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REVIEW ON ATTITUDE DETERMINATION AND CONTROL SYSTEM OF CUBESAT

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Abstract

The Attitude Determination and Control System (ADCS) is of great importance because satellites usually needs to point in specific directions in order to perform its assigned tasks. The failure of the ADCS has been a huge problem on CubeSat projects. This tends to be towards the Earth, sun or stars, while other parts such as antennas may need to point towards the Earth, while solar panels needs to be directed towards the sun. The disturbance emerged as a variable that can interfere ADCS pointing, and may appear in one of ADS or ACS sub system. These report study on ADCS disturbance that can be used to determine control method, device, algorithm in accordance to the disturbance .

Keywords: Disturbance, torque, ADCS, reaction wheel

1. Introduction

Attitude Determination and Control System (ADCS) is a sub-satellite system that works for satellite attitude control. At the time of the satellite rotates around its orbit and at the time of pointing, the satellite is controlled to keep leads to the earth's surface. In figure 1, satellites can perform pointing properly at the time of the satellite equilibrium on three axes, namely the X-axis (roll), Y (pitch) and Z (yaw), by controlling so that the satellite at the equilibrium position on three axes will be able to perform pointing with high accuracy.

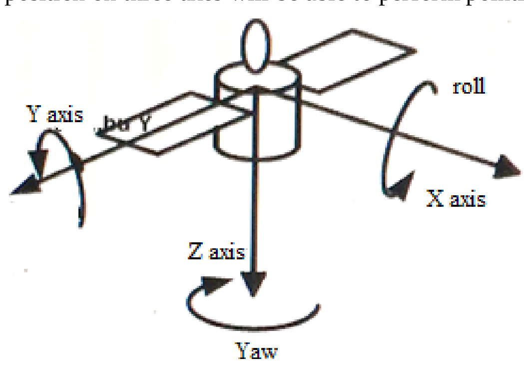


Figure 1. Three axis attitude satellite

In studying the ADCS there are some things that need to be understood, is the concept of stabilization system, sensor, actuator and algoritm. There are three important things that are required in satellite attitude control is the accuracy in determining satellite attitude, accuracy control and the stability of the satellite at the time of the satellite attitude do the pointing. Basically, there are several methods to achieve stability in the satellite, one of them using a three-axis stabilization. This method is used aims to achieve higher accuracy. With a three-axis stabilization of the satellite is conditioned to be at zero momentum that conditioned the satellite attitude remains at its original position if there is disturbance. In addition to the three-axis stabilization of the satellite is conditioned tolerance for disturbances or so-called bias momentum.

Control is done by using a variety of sensors to determine the interference on the satellite attitude. As for moving the actuator required to conform to the desired attitude. According to (Slamet 2012) there are many sensor, sun sensor, earth sensor, star sensor and gyroscope are generally used. While actuators generally used reaction wheel, gyroscope, magnetotorquer and thruster.

2. State of The Art

2.1 Satellite Mechanic and Modelling

The angular velocity of a satellite is known as inertial space around the center of mass. In this process the kinematic equations are signified by its angular attitude equations. the Euler angles used in the satellite kinematic model. In order to avoid the singular problems of Euler angles, the satellite attitude determination and control studies use quaternion method. The satellite model can be simplified as a rigid body model.The following is equation of satellite kinematic.

$$\varpi_{0i} = \begin{bmatrix} 0 & -\omega & 0 \end{bmatrix}^T \tag{1}$$

where ω is the orbital angular velocity.
The satellite attitude dynamics equation is as follow:

$$\vec{\omega} = \vec{\omega}_{b0} + T_{b0}\ (\psi, \boldsymbol{\varphi}, \boldsymbol{\theta})\ \vec{\omega}_{0i} \tag{2}$$

$$= \begin{bmatrix} \varphi\cos\theta - \psi cos\varphi\ sin\theta\ -\omega_0(\cos\theta\sin\psi + \sin\theta\sin\varphi\cos\psi \\ \theta +\ \psi\ sin\varphi -\ \omega_0\cos\cos\psi \\ \psi\cos\theta\cos\varphi + \varphi\sin\theta -\ \omega_0(\sin\theta\sin\psi - \cos\theta\sin\varphi\cos\psi) \end{bmatrix}$$

The (**ψ**, φ, θ, ω) represents the small rotation angles.

