Geometric Modeling and Global Overview of Stabilization Algorithms for a Mexican Picosatellite

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Abstract

The Institute of Engineering UNAM is currently developing all subsystems that comprise a 1 Kg real picosatellite to be sent into space. The work exposed in this paper is based on a previous project which developed the first Mexican didactic satellite (SATEDU) in a fully successful way, [1] and [2]. This paper presents the geometric design made until now, which integrates changes and adjustments required by the picosatellite project. These changes primarily affected the geometry and mass of the subsystems embedded in PCBs, thus the selection and placement of components on PCBs as well as in the structure is essential to accomplish the satellite design. The paper shows the results in terms of inertia matrix, total mass as well as location of the center of mass and principal axes of inertia. These parameters are essential to develop the satellite stabilization algorithms and 3 axes attitude control, from which this article presents the main achievements so far obtained with the help of numerical simulations of a nonlinear controller. Particularly the paper presents satellite attitude stabilization results obtained with Simulink of Matlab and Virtual reality models.

Introduction

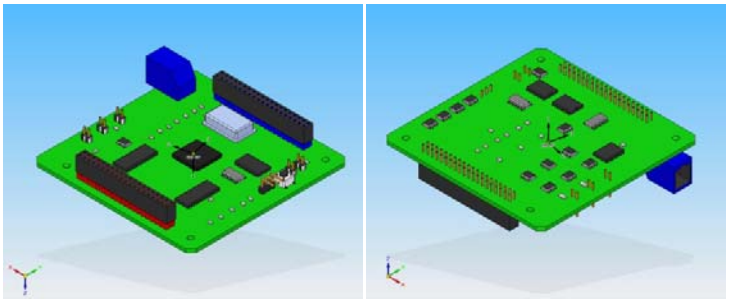
The work of geometric design is based on parts measurements obtained with digital Vernier due to its versatility for measuring depth or height, length as well as internal and external distances between pieces. Another important tool is the digital scale to find the mass of each subsystem with an accuracy of 0.01g.

The software employed to model the subsystems was Solid Edge V20, [3], which is more flexible than other geometric software tools. In addition, it was required to include electronic components galleries and assembled subsystems in a manual way. To integrate those elements that were not modeled, the databases of manufacturers were employed and also the *www.traceparts.com* website was used because it offers a wide range of mechanical, electrical and electronic parts. Similarly, in some cases were used the manufacturers specifications for several components.

Capture of Components for the Flight Computer

This subsystem was modeled to fully retain its components, [4], except for the RJ11 connector, blue part in Figure 1. This was relocated in the model to match the mechanical interface provided in the structure to ensure compliance with the cubesat standard developed in 1999 by Stanford University, USA.

The mass obtained for this subsystem was $m_{cv} = 51.01g$

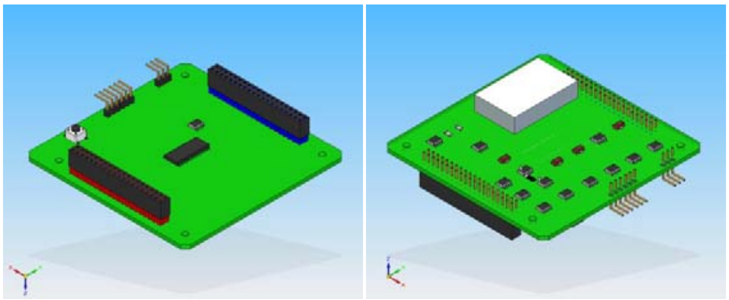


a) *b)*

Figure 1. Flight Computer, a) Top view, b) Bottom view.

Capture of Components for the Power Subsystem

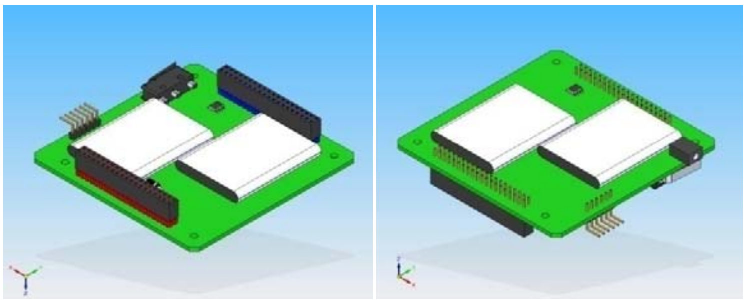
This subsystem consists of two PCBs, one manages energy, figure 2a, while the other contains and recharges the batteries, Figure 2b.



a) *b)*

Figure 2. Power Subsystem Board A, a)Top view, b) Bottom view .

