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Overview of the NUTS CubeSat Project

Roger Birkeland, Odd Gutteberg***

The NTNU Test Satellite (NUTS) project is a student satellite project at the Norwegian University of Science and Technology (NTNU). The project is part of the national student satellite program in Norway, managed by the Norwegian Centre for Space related Education, NAROM. The NUTS project aims to design, develop, test, launch and operate a double CubeSat by 2014. Students from different study programs will do the main part of the work, supported by project management and technical staff. The work will be performed as part of the student's project- and master thesis. The design has been chosen to be generic and modular, so the satellite-bus can support different payloads. As a payload for this satellite, an IR-camera will be implemented. Recruitment and education of skillful students constitute a main part of the projects goals. Through hands-on experience, the students will be able to master different skills needed in their jobs after graduation. NTNU is a university offering a wide range of field of technological studies. Accordingly, a strategy to develop all subsystems ”in-house” has been chosen. This means that if problems and delays in the project are experienced, this could not be ”repaired” by buying missing sub-systems. The internal layout of the satellite electronics is different from most CubeSat projects. A backplane layout where cards for other systems can be slotted in, will be implemented. The system is distributed in hardware, meaning different subsystems, such as the OBC, ADCS and radio subsystem, will have their own MCUs. The main processor will be an Atmel AVR32 UC3. For attitude determination and control, the solar panels will be used as sun sensor and the actuators will be magnetic coils integrated in the main structure of the satellite. This structure will be based on composite material instead of using aluminum, and to our knowledge, be unique to NUTS.

The paper gives an overview of the satellite and its subsystem and purpose.

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Introduction

The Norwegian University of Science and Technology (NTNU) hosts the NTNU Test Satellite (NUTS) CubeSat project. This project is part of the Norwegian Student Satellite Program (ANSAT), managed and partially funded by the Norwegian Centre for Space related Education (NAROM) [1]. In total, the ANSAT program comprises three satellites, HiNCube from Narvik University College (HiN), CubeStar from University of Oslo (UiO) and NUTS.

The NUTS satellite will be a double CubeSat, fully designed and built by NTNU students. NTNU has also heritage from the nCube student satellite project. During this project two satellites where built in cooperation with three other Norwegian universities [2]. Before the NUTS project officially started in late 2010, there has been continuously CubeSat related work going on at several departments since 2002. These activities have not been part of a common project before 2010.

The NUTS Satellite

The NUTS satellite is a typical university mission, and the satellite will be a bit more advanced than just a “beep-sat”. The focus will be on some main topics to not over-complicate the project.

While CubeSat kits and subsystems can easily (but still expensive) be bought online with a few mouse clicks, NTNU would like to make NUTS their own design. Since NTNU is a broad technical university providing study programs covering all needed subjects for the satellite mission, it should be feasible to design and build the satellite “in-house”.

The earliest ideas for this project surfaced in 2006 [3], and the main ideas are still the foundation of this project: design a satellite platform that can be used to support several payloads with little change.

Overall Design

Figure 1 shows an overall block diagram of the satellite. The main architecture employs a distributed system; giving most subsystems their own microcontroller (MCU). This corresponds to the common CubeSat design idea. However, instead of using the de-facto CubeSat standard way of stacking the electronic boards, a backplane will be implemented with slots for each subsystem (similar to a mother board, a design that also were part of the nCube satellites).

