR result of all interferogram pairs. (A-C) Interferogram pair of ALOS PALSAR data for 20070131-20080203, 20080203-20081105 and 20081105-20090205, respectively (D) Interferogram of 20100809-20110613 TERRASAR-X pair (E-H) Interferogram pair of ENVISAT-ASAR data for 20070210-20080719, 20080719-20090927, 20080927-20081206 and 20081206-20090912, respectively.

Giving a side of less similarity result, the subsidence on the northern part of Jakarta can be easily recognized. The subsidence occurrence in this area can be expected since this area formed on alluvial geological structure as seen in Figure 1B.

The discussion will go deeper to the subset area that fringes constantly appear in each pair of interferogram data. The subset area location can be seen on rectangle area of Figure 3(A), hereafter called Cengkareng area.

The Cengkareng area is a newly developed residence area with more than 300 hundred households living over this area. The cause of subsidence was predicted as the result of ground water extraction, the building construction load and human activity over this area.

The DInSAR result of Cengkareng area shown in Figure 4. The land subsidence is getting worse as the temporal baseline increased. It gives the indication that the subsidence continuously occur in this area. The maximum subsidence for ALOS PALSAR pair was about 1.5 fringes and corresponds to 17.7 cm. As for ENVISAT ASAR pair, the maximum detected subsidence was about 8 fringes and correspond to 22.4 cm. Unfortunately, Cengkareng area cannot be covered on TERRASAR-X pair data as seen on figure 4 (D), but the available DInSAR result shows 8 fringes and correspond to 12 cm. The maximum estimated subsidence for each pairs shown in Table 2.
The comparison between three pairs of DInSAR result, ALOS PALSAR pair on 20080203-20081105, ENVISAR ASAR pair on 20081206-20090912 and TERRASAR-X pair, gives similar subsidence estimation in term of same temporal baseline (about 40 weeks). The subsidence estimation for ALOS, ENVISAT and TERRASAR-X result was 11.8 cm, 12.6 cm and 12 cm, respectively, with the condition of incomplete DInSAR result of TERRASAR-X.

Three different satellite images showed the agreement in term of similar temporal baseline.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Pair Number</th>
<th>Pair Combination</th>
<th>Estimated maximum subsidence (cm)</th>
<th>Subsidence rate (cm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS</td>
<td>1</td>
<td>20070131 20080203</td>
<td>17.7</td>
<td>18.38</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20080203 20081105</td>
<td>11.8</td>
<td>16.34</td>
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<td>3</td>
<td>20081105 20090205</td>
<td>5.9</td>
<td>24.51</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>1</td>
<td>20070210 20080719</td>
<td>22.4</td>
<td>16.13</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20080719 20080927</td>
<td>2.8</td>
<td>15.12</td>
</tr>
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<td>20080927 20081206</td>
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<td>22.68</td>
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<td>4</td>
<td>20081206 20090912</td>
<td>12.6</td>
<td>17.01</td>
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<td>TERRASAR-X</td>
<td>1</td>
<td>20100809 20110613</td>
<td>12</td>
<td>14.73</td>
</tr>
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</table>
6. Conclusion
In this study, the ability of three different wavelength satellite data has been investigated to detect monitor land subsidence over urban area. Despite of inhomogeneous data set, the result showed the agreement for Cengkareng area. From an applicative perspective, it gives the possibility to monitor the subsidence of urban area by using inhomogeneous data set.
In order to improve the analysis, the transformation to common geometry of one satellite will be conducted in the future.

7. Acknowledgement
The author would like to thank the PASCO Corporation for the support that has been given to this study in many ways not limited only for providing the TERRASAR-X data.

8. References
Design of a Broadband Antenna for CP-SAR Installed on Unmanned Aerial Vehicle

Yohandri¹, J. T. Sri Sumantyo¹, and Hiroaki Kuze¹
¹Microwave Remote Sensing Laboratory, Center for Environmental Remote Sensing, Chiba University, 1-33, Yayoi, Image, Chiba 263-8522 Japan
²Physics Department, State University of Padang, Kampus UNP Jln. Prof. Hamka Air Tawar, Padang, West Sumatera, 25131 Indonesia, andri_unp@yahoo.com

Abstract
A broadband antenna for circularly polarized synthetic aperture radar (CP-SAR) sensor has been designed. This L-band sensor is projected to reduce the Faraday rotation effect and generate the axial ratio image (ARI), which is a new data that expectantly will reveal unique various backscattering characteristics. The sensor will be installed onboard unmanned aerial vehicle (UAV) which will be aimed for fundamental research and applications. To satisfy the requirements of the CP-SAR system onboard UAV, a new broadband microstrip antenna design is presented in this paper. The finite-element method is employed for optimizing the design and achieving a good circular polarization at the center frequency of 1.27 GHz. The broadband axial ratio bandwidth and reasonable gain indicate that this antenna is promising for the CP-SAR sensor. This research will contribute to the field of radar for remote-sensing technology.

