Jurnal Teknologi

Full Paper

ANALYSIS ON ATTITUDE POSITION OF EARTH CENTERED INERTIAL (ECI) BASED ON RAZAKSAT DATA

Article history
Received
1 June 2015
Received in revised form
13 July 2015
Accepted
20 August 2015

Mohd Zamri Hasan[a*], Sazali Yaacob[b], Amran Ahmed[c], Nor Hazadura Hamzah[c], Shamshul Bahar Yaakob[d], Muhd Hafizi Idris[d], Md Azlin Md Said[e]

[a]Faculty of Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia
[b]School of Mechatronic, Universiti Malaysia Perlis, Perlis, Malaysia
[c]Institute of Mathematical Engineering, Universiti Malaysia Perlis, Perlis, Malaysia
[d]School of Electrical System Engineering, Universiti Malaysia Perlis, Perlis, Malaysia
[e]School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, Pulau Pinang, Malaysia

*Corresponding author
zamrihasan@unimap.edu.my

Graphical abstract

Abstract

Attitude determination system (ADS) is a process to control the orientation of satellite to make sure that the orientation of satellite is relative to inertial reference frame such as Earth. Earth Centered Inertial (ECI) is one of reference frame for satellite that determines the attitude in three dimensional spacecraft. Since RazakSAT orbits on earth, ECI coordinate system will be used for satellite relative to earth rotation. This paper is about the analysis on attitude position of ECI and velocity at X, Y and Z axis based on RazakSAT data. Satellite Tools Kit (STK) is used to estimate the attitude and velocity based on Two Line Elements (TLE) of RazakSAT. The result is compared with RazakSAT measurement data to observe the accuracy of estimation by using STK.

Keywords: Attitude position, Earth Centered Inertial (ECI), velocity, RazakSAT, Satellite Tools Kit (STK)

Abstrak

Sistem Penentuan Attitud (SPA) ialah satu proses untuk mengawal orientasi satelit dalam memastikan orientasi satelit adalah relative kepada rangka rujukan inersia seperti Bumi. Inersia Berpusat Bumi (IBB) adalah salah satu rangka rujukan bagi satelit yang menentukan attitude kapal angkasa dalam tiga dimensi. Sejak RazakSAT mengorbit bumi, system koordinat IBB akan digunakan bagi satelit relative kepada putaran bumi. Kertas ini berkenaan analisis ke atas kedudukan attitude bagi IBB dan halaju pada paksi X, Y dan Z berdasarkan data RazakSAT. Kit Peralatan-peralatan Satelit (KPS) digunakan untuk menganggarkan attitude dan halaju berdasarkan Elemen-elemen Dua Talian (EDT) RazakSAT. Keputusan-keputusan dibandingkan dengan data pengukuran RazakSAT untuk memerhatikan ketepatan penganggaran yang dibuat menggunakan KPS.

Kata kunci: Kedudukan attitude, Inersia Berpusat Bumi (IBB), halaju; RazakSAT, Kit Peralatan-peralatan Satelit (KPS)

1.0 INTRODUCTION

RazakSAT is a Malaysia's mini satellite which was developed by Astronautic Technology Sdn Bhd (ATSB). The main mission of RazakSAT is to take image at the equatorial region from orbit. Therefore, RazakSAT is carrying high resolution camera at Near Equatorial Orbit (NEqO) to provide high resolution imaging for land management, resource development and forestry. RazakSAT image is shown in Figure 1.

Quality of image taken from RazakSAT depends on the attitude position, and light intensity of satellite. Therefore, attitude determination and control system (ADCS) is one important element in satellite system for carrying out its task to ensure the satellite stays in its designated orbit during its entire mission. The accuracy and reliability of attitude determination is very important during the mission. The problem such as noise measurement, bias and misalignment will affect the attitude estimation [1-4]. Attitude determination system starts from calculating the satellite position in its orbit with respect to inertial frame using Kepler model. The model calculates the initial position that provided by TLE data and will produce position vector of ECI [5].

In this paper, the attitude position of earth centered inertia and velocity at X, Y and Z axis based on RazakSAT data are analyzed. STK is a method used to estimate the attitude position on ECI and velocity of satellite based on TLE of RazakSAT. The result is then compared with RazakSAT measurement data to observe the accuracy and performance of estimation using STK.

