# Implementation of three axis attitude determination and control system for a double cubesat

F.S. Holberg, R. Birkeland, J.T. Gravdahl

Dept. of Eng. Cybernetics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

fredrhol@stud.ntnu.no roger.birkeland@iet.ntnu.no

## About the project

The NUTS (NTNU Test Satellite) is a satellite being built in a student CubeSat project at the Norwegian University of Science and Technology. The project was started in September 2010 and is a part of the Norwegian student satellite program run by NAROM (Norwegian Centre for Space-related Education). The NUTS project goals are to design, manufacture and launch a double CubeSat by 2014. As the payload an IR-camera observing waves in the air-glow layer is planned, as well as a short-range RF experiment. The satellite will fly two transceivers in the amateur radio bands. Final year master students from several departments are the main contributors in the project.

## Introduction

The main payload of our system is an IR-camera which will take pictures of the atmoshphere. The payload requires an accurate and reliable ADC system with a pointing accuracy of less than 10 degrees in every axis. We aim to complete these control goals by using magnetorquers as actuators and a combination of a gyroscope, a magnetometer and the solar panels as sun sensors for attitude determination.

## EQUEST

The EQUEST method has been developed from the QUEST algorithm in order to make use of non-vectorized gyroscope measurements for the attitude estimation. The main idea behind the EQUEST is to modify the cost function. This is done by adding another term, containing the gyroscope measurements. [Yabar and Jenssen (2011)]

$$J = \frac{1}{2}\sum_{j=1}^{n}\left\{\frac{1}{\sigma_j}^2 (b_j - R_b^i(q)r_j)^T(b_j - R_b^i(q)r_j)\right\} + \frac{1}{2}(q-\hat{q}_{gyro})D(q-\hat{q}_{gyro})$$

Further, a linear prediction term may be added due to the slow and predictable attitude change of a satellite to help filter out noise.

$$J = \frac{1}{2}\sum_{j=1}^{n}\left\{\frac{1}{\sigma_j}^2 (b_j - R_b^i(q)r_j)^T(b_j - R_b^i(q)r_j)\right\} + \frac{1}{2}(q-\hat{q}_{gyro})D(q-\hat{q}_{gyro}) + \frac{1}{2}(q-\hat{q}_{pre})^T S(q-\hat{q}_{pre})$$

The minimization problem is then put on standard form and solved by use of the Langrangian multiplier method.

The estimation method has been compared with the well known Extended Kalman Filter as well as an xsens reference motion tracking system, and found to give accurate and reliable attitude information. This semester the method has been further developed by changing the quaternion substraction terms into quaternion products [Rinnan(2011)], which will represent proper rotations and form new attitude quaternions.

