Opportunity of Near Equatorial Orbit (NEO) for Thailand's Earth Observation System

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Manuscript received October 24 27, 2016
Revised December 5, 2017

ABSTRACT

This paper reviews the suitable satellite orbit for remote sensing applications, particularly over the near equatorial regions. Generally, the selected satellite orbit for observing the Earth is the Sun synchronous orbit (SSO). However, there is some limitation of SSO to serve the requirements of critical circumstances for disaster or defence events, such as high visibility and high-rate revisiting over the target area. One possibility is to make use of a low-inclined orbital plane. Nevertheless, this orbit type provided the intermittent of revisiting time. This may not exactly meet the full requirements. This paper reviews approaches of making use of Near Equatorial Orbit (NEO) associated with other orbit types for observing the region in low latitude near the Earth equator.

***Keywords**: Satellite Orbit, Near Equatorial Orbit (NEO), Earth Observation System, Satellite Revisit Time*

1. INTRODUCTION

Over the past decade, the economics in South East Asia region has rapidly growth. Nevertheless, the socioeconomics and environmental problems become the substantial issues which impact to people life and communities. In order to handle and mitigate these, several countries in this region have making use of the Geo-Informatics solutions from satellite image and ground informatics in various fields such as agricultural management, disaster monitoring and mitigation, land-use management, water management, urban planning, and defense purposes etc. Recently, it was a first time that the NESD Board of Thailand (National Economic and Social Development) agreed to push forward the space technology in the current national plan for developing the country with awareness of socioeconomics and environmental impacts [1]. This affirms that the low Earth orbit satellite has played a major role in remote sensing, particularly for very large area of observations.

To serve the user requirements, the various resolutions of spatial, spectral, temporal and radiometric of satellite images are required. However, the selected orbit type and its altitude would affect these resolutions. Traditionally, most of the Earth observation satellites will be launched into the Sun synchronous orbit (SSO). The SSO was a specific orbit type which allowed the satellite orbits over the same area on the Earth at the same local solar time for each day [2]. Therefore, the inclined orbital plane has to relate its altitude in order to be keeps the SSO condition. The relationship between altitude and inclination angle is shown in Fig. 1, and its mathematical formulation was expressed in [3].

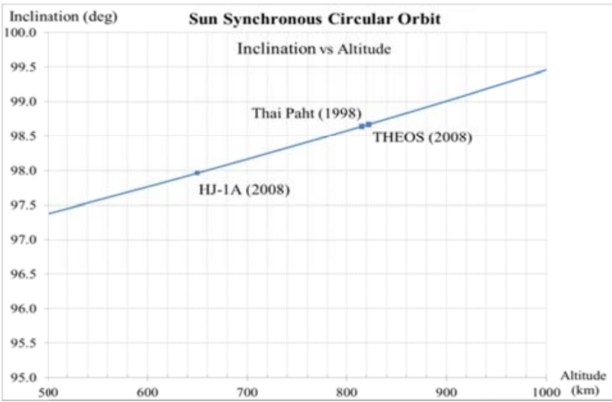

***Fig. 1** Relationship between altitude and inclination angle for SSO*

Technically, the SSO provides plausible Sun angle for satellite in taking Earth and weather photos. The direction of taken image relative to the Sun is the one major factor for image processing and mapping in Geo-Informatics applications. For typical SSO at 800 km altitude, inclination 98 degrees and orbital period of 100 minutes, the repeat cycle over the same area at nadir pointing was approximately 26 days [4]. However, there were two possible ways for off-nadir observation for target area [5]. The first way was that the swath width of the optical sensor was wide enough to allow the off-nadir areas in its field of view. The second way was making use of maneuver capacity for the satellite or EOS sensor. The recommended field of regard (FOR : largest incidence angle of any covered target within revisit time) for very high resolution (VHR) optical satellite, shall not exceed 30 degrees on nominal acquisition [6]. However, for some applications which required very high accuracy on mapping, therefore the Fig. of FOR will be significantly decreased. The drawback of SSO was the low number of passes over the target areas during the daylight. It was approximately 2-3 times per day.

In practical operations for satellite based observations, each category of GIS application required a different revisit time and spatial resolutions as shown in Fig. 2 [7].