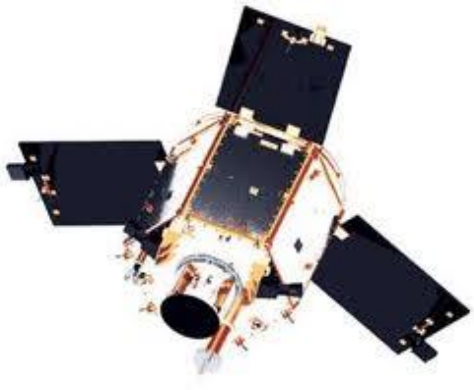


Figure 1 RazakSAT

2.0 THEORIES OF ATTITUDE DETERMINATION

2.1 Orbit Parameter

Orbit shape and orientation can be described by using the method developed by Johannes Kepler [3]. Six elements required for orbit description are:

i. Semi major axis
ii. Eccentricity
iii. Inclination
iv. Right Ascension of Ascending Node (RAAN)
v. Argument of Perigee
vi. True Anomaly

Semi major axis, a_s as in (1) is the largest radius of eccentric orbit, as shown in Figure 2.

$$a_s = \left[\frac{m_g}{\left(\frac{2n_{rev}\pi}{86400}\right)^2}\right]^{1/3} \tag{1}$$

n_{rev} is the mean motion from TLE. The inclination i_s is the angle between orbit plane and earth's equatorial plane as shown in Figure 3.

Eccentricity e_s is given by (2).

$$e_s = (c_f)/(a_s) \tag{2}$$

c_f is the distance from the eclipse center to the Earth as shown in Figure 2.

Argument of Perigee, w_s as in (3) is the angle measured in satellite direction of motion from ascending node to the perigee as shown in Figure 3.

$$w_s = 4.98204\left[\left(\frac{r_{Earth}}{a_s}\right)^{3.5}\right][5cos(i_s)^2 - 1][(1 - {e_s}^2)^2]^{-1} \tag{3}$$

r_{Earth} is the Earth's Equatorial Radius.

$$\mathrm{RAAN} = 9.9641\left[\left(\frac{r_{Earth}}{a_s}\right)^{3.5}\right][\cos(i_s)^2][(1 - {e_s}^2)^2]^{-1} \tag{4}$$

RAAN, Ω_s as in (4) is the angle measured from Vernal Equinox to ascending node where satellite point crosses the equator plane from south to north as shown in Figure 3.

True anomaly, $v_s$is calculated from mean anomaly, M_a. Mean Anomaly, M_a is satellite position in its orbital path. Mean anomaly and true anomaly equations are given by (5) and (6) respectively [3].

$$M_a = M_{Epoch} + 360n_{rev}T_{se} \tag{5}$$

$$v_s = M_a + 2e_s\sin(M_a) + 5{e_s}^2\frac{\sin(2M_a)}{4} \tag{6}$$

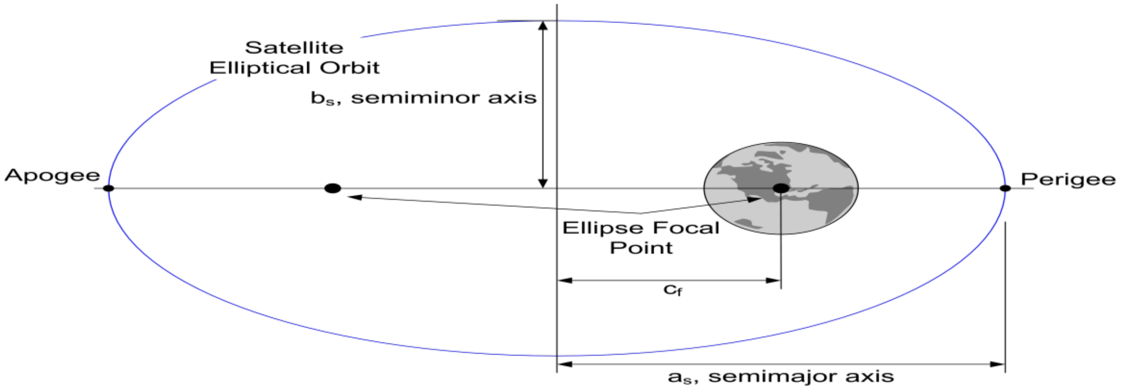


Figure 2 Geometric properties of an elliptical with Earth as a focal point [4]