The geometric model of this subsystem was a true copy of the SATEDU prototype. It was only necessary to relocate the remove before flight switch (to the left of the blue connector in figure 3a) and the jack connector for battery charging (to the right of the battery in Figure 3b).



a) *b)*

Figure 3. Power Subsystem Board B, a) Top, b) Bottom.

The mass of board A, Figure 2 is 53.18g = m_A, while B has a mass m_B = 116.9g.

Data Capture for the Communications Subsystem

This model differs from the SATEDU prototype, [6], because it includes a commercial Microhard modem model MHX2420, Figure 4, with higher power than that used in SATEDU. This modem is also used in commercial picosatellites that sells Pumpkin company in USA. The location of the equipment is completely compatible with the structure.

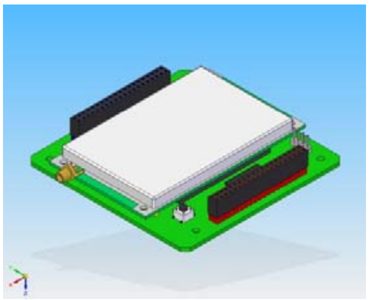


Figure 4. Communications Subsystem.

The mass of the modem, according to the data sheet, is m_m = 55g. For the rest of the system we have m_c = 42.82g, giving a total mass m_{com} = 97.82g

Data Capture for the Sensors Subsystem

This board is very different from that of SATEDU prototype, because it includes an inertial navigation unit, Figure 5, of Analog Devices, Model: ADIS16365. It contains accelerometers, gyroscopes, temperature sensors, Analog to Digital Converters and few stages of signal conditioning. In addition, we included three magnetometers alike to those used in cubesats missions. These provide fault tolerance because each one of them measure two components of Earth's magnetic field.

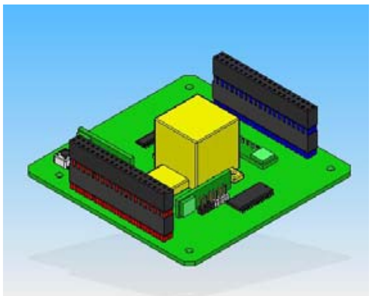


Figure 5. Inertial Navigation Sensors Subsystem

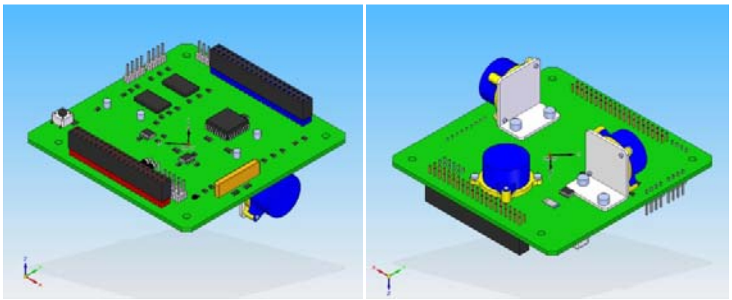
Due to the height of the inertial navigation unit it was necessary to add few headers to increase the separation between boards.

The mass of this system was estimated as follows: mass card m_t = 45g + mass of the inertial unit m_{ui} = 16g + mass of three magnetometers $3m_{mg}$ = 3g + mass of two headers $2m_h$ = 10.8g = 74.8g.

Data Capture for the Stabilization Subsystem

This model differs from the SATEDU PCB since the stabilization to be achieved in the picosatellite is on three axes, while SATEDU provides only one axis stabilization, [5]. This was achieved by replacing the SATEDU inertial/reaction wheel by three orthogonal inertial/reaction wheels Rw1, Figure 6b.

The mass and the geometric model for the inertial/reaction wheels were obtained from specifications provided by the GmbH manufacturer Astround Feinwerktechnik Adlershof. The obtained results were the followings: the mass for each inertial/reaction wheel is m_{ri} = 12g and the mass of the board m_t = 60.91 g, giving a total mass for this system of $m_{est} = 3m_{ri} + m_t$ = 96.91g.

