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CUBESAT TECHNICAL ASPECTS

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ABSTRACT

This paper gives insight into how a student team at the University of Applied Sciences Aachen has implemented individual approaches to meet the stringent technical requirements that are set by the commonly known CubeSat specifications. It is a selection of examples and is by no means a complete overview of the satellite. The authors' intentions are twofold: First, the paper shall inspire other students to start their own similar projects by showing them what is realizable even with low budget and small equipment. And second, an improved collaboration among CubeSat groups, in particular regarding the testing of components and their results, is strongly encouraged.

FULL TEXT

1. INTRODUCTION

Compass-1 is the name of the first picosatellite being developed at the University of Applied Sciences Aachen, Germany [1]. Since the project's initiation in September 2003 it is being managed and carried out by students of different engineering departments, with a majority being undergraduate students. Currently the team consists of ten students but the task's challenging and interesting nature attracts more students to join. The project focuses on a number of goals. Mainly the students will gain essential practical experience in realizing a research and development project from start to end. Moreover, an adequate infrastructure shall be created that enables more space engineering activities to take place at our university in the future. And definitively not least, a fully functional picosatellite is going to be built and finally launched into orbit!

The satellite is being built according to the CubeSat specification documents [2] published by Stanford and Calpoly University, which define a cubical structure with 10cm edges and a mass of not more than 1kg. Powered by solar cells, such a satellite will have an average of $1.5W_e$ for operation. Attempting to develop a spacecraft within the stringent constraints mentioned above becomes reasonable when considering the satellite being stored inside a container (P-POD) for simultaneous launch with other CubeSats, which in turn helps decreasing launch costs significantly.

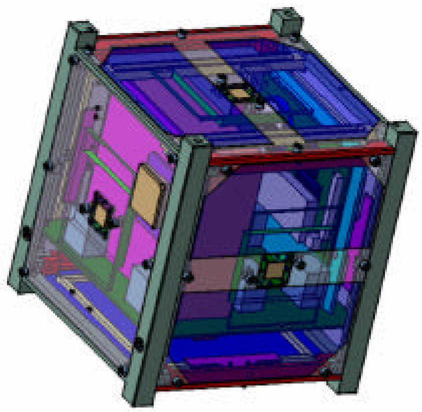

Figure 1: Compass-1 CAD model

The launch date of Compass-1 is not yet determined as a previous launch opportunity had been canceled. It is planned to conclude the development for launch acceptance testing by May 2005.

2. PAYLOAD AND EXPERIMENTAL SYSTEMS

Above all, the satellite will be a platform for experimental technologies composed of components that have not been originally designed for use in space (i.e. commercial-of-the-shelf (COTS) products), as well as cutting-edge space technologies.

2.1 Camera Module

The OV7648 CMOS camera module has been selected as the imager payload. It integrates a fourth generation sensor chip from Omnivision and is offered fully assembled with lens system and electrical interface. The sensor can capture VGA resolution pictures which will result in earth images of about 380 km x 450 km at nadir for the designated orbit.

The camera's exposure time is programmed via the two-wire I²C bus interface and data is streamed out over an 8-bit parallel bus. The images are in raw data format. Pictures can be triggered and received by ham users worldwide that comply with the communications architecture of the spacecraft.

2.2 Attitude Determination and Control

Active attitude control on Compass-1 is achieved by three mutually perpendicular magnetorquers using a linear quadratic regulator. The targeted nadir-error envelope is 8° or better. The attitude information is extracted by means of an extended Kalman filter from vector observations from a 3-axis magnetometer and five 2-axis MOEMS[1] sun sensors [3]. The sun sensors have been developed by the Denmark Technical University, Copenhagen, for application on a spacecraft similar to Compass-1. These sensors are currently undergoing a test campaign in order to validate their proper function under vacuum and thermal cycling conditions. Also, the electronic sensor interface is in a re-design stage with the aim to reduce mass, size and power consumption.

2.3 Miniature GPS Receiver

The GPS receiver is originally COTS, but uses advanced software, developed specifically for LEO satellites by the German Aerospace Center. The 22g receiver, called Phoenix [4], has never been flight tested and as such is considered part of the payload of Compass-1. As long as activated, it provides the ADCS with (autonomous) orbit information, which will be computationally propagated in between the receiver's operational phases. The target orbit for Compass-1 is a sun-synchronous orbit at 600km altitude with an inclination of about 98°.