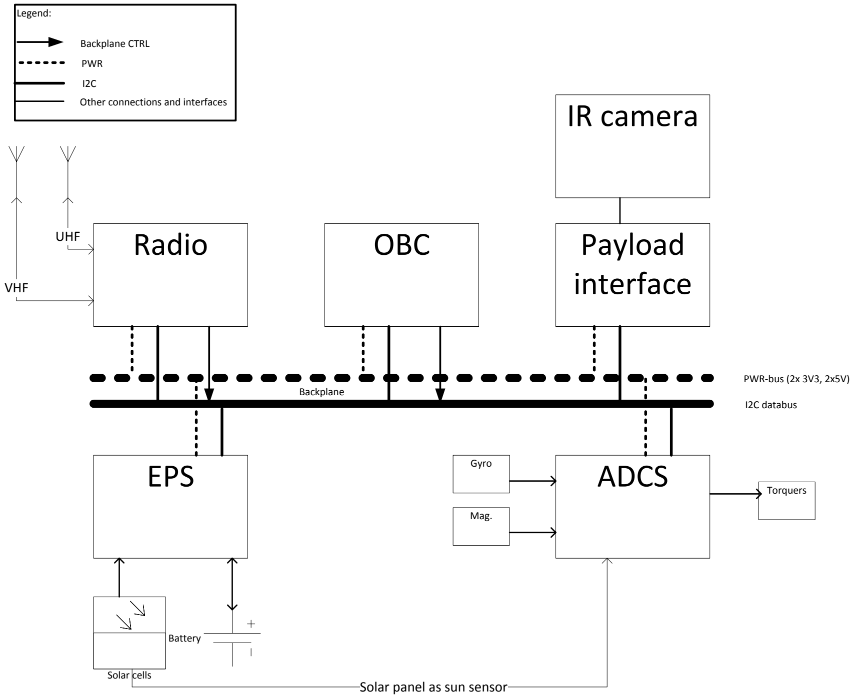

Figure 1. A simple overview over the main sub systems and components in NUTS.

Design Breakdown

One could argue that the list of the different components shown in Table 1 not necessarily is in accordance with the keep-it-simple statement mentioned earlier. However, by splitting the satellite into individual subsystems, it should be a manageable task to build the satellite. This will hopefully make the NUTS project a good academic project and give a better experience for the students.

Component	Properties
Structure	2U carbon fiber main structure with plastic secondary structure
OBC	Atmel AVR32 UC3 MCU, flash and RAM
ADCS	Atmel AVR xMega MCU, magnetometer, magneto torquers and solar panels as sun sensors
EPS	Azurspace 3G InGaAs solar cells, LiFePo4 batteries, solar panel battery chargers with built-in MPPT
Payload	IR camera, frame grabber
Communication	VHF and UHF transceivers, Atmel AVR32 UC3 MCU, turnstile antennas

Table 1. Overview of satellite subsystems

Structure

The satellite main structure will, in contrast to most other CubeSats, be made of carbon fiber. This is a fairly new concept, as only a few other CubeSat projects have been looking into the use of composites for the main structure.

Carbon fiber composites offer high strength and stiffness properties and have low weight. By using such materials, it is possible to decrease the structural weight leaving more capacity for instruments and payload.

In addition to the main structure, an inner structure of a polymer material will be used to hold the backplane and subsystem circuit boards in place. Lightweight fasteners and polymer and composite materials for auxiliary parts will be used where applicable. The inner structure can be easily changed and fitted inside the main structure without the need to change that. This is shown in Figure 2.

Using composite and polymer materials offers new challenges since material properties differ from metals. Properties like friction, wear and outgassing must be established by testing.

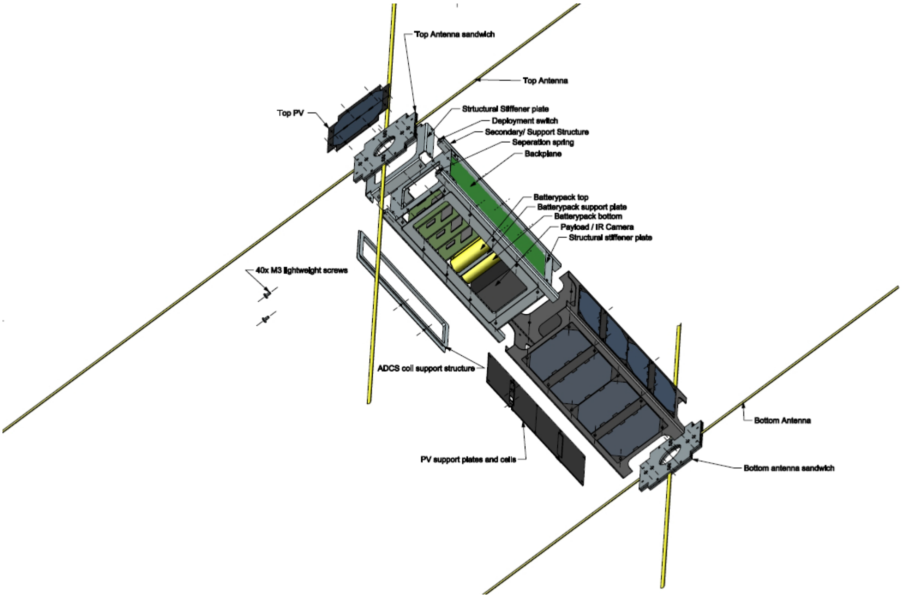

Figure 2. NUTS structural layout. The figure shows the main structure with solar panels mounted and electronics mounted in the inner structure.