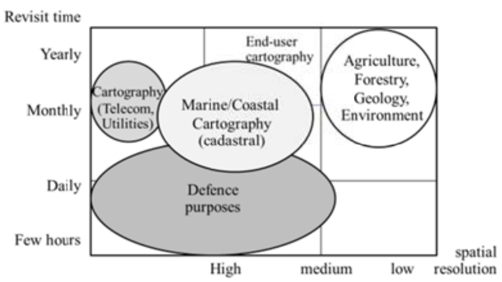

Fig. 2 *Typical Revisit Time vs Spatial Resolutions per categories of applications*

As presented in Fig. 2, the defence operations required the high resolution image and high-rate revisiting over the target area. For marine/coastal cartography, the high-medium resolution image and moderate revisit time were required. Whereas the applications of agriculture, forestry, geology and environment required low resolution image and moderate revisit time.

To cope with the high revisiting requirements, particularly for critical circumstances, the low inclination orbit for GI (Geo-Informatics) applications is one possibility to meet this requirement. This paper will review the opportunity of near equatorial orbit (NEO) for Thailand's earth observation system.

2 THAILAND'S SPACE ACTIVITIES

Space activities in Thailand have initiated since 1967 as shown in Fig. 3. However, apart from satellite communications activities, Thailand has experienced in making use of foreign satellites for Earth observations since 1971. However, in July 1998, Thai Paht, the first Thai micro-satellite was launched into SSO, 815 km altitude and 98.64 degrees inclination. The Thai-Paht programme was collaboration between Mahanakorn University of Technology (MUT), United Communication Industrial Ltd. (UCOM) and University of Surrey. The 50 kg class micro-satellite carried the multi-spectral cameras and digital store-&-forward communications payloads for education and technology transfer proposes. It was a medium resolution (15 metre) of multi-spectral (MS) optical system carried onboard. The satellite images were used in agriculture applications and disaster monitoring. The onboard DSP (digital signal processing) was used to experiment the digital communications.

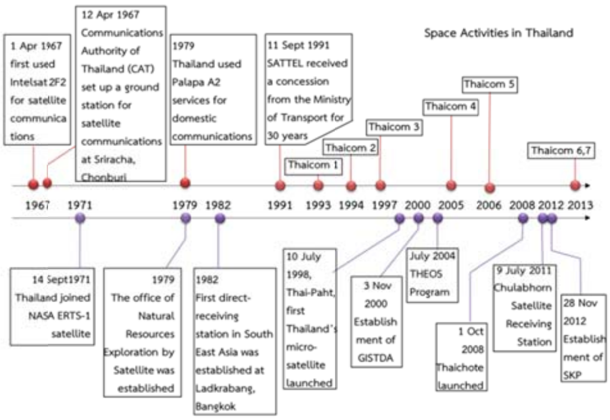

Fig. 3 Space Activities in Thailand since 1967

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In 2008, Ministry of Science and Technology by the Geo-Informatics and Space Technology Development Agency (GISTDA) launched the mini-satellite Thaichote (under THEOS program) into SSO, 822 km altitude and 98.76 degrees inclination. The high resolution (2 metre) PAN optical system was carried onboard THEOS for GIS applications. The THEOS's satellite images are widely used in various applications such as agriculture and land use, disaster monitoring, water management, urban planning and defence proposes.

For HJ-1A, the Small Multi-Mission Satellite (SMMS) of Asia Pacific Space Cooperation Organization (APSCO), the onboard optical system provides the hyper-spectral images with spatial resolution 100 metre. The former ministry of Information and Communication technology (MICT) provided the funding for Ka band experimental payload. The HJ-1A was launched in September 2008. The satellite images can be daily accessed via the

Chulabhorn Satellite Receiving Station (CSRS), which is located at Kasetsart University, Bangkok, Thailand.

3 PREVIOUS MISSIONS OF LOW INCLINATION ORBIT

The reference [8] reviewed the handbook of Committee on Earth Observation Satellites (CEOS). that approximately 80 percent of all satellite missions in low Earth were sun-synchronous; 10 percent were non sun-synchronous; 7 percent were inclined between 40-80 degrees, and only 3 percent had an inclination less than 40 degrees.

In addition, the database of low inclination from several sources [9-12], can be categorised into 3 groups; Earth observation missions, communication missions and scientific missions.

