Title: Sea Ice Measurements using GNSS Reflectometry from Nano-Satellites

Primary Point of Contact (POC) & email: Peter Kruzlics (pmkruzli@uwaterloo.ca)

Co-authors: Shahid Haider, Jason Pye, Arsalan Alim

Organization: WatSat – University of Waterloo

(X) We apply for Student Prize.

( ) Please keep our idea confidential if we are not selected as finalist/semi-finalist.

Need

Analysis of the arctic sea ice coverage is a growing concern in scientific and commercial circles. Scientists commonly use the arctic sea ice extent as a metric of global warming and predicting migration patterns of polar bears, and commerce is concerned with the ice flow movement patterns to plan shipping routes. Current measurement methods rely on whole-field visual, hyper-, and multi-spectral imagers to acquire images. Issues that can arise from such imaging is that they can experience considerable attenuation due to atmosphere and it can be difficult to infer the states from the state from these measurements thereby leading to the extensive literature base that exists on remote sensing of the arctic sea ice extent[1].

A relatively new modality for sea ice imaging is Global Navigation Satellite System (GNSS) Reflectometry. This modality utilizes the unique dielectric characteristics of sea ice to differentiate it from the surrounding environment. It correlates the GNSS signal captured directly from the GNSS constellations with the corresponding GNSS signal reflected from the sea ice surface and the correlated reflected and raw signal can then be characterized. GNSS Reflectometry has the benefit of not being affected by the attenuation due to atmosphere [2].

Mission Objectives

By using a nano-satellite in low earth orbit, GNSS signals are collected to fulfill the following objectives:

1. Demonstrate the viability of nano-satellites for performing GNSS Reflectometry experiments
2. Measure reflected GNSS signals over the Northwest Passage, the Labrador Sea, Gulf of St. Lawrence

The final mission objective will be upgraded to actually classifying sea ice when validation data can be provided that spatially correlates with the reflected signals. This validation can be in the form of classified sea ice from SAR imagery or from ice charts provided by the Canadian Ice Service. The next step will then be to create an open database of sea ice extent information to be available to marine and arctic life researchers are well as global warming scientists.

Concept of Operations

The WatSat-1 satellite is a 3U nano-satellite that will be launched into a 700 km (+/- 100km) polar orbit with a 98 deg. inclination and a roughly 10:30am/pm equatorial crossing time. The satellite will contain two GPS Front Ends and two patch antennas to sample the raw L1 GPS signals. One front end will sample the direct GPS satellite signals using one right-hand circularly polarized (RHCP) zenith-pointing antenna, and one front end will sample the reflecting GPS satellite signals using one left-hand circularly polarized (LHCP) nadir-pointing antenna since the signal polarization flips when reflecting off the earth's surface. The antenna orientation is shown in Figure 1.

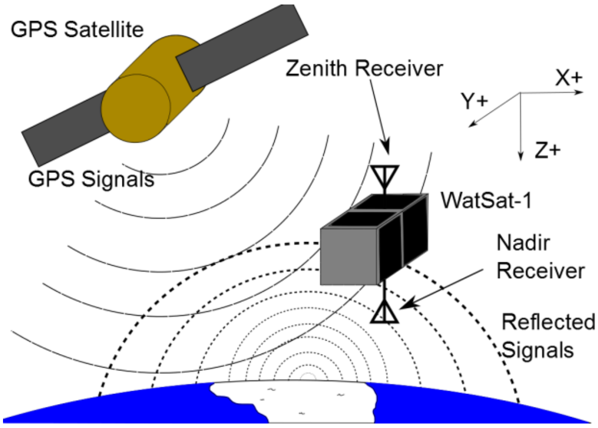

Figure 1: WatSat-1 Antenna Orientation

The satellite is designed to survive in orbit for a minimum of one year. The initial period of the satellite's timeline will involve:

Launch Vehicle Ascent

- Satellite is stored in PPOD deployer during launch

Event: Satellite-Vehicle Separation

- Satellite is deployed from PPOD and power is restored to internal components
- Satellite enters "Start-up" mode