In launch and orbit environments the structure should behave similar to current aluminum structures. Strength and stiffness loads as well as environment parameters are established by launch vehicle documentation. Finite Element Models (FEM) is showing the structural stress and deformation response and will be the basis for sizing and testing preparation. Carbon fiber composites have different properties in fiber and cross fiber directions, and are built in layers in the simulation model [4, 5, 6].

Several students have worked with this subject, and a version 2 of the frame is soon to be finalized.

Backplane

The backplane provides the electronic infrastructure in the satellite. Each subsystem will be designated its own slot in the backplane, giving the subsystem access to a double, regulated, 3.3 V bus and a double, regulated, 5 V bus as well as the main data bus, an I^2C-bus.

Efforts have been taken to increase reliability of the satellite bus. One measure is to split the power supply into two physically separate busses for each regulated voltage. Each bus will be able to provide power to all satellite subsystems, if the other one fails. Shorting one of the busses will still leave the other bus operational. At each backplane slot, control electronics provides functionality to disconnect the subsystem from the power busses as well as isolate the subsystem from the databus. [7, 8]. The backplane concept is seen in Figure 3.

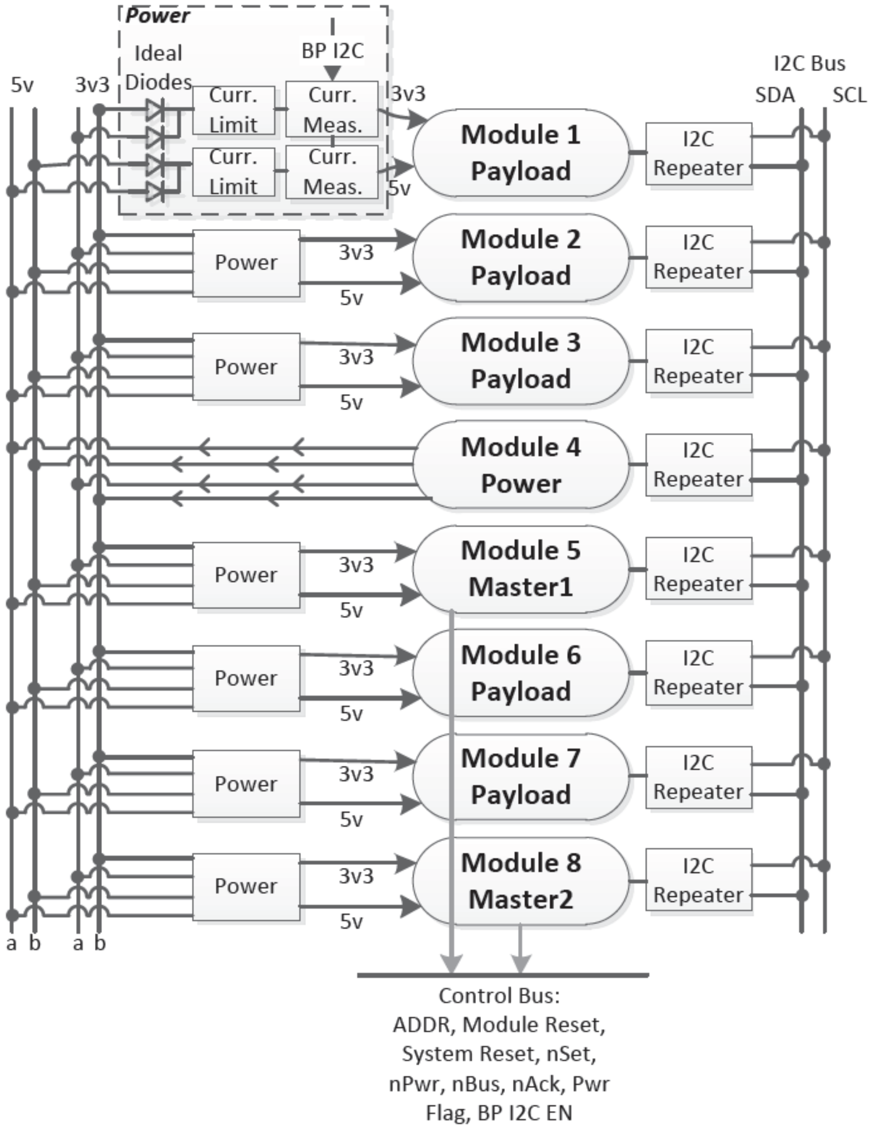

Figure 3. Overview of the backplane. From [8].

