Design and Analysis of AAUSAT Cube Satellite Attitude Determination with PID Algorithms and Orbitron TLE

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DOI: 10.13111/2066-8201.2023.15.2.5

Received: 11 February 2023/ Accepted: 25 April 2023/ Published: June 2023

Abstract: *Satellites are intended to be of massive cost, hard, or hard to keep up and fix in circle. The point of this task is to decide an effective strategy to decide the orbital and heading data for the Nano satellite. To design the exact trajectory and circle for a satellite, information regarding the components which are liable for the deviation in the method of satellites. The factors that should be taken into account to determine the exact location of the satellite. It could be accomplished with the assistance of software responsible for orbit simulation, to do programming with Orbitron so as to get the required output. Orbitron is a simple 2D solver in which TLE files are uploaded, for AAUSAT CUBESAT. The various impacts on the satellite in space are slight deviation in the satellite from its orbit. The motion of the body with includes the disturbing forces in the orbit. However, a satellite has deviated from its normal path due to several forces. This deviation is termed as orbital perturbation. The changes in the orbital element with respect to secular variations are considered using orbital quaternions. The output from satellite dynamic model is received from attitude sensor. The comparative data (Input and Feedback) will generate error signal. To minimize the error signal using proportional integral and derivative (PID) is proposed controller implemented with MATLAB environment.*

Key Words: *Cube Satellite, Orbitron, PID, TLE files*

1. INTRODUCTION

One of the most critical subsystems of a satellite is the trajectory determination and system. This includes the attitude system, which can provide the satellite with high manoeuvrability, pointing stability, and attitude accuracy while in orbit. Satellite subsystems include actuators, sensors, other processes for automatic control, and the satellite's control algorithm [1]. To optimize the stabilization of space dynamics systems, the (PID) proportional, integration, and derivative is proposed.

Low Earth Orbits: A low Earth orbit is typically less than 1000 km above the Earth and can be as low as 160 km. Satellites in this circular orbit travel at a rate of approximately 7.8 km per

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second. A satellite takes about an hour and a half to circle the Earth at this speed. These orbits are commonly used for remote sensing, military purposes, and human spaceflight because they provide close proximity to the Earth's surface for imaging and the short orbital periods allow for quick returns. The AAUSAT is orbiting the Earth surface at LEO orbit [2].
Trajectory Analysis: A trajectory, also known as a flight path, is the path that an object with mass moves through space as an element of time. A trajectory is defined by position and force at the same time. Because of Heisenberg's vulnerability, the trajectory in quantum mechanics is not characterised, which states that both energy and position cannot be taken into account at the same time.

1.1 Space Dynamics

The factors that should be taken into account while selecting the Attitude Control Systems (ACS) for small satellites. Some of these are listed and explained below:
Payload stabilization and pointing requirements: some small satellites such as communication satellites have high pointing requirements [3]. According to the pointing requirements, the ACS is either put into the spin stabilization or three axis stabilization configuration.
Vehicle design: the selection of the ACS is affected by the moment of inertia of the system.
System budgets: Mass, volume and power budgets.
Orbit and environmental disturbance: torque, solar radiation, magnetic, Gravity gradient, aerodynamic torques.

1.2 Quaternion and Euler Angles

Quaternions are mathematical notations utilized for defining rotations and orientation in three-dimensional space in the simplest possible terms. Quaternions are impossible to envision in a three-dimensional space [4]. The initial three terms shall be equivalent to the coordinate system; however by means of Quaternion we add another vector quantity into the equation through which we can actually accentuate on how we can account for all the rotational quantities.

2. LITERATURE REVIEW

Sigurd Skogestad, “Attitude estimation using PID controller truing method”. In this paper, orbit design optimization is done using a PID and a semi-analytical approach. By the implementation of a semi-analytical approach, this case study showed that load in the computational was nine times less within 0.5% error without integrating satellite position numerically. By the obtained result, we can conclude that we can achieve well-optimized and accurate data from the satellite by implementing the semi-analytical approach [5].
David Hobbs, “Precise orbit determination of low earth satellites”: research of the dynamics and possibilities of orbit determination problems for LEO satellite [6]. In this paper the uncontrolled motion about the mass centre of aerodynamically stabilized Nano-satellite with transformable structure moving along the LEO circular orbit was considered. At LEO orbit navigation satellites are, radio navigation systems like GLONASS/GPS and low-altitude satellite communication network like Global Star. The results reflect general patterns of movement and the conditions for the realization of the Mission aerodynamically stabilized transformable Nano-satellite. The obtained results allow for generating the limitations for errors in the angular velocity caused by the utilized separation system of nano-satellites.
Ali Siapush, Janet Gleave, “A brief survey of Attitude Control Systems using momentum concepts”. A method to predict the trajectory of moving objects in a robotic environment in