Keywords: Synthetic aperture radar, Circular polarization, Broadband antenna

1. Introduction
The role of Synthetic Aperture Radar (SAR) is critical in currently remote-sensing applications due to ability penetrate the cloud, operate in all-weather condition at night and day time. Various applications of SAR data can be found in many areas such as for determination land subsidence [1], volume change estimation of land deformation [2] and, etc.. However, the today SAR with linear polarization has limited information data, which consists of amplitude and phase. To obtain a more thorough measurement data, a SAR sensor with more information will be contributed. Hence, we propose the new SAR system called Circularly Polarized Synthetic Aperture Radar (CP-SAR).

A CP-SAR sensor is projected to generate the axial ratio image, which is a new data that expectantly will reveal unique various backscattering characteristics. In other hands, the CP-SAR sensor also can be applied to reduce the Faraday rotation effect occurring in linear polarization when propagates through the ionosphere [3-5]. The L-band (1.27 GHz) CP-SAR sensor will be installed on an unmanned aerial vehicle (UAV). In UAV experiment, the microwave signal from UAV platform is transmitted by either the left-hand or right-hand circularly polarized (LHCP or RHCP) antenna. The backscattering signal from the target is captured by both the LHCP and RHCP antennas to generate the axial ratio image (see Figure 1). The CP-SAR parameters, including size, weight, power consumption, etc. have been thoroughly considered to achieve the CP-SAR measurement while maintaining the aerodynamic stability of the UAV system. This sensor is intended for several targets such as land cover and snow cover mapping, oceanography, and disaster monitoring.

To realize this CP-SAR sensor, the link budget calculation of the system has been done in the Microwave Remote Sensing Laboratory (MRSLS), Chiba University. The key parameters of the system are presented as listed in Table 1. Based on these parameters, the CP-SAR system and a circularly polarized (CP) antenna are designed.

In previous research, a number of CP microstrip antennas for CP-SAR have been developed [6-10]. Nonetheless, the axial ratio bandwidth of these antennas is quite narrow (≤ 1%). In CP-SAR system onboard UAV, the broadband axial ratio antenna is required to maintain the fine resolutions of the sensor. Therefore, the purpose of the present paper is to describe the design of a broadband CP microstrip antenna for CP-SAR installed on UAV.

2. CP-SAR Sensor System and UAV
Generally, the major parts of the sensor system are composed of a transmitter (Tx), a receiver (Rx) and antennas as shown in Figure 2. The transmitter sub-system consists of a chirp generator, band-pass filters (BPF), an up-converter, a
Table 1 The key antenna parameters for CP-SAR sensor onboard UAV[11].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency center (GHz)</td>
<td>1.27</td>
</tr>
<tr>
<td>Pulse Bandwidth (MHz)</td>
<td>233.31</td>
</tr>
<tr>
<td>Axial ratio (dB)</td>
<td>≤3</td>
</tr>
<tr>
<td>Antenna efficiency</td>
<td>&gt;80%</td>
</tr>
<tr>
<td>Antenna gain (dBic)</td>
<td>14.32</td>
</tr>
<tr>
<td>Azimuth beamwidth</td>
<td>6.77°</td>
</tr>
<tr>
<td>Elevation beamwidth</td>
<td>3.57° - 31.02°</td>
</tr>
<tr>
<td>Antenna size (m)</td>
<td>1.5 x 0.4</td>
</tr>
<tr>
<td>Polarization (Tx/Rx)</td>
<td>RHCP + LHCP</td>
</tr>
</tbody>
</table>

Fig. 1 Transmitting and receiving signal on UAV.

Fig. 2 Design of CP-SAR sensor system.

Power amplifier (PA), a local oscillator (LO), and a switch that chooses either the LHCP or RHCP transmitted from the UAV platform. Thus, the receiver sub-system is capable of processing both the LHCP and RHCP signals simultaneously. Major components of the receiver subsystem are a low-noise amplifier (LNA), two BPFs, two I/Q demodulators, 4 channel analog to digital converters (ADCs) and a data recorder (memory).

Fig. 3 Unmanned aerial vehicle: (a) Profile of UAV, and (b) Photograph.