***Table 1** Earth Observation Missions (Low Inclination)*

Launch	**Owner**	**Mission**	**Inclination**	**Altitude (km)**
Feb 1967	CNES	Diadème1 & 2	39.4°	550–1,731
Feb 1993	INPE (Brazil)	SCD 1	25˚	750
Nov 1997	NASA/JAXA	TRMM	35˚	402
Oct 1998	INPE (Brazil)	SCD 2	25˚	750
July 2009	ANGKASA/ ATSB	RazakSAT	9 ˚	660-690
Oct 2011	CNES/ISRO	Megha-Tropiques	20˚	865
Oct 2011	Indian Institute of Technology	JUGNU	20º	837-864
Oct 2011	Sri Ramaswamy Memorial University	SRMSAT	20º	849-866
Sept 2015	LAPAN	LAPAN-A2 (IO-86)	6º	631-650
Dec 2015	ST Electronics	TeLEOS-1	15º	550
Dec 2016	University of Michigan Southwest Research Institute	CYGNSS (8 satellites)	35º	514-536

The above information insists that 28 missions have been flown in low orbital inclination since 1960. Particularly, the 70 percent of all were launched in last 15 years. In addition, 93 percent were the Earth observation and scientific proposes.

For Earth observation, the remarkable mission was the TeLEOS-1. The low inclination of 15 degrees at altitude of 550 km increased imaging opportunities in comparison to the traditional SSO. The orbital period was 96 minutes. It provided the one metre resolution imagery with mean revisit time 12 to 16 hours [13]. The TeLEOS-1 provided availability 6 daylight imaging passes per day with 3 imaging modes; multi-point, strip and area. The satellite images can be used for various applications covering urban planning and infrastructure management for smart cities, environmental and resources monitoring, humanitarian aid and disaster relief (HADR), maritime security and safety, border and territorial water protection.

***Table 2** Communication Missions (Low Inclination)*

Launch	Owner	Mission	Inclination	Altitude (km)
Oct 1960	USAF	Courier 1B	28º	938-1,237
Feb 2016	Nagoya University (NU) and Mitsubishi Heavy Industries (MHI)	CHUBUSAT 2, 3	31º	558-577

***Table 3** Scientific Missions (Low Inclination)*

Launch	Owner	Mission	Inclination	Altitude (km)
Dec 1968	NASA	OAO 2	35º	735-743
Aug 1972	NASA	OAO 3	35º	695-705
Apr 1990	NASA	Hubble	28º	538-542
Feb 2002	NASA	RHESSI	38º	472-487
Nov 2004	NASA/PSU	SWIFT	21º	547-563
July 2005	JAXA/ NASA	SUZAKU (ASTRO-EII)	31º	515-521
Apr 2007	ASI	AGILE	2º	467-485
Jun 2008	NASA/U.S. Department of Energy	FGRST (GLAST)	26º	525-542
Sept 2011	CNSA	Tiangong-1	43º	314-338
Jun 2012	NASA/JPL	NUSTAR	6º	597-613
Aug 2012	NASA	RBSP A, B	10º	618-30,414
Sept 2013	JAXA	HISAKI (SPRINT-A)	30º	952-1,155
March 2015	NASA	MMS	24º	1498 - 153,548
Sept 2015	ISRO	ASTROSAT	6º	635-648
Feb 2016	JAXA	ASTRO-H (HITOMI)	31º	563-581

The other impressive missions were the Megha-Tropiques and CYGNSS. The Megha-Tropiques (MT) at 20 degrees inclination orbit provided 4-6 observations per day (within ± 10–15° latitude band), for studying the convective systems (water cycle and energetic exchanges) in the tropical atmosphere [14]. To design the inclined orbit for MT, 3 characteristics of engineering challenges during the realisation phase were taken into account; power generation, star sensor configuration and thermal control. Three payload instruments; MADRAS (Microwave Analysis and Detection of Rain and Atmosphere Systems), SAPHIR (Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie) and ScaRaB (Scanner for Radiation Budget) were accommodated onboard MT. The MADRAS was a multi-frequency radiometer /imager for measuring precipitation and cloud properties. The SAPHIR was a multi-channel cross-track millimeterwave sounding instrument for measuring water vapor profiles in the troposphere. The ScaRaB was a cross-track scanning radiometer.