real-time is proposed and evaluated. The position, velocity, and acceleration of the object are estimated by orbit determination using the six most recent measurements of the object coordinates as inputs [7].

Vadali, S.R., and Junkins, J. "Optimal Open-Loop and Stable Feedback Control of Rigid Spacecraft Attitude Manoeuvres" on the comparison of feedback controller tuning methods, discussed about tuning with different orders and distinguished in terms of load disturbances and set point changes. Open loop and closed loop systems are also acknowledged [8].

3. METHODOLOGY

3.1 AAUSAT satellite's orbit

From figure 1, one can without a very remarkable stretch read the orbital segments to design an orbit of a particular satellite. The second term of the second line addresses the point of the tendency of the AAUSAT satellite's orbit from Earth's orbital plane.

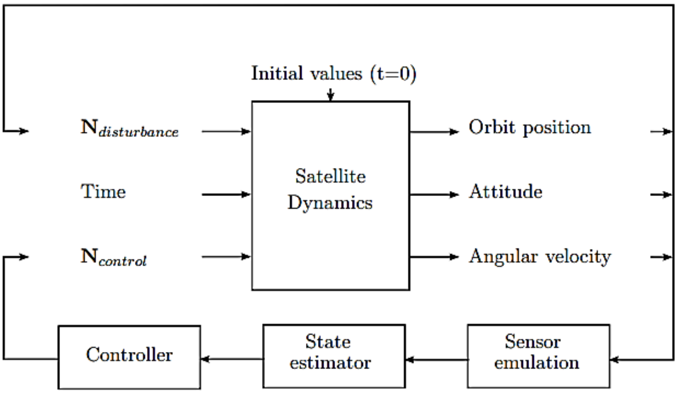


Fig. 1 Schematic diagram – AAUSAT Satellite modelling

The third term of the second line addresses the Right ascending of climbing center/ which is the point between the vernal equinox and the rising center [8]. The abnormality of the orbit of the satellite is given by the third term of the second line and the dispute of perigee and mean peculiarity by the fifth and sixth term separately.

Orbital parameters such as:

Table 1. Orbital Elements

Orbital Parameters	Details
Inclination	Angle between earth equator planes with respect to satellite orbit.
RA of A. Node	Angle between vernal equinox and perigee
Eccentricity	Determine the shape of the orbit
Argument and Perigee	Line of nodes to Perigee point
Semi major axis	Determine the size of the orbit
True anomaly	Satellite position vector to perigee point

3.2 Averaging of Quaternion

To accomplish ideal precision, we regularly utilize a large amount of quaternion information. Averaging Quaternions: to achieve ideal accuracy, we routinely use various quaternion data while evaluating attitude. So in order to reduce the 4 -D Gaussian circulations to zero, what we need to do is to decrease the economic expenditure of the basic quaternion [9]. The typical quaternion is the Eigen vector that identifies with the best Eigen regard. This restricts the weighted measure of lengths of vector ways and the blunder quaternion.

$$\overline{\mathbf{q}} = \pm \frac{[(\mathbf{w_1} - \mathbf{w_2} + \mathbf{z})\mathbf{q_1} + 2\mathbf{w_2}(\mathbf{q_1^T q_2})\mathbf{q_2}]}{||(\mathbf{w_1} - \mathbf{w_2} + \mathbf{z})\mathbf{q_1} + 2\mathbf{w_2}(\mathbf{q_1^T q_2})\mathbf{q_2}||} \tag{1}$$

The important solution performing a decomposition of a matrix is composed of Quaternions and weights. The conversion to Quaternions uses the equations below:

$$\mathbf{q} = \begin{bmatrix} \cos\left(\frac{\theta}{2}\right) \\ \mathbf{u}\sin\left(\frac{\theta}{2}\right) \end{bmatrix} \tag{2}$$

where, θ *is* the rotation angle and u is a 3D unit vector.

