Subsystem Description

1. Document scope

In satellite systems, the ADCS is essential to maintain the proper orientation and stability of the spacecraft. This section will initially present the ADCS of the project, presenting some inicial concepts needed for understanding the theory and finishing with some requirements and the physical architecture of the ADCS with other subsystems.

2. State of the art

The limited space and power constraints of the PocketQubes pose significant challenges for the design and implementation of subsystems, particularly the ADCS. Thanks to the rapid development of micro-electronics, micro electromechanical systems and integrated circuits, the miniaturization of PQ technology is accelerating.

The ADCS is formed by the attitude determination part, which is the responsible of determine the 3D orientation of the PQ. It uses sensors to obtain information about the environment to determine its orientation. The most common sensors used are magnetometers, Sun sensors, earth sensors, gyroscopes and star trackers. The ADCS that has been developed in this project, is formed by a gyroscope, a magnetometer and photodiodes used as Sun sensors.

Concerning attitude control, it can be achieved passively using magnets located inside the PQ and gravity-gradient stabilization. Additionally, active attitude control can be implemented with actuators such as reaction wheels or magnetorquers. Magnetorquers are the most common actuators used in PQ and will be used in this project. Because of the extremely tight available space, they will be incorporated into the internal layers of the Solar Panels PCBs.

3. Initial concepts

3.1. Coordinate reference frame

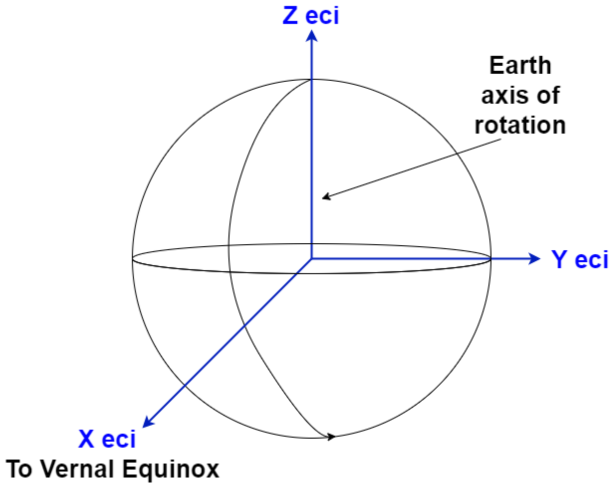
In order to understand this subsystem, some terms must be defined:

- **Frame:** Coordinate system of the 3D space that follows the right-hand rule.
- **Body frame:** Cartesian frame with its origin at the centre of mass of the satellite.
- **Reference frame:** A determined known frame.
- **v_b:** Representation of vector v in the body frame.
- **v_r:** Representation of vector v in the reference frame.

It is recommended for the reader to understand a vector as a unique entity in the 3D space. It is essential to distinguish between the vector entity, and the representation of the vector with respect to a frame. The representation of the vector will vary depending.

Inertial frame

As an inertial frame, the Earth Centered Inertial frame (ECI) will be used. It is a global cartesian reference frame that has its origin at the center of the Earth.



- X axis points to the Vernal Equinox.
- Y axis completes the set with the right-hand rule.
- Z axis aligned with the Earth’s rotation axis.

Figure 1: ECI frame chematic

Body frame

The body frame will have its origin at the centre of the PocketQube. The axis definition is the following:

- X axis aligned with the PocketQube width, parallel to the sliding plate and perpendicular to the direction of insertion into the PocketQube deployer.
- Y axis aligned with the PocketQube height direction, pointing upwards from the sliding plate.
- Z axis aligned with the PocketQube length, the direction of insertion into the PocketQube deployer and completing the right handed reference frame.

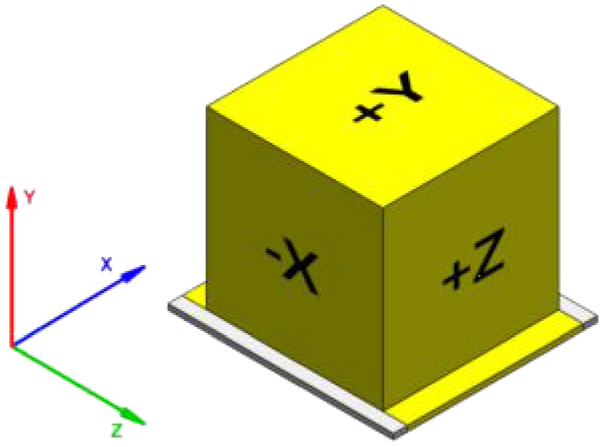


Figure 2: Satellite body frame schematic

3.2. Quaternions

Quaternions are a mathematical concept equivalent to a rotation matrix. They are used in software for their computational efficiency and to avoid singularities. According to Euler's Theorem, any rotation is a rotation about a fixed axis, which is represented by the unit vector □□. The angle of rotation is represented by □□. In other words, for any rotation matrix □□, there is a unique □□ and □□ that uniquely define the rotation with respect to the right-hand convention. A quaternion □□ is a four-dimensional vector where the first component is called the scalar part, and the last three components are the vector part. The quaternion is related to the Euler axis-angle in the following manner:

$$\mathbf{q} = \begin{pmatrix} \cos\left(\frac{\theta}{2}\right) \\ \mathbf{e}\sin\left(\frac{\theta}{2}\right) \end{pmatrix}$$

If □□□□□ is the element of □□ in its □□**-th** row and □□**-th** column, then:

$$\theta = \cos^{-1}\left(\frac{\mathrm{tr}(\mathbf{A}) - 1}{2}\right) \qquad \mathbf{e} = \frac{1}{2\sin(\theta)}\begin{bmatrix} A_{23} - A_{32} \\ A_{31} - A_{13} \\ A_{12} - A_{21} \end{bmatrix}$$

Therefore, a quaternion ◫ can be expressed as a function of its rotation matrix ◫ using these properties:

$$\mathbf{q} = \begin{bmatrix} \cos\left(\frac{\theta}{2}\right) \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \cos\left(\frac{\theta}{2}\right) \\ \frac{1}{4\cos\left(\frac{\theta}{2}\right)} \begin{bmatrix} A_{23} - A_{32} \\ A_{31} - A_{13} \\ A_{12} - A_{21} \end{bmatrix} \end{bmatrix}$$

Where ◫ is the vectorial part of the quaternion. Note that if ◫ = 180º, the vector ◫ is indeterminate. In such cases, ◫ is parallel to any non-zero column of ◫. Additionally, it’s crucial to maintain the sign convention.

For any rotation matrix, there exist two corresponding quaternions that differ only in sign. For instance, a rotation of ◫ = 180º and another of ◫ = 540º are equivalent, but the resulting quaternions are opposite. To uphold the sign convention, it’s necessary to ensure that the scalar part is positive, i.e., to enforce ◫ ≦ 180º. This is achieved by changing the sign of the entire quaternion if the scalar part is negative.

There is an essential property for achieving attitude control in the ADCS. If there are two quaternions, **q1** and **q2**, and **q1** is conjugated and then multiplied by **q2**, the resulting quaternion represents the relative rotation between the two quaternions.

$$q_{\text{error}} = q_1^* \times q_2$$

In this case **qerror** would be the quaternion that represents the rotation needed to align **q1** to **q2**. The qerror can also be named **error quaternion**.

3.3. Orbital propagator

An orbital propagator is used to determine the position and velocity of the satellite at a given instant of time, given by the initial position of the satellite and the velocity at this position. In the satellite we are using the J2 propagator, whose main property is that it accounts for the Earth’s oblateness while propagating the orbit. Additionally, this propagator is ideally for our PQ because of the balance of memory requirements and complexity fits in the OBC.

There are more precise orbital propagators like the SGP4 model which accounts for atmospheric drag and other secular effects apart from the Earth oblateness, but it is much more complex, and it requires more memory than the one available in our satellite.

3.4. Geomagnetic field model

The geomagnetic field model is essential for calculating the Earth’s magnetic field at specific coordinates and dates. This model helps to understand and predict the variations in the Earth’s magnetic field. In this work, the IGRF model is used, but simplified up to order 2 , commonly referred to as the Tilted Dipole model. The Tilted Dipole model approximates the Earth’s magnetic field as a dipole that is tilted relative to the Earth’s rotational axis. Despite its simplicity, this model provides a reasonably accurate representation of the geomagnetic field for many practical purposes. The coefficients for the Tilted Dipole model are derived from the IGRF model, which is updated every five years based on satellite and ground-based observations .