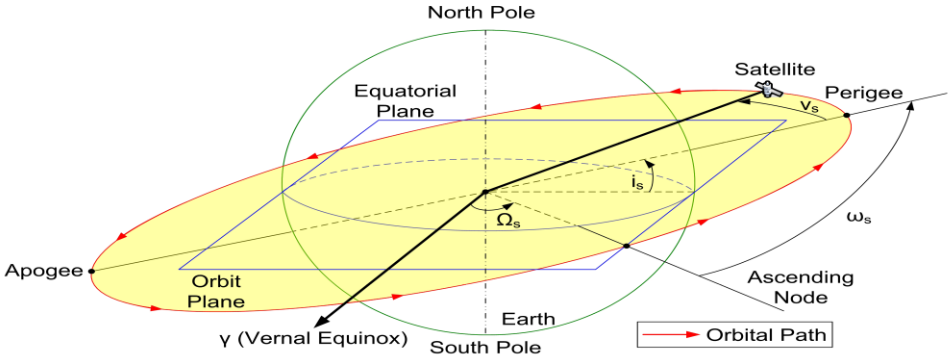


Figure 3 Keplarian orbit elements describing satellite of Earth orbit [6]

2.2 Earth Center Inertial (ECI)

Since RazakSat on the earth orbit, ECI coordinate system is required for reference frame to the satellite. ECI represents as coordinate system with its origin in the center of earth rotation. The X axis is parallel to the direction of Vernal Equinox. The Vernal Equinox is the point where the plane of the earth orbits the sun, crosses the equator going from south to north. The Z axis is parallel to the earth rotation axis [7-9]. The ECI coordinate frame is shown in Figure 4.

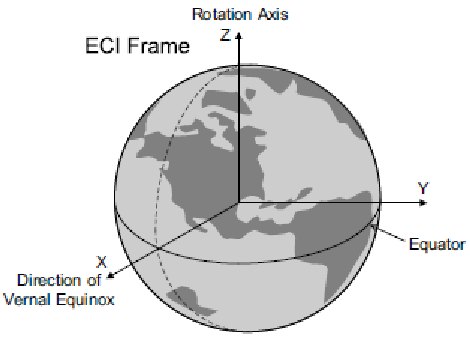


Figure 4 ECI coordinate frame [6]

3.0 MODELING USING SATELLITE TOOLS KIT (STK) AND MATLABSIMULINK

3.1 ADS Simulation Parameter

TLE is a simple data format of two lines sets having 69 characters which describe the orbit of an Earth satellite. These general perturbation element sets are available for all space objects and are maintained by North American Aerospace Defense Command (NORAD) [6]. TLE of RazakSAT data provided by ATSB is shown in Table 1. From TLE data, the orbital parameters can be determined as shown in Table 2.

Table 1 RazakSAT TLE DATA (Courtesy of ATSB)

RazakSAT
1 35578U 09037A 14159.74046634 .00000748 00000-0 34706-4 0 3167
2 35578 8.9895 213.5248 0017552 36.5867 323.5560 14.66093039263050

Calculation result was inserted into STK inside Simulink and the attitude along with velocity of satellite was generated. RazakSAT is following the orientation of orbit based on Table 2 and TLE data as shown in Figure 5(a) and (b). The effect of perturbation in this simulation was not considered during the orbit orientation.

Table 2 Orbital Parameters of RazakSAT

Parameters	Value	Unit
Inclination	9.0000	deg
Mean Anomali	213.5248	deg
Eccentricity	2.00E-07	deg
RAAN	213.5248	deg
Argument of Perigee	36.5867	deg
Mean Motion in Revolution	14.6609	/ day

3.2 STK

STK is an application for developing and designing complex and dynamic simulation of real world relating to ground vehicle, aircraft and satellite. For satellite researcher, this is an opportunity to carry out simulation and test before launching into the orbit. In this research, STK 10.1 is used to simulate the attitude position of ECI and velocity of RazakSAT using TLE data provided by ATSB.