4. PID OPTIMIZATION ALGORITHM

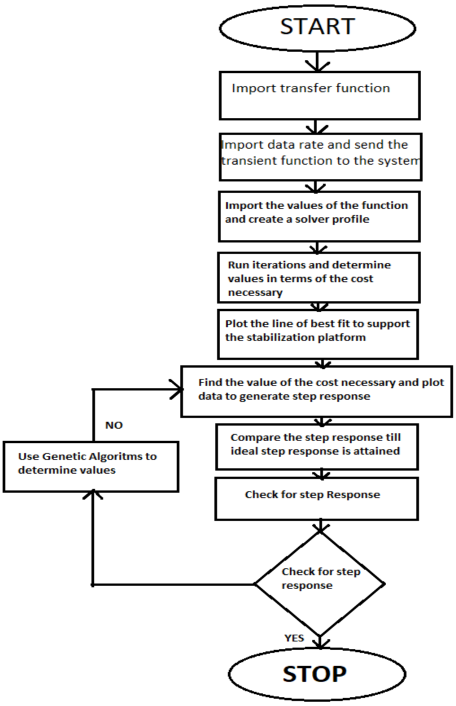


Fig. 2 PID optimization algorithm

4.1 PID optimization algorithm steps

1. Start
2. Import transfer function from the moment of inertia approach.
3. Set values for initial gain values which are variables for the overall system.
4. Create feedback loop and run it continually to achieve the transient response of the system
5. Import the solver data and run the data for continuous iterations till an ideal step response is generated.

6. Input the values of the data rate and step timing.
7. Run the solver whilst measuring the line of best fit, measurements, score and diversity.
8. Check for errors whilst measurement and remove them in the iterations.
9. Use the value to define the PID model for the self-stabilization platform.
10. End

- Laplace transform: It allows us to evaluate and understand the stability and frequency response of a system. Additionally, it provides us with a method for easily solving differential equations.
- Bode plot and Root locus: One of the frequency response methods is used to plot the magnitude and phase variation with respect to natural frequencies (rad/sec). Bode plots are also known as gain and phase margins because they provide a measure of the stability of the satellite systems.
- The poles of a system transfer function at the Root locus on the left side are to be considered stable otherwise/or unstable. The system's stability can then be determined by examining how the poles move in the plane.

4.2 Transfer Functions

The Torque (T) is derived from the electromotive force of the DC motor's powerful circuit equation.
Similarly, with a satellite model we can calculate the transmission function and check the stability of the system.

Dynamic equations

Total Torque = T(s) = $T_{load}(s) + T_{disturbance}(s)$

$$T(s) = J\left(\frac{d^2}{dt^2}\Theta(t)\right) + B\left(\frac{d}{dt}\Theta(t)\right) \tag{3}$$

For the motor transfer function

$$\text{Output/Input} = \frac{\theta}{V} = \frac{k}{[(Js+b).(Ra+La(s))]+K^2} \tag{4}$$

For the satellite transfer function

$$\frac{\theta}{T} = \frac{1}{Bs+JS^2} \tag{5}$$

5. SIMULATION RESULTS

ORBITRON: One of the most basic satellite tracking systems is Orbitron. This tool contains crucial information for UFO enthusiasts. The application displays the satellite positions at any given time (in real or simulated time).
The computer software can calculate a satellite's position for a particular moment due to predictable conditions of the satellite movement in space (absence of atmosphere). The calculations are based on the linked satellite's known orbit characteristics.
Inclination, eccentricity, argument of perigee, mean motion (revolutions per day), and tracks satellite for reasonable period after epoch are the six Keplerian elements, commonly known as orbital parameters [9].

5.1 Design and simulation of trajectory

In Orbitron, an AAUSAT CUBESAT 2 trajectory is created and simulated. It is a student-built satellite that was launched on a PSLV rocket from India's Satish Dhawan Space Centre at 05:54 UTC on April 28, 2008.

