Investigation of Malaysian Low Earth Orbits for Remote Sensing Applications

M Okasha\textsuperscript{1}, I Shuib\textsuperscript{2} and M Idres\textsuperscript{3}

\textsuperscript{1,2,3} Dept. of Mechanical Engineering, International Islamic University Malaysia (IIUM), Kuala Lumpur 50725, Malaysia

E-mail: mokasha@iium.edu.my

Abstract. This paper explores the orbit design procedures of a low Earth satellite orbit for remote sensing mission. The mission objective is to gather images over Malaysia as an area of interest for a variety of applications such as land monitoring and digital mapping. The design procedures are mainly driven by the payload performance, lighting conditions and the coverage requirements. Standard CubeSat platform with a NanoCam is considered for the mission. Numerical investigations show the trade studies of various satellite orbital parameters and their impact on the performance. The orbital parameters are optimized to meet the mission design requirements.

1. Introduction

“Remote sensing is the practice of deriving information about the Earth’s land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth’s surface” [1]. It is the process of gathering information about an object without direct physical contact. The photographic images taken by a camera, is the most common remote sensing method for collecting of information.

Recently “CubeSat” satellites are widely popular for a wide range of remote sensing applications. These include not only educational but commercial applications such as mapping, real estate and construction, and oil and gas monitoring as defined by the NASA web site. Orbit design is a crucial process for remote sensing applications. It involves the selection of the orbital parameters to satisfy the mission objectives successfully. This process is driven basically by the payload performance, lighting conditions, access and coverage requirements and the satellite lifetime [2-4].

In this paper, the process of selecting the orbital parameters are presented. Malaysia is considered as an area of interest. Standard CubeSat platform with a NanoCam is selected for this mission [5]. Numerical investigations and trade studies are performed using MATLAB [6] and AGI/STK [7] software packages to define the optimum orbital parameters to meet the design objectives. The paper is arranged as follow. Section 2 presents a brief description of the orbital parameters and defines the mission requirements. Section 3 shows the impact of various orbital parameters on the satellite performance through trades studies. Finally, Section 4 provides conclusions and recommendations.
2. Orbital parameters and mission requirements

The six classical Keplerian orbital elements can be used to define the satellites orbit as shown in Figure 1. These elements are: semi-major axis $a$, eccentricity $e$, inclination $i$, ascending node $\Omega$, argument of perigee $\omega$ and true anomaly $\nu$. The main goal of orbit design is to find the optimal set of these parameters to meet the mission objectives (see Figure 2).

The mission primary objective is defined to gather images over Malaysia with the following requirements:

- 100% coverage of the entire territory within two weeks time period;
- At least, 10 minutes daily access with the Malaysian Space Centre ground station;
- At maximum, 100 meters ground sample resolution;
- All the captured images are during the direct Sun light;
- At least 5 years satellite lifetime.

NanoEye CubeSat platform is selected with a NanoCam as shown in Figure 3 and Figure 4 [5]. This type of satellite provides a standard design for picosatellites which helps in reducing cost and development time, as well as enable small organizations with limited budget to get involved in space exploration activities. This system is designed specifically for low cost Earth observation missions with effective resolution better than 100 meters per pixel.

To better understand how the low Earth satellite orbit and payload parameters impact on access, coverage and lifetime mission requirements, a series of parametric studies is considered. For each parametric study, a single design parameter is varied through a range of values and at each value the design requirements are analysed. MATLAB and AGI/STK software are used through numerical investigations to select the orbital parameters that compromise the fulfilment of all the mission requirements.
3. Numerical studies

Table 1 shows the basic properties of the STK scenario. It includes the properties of the scenario, satellite, payload, and ground station. In this scenario, a CubeSat satellite is launched to monitor the territories of Malaysia and to scan its surface. Data and images that collected from the sensors are then transferred to Malaysian Space Centre ground station for processing during the communication sessions as shown in Figure 5.