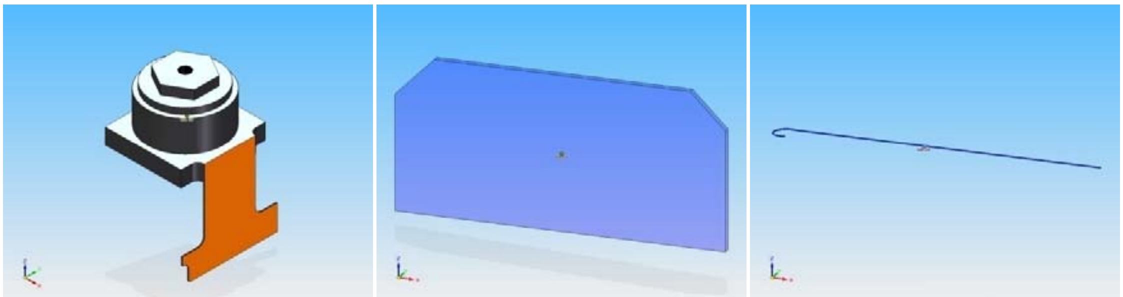


a) *b)*

Figure 6. Stabilization Subsystem, a) Top view, b) Bottom view.

Geometric Modeling of other devices

The pictures below show 3 devices that were modeled to obtain the inertia tensor of the picosatellite. These are: the camera, Figure 7a, trade mark OVNIVISION model OV7648FB employed in the CubeSat mission XI IV from Japan; an array of solar cells from EMCORE, BTJM model, commonly employed in cubesats missions, and Nitinol rods of 33 cm length and 0.75mm diameter, a standard measure, Figure 7c.



a) *b)* *c)*

Figure 7. Other devices, a) Camera OV7648FB, b) BTJM Solar cell array c) Antenna.

The masses obtained were: 5g for the camera, 1g for each antenna and 2.26g for each of the eight arrangements of cells.

Picosatellite Assembly

The incorporation of parts and boards was performed with Solid Edge V20 assembly module, Figure 8. The number of parts involved in the structure is 20, while for electronics is 21 and about 100 parts for screws, spacers and nuts, giving a total amount of 130.

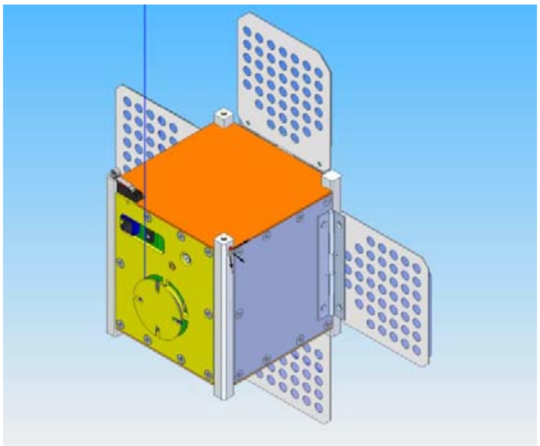


Figure 8. Picosatellite Isometric View.

Figure 9 shows the exploded diagram of Figure 8. This type of diagram is a quick reference to parts and a guide for the assembly and disassembly of the satellite

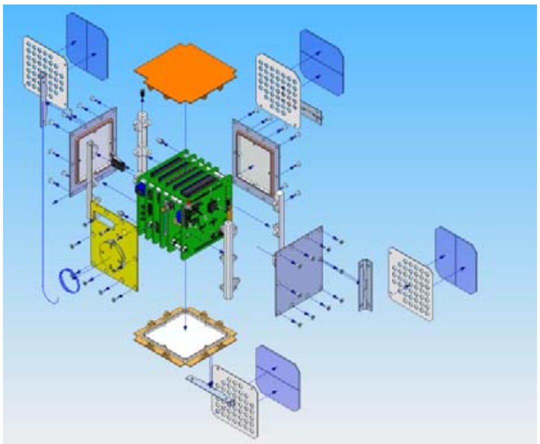


Figure 9. Explosion view of parts and pieces from the Picosatellite.

Center of mass and inertia tensor

Center of mass

According to the CubeSat standard, the center of mass of a satellite should be at a maximum distance of 2cm from its geometric center. To verify compliance of this requirement is necessary to introduce the mass or density of each component of the Picosatellite into the CAD software (Solid Edge V20) and assemble the parts in the required configuration.