2.4 Command and Data Handling

Core of the Command and Data Handling System (CDHS) is an 8051-based micro-controller with powerful features that ease its handling and respond to the system requirements. It is a low power IC with tiny TGFP-64 footprint. A JTAG interface allows in-system programming and debugging of the internal Flash memory which stores the flight software. A FIFO is used to buffer the data from the payload which is streamed out at a very high frequency. Later on the buffer content is transferred to the external Flash device for non-volatile data storage. None of those ICs has yet been tested in space. In particular the characteristic of the Flash memory, when exposed to LEO environment, is of interest for future missions.

3. APPROACHES

Facing the design and development of an entire satellite is always a challenging

[1] Micro-Opto-Electro-Mechanical System

venture, regardless of the satellites proportions. In fact, the creation of pico-satellites seems to be even more demanding since it is not achievable by simply down-sizing the subsystems and components in order to derive a small satellite from its larger example model.

Picosatellite engineers have to go other ways. They have to nurture new solutions for the existing requirements. The use of miniaturized electrical and mechanical parts is essential and its integration into the whole system becomes a crucial aspect. The following chapters will elaborate those aspects in regards to the Compass-1 CubeSat.

3.1 COTS Components

To date, with a few exceptions, cost and technical budget requirements make original spacecraft components prohibitive for CubeSat developers. It is well understood that implementing COTS components comes with a certain risk. However, the comparably low cost of picosatellites sets the whole concept of reliability into a new perspective. As part of this awareness, many developers conduct environmental testing. These tests typically include vibration, vacuum, thermal cycling and rudimentary radiation testing, possibly a combination of the above. Only those parts with acceptable stability will be implemented in the final flight model. Ultimately, only their exposure to the harsh space condition in LEO orbit will show if they can be reliably used for subsequent missions.

3.2 Sun Sensor Re-Design

The sun sensor developed by the MIC at DTU is an excellent example of how picosatellite applications can benefit from MEMS technology. The sensor area itself has an extremely small low profile outline of (7 x 8) mm² and does not require any power. A drawback is the size and power requirement of the necessary interface electronics. In fact, the interface size is one of the most common arguments against the use of MEMS in space. But other than discarding the indisputable potentials of MEMS, solutions have to be found for the interface problem. Important inputs can be gained from other miniaturization advances, such as those made in mobile tele-communication, which faces very similar constraints. Solutions adopted from this field are power efficient microcontrollers, small outline interconnects and light-weight flex-cable connections.

3.3 Modular System Architecture

One of the design philosophies the team agreed on in the initial design stage was a modular architecture of the satellite system. Generally speaking, this can be achieved by minimizing the interfaces (electrical, data, mechanical) between individual subsystems. In Compass-1 this is done by agreeing on a simple, yet efficient, common bus system. Since all subsystems are arranged in a slot configuration, with the CDHS board acting as the ‘motherboard’, as opposed to the popular stack configuration for instance, the electrical connections also serve as a mechanical interface. The connectors have been selected specifically to withstand the high loads during launch.

The modular approach also means that all subsystems contain their own processing units, such that only a limited volume of commands and high-level data will be communicated between the distributed processors over the common system bus. This enables an easy implementation of the developed subsystems on other CubeSats as long as the few interface requirements are met.

Another example of how modularity enhances the flexibility of the systems as it is necessary when implementing them on different platforms is highlighted by an attempt to separate the ADCS hardware from the (application) flight software. This is particularly interesting for a system which is as software-driven as an attitude control system. This way, spacecraft specific parameters can be easily adjusted. Even completely different flight software (e.g.

control law and/or estimation technique) can be easily implemented in a ‘plug-n-play’ fashion without having to redevelop the entire hardware platform.

3.4 System Bus Concept

For the data and command traffic among subsystems the (in particular for consumer electronics) widely used I^2C bus from Philips was selected. This bus concept uses only two wires (one for the clock and one for the data) and thus greatly simplifies the interface of the subsystems to the system bus.

Since the I^2C specification does not implement a specific protocol format for communication, a suitable one was designed. Originally there are four modes of bus communication, but for Compass-1 only two of them will be used to avoid unnecessary bus occupation. The two modes are Master-Transmitter and Slave-Receiver. Every chip that starts a transfer on the bus by writing a 7-bit address and the logic ‘0’ for write will become the Master for that transfer. The addressed chip is then the Slave and receives the command/data as shown in figure 2.

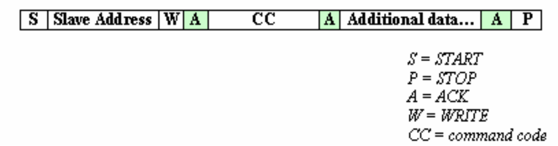

Figure 2: Protocol Format

In the Compass-1 satellite, each subsystem board has its own microcontroller (micro-control unit, MCU) that can initiate such a transfer. In order to structure the bus communication, a list of command codes (CC) was established that applies to all subsystems. A CC is 8bit; hence there are 256 different commands realizable.