4.0 SIMULATION RESULTS AND DISCUSSIONS

This section presents the results of ECI position and velocity from RazakSAT Measurement Data and Simulink STK. Table 3 is real data from RazakSAT provided by ATS Band. Table 4 shows the results of simulation by using STK. Figure 6 and Figure 7 show that vector X and Y axis of ECI are the same, but Z axis gives the opposite direction as shown in Figure 8. Same result also for velocity of RazakSAT. For Figure 9 and 10, X and Y axis give the same direction for RazakSAT measurement and STK, however velocity of Z axis is in opposite direction as shown in Figure 11.

From the result, the difference between X and Y is small and the error is minimum for attitude and velocity of RazakSAT. However, Z axis gives the opposite value for attitude position of ECI and velocity. This happened because the value of RAAN is changed every second on the orbit. When RAAN changes, the pole Z direction also changes. To solve this problem, several estimation methods will be proposed for next project.

5.0 CONCLUSION

This paper presents the analysis of the attitude position of ECI and velocity based on RazakSAT data. By using STK, attitude position and velocity of RazakSAT can be estimated and compared with raw data of RazakSAT. The result shows that minimum error of attitude position and velocity can be obtained by using STK for X and Y axis. However, Z axis gives the opposite result.

The future work is to analyze two measurement sensors (sun sensor and magnetometer) of RazakSAT, and angular velocity using STK to get the estimated results. Besides that, Residual Analysis method is needed to add for precise measurement data. Other estimation method such as Kalman Filter (KF), Extended Kalman Filter (EKF), Particular Filter and some mathematical modeling are suggested to reduce the opposite error of Z axis and to get the better estimation for attitude determination system of RazakSAT.

Acknowledgement

Many thanks to ATSB Sdn Bhd which has been providing much information and data of RazakSAT and Universiti Sains Malaysia (USM) which has been giving many help in making the success of this project.

References

[1] Wertz JR. “Attitude Determination and Control”. Boston: Kluwer Academic Publisher, 1978.

[2] Marcel J. SIDI, “Spacecraft Dynamic and Control”, Cambridge University Press, 1997.

[3] Sellers, J., Astore, W., Giffen, R. and Larson, W.(2003). “Understanding Space”, *Space technology series*.

[4] M. Fadly, O. Sidek, M. A. Md Said, “Development of Atitude Determination for Student Pico-Satellite INNOSAT”, *Regional Conference on Mechanical and Aerospace Technology*, February 9-10, 2010, Bali, Indonesia.

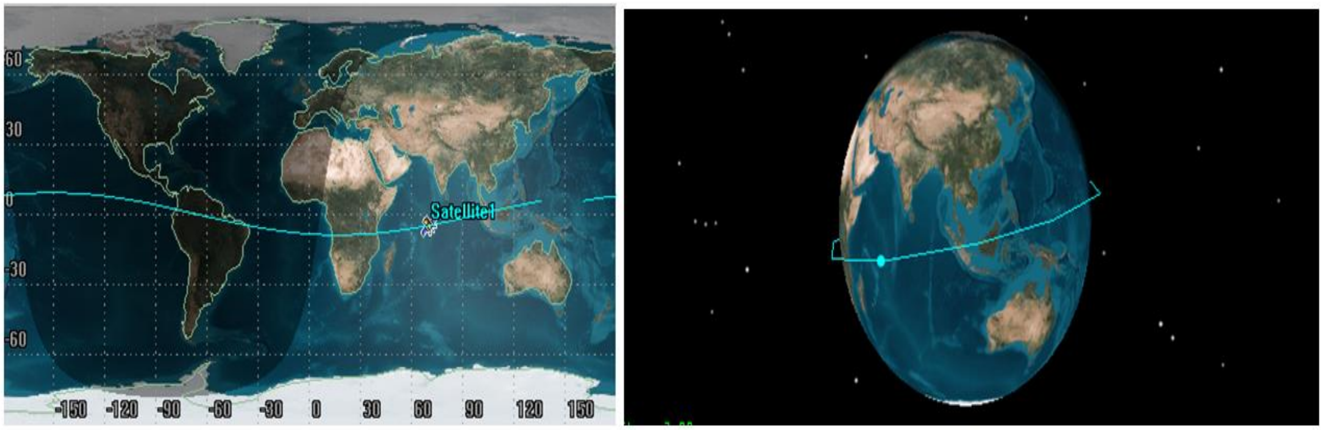
[5] M. A. Md Said, M. Fadly, O. Sidek, A. Ain, M. F. Alaudin, H. Djojodihardjo, R. Razali, “Low Cost Space Experimental Attitude Determination Systems (SEADS) for INNOSAT Project”, Proceedings, *The 8th CSA-IAA Conference on Advanced Space Technology*, 20-23 May 2013, Shanghai, China.