Table 2 General specification of the UAV.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload (kg)</td>
<td>20-25</td>
</tr>
<tr>
<td>Endurance (hrs)</td>
<td>4-6</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>1000-4000</td>
</tr>
<tr>
<td>Speed (km/h)</td>
<td>100-120</td>
</tr>
</tbody>
</table>

The UAV platform has 4.75 m main body length and 6 m wingspan, with a maximum payload of 25 kg. General specifications of the UAV are described in Table 2. The profile and photograph of UAV are shown in Figures 3(b) and 3(c), respectively.

3. Antenna Geometry Design

The geometry of the proposed antenna is shown in Figure 4, where Figure 4(a) gives the top and side view structure, and 4(b) show the 3D view of the antenna structure. The circular microstrip antenna is designed on two layers substrate (NPC-H220A, Nippon Pillar) having a permittivity \( \varepsilon_r = 2.17 \) and a loss tangent \( \delta = 0.0005 \). In addition, to obtain a broadband antenna, a Wilkinson power divider is implemented on the feed structure.

The proposed antenna is optimized using Ansoft High Frequency Structure Simulator (HFSS). Based on the simulated result, the optimum geometry parameters of the antenna are the following: \( L = 148 \) mm, \( W = 124 \) mm, \( h = 1.60 \) mm, \( W_f = 4.70 \) mm, \( L_f = 40.0 \) mm, \( R = 46.0 \) mm, \( R_f = 25.7 \) mm, and \( d = 17.7 \) mm.
Fig. 4 Geometry design of the proposed antenna: (a) Top and side view; and (b) 3D view.

Fig. 5 Reflection coefficient plotted as a function of frequency.

4. Simulation Results and Discussion

Figures 5 to 10 shows the reflection coefficient ($S_{11}$), axial ratio ($AR$), gain ($G$), and radiation pattern of the antenna. The broadband CP antenna characteristic can be achieved as shown in Fig. 5 and Fig. 6.

Fig. 6 Axial ratio ($AR$) plotted as a function of frequency.

Fig. 7 Relationship between antenna gain and frequency at $\theta$ angle $= 0^\circ$.

Fig. 8 Radiation pattern of the antenna at $f$ = 1.27 GHz.

Fig. 9 Axial ratio plotted as a function of theta angle.
Fig. 10 A 3D beampattern of the antenna at $f = 1.27$ GHz.

4. Summary
The design of a broadband antenna for CP-SAR sensor onboard an unmanned aerial vehicle has been presented in this paper. The good CP performance has been attained over a 3-dB axial ratio bandwidth of around 540 MHz (42.5%), with fairly high gain of about 6.02 dBi in the operating band (1.27 GHz). In general, the simulated result performance in terms of return losses, axial ratio, and radiation patterns, mostly satisfy the requirements for the CP-SAR sensor onboard UAV. In the future work, the fabrication and array configuration of the broadband antenna will be realized and installed onboard UAV.

Acknowledgements
The authors would like to thank National Institute of Information and Communication Technology (NICT) for International Research Collaboration Research Grant; Chiba University COE Start-up Programme “Small Satellite Institute for Earth Diagnosis”; and The Japan Society for Promotion of Science (JSPS) Japan - East Network of Exchange for Students and Youths (JENESYS) Programme.

References
SAR Imaging Technology using Reflected GNSS Signal

Yoshinori Mikawa¹, Takuji Ebinuma¹, Shinichi Nakasuka¹
¹Department of Aeronautics and Astronautics, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
mikawa@space.t.u-tokyo.ac.jp

Abstract
Global Navigation Satellite System (GNSS) is usually used for positioning and navigation application and reflected GNSS signal is called "multi-path" and considered as an undesirable noise. However, this reflected signal can be utilized for remote sensing applications because it might contain information about the scattering surface of the Earth. In this paper, the concept of remote sensing technology using reflected GNSS signal is introduced and a method to reconstruct imagery with the aperture synthesis technique is discussed.

Keywords: GNSS, Bi-static Radar, Aperture Synthesis

1. Introduction
Global Navigation Satellite System (GNSS) is one of the most successful space technologies and we can receive the signal of GNSS anytime and anywhere on the Earth which is not only achieved directly from GNSS satellites but also reflected and scattered by the Earth's surface. The GNSS Signal is usually utilized to identify the location and motion of the user for some navigation applications and on the other hand, the reflected signal is called multi-path which is considered as an undesirable noise source and deteriorates the accuracy of navigation. However, the reflected signal has a potential to be utilized for many kinds of remote sensing applications because meaningful information about the scattering surface can be obtained through this reflected signal.

