PACE - TAIWAN'S FIRST NANOSATELLITE FOR EVALUATION OF MOMENTUM-BIASED ATTITUDE CONTROL

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ABSTRACT

The Department of Electrical Engineering and the Department of Astronautics and Aeronautics of the National Cheng Kung University in Taiwan have collaborated on the development of Taiwan's first university satellite, a two kilogram nanosatellite. Main objective of the PACE mission is the demonstration of advanced attitude control, which is expected to be of interest for the ever-more challenging mission goals put forward in the small satellite community. The paper presents the control laws implemented on PACE and shows the results of performance simulations. The satellite is currently undergoing its qualification testing and is planned to be launched in end of 2009.

1. INTRODUCTION

Stimulated by the CubeSat standard [1] and a university course on space system engineering, the Department of Astronautical and Aeronautical Engineering and the Department of Electrical Engineering of the National Cheng Kung University of Taiwan had established a joint laboratory in 2003, labeled PACELAB, in order to pursue the development of satellite components and systems. The laboratory was formed in order to provide the students with hands-on training for the design and development of space systems, and thus to enhance the education of the students to capable space system engineers. Up to present two design studies for small satellites had been carried out, namely PACE [2], and LEAP [3]. A third one is under preparation, called CKUTEX. All three programs received generous technical support by the National Space Organization (NSPO) of Taiwan. The very first satellite project was labeled PACE and initiated in 2003 [4]. PACE is a two unit (2U) CubeSat and was supported with design heritage from the YAMSAT program of NSPO [5]. Its main objectives are the demonstration of precise attitude determination and control, as necessary for remote sensing and other mission goals. It comprises the use of magnetometer, gyros, and sun sensors for attitude sensing, and a pitch-mounted momentum wheel and magnetic coils for actuation. With the recent completion of the Engineering Model of PACE, a launch for

2009 is now in planning.

2. MISSION OVERVIEW

The PACE satellite is designed to operate in orbit for a period of six months, to obtain enough data for detailed assessment of the satellites' performance. The orbit is chosen to be a sun-synchronous or highly inclined low earth orbit with an altitude in the range of about 600-800 km.

2.1 Mission Objectives

The PACE spacecraft serves as a test-bed for (i) the precise attitude control of nano-satellites as well as (ii) the newly developed spacecraft bus, which is mainly based on COTS parts. The technical objectives are:

- Attitude determination within 1º accuracy;
- Three-axis attitude control with 10º accuracy;
- Technology demonstration of in-house developed spacecraft bus, including a third-party momentum wheel, newly developed sun sensors, an electrical power system based on Lithium-Ion accumulators, a UHF FSK communication system, etc. In addition to the technical objectives the PACE project is expected to provide valuable output in terms of satellite engineering knowledge, with the aim to establish a national center of excellence at the National Cheng Kung University for the development of small satellites.

3. SPACECRAFT DESCRIPTION

PACE is built in accordance with the CubeSat standard and uses mostly COTS (commercial off-the-shelf) components as well as in-house developed parts, to reduce the costs of the spacecraft. The dimensions of the satellite are 100x100x227 mm^3 at a weight of less than 2 kilograms. During launch the satellite is carried in a dedicated launch container and deployed from it when the upper stage of the rocket has reached its destination orbit.

3.1 Satellite Bus

The satellite structure is entirely made from machined Al-6061 and offers a rigid housing for all other subsystems. The hard-anodized corner bars are the gliding guidance for the ejection from the storage container. These bars also include the shutdown switch mechanism, which keeps the satellite unpowered during launch. The satellite draws its power from a total of 20 ATJ (Advanced Triple-Junction) body-mounted solar cells. The input from the solar cells is used to supply the system and to charge the two Li-Ion batteries, which supply the satellite during eclipse. Three switching converter circuits provide stable 3.3V, 5V, and 9V to the satellite's loads. For the communication with the satellite in the 70cm amateur frequency band, the spacecraft is equipped with an FSK transceiver modem, and a microcontroller TNC that takes care of the Ax.25 encoding/decoding. The RF communication operates at 9600 bps for the uplink of commands and downlink of data. A periodic beacon in CW is also implemented. Passive thermal control is applied to the spacecraft design. All components are operated within their allowed temperature range as shown by thermal simulations. An 8051 microcontroller forms the heart of the command and data handling system and takes care of the interfacing to the communication system, and the storage of mission data in its mass memory unit.