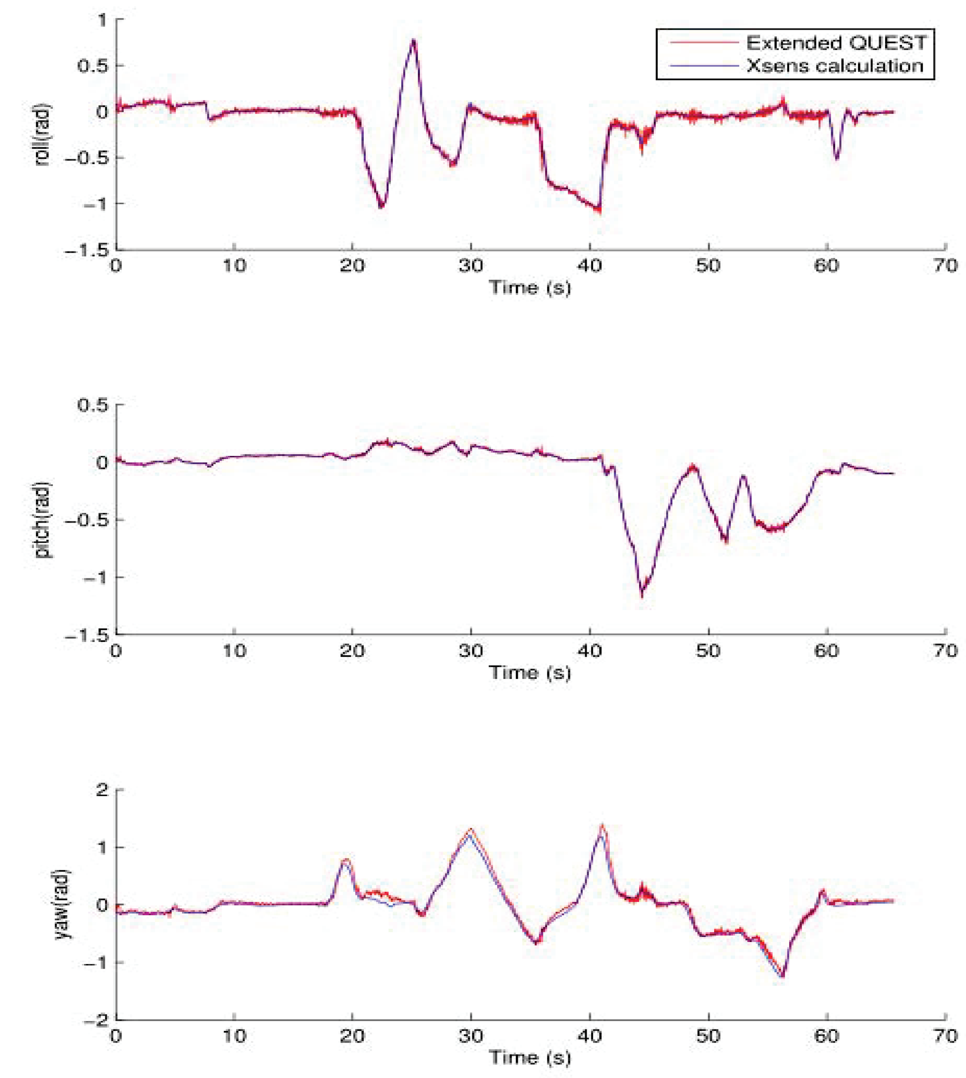


Figure 1: Comparison of EQUEST method to reference xsens unit

## Sun sensor

For this satellite we will utilize the solar panels already present for use as sun sensors. The values for power delivered from each of the panels will provided by other parts of the satellite and is integrated into the EQUEST algorithm. For testing purposes an accelerometer has been used in the EQUEST method, a measurement which is easily replaceable by finding the directional sun intensity from the intensity measured by each of the panels to change the $b$ and $r$ vectors in the cost function. The sun vector is found via the intensity measured at each solar panel.

$$s_{meas} = \begin{bmatrix} 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} Int_{x+} \\ Int_{x-} \\ Int_{y+} \\ Int_{y-} \\ Int_{z+} \\ Int_{z-} \end{bmatrix}$$

## Control

The control part is comprised of two phases

- Detumbling. So far a dissipative controller has been explored and implemented which seems to be working. The choice for this controller is however still left open, as use of the more popular B-dot controller might be considered a safer choice for cubesat with many other possibilities of failure.
- Stabilization The choice of a stabilization controller is very much considered work in progress still, but for the purposes of prototype testing, a reference controller has been used that seems to be working during simulations. This controller is defined by the control law

$$m^B = -\frac{d}{|B^B|^2}B^B \times \omega_{OB}^B - \frac{k}{|B^B|^2}B^B \times \varepsilon$$