Early Orbit Phase (24 hours)

- Batteries are charged using exterior solar cells
- Satellite attitude is stabilized
- Interior electronics are tested and verified
- Establish regular communication with Ground Station

Event: Initialize Standby Mode

- Satellite leaves "Start-up" mode once components have been determined to be functioning properly
- Satellite enters "Standby" mode for sensor calibration

Calibration (4 weeks)

- Begins initial payload collection
- Onboard sensors are calibrated using ground measurements
- Ground station creates orbital position models using GPS data collected onboard satellite

Event: Begin Normal Satellite Operations

- Satellite is officially commissioned for payload collection
- Begins normal satellite operations

Active Payload Data Collection (11+ months)

- Satellite periodically gathers payload and telemetry data and communicates with the ground station

Key Performance Parameters

- 50% Coverage of Northwest Passage, Labrador Sea, and Gulf of St. Lawrence per orbit.
- Spatial resolution of detection < 20km x 20km.
- GNSS Receiving antenna with 11.8 dBiC[3] gain earth-facing
- Earthbound storage has to be high fidelity with high resolution sampling signal sampling.

Space Segment Description

Power

The satellite's power usage is split into different operational modes: Start-up, Communications, Attitude Adjustment, and Payload. Start-up mode is while the satellite is verifying all components are functioning properly. The Communications mode is as the satellite is transmitting/receiving data to/from the ground station. The Attitude Adjustment mode is when the satellite is actively determining and controlling its orientation. The Payload mode is when the satellite is gathering payload data from the GPS Front Ends.

The satellite is covered by solar cells that generate on average 5.5 Watt-hours of power per orbit. The average power consumption of the various operational modes are:

- Standby: 1.9W
- Communication: 6.8W
- Attitude Adjustment: 4.0 W
- Payload: 7.0W

Communication

The communications system in the satellite consists of an S-band transceiver and antenna onboard the satellite and is capable of transmitting data at 230kbps. The satellite will be able to communicate with the Waterloo ground station 5-6 times per day for an average of 45 minutes per day.

Payload

The payload of the satellite will acquire the raw and reflected GNSS signals and compress them for storage. The key parameters involved with this system are antenna gain, beam width, storage ratio and throughput.

Compression is an important portion of this subsystem due to the large amount of information acquired per second from a GNSS sampler. The proposed form factor of the satellite does not accommodate large data storage solutions, hence compression is necessary to fit on the smaller form factor devices and thereby decreasing the number of orbits required to downlink the information.

Computing

WatSat-1 is using an embedded Debian system to control the operational modes of the satellite for space segment operation and power management. It will act as a state machine utilizing dead reckoning with a time scheduler to determine what operational mode the satellite needs to be in.

Structure

WatSat-1 will consist of an exterior frame made of Aluminum 6061, onto which PCB's will be mounted. These PCB's will have solar panels soldered directly onto them. The exterior frame will house an interior structure made of both Aluminum 6061 and ProtoTherm. The interior structure will house all of the components in a standardized tray configuration which allows easy access to the components. The total mass of the satellite will be 3.5 kg, with dimensions 10 cm x 10 cm x 34 cm.

ADCS

The attitude determination and control system (ADCS) is responsible for acquiring information about the current attitude of the satellite and rotating the satellite to a desired attitude. The desired attitude of the satellite is such that the LHCP GPS antenna and communications antenna are always pointing towards the Earth. This is accomplished with a suite of attitude sensors and magnetic actuators. ADCS is activated after launch to perform detumbling as well as during every orbit when the satellite is between +/- 45 deg. latitude to control the attitude and angular velocity of the satellite.

The sensor suite is based on [4] and consists of photodiodes placed on each external face of the satellite which act as coarse sun sensors, two- and three-axis magnetometers at various locations throughout the satellite to measure the Earth's magnetic field vector, and micro-electromechanical gyroscopes to measure angular velocity. A Kalman filter takes all of the sensor attitude measurements and angular velocity measurements to give an estimate of the attitude and angular velocity in the orbital frame.