The configuration of this concept is considered as bi-static but actually our configuration is called the space-surface bi-static geometry because a transmitter is usually non-cooperative one such as GPS satellite and is very far away from the Earth but on the other hand, a receiver platform would be an Unmanned Aerial Vehicle (UAV) which flies near the Earth’s surface. This asymmetry in its geometry is the difference from normal bi-static configuration and would be the key to construct the imaging algorithm using GNSS signal. This space-surface bi-static configuration has several advantages against the conventional bi-static configurations and the biggest advantage is its high availability. We can receive the signal all the time wherever we are due to the GNSS constellation. In addition, GNSS is usually maintained to keep its navigation accuracy and we benefit from it in that we can utilize this high quality signal without preparing our own transmitter. This also makes the whole system simpler because all we have to develop is the devices for receiving.

This concept has several disadvantages and problems to be solved as well. Weak signal strength is on the top of the list and for example, the signal strength of GPS signal on the Earth’s surface is about -160dBW and that of the scattered signal is even weaker. The development of the imaging algorithm for the aperture synthesis comes following and the conventional stop-and-go model is not suitable for the configuration where GNSS satellite is available as a non-cooperative transmitter because much longer stop-time is necessary due to the long propagation distance and the correlation process with the reference signal, which influences the azimuth sampling frequency and eventually the matched filter in the slow-time domain. This limitation on the azimuth sampling frequency might result in the azimuth ambiguity in the slow-time frequency domain. We discuss a method to simulate the space-surface bi-static configuration by considering actual signal spectrum and property of GPS CDMA signal in this paper.

2. Method
In general processing of SAR imagery, a geometry model called “stop-and-go” model is utilized to describe the echo signal. This model assumes that

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geometry including SAR platform and target points is stationary between transmission and reception of signal because the speed of signal is much faster than that of SAR platform. However, this model is not suitable for SAR geometry using reflected GNSS signal because the signal propagation time is quite longer compared to conventional mono-static SAR geometry and it takes about 70 milliseconds in general. Such a long stop time would affect the sampling frequency in the slow time domain and eventually the bandwidth of sampled Doppler frequency would get quite narrower.

Fortunately, GNSS signal is not a pulse signal but a continuous signal and we can receive anytime once the receiving window is open. From here, we discuss using C/A code signal on L1 carrier of GPS. Due to this property of GPS signal, we don't have to wait for the echo signal using conventional stop-and-go model but all we have to do for reception is just to open window. The slow time sampling frequency depends on the signal correlation process and in this case, 1 millisecond is necessary for C/A code correlation. The problem which occurs when this modified geometry is utilized is definition of signal delay. The reason why the geometry is assumed to be stationary during waiting and receiving echo signals is to align the time corresponding to zero delay among slow time sample bins, that is:

\[ t_d(t) = \frac{R_R(t) + R_T(t)}{c} \]  \hspace{1cm} (1)

\( R_R \): distance between receiving platform and target point
\( R_T \): distance between transmitting platform and target point
in mono-static case, \( R_T = R_R \)
\( t \): slow time sample bin

On the other hand, the modified delay is described using continuous signal as below:

\[ t_d(t) = \frac{R_R(t) + R_T(t - t_d)}{c} \]  \hspace{1cm} (2)

\( R_R \): distance between receiving platform and target point
\( R_T \): distance between transmitting platform and target point
\( t \): slow time sample bin

The geometry is no longer stationary between transmission and reception of signal and (2) equation should be solved using iteration calculation. What matters most from the point of view of SAR imaging process is how this delay appears in the imaging space which is described using slow time and fast time. This problem can be solved using the GPS time synchronization process. GPS signal is encoded with a kind of PRN (Pseudo Random Noise) code and this PRN code is utilized to determine the GPS time. In the case of C/A code, the whole timespan of code is accurately 1 millisecond and synchronized with GPS time to a precision of 1 millisecond. This property is very helpful for users to synchronize their clock to GPS time. Once the reference signal is selected appropriately, the delay appears in the imaging space with the ambiguity of 1 millisecond as follows:

\[ t_d = N \times 1ms + \text{Frac} \]  \hspace{1cm} (3)

\( N \): ambiguity of 1 millisecond

1 millisecond corresponds to 300 kilometers and it would be enough for imaging because the range swath of imaging region might be less than 300 kilometers. On the other hand, the geometry is assumed to be stationary during this 1 millisecond in this modified model because the change of geometry during this 1 millisecond is not critical compared to the resolution of C/A code. Chip duration of C/A code is about 1 microsecond which corresponds to 300 meters but the change of geometry during 1 millisecond might be less than several meters. It is clear that this small difference does not affect the result of aperture synthesis.