Motion of the satellite can be abstracted simply as a rigid body motion by the translational and rotational components. Assume orbital coordinate system in spatial reference coordinate system, expressed as o, rotation coordinate system for the satellite body coordinate system is expressed as b, and b system at some moment relative to o system by quaternion vector is expressed as q and I is inertial reference coordinate system, with quaternion satellite kinematic equations is:

$$\dot{q} = \frac{1}{2}\ q\ \otimes \omega = \frac{1}{2}\begin{bmatrix} -q_1 & -q_2 & -q_3 & q_0 \\ q_0 & -q_3 & q_2 & q_1 \\ q_3 & q_0 & -q_1 & q_2 \\ -q_2 & -q_1 & q_0 & q_3 \end{bmatrix}\begin{bmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} \tag{3}$$

$$\dot{q_0} = -\frac{1}{2}q^T\omega \tag{4}$$

$$\dot{q} = \frac{1}{2}([q\times +q_0 I])\omega \tag{5}$$

$$[\omega\times] = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix} \quad (6)$$

2.2 Disturbance

Disturbances in is one thing that must be anticipated on the ADCS, especially when the satellite tracking and pointing it takes control with high accuracy (Cao and Wu 2015). Actuators becomes very important because it will propel the satellite into the attitude expected. The device is often used as actuators in the attitude control system is a reaction wheel. Interference torque is also an disturbance with the reaction wheel resulting in impaired system stability. Disorders that appear on reaction wheel is derived from two factors: on the reaction wheel and the environment around the satellite.

In a study conducted by the (Cheon et al. 2011), (Karimian et al. 2014) and (Dongbai Li 2016) disorders of the reaction wheel are grouped into static and dynamic imbalance. Static imbalance represents an imbalance in the reaction center of mass of the wheel, while the dynamic imbalance caused by the angle of the rotary axis leads to a disturbance torque (Karimian et al. 2014). Torque can also arise from the environment around the satellite, namely torque magnetic, gravity and aerodynamic torque. The other disturbance can be seen in Table 3.

2.3 Control Method

ADCS should use a controller that has a fast response time and precision. In (Li et al., 2013) also explained that accuracy of attitude control can be achieved by applying the algorithm intelligence and law PD to further strengthen against external interference. As already mentioned in the introduction when designing ADCS many unknown variables that it takes Attitude Control System (ACS) is an adaptive, in that it is the Adaptive Neuro Fuzzy Inference System (ANFIS) controller.

Table 1. The types of Controller

Controller	**Advantage**	**Disadvantage**
H_2 *controller*, $H_\sim$ *controller* combination of H_2 / $H_\sim$. (Won 1999)	▪ H_2 has the fastest response time	▪ $H_\sim$ *controller* has the slowest response time. ▪ H_2 / $H_\sim$ has the medium respon time.
PID *controller* dan *optimal controller.* (Angelucci, Straub, and Tarabini 1996)	▪ PID controller is relatively easy to operate and only need regular microprocessor that its performance. ▪ Optimal control is needed to minimize the cost function of attitude control.	▪ PD controller has a limitation that can not approach the zero angle.
Linier controller dan Sliding controller (Abdulhamitbilal and Jafarov 2006)	▪ Sliding controller at geosynchronous satellite has a good performance and settling time is relatively small	▪ linear controller causes the high cost and performance deteriorates when the geosynchronous satellites maneuver
Fuzzy *controller* dan PID *controller*	▪ Fuzzy controller is more efficient when doing single	▪ High complexity

(Calvo, Avils, Lapuerta, & Lavern-Simavilla, 2016)	maneuver (to save power up to 65%), as well as more precision when compared with PID controller.	

2.4 Determination Method

In addition to selection controller determination method is also very important to justify the attitude of a satellite in the expected position (to achieve the mission). Quaterneon Direct method is the method most rapid when compared with Optimized TRIAD, Wahba and QUEST, thus temporarily Quaternion Direct method chosen as a method in Attitude Determination System (ADS).

According to (Celik and Hajiyev 2013), TRIAD and q-method has the same accuracy, q-method can perform two measurements but for some regions q-method has a low enough accuracy because only two measurements. However Optimized TRIAD is an estimation method is more expensive than the QUEST but in general these algorithms can be applied to multiple measurements. On the other hand, direct quaternion estimation method is much faster than QUEST, but these two methods are flawed can not do the computation for an exceptional case. Comparison of accuracy that algorithm can be seen in Table 2.

Table 2. Evaluation of different algorithm regarding accuracy (Hasan et al. 2016)

Algorithm	Accuracy	Speed	Output Format
TRIAD	Low	Very high (120 flops)	Rotation Matrix
Q-METOD	High	Low (> 900 flops)	Quaternion
QUEST	Low	High (<400 flops)	Quaternion

3. Discussion

ADCS role directly related to the success of satellite missions. Since the device is fully in charge of controlling the movement of the satellite in order to remain in orbit, to control the movement when there is interference and control during the mission. Section 2 has been described advantages and disadvantages of the device used in ADCS also accuracy algorithm.