Table 2. AAUSAT Orbital Elements

Name	**AAUSAT CUBESAT 2**
NORAD #	27846
COSPAR designator	2003-031-G
Epoch (UTC)	2005-09-05 11:35:12
Orbit # at Epoch	11327
Inclination	98.725
RA of A. Node	256.205
Eccentricity	0.0009471
Argument and Perigee	816X830 km.
Mean anomaly	218.980
Propagation model	SGP4
Diameter	Cylinder: R=0.3, L=0.3m
Orbit	92863
Altitude	600
Velocity	7.56
Period	96.27
RAAN	351.76
True anomaly	289.9

ORBITRON SIMULATION: Orbitron is a simple 2D solver in which TLE files are uploaded, for AAUSAT satellite shown in the figure below. TLE file for AAUSAT is available in Directories of NASA and NORAD.

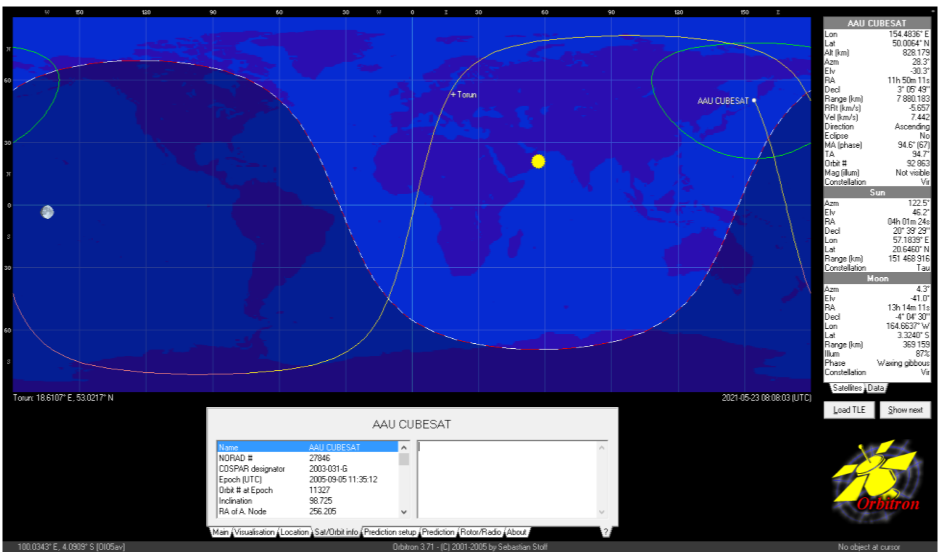


Fig. 3 The simulated ground track view of the satellite which is the projection of the AAUSAT CUBESAT on Earth's surface.

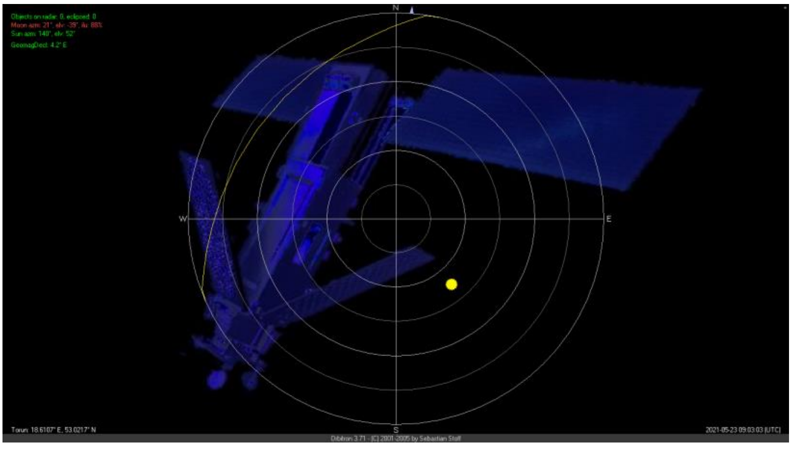


Fig. 4 The simulation of AAUSAT CUBESAT with a viewpoint of radar

Over the last two decades, Nano satellite or cube satellite technology has progressively emerged as a key technology in the space industry. Emerging space nations and non-space nations are now competing to operate the Nano satellites. It is gaining popularity in poor countries due to its low-cost, high-capability programme. The use of small satellites in space is increasing the number of satellites available for specialised missions, both commercial and military. As a result, the number of linked launches, ground stations, and data gathering and delivery systems are becoming increasingly important. As a result, there is a growing demand for LEO satellite tracking systems for data collection and delivery.