[6] Adam Ain Bin Mohd Poin Keui, “Development and Implementation of Embedded Attitude Based termination System Using Extended Kalman Filter Based on ARM7TDMI Platform”. 2013.

[7] Kerem K, May – Win L. T, “Attitude and Angular Rate Estimation Using the Sliding Mode Observer With Additive Quaternion Correction”, *Proceeding of American Control Conference*, 2006.

[8] Eli Jerpesth Overby, “Attitude Control for the Norwegian Student Satellite nCube”, Master Thesis, Department of Engineering Cybernatic, NTNU, 2004

[9] Jan Rohde, “Kalman Filter for Attitude Determination for Student Satellite”, Master Thesis, Department of Engineering NTNU, 2007.



(a) (b)

Figure 5 Orientation of RazakSAT. (a) 2D graphic view (b) 3D graphic view

Table 3 RazakSAT measurement

SATELLITE POSITION ECI X(km)	SATELLITE POSITION ECI Y(km)	SATELLITE POSITION ECI Z(km)	SATELLITE VELOCITY ECI X(km/sec)	SATELLITE VELOCITY ECI Y(km/sec)	SATELLITE VELOCITY ECI Z(km/sec)
-2152	-6532	674	7.26	-2.30	0.94
2345	-6448	1056	7.19	2.56	0.29
5880	-3697	1002	4.19	6.27	-0.46
7064	546	546	-0.35	7.38	-1.01
5513	4586	-123	-4.63	5.65	-1.15
1879	6901	-747	-7.09	1.82	-0.86
-2457	6633	-1091	-6.89	-2.70	-0.25
-5854	3852	-1021	-4.04	-6.28	0.48
-6958	-427	-552	0.52	-7.49	1.03
-5246	-4522	138	5.01	-5.66	1.19
-1357	-6733	770	7.49	-1.44	0.84
3101	-6128	1080	6.84	3.36	0.15
6292	-2999	946	3.44	6.68	-0.58
6981	1335	434	-1.19	7.27	-1.06
4981	5164	-246	-5.24	5.08	-1.13
1106	7054	-835	-7.26	1.02	-0.77

Table 4 Simulation results using Satellite Tools Kit (STK)

SATELLITE POSITION ECI X(km)	SATELLITE POSITION ECI Y(km)	SATELLITE POSITION ECI Z(km)	SATELLITE VELOCITY ECI X(km/sec)	SATELLITE VELOCITY ECI Y(km/sec)	SATELLITE VELOCITY ECI Z(km/sec)
-1614	-6858	-424	7.25	-1.65	-1.09
2766	-6430	-948	6.85	3.03	-0.60
6057	-3468	-1097	3.75	6.51	0.12
6962	859	-813	-0.83	7.42	0.79
5121	4847	-208	-5.09	5.41	1.15
1256	6917	480	-7.35	1.25	1.06
-3107	6243	976	-6.69	-3.42	0.54
-6234	3087	1084	-3.37	-6.74	-0.19
-6882	-1298	759	1.29	-7.37	-0.85
-4796	-5167	132	5.42	-5.08	-1.17
-793	-6993	-550	7.41	-0.77	-1.02
3511	-6046	-1012	6.45	3.82	-0.47
6432	-2717	-1074	2.95	6.90	0.27
6820	1682	-712	-1.71	7.26	0.90
4517	5416	-69	-5.71	4.76	1.17
427	7007	602	-7.46	0.36	0.98