The reflected signal of GPS signal is described as below:

\[ s_r(t, \tau) = \sigma \sqrt{2p} x(t + \tau - t_d) \cos(2\pi f_c + f_d(t + \tau - t_d)) \]  \hspace{1cm} (4)

\( t \): slow time sample bin
\( \tau \): fast time sample bin
\( t_d \): delay which is defined from (2)
\( f_d \): Doppler frequency
\( x(t) \): C/A code function

Doppler shift due to the motion of GPS satellite works as constant bias in the frequency domain because the line of sight vector between GPS satellite and target point is assumed to be constant during aperture synthesis integration time and can be removed easily. Therefore, Doppler shift due to the motion of
receiving platform is only considered in the following discussion.

3. Simulation and Result

Simulation parameters are defined as follows:

![Geometry in simulation](image)

**Fig. 1** Geometry in simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_T$</td>
<td>20,000 [km]</td>
<td>@ t = 0</td>
</tr>
<tr>
<td>$\theta_E$</td>
<td>30 [deg]</td>
<td></td>
</tr>
<tr>
<td>$\theta_L$</td>
<td>30 [deg]</td>
<td></td>
</tr>
<tr>
<td>$V_T$</td>
<td>3000 [m/s]</td>
<td></td>
</tr>
<tr>
<td>$V_R$</td>
<td>100 [m/s]</td>
<td></td>
</tr>
<tr>
<td>$Z_R$</td>
<td>577 [m]</td>
<td></td>
</tr>
<tr>
<td>$X_T, Y_T$</td>
<td>0, 1000.0 [m]</td>
<td></td>
</tr>
<tr>
<td>$\theta_{beam}$</td>
<td>0.1 [rad]</td>
<td>Beam width</td>
</tr>
<tr>
<td>$B_{C/A}$</td>
<td>2.0 [MHz]</td>
<td>Band width</td>
</tr>
<tr>
<td>$f_c$</td>
<td>1.5 [GHz]</td>
<td>Carrier Freq.</td>
</tr>
</tbody>
</table>

Table 1 Parameters in simulation

The range migration in this geometry is quite different from that of conventional mono-static geometry because the range between GPS satellite and target is assumed to a linear function.

![Range Migration in simulation](image)

**Fig. 2** Range Migration in simulation

The replica code derives from the signal which has no delay and no Doppler shift. After range compression using this reference signal, the range migration correction is processed. This interpolation process utilizes the delay history in the slow time domain and this delay history can be calculated using the position of GPS satellite and user’s receiving platform. This means that the positioning should be established using direct signal of L1 during the aperture synthesis integration time. Azimuth compression process follows and finally the PSF (Point Spread Function) can be obtained in the imaging space.

As shown in the figure below, the PSF of target point is successfully obtained. In the fast time domain, we can see clear auto-correlation peak of C/A code and its width in range is 2 chips of C/A code. The resolution in the fast time domain is defined as 1 chip if the resolution is defined with Sparrow's criterion. Due to the auto-correlation property of C/A code, no other peak is seen in the fast time domain. Compared to the resolution in the slow time domain, the resolution in the fast time domain is rather worse because of the chip duration of C/A code which corresponds to 30 meters. This is to be improved using the signal which has wider bandwidth such as L5 signal of GPS or E5 signal of Galileo.

![Reconstructed PSF of target point](image)

**Fig. 3** Reconstructed PSF of target point

![Colormap: Reconstructed PSF of target point](image)

**Fig. 4** Colormap: Reconstructed PSF of target point
4. Conclusion
We proposed the modified stop-and-go model which can be applied into the space-surface geometry. The PSF of target point was successfully reconstructed using this model and the signal property of C/A code of GPS signal.

5. Future Work
As mentioned before, the next step is to improve the range resolution using GPS L5 signal property whose bandwidth is ten times wider than that of L1 C/A code. Besides that, the aperture synthesis algorithm should be modified in order to process whole target region because all the target points have different range migration history in this space-surface geometry. The Doppler phase profile also should be examined in great detail to establish an imaging algorithm which can deal with many target points at once.