3.2 Attitude Determination and Control Hardware

Attitude measurements are obtained from a three-axis magnetometer, and four digital sun sensors (placed on the center of each side panel). These vector measurements are augmented by a rate sensor, in the form of a three-axis gyroscope. For the active control of the satellites' attitude, two types of actuators are used, i.e. magnetic coils and a momentum wheel. The three orthogonally placed magnetic coils are used either for pure magnetic attitude control, or for momentum-dumping when used in combination with the momentum wheel in a momentum-biased operation.

4. ATTITUDE CONTROL

For the attitude control of PACE, different control modes are implemented. A detumbling controller takes care of reducing rotational kinematic energy after separation from the launcher. For most of the mission, pure magnetic control is activated, with a controller based on LQR theorem. The following section discusses the momentum-biased control, which is expected to enable precision pointing of the satellite [7].

The operation of the momentum wheel provides inertial stability to the satellite's pitch axis due to the gyroscopic effect of the spinning wheel. The satellite can be directly controlled about the pitch axis by applying torque on the momentum wheel. The control law for the pitch control is established as

$$T_w = K_p q_2 + K_d \omega_y \tag{1}$$

For the pointing control, the following magnetic control moment is produced:

$$M_y = -K \cdot B_x \cdot q_1 \tag{2}$$

The control law in (2) only considers the variation on the first element of the quaternion vector. This is possible due to the coupling between the roll and yaw axis. Thirdly, for the momentum dumping the control law in (3) is added.

$$\vec{M} = -\frac{K}{\left\|\vec{B}\right\|^2}\left[\vec{B} \times J\left(\omega_w - \omega_{bias}\right)\right] \quad (3)$$

5. SIMULATION RESULTS

For the simulation of a realistic implementation, the estimation of the attitude as delivered by the Extended Kalman Filter was used as input to the controller. The hardware models for the simulation included imperfectness and noise. The satellite is exposed to external disturbances (aerodynamic drag, sun pressure, and gravity-gradient respectively).

A high control performance for this scenario is achieved by the momentum-biased control, with accuracies of ±2º, ±4º and ±2º, for the roll, pitch and yaw axis respectively. Figure 1 shows the attitude behavior over five orbits, including the initial momentum wheel start-up.

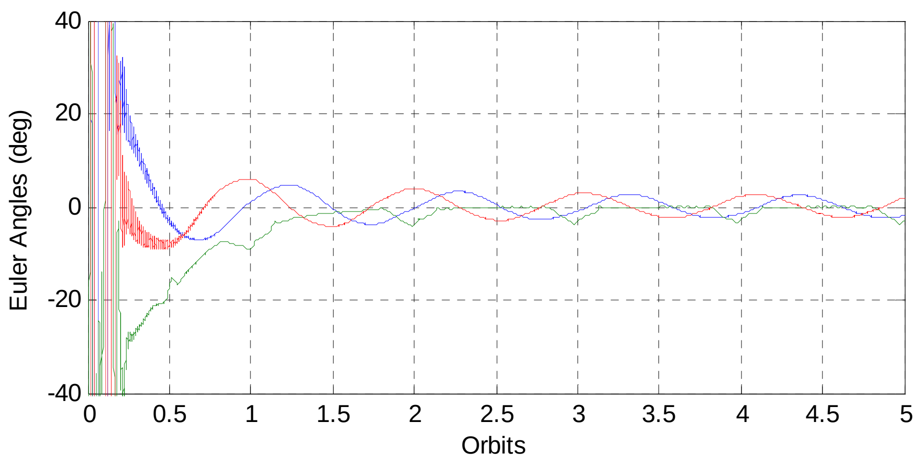

Figure 1: Momentum-Biased Attitude Control

6. CONCLUSIONS

This paper gave a brief overview on the momentum-biased attitude control for PACE, the first CubeSat being developed at the National Cheng Kung University of Taiwan. The controller achieved a pointing accuracy in realistic simulations well within the proposed pointing requirements of 10º accuracy.

7. ACKNOWLEDGMENTS

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