4. Functional architecture

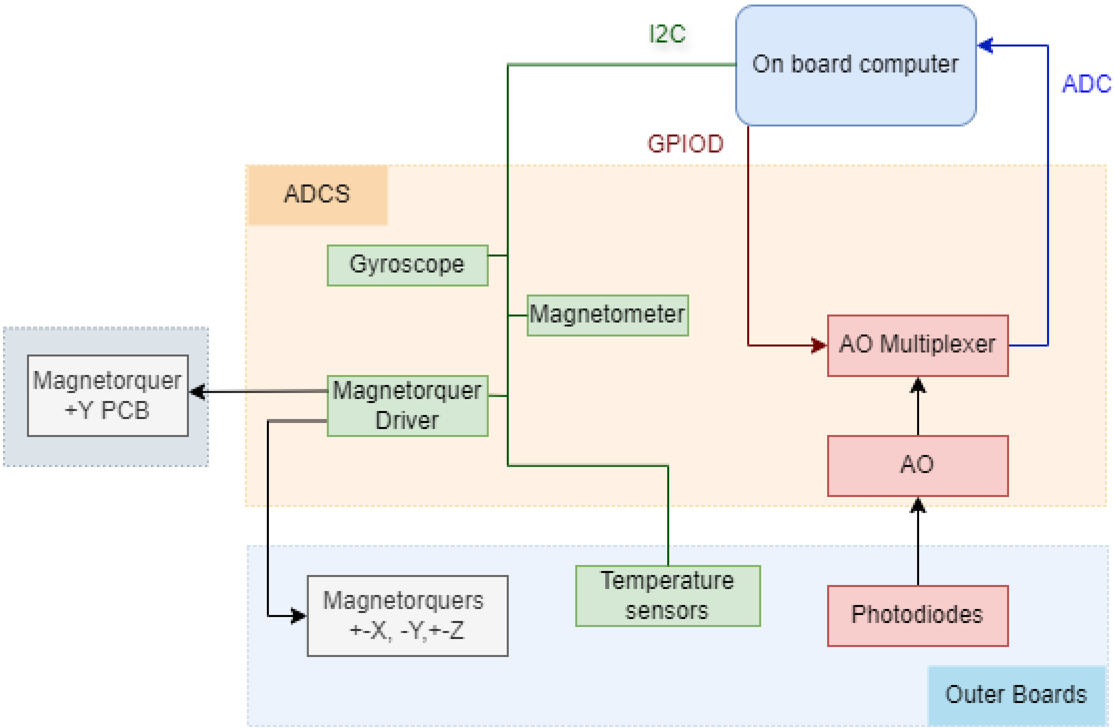


Figure 3: ADCS functional architecture schematic with the rest of the subsystems

The ADCS in the PocketQube serves as an interface between the outer boards and the inner PCBs of the satellite. As shown in [Figure 3], the ADCS is connected to three main structural components: the outer boards, the inner +Y magnetorquer PCB, and the on-board computer (OBC).

On the outer boards, there are magnetorquers used for the ±X, -Y, and ±Z axis, photodiodes, and some temperature sensors. Additionally, the +Y magnetorquer is connected just below the ADCS PCB. This location is chosen due to space constraints within the PocketQube, as it is not optimal to place it on the top board, where the payload will be inserted.

Finally, the ADCS is connected to the OBC, which is responsible for processing all data gathered by the ADCS. The connections between the ADCS and the OBC are not simple power lines each has a specific function:

- **I2C conection:** This connection is primarily used for transmitting data from the sensors to the OBC using the I2C protocol, enabling full-duplex communication between the sensors and the OBC.
- **GPIOD conection:** The GPIOD is an output from the OBC used to send signals of 0 volts or 3.3 volts. In the ADCS, it serves as an input for the multiplexer.
- **Analog to digital converter (ADC):** This is an input to the OBC used to convert the signal from the operational amplifier multiplexer into a digital value.

5. Requirements

SS	ID	DESCRIPTION
ADCS	ADCS-0000	The communication between the chips of the ADCS and the OBC must be conducted via I2C.
ADCS	ADCS-0010	The PQ must be able to detumble using the BDOT algorithm.
ADCS	ADCS-0020	The satellite must be able to point the Payload at the nadir angle using the magnetic control law.
ADCS	ADCS-0030	The ADCS must be able to estimate the satellite's position in an inertial reference frame.
ADCS	ADCS-0040	The ADCS must be able to obtain the magnetic field in an inertial reference frame.
ADCS	ADCS-0050	All sensors used in the ADCS must be calibrated and characterized by temperature.
ADCS	ADCS-0060	The magnetorquers must have a reliable current supply to ensure optimal performance.
ADCS	ADCS-0070	The ADCS must have a fail-safe mechanism to enter a safe mode in case of anomalies.
ADCS	ADCS-0080	The ADCS sensor's calibration parameters must be able to be modified via telecommand.

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