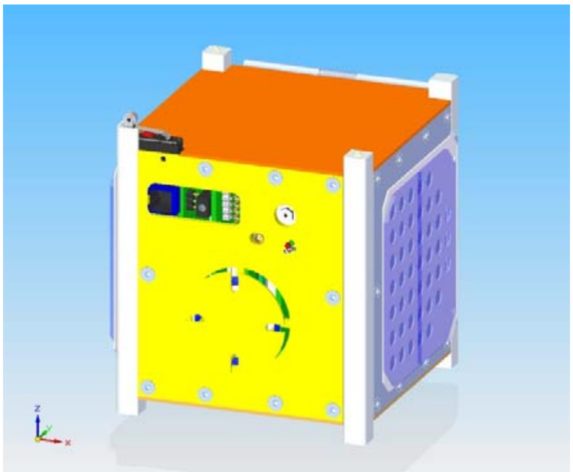


Figure 10. Picosatellite with panels and folded antennas.

In this case the configuration of the Picosatellite considers that solar panels and antennas are folded at launching time, Figure 10.

The results were as follows:

	Center of mass	**Geometric center**
X	**49.010897 mm**	**48.006516 mm**
Y	**3.120318 mm**	**2.494281 mm**
Z	**-0.622540 mm**	**-1.255003 mm**

Table 1. Coordinates of the center of mass and geometric center for the Picosatellite.

Based on above coordinates, the distance between the center of mass and the geometric center is 1.34mm, therefore it is fully feasible the current configuration of subsystems for the Picosatellite.

Inertia tensor

When a picosatellite is launched into space by the mechanism called P-POD, the vehicle experiences a very complex dynamic, later it must deploy its solar panels and antennas to be stabilized and pointed with the intention of taking pictures or increasing the power captured by the solar panels.

The calculation of inertia tensor for the satellite is employed in mathematical models and control algorithms to accomplish attitude pointing and satellite stabilization.

With data obtained from geometric modeling and the density of each of its parts is possible to determine the following inertia tensor, and other relevant data of the model.

$$I := \begin{bmatrix} 0.002066 & 0.000199 & 0.000011 \\ 0.000199 & 0.004351 & -0.000014 \\ 0.000011 & -0.000014 & 0.004210 \end{bmatrix} (kg\, m^2)$$

Regarding the main moments of inertia, also provided by Solid Edge, they are: I1 = 0.002178 kg-m^2, I2 = 0.002046 kg-m^2 and I3 = 0.002010 kg-m^2, which are usually located within a diagonal matrix to operate with different parameters.

The above results show that vector 1 has the highest moment of inertia and can be considered as parallel to the axis of reference, Figure 11.

Notably, it is not necessary a new satellite configuration to obtain a default inertia matrix, because control algorithms accept any value that could be obtained with the software.

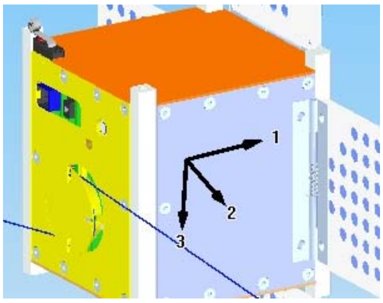


Figure 11. Orientation of the principal axes of inertia in the Picosatellite.

Employing the Inertia Tensor in Picosatellite Stabilization algorithms

In order to verify the stabilization algorithms for the picosatellite, the inertial tensor has to be entered into the numerical simulation. In our case this process is achieved with Matlab Simulink, particularly using the Virtual Reality Toolbox. This is why the geometric modeling is so important in order to generate well balanced picosatellite. The best balanced the satellite, the better possibilities to generate fast satellite stabilization. Therefore, this modeling stage is very important for a satellite project during the design stage.

Global Overview of Stabilization Algorithms for the Mexican Picosatellite

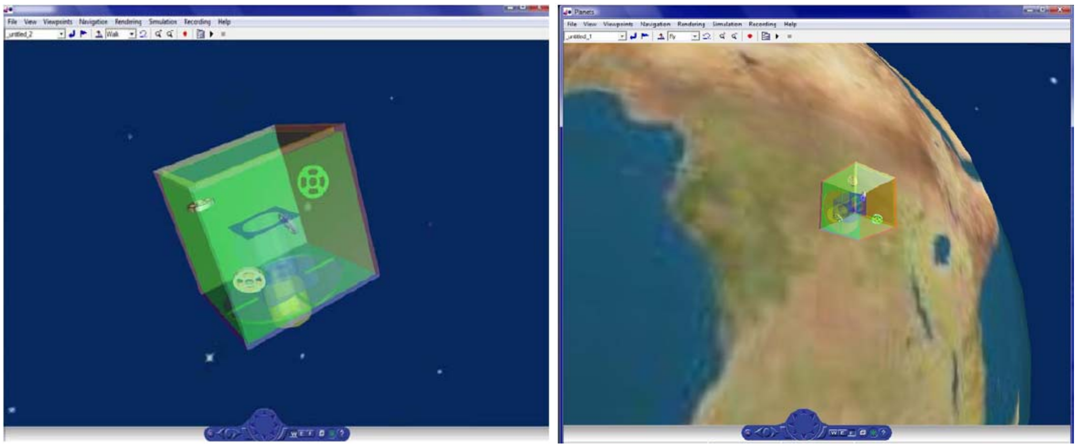
With basis on the dynamics and kinematic equations of a satellite, it was developed a nonlinear attitude control which generates control torques with the help of Inertial/Reaction wheels, [7]. The attitude control algorithm has the following form:

$$\Omega_{ob} = R_o^b \Omega_{io} + \Omega_{ib} \qquad \Omega_{ob_d} = \pm \frac{\Delta \tilde{\epsilon}}{1 + \tilde{\epsilon}^\top \tilde{\epsilon}} \qquad y = \Omega_{ob} - \Omega_{ob_d} \qquad \tau = -Ky$$

Where Ω_{ob} is the angular rate of the satellite expressed in body coordinate system Ω_{ib} is the angular rate of the satellite expressed in inertial coordinate system, and thay are related by a rotation matrix R_o^b defined by the unit quaternion $q = \begin{bmatrix} \eta & \epsilon^\top \end{bmatrix}^\top$ that represents the satellite attitude, and Ω_{io} that represents the angular rate of the satellite travelling in its space orbit. It is defined a virtual control Ω_{ob_d} in terms of a gain diagonal matrix Δ and the error vector $\tilde{\epsilon}$ obtained from the error attitude quaternion. These functions allow to define another error function *y* that is used to calculate the control torque τ.

The control torques are obtained with the inertial/reaction wheels and once defined the proper gains the satellite will achieve its desired attitude.

To verify the satellite stabilization process, two virtual reality models were developed. One shows the inertial/reaction wheels evolution and its effect in the satellite structure, figure 12a, this model was developed in Solid Edge software. The second one shows the satellite attitude evolution during the control process and its orbital travel around the Earth, it was also developed in Solid Edge software.



a) b)

Figure 12. Virtual reality simulates a) Rigid body dynamics simulation, b) Satellite attitude control simulations

By adding the inertia matrix in the simulation, the stabilization algorithms can be verified obtaining the results shown in figure 13. The figure depicts the error unit quaternion evolution. The first moments of the simulation the satellite was launched with an initial angular rate, then the controller reduces its angular rate, taking the satellite to the desired attitude described by the value of the error quaternion q = [1 0 0 0]. This means that if a desired attitude q_d is defined, the controller automatically will reach the desired satellite pointing.

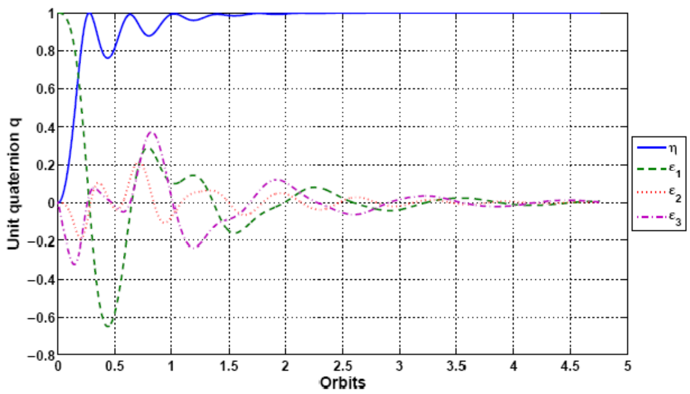


Figure 13. Evolution of the error unit quaternion for the satellite.

Concluding Remarks

This paper has shown the work developed so far at UNAM under a project to develop the first Mexican picosatellite. Specific details regarding the geometric design made until now for the satellite has been presented. In addition, generated results obtained for the inertia matrix, total mass as well as location of the center of mass and principal axes of inertia were presented. These parameters are essential to develop the satellite stabilization algorithms and 3 axes attitude control. In this sense, the paper presented the main results so far obtained with the help of numerical simulations of a nonlinear controller obtained with Simulink of Matlab and Virtual reality models.

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