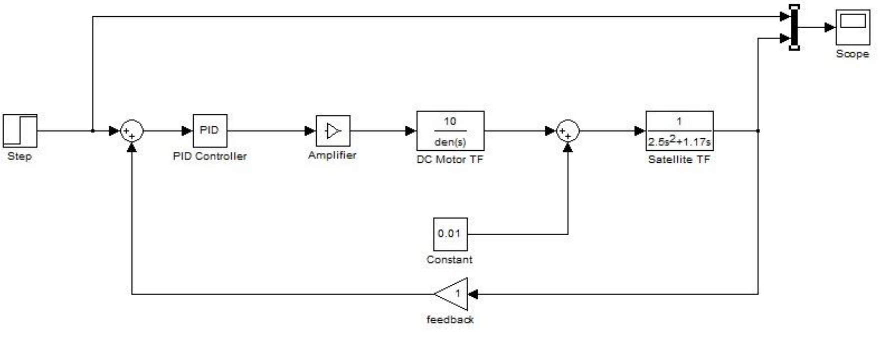
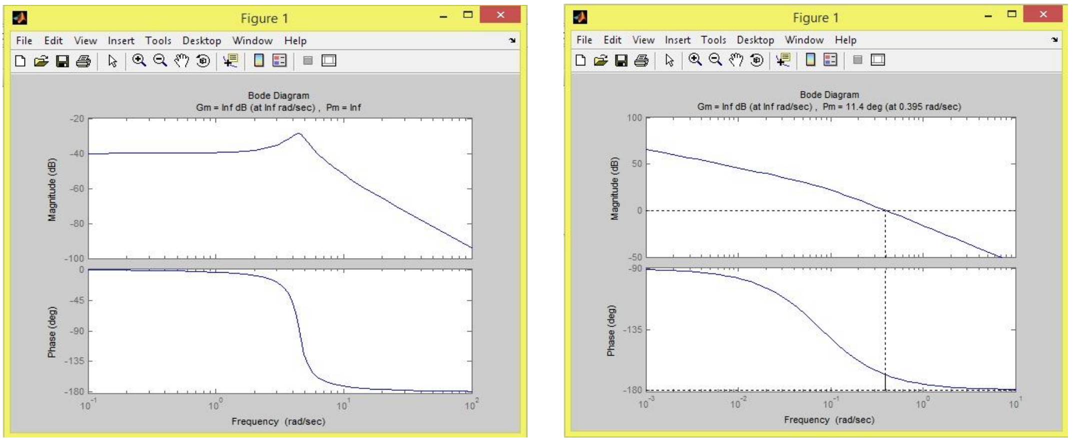


Fig. 5 Frequency Response PID Controller

In Figure 5 above, we can see that the output from satellite dynamic is compared to the reference input. The comparator generates the error that needs to be minimized by the PID controller.

5.2 Gain and Phase margin

- The gain and phase margins are plotted. They are also known as the bode plot. It is common that no system will stay stable at every operating frequency. At some frequencies it will be over-damped system, under-damped or critically-damped respectively. When the gain and the phase margins can be seen with a decreasing plot, it basically means the system is not stable.



(a) (b)

Fig. 6 Frequency a) DC Motor b) AAUSAT CubeSat

- The Bode plot is a popular tool among control system engineers because it allows them to achieve the desired closed loop system performance by graphically shaping the open loop frequency response using clear and easy-to-understand rules.
- Another application is to gain insight into the behaviour of dynamic systems. For example, the plot clearly shows if the system is stable, how quickly it will respond to commands, and if the system will have a resonance at one or more frequencies.

6. CONCLUSIONS

A design for a PID controller is created and implemented. The changes of satellite position from perigee can be determined with help of step commands. (A Proportional – Integrator – Derivative (PID) controller was chosen for its transient and zero steady-state qualities. A theoretical MATLAB and Simulink model was used to design a transient parameters to obtain the quickest settling time without excessive overshoot. An extension was explored to look at dynamic PID controlling dependent on the satellite behaviour during operation to find a faster response. The transfer functions for the determination of the overall satellite used for attitude control of the satellite. AAUSAT phase margin is 11.4 degree to attain the limitedly stable systems. The performance should be faster than the PID controller. For ground tracking, the satellite is tracked by the projection on the Earth's surface with the AAUSAT CubeSat. Some models are simulated using the view by its position and projection.

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