| Item                          | Value                                                                 |
|-------------------------------|-----------------------------------------------------------------------|
| **Scenario Properties**       |                                                                       |
| Start                         | 22 Jun 2016 04:00:00.000 UTCG                                         |
| Stop                          | +15 days                                                              |
| **Satellite Properties**      |                                                                       |
| (CubeSat)                     |                                                                       |
| Propagator                    | High-Precision Orbit Propagator (HPOP)                               |
| **Orbital Parameters**        |                                                                       |
| Mass, drag area, radiation area | Mass = 1 kg               |
| Drag Area = Radiation Area = 0.02 m² |                                 |
| **Payload Properties**        |                                                                       |
| (NanoCam C1U)                 |                                                                       |
| Sensor Type                   | Rectangular                                                           |
| **Resolution**                |                                                                       |
| Focal length = 0.035 m         |                                                                       |
| Detector Pitch = 0.0032 mm    |                                                                       |
| **Constraints**               |                                                                       |
| Resolution/Ground Sample Distance/Max | 100 m                  |
| **Ground Station**            |                                                                       |
| (Malaysian Space Centre)      |                                                                       |
| Position                      | Latitude = 2.784 deg                                                  |
| Longitude = 101.508 deg       |                                                                       |
| Altitude = 0.005 km           |                                                                       |
| **Coverage**                  |                                                                       |
| Area of interest              | Malaysia                                                              |

Figure 6 and Figure 7 show the basic configuration of the imaging sensor (NanoCam C1U). It is a rectangular CMOS sensor with 35 mm focal length and 2048 x 1536 pixels. The formulas in Figure 6 are used to compute the sensor detector pitch (DP) and vertical and horizontal half angles. This sensor can provide 60 m resolution at 650 km altitude.
It is required here to specify the orbital parameters and sensor configuration to meet the mission requirements mentioned in the previous section. To do that, a series of parametric studies will be run to better understand how the satellite orbit and sensor parameters impact coverage capabilities. For each parametric study, a single design parameter will be run through a sweep of values and coverage statics on each grid shown in Figure 5 will be collected using the Figure of Merit object in STK. The coverage per day statics of the Figure of Merit will be used to determine the minimum, maximum and average values for each grid during the scenario time period. The goal here is to find the optimal configuration of these parameters to best cover the territories of Malaysia.

To determine the impact of inclination of coverage, Figure 8 shows the inclination trade study. Results from this study are expected, the closer from the country latitude, the better coverage capabilities will be. This study gives a better understanding on how to assure maximum coverage of the whole country. The inclination region of interest between 5 and 12 degrees will assure at least few seconds coverage per day. An inclination of 5.5 degree will be selected from this study.
Figure 8. Inclination Trade Study Including Zoom In Part In The Region of Interest.

Figure 9. RAAN Trade Study Including Zoom In Part In The Region of Interest.
Another parameter that might impact the coverage capabilities is the RAAN. Figure 9 shows the RANN trade study. From this study, two regions are interested. One is between 0 and 50 degrees and the other is between 300 and 360 degrees. A 24 degree RAAN is selected from this study to maximize the grid minimum coverage per day.

Altitude or alternatively the classical orbital parameter, semi-major axis, is another parameter that impacting coverage. For this study, semi-major axis is varied form 6,300 km to 7,500 km as shown in Figure 10. As expected, coverage increases rapidly with semi-major axis until certain altitude is reached at which point there is an equally sharp drop off. This due to a resolution constraint of 100 metres. Beyond 7450 km semi-major axis, the sensor can no longer resolve 100 meter objects.

The final orbital parameters considered in this study that might impact coverage capabilities are eccentricity and argument of perigee. Figure 11 and Figure 12 show the trade study of these parameters respectively. From these figures, the data appears to be insensitive to eccentricity and argument of perigee. In summary, the orbital parameters listed in Table 2 are selected to be the initial guess of the influenced parameters that expected to achieve all the mission requirements.