It is understandable that this approach is straight-forward, with a Master sending command/data to a Slave. But what about the cases the Master expects data from the Slave (for example it asked for house-keeping information from its sensors)? First the Master sends the respective command to the Slave to get data. Then the Master enters a polling loop that waits until the Slave reacted with the correct command code and then reads the data from the bus. Now the former Master becomes the Slave and vice versa. During polling by the Master the Slave might be busy collecting the data, but for all this time the bus is free and can be used by other participants.

Most of the time however, a MCU does not poll for certain data but is rather controlling its own system or doing housekeeping. To verify that no command that is sent over the bus to a specific participant is lost or falsely ignored, each MCU implements an interrupt service routine (ISR) that receives those commands and prepares the necessary actions. In most cases it will trigger status flags of the MCU that will cause the main program to run its respective program module.

There is a major drawback for that bus. Since all members are wired-AND connected, a failure where one device pulls the bus lines to ground permanently will demolish bus communication. So, other devices than the subsystem MCUs shall be avoided to be plugged to the bus to minimize this risk.

Nowadays a lot of ICs have the I^2C specifications implemented in hardware, which facilitates its use significantly. This is the case for all MCUs on the Compass-1 spacecraft. Yet, it would also be possible to emulate it via software, with the drawback of the associated computational overhead.

In particular for a bus system, the effects of radiation could be disastrous. One could imagine a corrupted command sent to an MCU, due to a bitflip. The command code implementation is an effective counter-measure to this scenario, because the combination of Slave address together with the CC provides extra security. The CC numbers are distributed in such as that no single bitflip could trigger another valid command. In the end, the bus system is not specially protected against radiation but provides with necessary precautions by its design.

4. HARDWARE TESTS

Satellites have to undergo a range of critical tests in order to verify their expected function in space. Successful tests add to the reliability of the system and reduce risks of failures. In particular for spacecrafts that rely on COTS devices, it becomes obvious that extensive testing would be required. Yet, testing is time and money consuming and therefore a trade-off between reliability and those factors has to be done.

Recommended test types for CubeSat satellites can be found in ECCS documents [5], [6]:

- Structural (shock, vibration, acoustic, load)
- Thermal (cycling, vacuum)
- Radiation (Total Dose, SEE)

All those tests aim to simulate the environmental conditions in orbit as close to reality as possible and to verify their functionality.

Universities, which possess or have access to facilities to conduct those tests, are clearly advised to make intensive use of them. A lesson learned by other CubeSat groups is to spend more time on test than on development (which does not imply that development time should come too short).

The FH Aachen owns a small vacuum chamber with an interior volume of about 35 liter. Due to the small dimensions of the CubeSat, the entire satellite will fit into the chamber. Prior to the mechanical integration of parts into the subsystems, they will undergo those vacuum tests. In particular the sun sensors and the camera are tested obligatory. By doing so, risks due to outgassing or burst can be avoided drastically.

The chamber and the mounting plates are made of stainless steal. The evacuation is done using a three-stage pump system which achieves a pressure of 10^{-5} bar. On one side of the T-shaped chamber there is an aperture covered by quartz glass to allow viewing of the specimen inside. It is also used for example to throw light upon the sun sensors with a xenon lamp, which has spectral characteristics similar to that of the sun.

Via a couple of access pins, the sample inside the chamber can be supplied with electrical power and simultaneously the generated data can be logged and evaluated real-time at a standard personal computer that runs LabView.

5. CONCLUSION

As stated in this paper, picosatellites (such as the CubeSats) are exposing a lot of challenges to the developing students. As a response new methods and concepts are engineered from ground up in order to meet the specific stringent requirements of such a tiny satellite.

So far all CubeSat projects have in common to make use of a major proportion of COTS components instead of expensive space-proofed parts. Intensive ground testing aims to reduce the thereby introduced risks. In the end, only successful missions in orbit can finally clear if assumptions about reliability were correct.

As all CubeSat groups (and in particular the newer ones) are facing the problematic of selecting appropriative COTS components for their design it would be a big relief if they could turn to documentations and test results from other groups. Then a database can be established that encompasses all already used devices together with recommendations, test proceedings and their operational status in space.

A constructive result of this practice would be that future CubeSat missions become more reliable, thus more attention and investment can be spent on the payload itself and its utilization.

6. REFERENCES

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