The mentioned control electronics can be operated by two of the subsystems, namely the OBC and the communications subsystem. The OBC will normally be in charge, but if it fails to operate correctly, manual control will be available over the radio link. This will greatly impede on the satellite operation, but it will be possible to control the satellite to some extent.

All communication between subsystems will use the CubeSat Space Protocol (CSP) communication protocol over the I^2C-bus. CSP will be used between all “active” parts of the satellite system, both internally and between the satellite and the ground station [9].

EPS, Power Conversion and Distribution

The EPS subsystem is made as simple as possible. Our design consists of solar panels, battery chargers from ST Microelectronics, a battery pack consisting of LiFePo4 batteries and voltage regulators. A sketch of the system can be viewed in Figure 4. It was a design driver that the system should operate on its own without the need of software or user involvement. This means that the EPS is responsible of charging (and protecting) the batteries, generating the needed voltages and distributing the power to all other subsystems [10]. No active control of the power consumption is done by the EPS board. The battery chargers with integrated Maximum Power Point Tracking (MPPT) takes care of charging and monitoring the batteries. In addition to this task, the EPS sub system also needs to monitor and control energy consumption in the satellite. This includes turning subsystems on and off, depending on energy availability and if the subsystem is considered healty or not. All this functionality will be handled in the OBC.

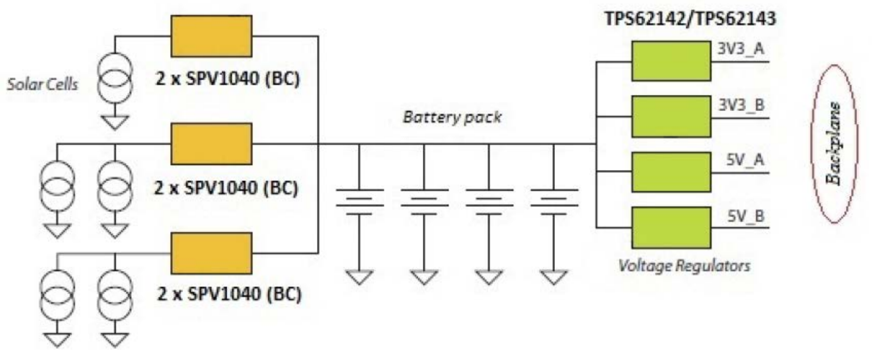

Figure 4. Overview of the EPS. From [10].

OBC

The OBC will be the satellites main controller. The hardware will be an Atmel AVR32 UC3 with access to external flash and RAM. The FreeRTOS lightweight operating system will be used and the OBC will be responsible for system monitoring, sensor logging, decision making if anomalies is detected, payload data processing and so on [8]. A prototype of the OBC can be seen in Figure 5.

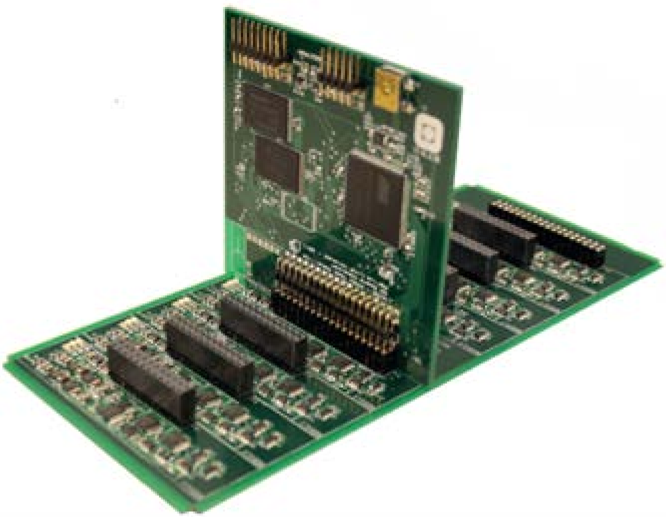

Figure 5. The picture above shows an early version of the backplane with the OBC mounted.