6. Acknowledgement
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7. Reference
Assessment of scene changes in multi-sensor and multi-temporal fusion images of very high resolution satellite imagery

Yuhendra1,2, Ilham Alimuddin1, Josphat Tetuko Sri Sumanyo1, Hiroaki Kuze1
1Center for Environmental Remote Sensing (CEReS), Chiba University, Japan
2Department of Informatics, Faculty of Engineering, Padang Institute of Technology, Indonesia
E-mail: yuhendra@graduate.chiba-u.jp

Abstract
Image fusion and subsequent scene analysis are important for studying Earth surface conditions from remotely sensed imagery. The fusion of the same scene using satellite data taken with different sensors or acquisition times is known as multi-sensor or multi-temporal fusion, respectively. The purpose of this study is to investigate the effects of the multi-sensor, multi-temporal fusion process when a pan-sharpened scene is produced from low spatial resolution multispectral (MS) images and a high spatial resolution panchromatic (PAN) image. It is found that the component substitution (CS) fusion method provides better performance than the multi-resolution analysis (MRA) scheme. Quantitative analysis shows that the CS-based method gives a better result in terms of spatial quality (sharpness), whereas the MRA-based method yields better spectral quality, i.e., better color fidelity to the original MS images.

Keywords: Multi-sensor, Multi-temporal fusion, Component substitution, Multi-resolution analysis

1. Introduction
Following the rapid advance of new and greatly improved remote sensing (RS) sensor systems, various kinds of remote sensing data have been acquired and applied to a number of interdisciplinary Earth observation studies. The combination of low spatial resolution multispectral (MS) and high spatial resolution panchromatic (PAN) imaging sensors is usually used for change detection studies, each one having its own specific advantage (Chibani, 2007). Nowadays various operating sensors that can produce very high resolution (VHR) imagery (WorldView, QuicBird, GeoEye, and Orbview, etc.) are employed for purposes including image sharpening, land classification, change detection, and object identification (Zeng, 2010). In order to enhance the applicability of such image analysis based on remote sensing data, it is useful to consider image fusion of the same scene taken at different acquisition times with the same or different sensors.

Since multi-sensor, multi-temporal, multi-resolution and multi-parameter image data are available from operational Earth observation satellites, possibly a more complete view of observed objects can be obtained through the fusion technique (Zhu and Tateishi, 2006). Studies of fusing multiple images provided by heterogeneous image sensors have been proposed in many literatures with different methodologies, context and purposes (Yuhendra et.al., 2012). The objective of this study is to analyze and assess the scene changes given to multi-temporal images by comparing two different algorithms of multi-resolution analysis (MRA) and component substitution (CS).

2. Study area and satellite imagery
2.1 Study area
The study area for this work is located in the downtown of San Francisco, California, with geographical coordinates of 122°23'1.08"W and 37°42'38.81"N. As shown in Fig. 1, the scene includes significant stretches of the Pacific Ocean and San Francisco Bay within its boundaries (Figure 1).

2.2 Satellite images
For this work, two optical images acquired by QuickBird (QB) and WorldView-2 (WV) on 11 November 2007 and 9 October 2011, respectively, were used for investigating the performance of multi-sensor, multi-temporal fusion. The characteristics of both images are summarized in Table 1.

Fig. 1 Study area in downtown San Francisco, US.
2.3. Spectral response of sensors
Significant spectral distortion in the fusion product image can occur due mainly to the wavelength extension of the new satellite PAN sensors. Table 2 shows the wavelength range and spatial resolution of different PAN sensors. In image fusion techniques, it is important to properly include the sensor spectral response information (Otazu, et al., 2005).

3. Methods
3.1 Pre-processing
Since the images used in this study were from two different sensors, several pre-processing steps are needed. From the original WV and QB, a total of 56 and 4 bands color combinations are produced and analyzed using the optimum index factor (OIF). The highest value of average OIF has been obtained for the band combination 3-5-7 and 2-3-4, both for WV and QB. The pixel size of WV PAN (0.5 m) is greater than that for QB PAN (0.6 m). Thus, in order to minimize the spectral difference, WV MS, QB MS and QB PAN image are used, after being re-sampled at 0.5 m using cubic convolution. Then, image registration is implemented by means of the rational polynomial coefficient with nearest neighbor transformation for attaining a good registration with the root-mean-square (RMS) error of 0.75 pixel value for all the ground control points (GCPs).