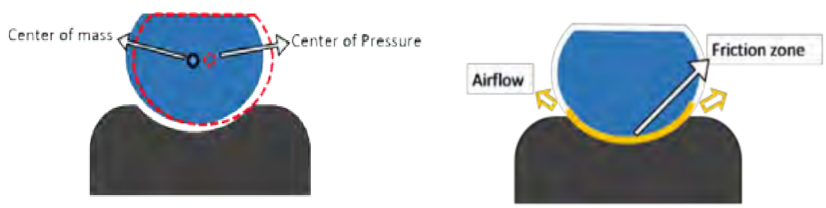
In addition to the selection of algorithms and devices, disturbance is also very important to be anticipated. Various disturbance is described in several papers along with the algorithm, as can be seen in Table 3. This table only partly covered disturbance, i.e disturbance that often appear on reaction wheel. Disturbance have been selected for reaction wheel is an actuator that is generally used in ADCS and which have a major influence in moving the ADCS to the object to be captured. Effect of the disturbance is able to degrade the accuracy of ADCS and cause failure of satellite missions. By controlling the disturbance is expected to remain in orbit ADCS and can do pointing with high accuracy.

Table 3. The Most Disturbances in reaction wheel

Reference	Disturbance	Description	Control Method
(Cheon et al. 2011)	Dynamic and static imbalance	Disturbance on of the reaction wheel that is caused by the offset of the center of mass of the flywheel from the axis of rotation.	Balancing Method
(Ousaloo 2011)	Disturbance in satellite	Disturbance during multi-axis attitude maneuver of a small satellite.	Fuzzy logic

	environment		
(Karimian et al. 2014)	Vibration	Disturbance caused by Unbalances in rotational machines.	Balanching Method
(Dongbai Li 2016)	Imbalance torque	High speed rotation in central motor that have serious impact on the ccuracy of imaging.	Balancing method
(Mehrjardi et al. 2015)	Friction	Disturbance on reaction wheel caused by temperature and speed	Balancing method
(Zhang, Meng, and Huo 2016)	Environmental torque	Torque arising from satellite environtment	Backstepping controller and Lyapunov method
(Faramin and Ataei 2016)	Disturbance torque	Disturbance that generated by indoor equipment of the satellite	Lyapunov method
(Figueiredo 2013)	Aerodynamic torque and unbalance torque	Torque that is caused by friction between the sphere and the aluminum layer of air	Lyapunov method
(Guanglin and Qinglei 2016)	Torque friction and external disturbances	Friction that arrising in reaction wheel	Lyapunov method

According to these reasearch, the most of disturbance caused by unbalance torque and external disturbance at reaction wheel. Generally unbalane torque is an internal disturbance of the reaction wheel, so that the required reaction wheel design with friction limit to zero. Otherwise, pressure point with the center of mass of the spere must be align as ilustrated in Figure 2. Misalignmmet of these two things can cause air flow friction.



(a) (b)

Figure 2. (a). Unbalance between center of mass and center pressure. (b) airflow friction (Figueiredo 2013)

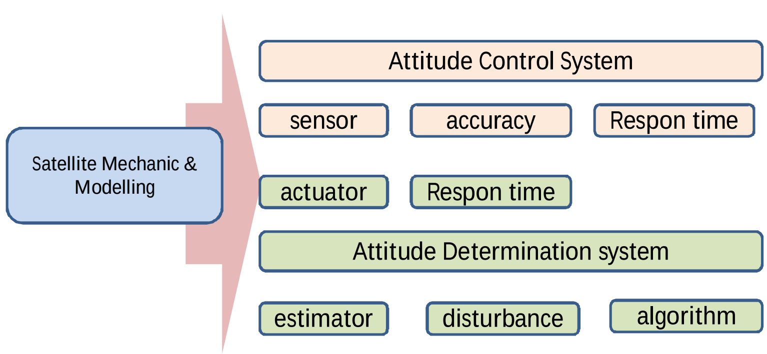


Figure 3. Variable consideration in ADCS

There are several important when examining ADCS depicted at Figure 3,

- Satellite mechanic and modelling. Satellite mechanic and dynamic modelling effect on ohter variables such as disturbance modelling, estimator, algorithm, etc.
- In Attitude control system (ACS) are required any sensor according to the satellite mission. Sensor selection should be consider the level of accuracy in achieving mission.
- In attitude determination system (ADS), selecting actuators are importance because it is used to direct satellite facing the object that has been determined at a certain moment. An Estimator used to estimate the magnitude of disturbance, the the output will be used in the control algorithm.

4. Conclusion

Sub ADCS system consists of two subsystems, namely ACS and ADS. There are some important things that need to get more attention, namely the disturbance, response time and accuracy. Disturbance that appear on the satellite as it orbits highly variable and difficult to predict, so it needs special handling on this matter. The next is a matter of response time, ADCS is expected to have a short time in response to disturbances that appear so much faster satellite stable. And the last is a problem of accuracy due to a disturbance in the ADCS. The decrease of accuracy is not only caused by the disorder around the satellite, but the use of actuators and control algorithms election also may decrease accuracy.

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