The ADCS uses four magnetorquer rods for actuation, three of which are orthogonal and the fourth is placed along the main diagonal (for redundancy). A b-dot algorithm is used for detumbling and controlling the angular velocity of the satellite. A PID controller is used for attitude control.

Orbit/Constellation Description

WatSat-1 will be a nadir pointing satellite in a sun synchronous polar orbit. The inclination of the orbit is to be about 98 deg. to allow the satellite to image the arctic sea ice. The orbit will be in low earth orbit with a semi-major axis of 7078 ± 100 km, which allows for the most accurate imaging of the sea ice. A sun synchronous orbit allows us to obtain consistent readings from our payload as well as providing us with a convenient orbit for data collection and communication

Implementation Plan

Interested Parties

WatSat-1 provides information on the amount of polar sea ice at any given time of the year. This data can provide to be useful for many organizations such as shipping companies who have shipping routes through the Canadian north. They will need accurate and up to date data on sea ice conditions to create safe and reliable routes for their ships. Customers such as professors or research parties interested in the changing arctic sea ice due to human factors would also find this data valuable. WatSat-1 will be able to provide them with long term data on sea ice and its coverage over the seasons.

Life Cycle Cost

Hardware Cost: $25,340.00

Operational Cost: $21,368.00

Launch Estimate: $80,000.00

Total Cost: $126,708.00

Testing

Testing the WatSat-1 satellite requires a shaker table to replicate the acoustic loads of the rocket launch, and a thermal vacuum chamber to verify that all the satellite components will survive the environment and thermal cycles in orbit. These tests will be performed at the University of Waterloo and in partnership with local aerospace companies.

Project Organization

WatSat is comprised of University of Waterloo students, both undergraduate and graduate, and faculty advisors. WatSat is also participating in the Canadian Satellite Design Challenge.

Project Schedule

October 2012: Satellite Design Begins

February 2013: Preliminary Design Review

September 2013: Critical Design Review

September 2014: Environmental Testing

~2016: Launch

Project Risks

1. Satellite crashing into debris {Level: Low, Severity: Very High}

Results: Satellite could be completely shut down

Avoidance: No orbit maneuver capabilities, not able to avoid

Mitigation: Using NORAD TLE Data, collision can hopefully be predicted

2. Satellite contact lost with Ground Station {Level: Medium, Severity: High}

Results: No longer able to communicate with satellite and use payload instruments

Avoidance: If satellite can't communicate with satellite for X number of orbits, have script that reorients satellite and waits for "ping"

3. Radiation causing a bit-flip {Level: Low, Severity: Very High}

Results: Partial functionality of satellite lost

Avoidance: Wrap computer components in Mylar to prevent radiation exposure. Also able to upload software updates and corrections from ground station

4. Software Update gets corrupted during transmission {Level: Medium, Severity: High}

Results: Partial functionality of satellite lost

Avoidance: Downlink freshly-uplinked software update to make sure it was received properly

5. Satellite is damaged during launch {Level: Medium, Severity: High}

Results: Partial functionality of satellite lost

Mitigation: Reduce functionality (e.g. number of Payload samples taken) of satellite to meet new capabilities

References

[1] L. Ventress, "Atmospheric sounding using IASI 1st Year Report", AOPP, University of Oxford, 2010.

[2] GLOBAL POSITIONING SYSTEM STANDARD POSITIONING SERVICE SIGNAL SPECIFICATION, 2nd edition, 1995.

[3] S. Gleason "Remote Sensing of Ocean, Ice and Land Surfaces Using Bistatically Scattered GNSS Signals From Low Earth Orbit", PhD Dissertation, Surrey University, Surrey, London, 2006.

[4] J. C. Springmann, et al. "The attitude determination system of the RAX satellite." *Acta Astronautica*, 75 (2012), 120-135.