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Band Name</th>
<th>Wavelength (µm)</th>
<th>Resolution (m)</th>
<th>Date Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB</td>
<td>B1(Blue)</td>
<td>0.45-0.52</td>
<td>2.44-2.88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B2(Green)</td>
<td>0.52-0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B3(Red)</td>
<td>0.63-0.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B4(NIR)</td>
<td>0.76-0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PAN</td>
<td>0.45-0.90</td>
<td>61-72 cm</td>
<td></td>
</tr>
<tr>
<td>WV-2</td>
<td>B1(NIR1)</td>
<td>0.77-0.89</td>
<td>2.07</td>
<td>11 Nov. 2007</td>
</tr>
<tr>
<td></td>
<td>B2(Red)</td>
<td>0.63-0.69</td>
<td></td>
<td>9 Oct. 2011</td>
</tr>
<tr>
<td></td>
<td>B3(Green)</td>
<td>0.51-0.58</td>
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<td></td>
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<tr>
<td></td>
<td>B4(Blue)</td>
<td>0.45-0.51</td>
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<td></td>
<td>B5(R.Edge)</td>
<td>0.70-0.74</td>
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<td>52 cm</td>
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<td>B6(Yellow)</td>
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<tr>
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<td>B7(Constr)</td>
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<td></td>
<td>B8(NIR2)</td>
<td>0.45-0.48</td>
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<td></td>
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<tr>
<td></td>
<td>PAN</td>
<td>0.45-0.80</td>
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<td></td>
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</tbody>
</table>

Table 2. Spectral range of different PAN sensors.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Wavelength range (µm)</th>
<th>Spatial resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAN</td>
<td>0.45 - 0.90</td>
<td>0.5</td>
</tr>
<tr>
<td>GeoEye-1</td>
<td>0.45 - 0.90</td>
<td>0.5</td>
</tr>
<tr>
<td>QuickBird</td>
<td>0.45 - 0.90</td>
<td>0.7</td>
</tr>
<tr>
<td>Ikonos-2</td>
<td>0.45 - 0.90</td>
<td>1.0</td>
</tr>
<tr>
<td>WorldView-2</td>
<td>0.45 - 0.80</td>
<td>0.46</td>
</tr>
<tr>
<td>Spot 5</td>
<td>0.48 - 0.71</td>
<td>5</td>
</tr>
<tr>
<td>EO1(ALI)</td>
<td>0.48 - 0.69</td>
<td>10</td>
</tr>
<tr>
<td>ALOS</td>
<td>0.52 - 0.77</td>
<td>2.5</td>
</tr>
</tbody>
</table>

3.2 Pan-sharpening Techniques
Two main approaches of pan-sharpening, namely MRA and CS, are compared in the present analysis. Multi-resolution analysis (MRA) is an approach based on fast Fourier transform (FFT)-enhanced intensity-hue-saturation (IHS) transformation (Figure 3). Since this method is capable of preserving the spectral characteristic, generally it is suitable for image analysis purposes (Ling, et al., 2007; Ehler, et al., 2010; Yohendra, et al., 2012). Another approach is the one based on component substitution (CS), a form of Gram-Schmidt transformation. The CS method performs fusion through CS transformation without any filtering operation of the PAN image. The re-sampled multispectral images are transformed from the RGB to IHS color space to obtain the intensity (I), hue (H), and saturation (S) components, and low-pass filtering (LPF) is applied to the intensity component. After high-pass filtering (HPF), the

Fig. 2 Multi-temporal optical images of QB and WV.
PAN image is added to the low-pass filtered intensity component by means of inverse FFT (FFT'). Finally, inverse IHS transformation (IHS<sup>-1</sup>) is performed on the IHS image to create the fused image.

![Diagram of MRA fusion using FFT-Enhanced IHS](image)

Fig. 3 MRA fusion using FFT-Enhanced IHS

3.3 Multi-temporal analysis

For analyzing information from multi-temporal observations, the following combinations are employed here: (1) both PAN and MS images of November 2007 (QB_PAN_MS), (2) PAN of November 2007 and MS of October 2011 (QB_PAN, WV_MS), (3) both PAN and MS images of October 2011 (WV_PAN_MS), and (4) PAN of October 2007 and MS of November 2011 (WV_PAN,QB_MS). For each of these choices, both MRA and CS pan-sharpening methods are applied.

In order to quantitatively evaluate scene changes from the resulting fusion images, comparison is made for the image quality in terms of quality indexes such as root mean square error (RMSE), relative average spectral error (RASE), and relative dimensionless global error in synthesis (ERGAS). These indexes have been given by (Deshmukh and Bhosale, 2010; Li et al., 2010).

\[
RMSE(B_i) = Bias^2(B_i) + STD^2(B_i)
\]

(1)

\[
RASE = \frac{1}{M \sum_{i=1}^{n} \left( RMSE^2(B_i) \right)^{1/2}}
\]

(2)

These formulae can be used for comparing errors obtained from different methods, different cases and different sensors (Wald, 2000). The ERGAS index is given as

\[
ERGAS = 100 \frac{d_h}{d_l} \left( \frac{1}{n} \sum_{i=1}^{n} \left( \frac{RMSE^2}{mean^2} \right) \right)^{1/2}
\]

(3)

where \(d_h/d_l\) is the ratio between the pixel sizes of the PAN and MS images (e.g., 1/4 for QB and WV data), and \(\mu(i)\) is the mean of the \(i\)th band. Since ERGAS is a measure of distortion, its value must be as small as possible.