Orbital parameters and sensor parameters have a large impact on coverage capabilities. In order to optimize these parameters, an optimization tool will be employed. Although, each parameter trends are clearly shown on previous analysis, guessing all parameters will be difficult because multiple parameters have a wide range. On previous studies, one parameter was changed at a time. To solve this complex problem, optimization techniques can be very useful. In these optimization algorithms, all the parameters are systematically modified until some goals are achieved. AGI/STK [7] optimizer is an automated tool that utilizes mathematical calculations about a design problem and incrementally attempts to find an optimal solution. The intelligent SEQOPT algorithm in this tool uses surrogate models to accelerate the optimization process. It systematically modifies variables in a Scenario until some objective is met.
**Figure 10.** Semi-major Axis Trade Study.

**Figure 11.** Eccentricity Trade Study.
Figure 12. Argument of Perigee Trade Study.

Table 2. Initial Orbit Parameters.

| Parameter        | Value      |
|------------------|------------|
| Inclination      | 5.5 deg   |
| Semi-major axis  | 7140 km   |
| RAAN             | 24 deg    |
| Argument of Perigee | 0 deg   |
| Eccentricity     | 0 deg     |

Two optimization cases are considered here. The objective for both is to maximize the minimum coverage per day to monitor each grid point on the map considering lighting and resolution constraints. In the first case, the satellite considered to be nadir pointing without attitude manoeuvres capabilities. While in the second one, the satellite has the ability to perform the attitude manoeuvres. The optimal results of both cases are presented in Table 3. It is observed that the attitude manoeuvres capabilities dramatically improve the grid minimum coverage. In both cases, the satellite can achieve more than 10 min communication access time with the ground station. In addition, the 5 years lifetime requirements are met.

Table 3. Nadir and Off Nadir Optimized Parameters.

| Parameter                     | Nadir/Value | Off Nadir/Value |
|-------------------------------|-------------|-----------------|
| Inclination                   | 5.8 deg     | 5.4 deg         |
| Semi-major axis               | 7245.1km    | 7250 km         |
| RAAN                          | 38.9 deg    | 10.5 deg        |
| Grid Minimum Converge         | 13.9 sec    | 104.4 sec       |
| Mean Access duration          | 14.1 min    | 14.2 min        |
| Satellite Lifetime            | > 5 years   | > 5 years       |
| Attitude Capabilities         | None        | ≈28 deg         |

4. Conclusion

In summary, the orbital parameters design trades are presented for a low Earth orbit considering Malaysia as an area of interest. The orbital parameters have been selected to meet all the mission requirements. Trade studies show that altitude, RAAN and inclination have the most impact on these mission requirements. Numerical optimization techniques are employed to optimize the coverage capabilities considering realistic sensor parameters and constraints. These studies show that attitude manoeuvres greatly improve coverage requirements.

References

[1] James B. Campbell and Randolph H. Wynne “Introduction to Remote Sensing,” The Cuilford Press New York, NY, 2001.
[2] J. R. Wertz, D. F. Everett and J. J. Puschell, editors, “Space Mission Engineering: The New SMAD,” Microcosm Press, Hawthorne, CA, 2011.
[3] L. Qiao, C. Rizos and A. Dempster, “Satellites Orbit Design and Determination for the
Australian Garada Project,” Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011), Portland, Oregon, September 20-23, 2011.

[4] Karim Kamalaldin and Mohamed Okasha “Low Inclination Circular Orbits for Remote Sensing Satellites,” Applied Mechanics and Materials, Vol. 629, pp. 298-303, 2014.

[5] GomSpace's systems for cubesats: http://www.gomspace.com/index.php?p=products

[6] Using MATLAB, TheMathworks Company, Inc., Natick, Massachusetts, Version 15.

[7] Satellite Tool Kit, Analytical Graphics, Inc., Malvern, PA.