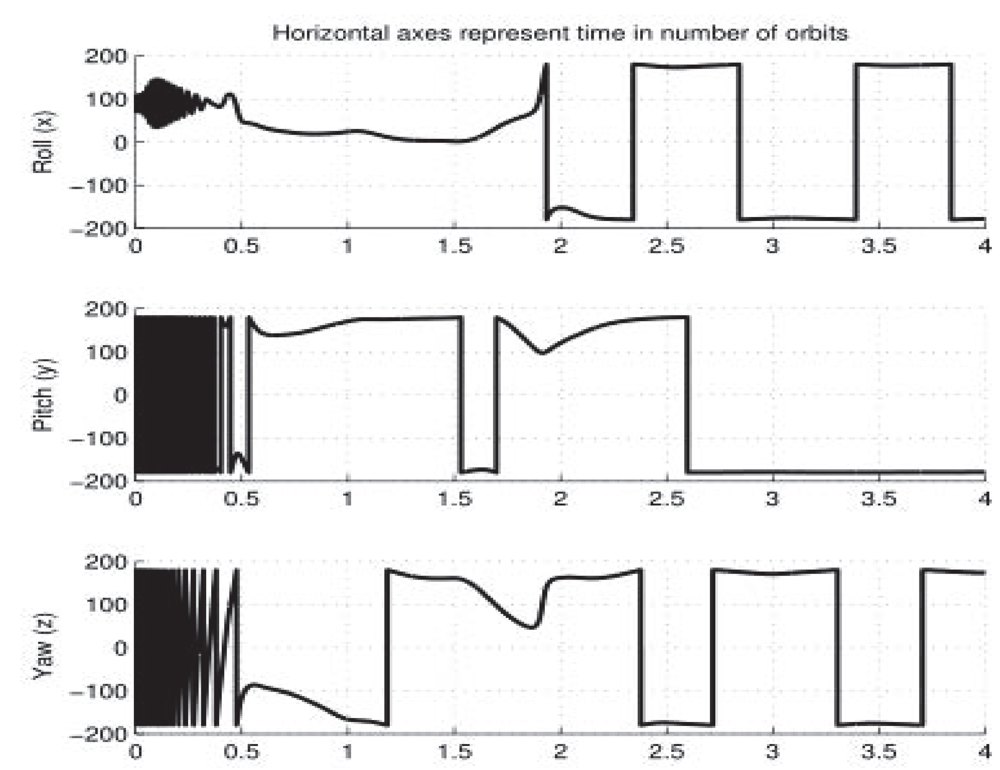


Figure 2: Euler angles for the full simulation.

## Prototype

The prototype is built around a 64-pin Atmel ATMEGA2561 microcontroller unit and the use of a CHIMU IMU, containing a gyroscope, accelerometer and magnetometer. This prototype has been tested extensively, performing all the tasks expected from the ADC system of our satellite. The prototype was designed as a collaboration between group members working on determination and control, and these subsystems were implemented and tested separately, [Yabar and Jenssen(2011), Tudor(2011)]. These implementations have now been combined, and the complete ADC system runs on a single 2561 MCU. Although the final design of the ADCS module is still incomplete the testing suggests this version is adequate for our mission.

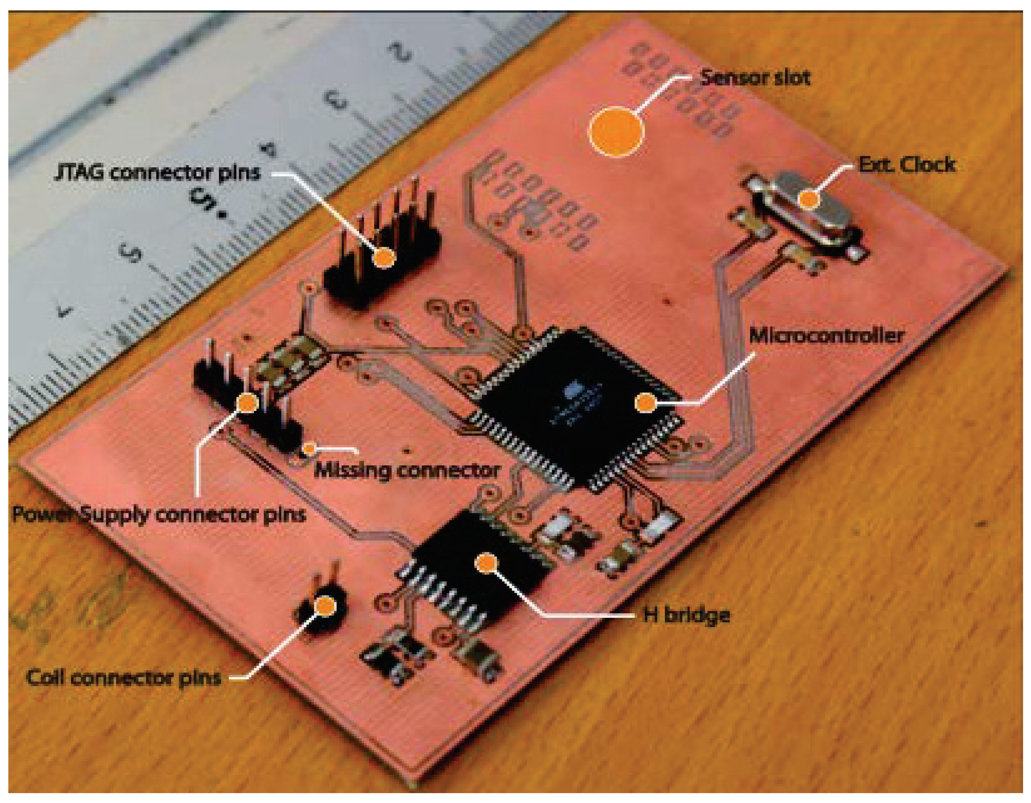


Figure 3: Prototype

## Conclusion/Further Work

Simulations and testing so far suggests that the ACDS module designed by our group will fulfill the requirements from our main payload within the allowed power budget. As mentioned earlier there has been alterations made to the EQUEST method which still needs to be implemented on the prototype, as well as the need for a good earth albedo model for the sun sensor and final decisions for the controllers used. Even with these challenges remaining, our system is nearing completion and is en-route to launch in 2014.

## References and other theses on this satellite project

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