ADCS

The ADCS-system is responsible for controlling the satellites attitude with respect to the Earth. Our version of the ADCS-system is similar to other systems; it will employ magnetic torquers in the form of coils wound inside the frame [11]. The sensors used are a gyro, magnetometer and the solar panels will be used as sun sensors [12]. An overview of the proposed system is shown in Figure 6.

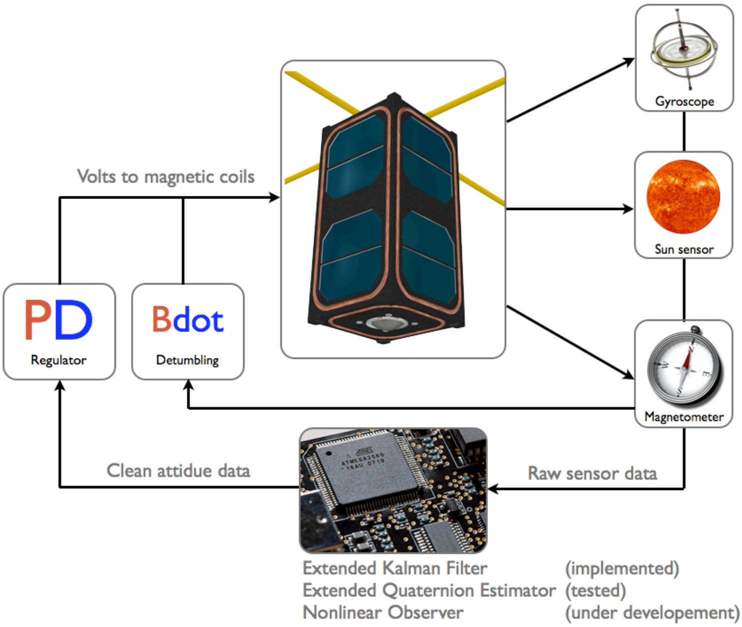

Figure 6. Overview of the ADCS sub system. From [14].

Different estimator algorithms and regulators are currently developed and tested [13, 14].

Payload

The main payload onboard the NUTS project is to our knowledge unique, as the plan is to use an infrared camera to capture images of short-period gravity waves in the OH airglow layer. This layer is situated at a height of approximately 90 km in the Mesosphere and lower Thermosphere (MLT) part of the atmosphere [15, 16].

The challenge is to find a suitable camera that meets the mechanical requirements and still delivers good scientific data under adverse conditions. Since the camera will not be directly linked to the OBC, a separate frame grabber has to be developed. This is currently one of the main tasks.

Due to the nature of the infrared radiation from the airglow layer, there will be constraints on the orbit selection. The infrared radiation is only measurable during local night, and in order to achieve the best results, one would have to make sure to image the atmosphere over a certain point on Earth at approximately five hours after local sunset [16].

With the data from the payload, the NUTS project hopes to make a contribution to the ongoing research of atmospheric gravity waves.

A challenge regarding this payload is the limited downlink capacity. Even if the captured images are not very large, they will pose a challenge for the downlink. Compression techniques and smart image processing methods have been investigated [17] and is still further investigated [18].

Communication Sub System

The onboard radio will use integrated transceivers, with necessary front end amplifiers. The standard ham radio bands will be utilized, making the data from the satellite available to the community. This should lead to a relatively simple radio design, but the drawback is limited bit rate. An increase of the data rate on the downlink is requested, but due to limited development time is not feasible.

The NUTS antenna system will consist of a VHF and a UHF circular polarized turnstile antenna. It is a complicated task to build small feeding networks, and feeds based on synthetic transmission lines [19] and slow wave structures [20] have been studied.

The NTNU ground segment is build up by common ham radio components, similar to the GENSO specification, [21], using IC9000 radio, Yaesu 5500 rotor and crossed Yagi antennas. The NUTS project is interested in joining relevant ground station networks for possibly helping and supporting other launches as well as being supported during our own upcoming campaign.

Concluding Remarks

The NUTS project is currently early in the prototyping and test phase, and not all parts of the satellite show the same level of completeness. The backplane has been tested over more than a year, but work is still under way on the first model of the communication system and the ADCS.

The plan is to complete the manufacturing of all subsystems for the engineering model within this year, as well as doing the integration and test of the satellite. The launch is anticipated to be in 2014 or 2015, pending on the availability of a suitable launch meeting our payload orbital requirements.

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