4. Results and discussion

Figure 4 shows the fused images obtained with the CS and MRA fusion methods for the four choices of band combinations. In visual (qualitative) analysis, it is seen that CS fusion yields relatively sharp images for both PAN and MS images of October 2011 (WV_PAN_MS) and PAN of October 2011 and MS of November 2007 (WV_PAN,QB_MS). Other results show somewhat blurred results due to temporal changes. For MRA fusion, the fusion of PAN and MS images of October 2011 (WV_PAN_MS) gives better spectral quality (i.e., fidelity of colors to original) than other three combinations, which show color distortion as compared with original MS images.

Table 3 and 4 summarize the values of RMSE, RASE, and ERGAS indexes based on the CS and MRA approaches. Smaller parameter values (ideally zero values) indicate better preservation of the original information. The resulting index values obviously depend on the MS images chosen as reference (see also Fig. 4). In the case of CS fusion, when the reference is the PAN of October 2011 and MS of November 2007 (WV_PAN, QB_MS), a better result is obtained as manifested in smaller values of RMSE, RASE and ERGAS.
Fig. 4 Scene changes after image fusion.

Table 3. Quality index based on CS fusion.

<table>
<thead>
<tr>
<th>Index</th>
<th>Scene changes temporal fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>1.81</td>
</tr>
<tr>
<td>RASE</td>
<td>4.46</td>
</tr>
<tr>
<td>ERGAS</td>
<td>1.91</td>
</tr>
</tbody>
</table>

Table 4. Quality index based on MRA fusion.

<table>
<thead>
<tr>
<th>Index</th>
<th>Scene changes temporal fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>16.60</td>
</tr>
<tr>
<td>RASE</td>
<td>15.55</td>
</tr>
<tr>
<td>ERGAS</td>
<td>2.01</td>
</tr>
</tbody>
</table>

5. Conclusion and Future Research
We have investigated the multi-temporal fusion by
multi-resolution analysis (MRA) and component substitute
ion (CS) algorithms. In both quantitative and qualitative results,
it has been found that the CS based method leads to better
spatial quality (sharpness), whereas the MRA based method
better spectral quality (fidelity to the original color). In the
future research, the methodology presented in this paper can
be extended to include the multi-temporal fusion of optical and
synthetic aperture radar (SAR) images from satellite
remote sensing.

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Development of 9.41 GHz Weather Radar

Adiya Sugar\textsuperscript{1}, Josaphat Tetuko Sri Sumantyo\textsuperscript{2} Osa Kohel\textsuperscript{3}, Hiroaki Kuze\textsuperscript{4}

\textsuperscript{1}Center for Environmental Remote Sensing (CEReS), Chiba University.
1-33 Yayoi-cho, Inage-ku, Chiba-shi, Chiba 263-8522 Japan (Mongolia), sugar@graduate.chiba-u.jp
\textsuperscript{2}Center for Environmental Remote Sensing (CEReS), Chiba University.
1-33 Yayoi-cho, Inage-ku, Chiba-shi, Chiba 263-8522 Japan, ttetukoss@faculty.chiba-u.jp

Abstract
For this purpose, we are developing 3 dimensional weather radar (3D-WR), where this radar has capability to retrieve rain drop distribution and its characteristics in three-dimensional position on a multiplicity of targets (range, azimuth, and height). We plan to deploy this 3D radar in the near future and deliver the information for digital television weather forecasting service. The 3D-WR system consists of patch array antenna, transmitter and receiver sub system. We focus the effort in developing the patch array antenna subsystem. In the preliminary of this research, we are developing array patch antenna by using finite element method (FEM) to simulate the compact shape of antenna and its electricity characteristics (beam width, gain, input impedance etc). We develop the antenna by using Finite Element Method (FEM) (HFSS software) to simulate the radiation pattern, input impedance etc. Then the satisfied design is fabricate by using chemical etching technique. The 3D-WR works in X Band (9.41 GHz) with bandwidth 15 MHz, The antenna fabricated in array configuration with the targeted beamwidth horizontal and vertical in elevation and azimuth direction is around 6 degrees. We choose commonly available, commodity of the shelf Furuno marine radar as our model and modify it according to our design. We aim to be able to create new modified 3D weather radar and will install 1000 unit of this radar in around Japan in the future.

Keywords: 3 dimensional weather radar (3D-WR), subsystem, X Band (9.41 GHz), (FEM) (HFSS software)