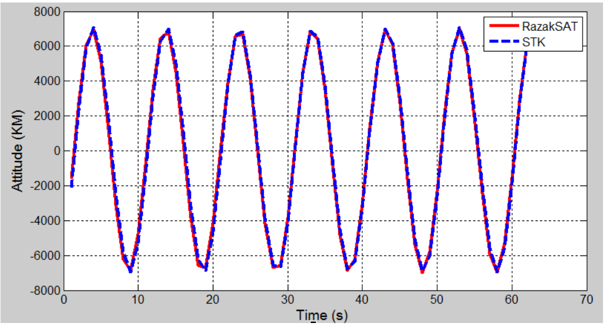


Figure 6 X axis position of ECI

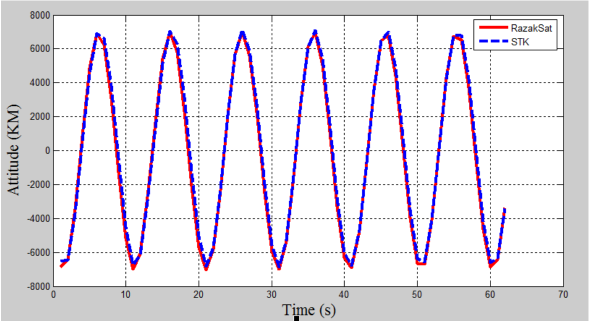


Figure 7 Y axis position of ECI

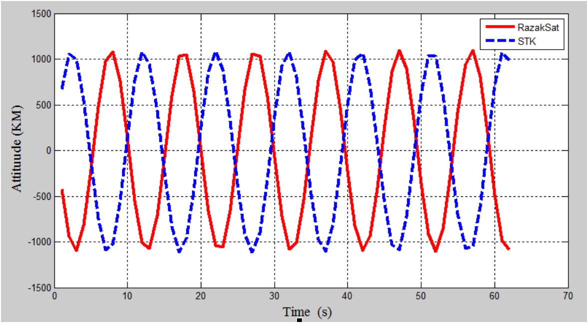


Figure 8 Z axis position of ECI

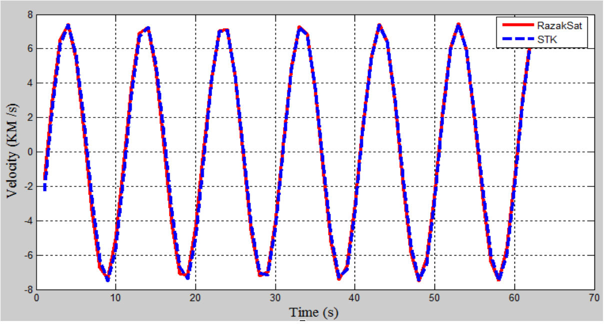


Figure 9 X axis velocity

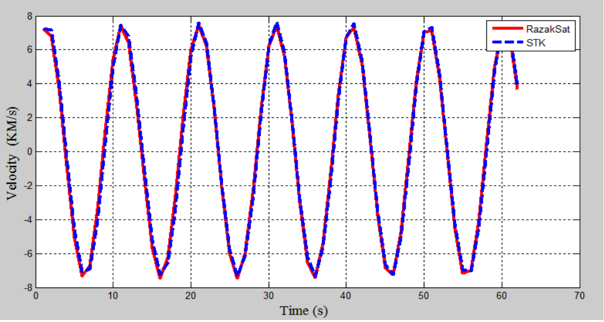


Figure 10 Y axis velocity

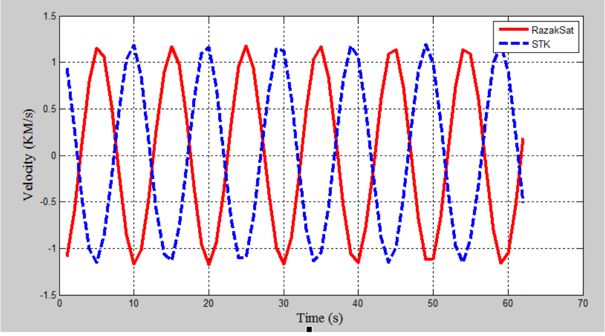


Figure 11 Z axis velocity