For CYGNSS mission, all eight satellites in the orbital inclination at 35 degree measured the GPS signals reflected by the ocean surface. Each satellite has capable to measure 4 simultaneous reflections, and result in 32 wind measurements per second across the globe. The ocean surface wind speed was used in the studying of tropical cyclone [15]. The key characteristics of CYGNSS observatory were power and AODCS (attitude/orbit determination and control system) subsystems. The operations in space, 8 CYGNSS observatories received direct and reflected signals from GPS satellites. The direct signals provided the CYGNSS observatory positions, while the reflected signals respond to ocean surface roughness, from which wind speed was retrieved.

4. REVIEWS APPROACHES

To cover the whole part of Thailand and achieve more revisiting per day, the satellite orbit has to capable for observing the region along the equator within 30 degrees latitude as shown in Fig. 4.

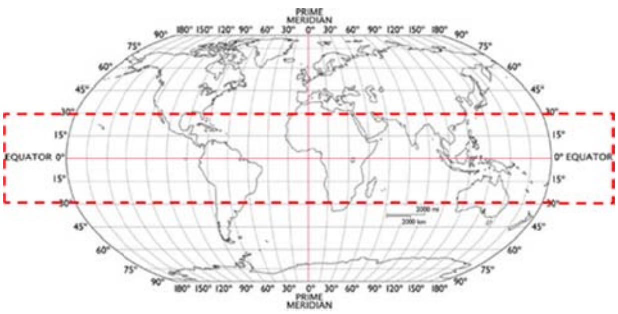

Fig. 4 *World map with latitude and longitude Source : https://www.theflatearthsociety.org*

The reference [16] posed a constellation of two orbital planes for 8 satellites to provide 24 hours of near-real time SAR (Synthetic Aperture Radar) images, over the equatorial region. The orbit design was a low orbital inclination at 10 degrees, and 700 km altitude. The first plane consisted of two active satellites separated in time. The second plane consisted of six passive satellites. To perform SAR interferometry, each active satellite was allocated for three slave satellites in order to collecting the returned echoes of signals which transmitted by the active satellite. Since this mission covered 45 countries within the equator region, therefore five ground segment sites were required along the equator region. The maximum time between successive contacts with ground station must be less than 10 minutes.

Nevertheless, the implementation of the proposed mission in [16] had to consider in various issues. Firstly, based on the technical issue of satellite system designing, the power demand per orbit for each satellite had to be considered for operating SAR interferometry. Secondly, the ground operations needed to coordinate with several countries. These required the collaboration as consortium or inter-government agency in order to gain the maximum utilisation of this mission. The third issue was the budget for capital expenditure and operational expenditure of the mission. There were questions for the program management at the beginning.

The reference [17] proposed the a single Earth observation satellite in Near Equatorial Orbit (9 degrees inclination) which provided user a Mean Revisit Time (MRT) of about 12 to 16 hours. The TeLEOS-1 mission provided variety of imaging modes such as multi-point mode, strip mode and area mode etc. For the operation, the TeLEOS-1 mission CONOPS (CONcept of OPerationS) adopted a centralised satellite approach to suppfort the customer. The ground receiving station of partner operated along with main ground station for optimising payload utilisation per orbit, and providing assured operational continuality and enhanced customer service experience. To cover all part of Thailand, the 45 degrees maximum tilted angle of satellite platform can be used to support the imaging. However, for agriculture and urban mapping applications, the image processing may face the difficulty on the classifications.

Another approach was proposed by GISTDA (Geo-Informatics and Space Technology Development Agency) Thailand, THEOS-2 program. In order to observe the whole part of Thailand and meet the requirement on periodic revisit time regularly, the combination of satellites in low inclination orbit and SSO was proposed. The substantial studies were described in [18, 19]

The satellite-1 (or THEOS) was simulated in SSO (red line) at 822 km altitude, 98.76 degree inclination and local solar time at descending node 9:30-10:00 AM. The satellite-2 was simulated in 30 degrees inclined orbit (yellow line) at 600 km as shown in Fig. 5.

Two scenarios were simulated in [18]. Scenario 1, the target was Bangkok, the three months span of simulation showed that the revisit time of satellite-1 (SSO) was regularly occurred. By contrast, the low orbital inclination of satellite-2 provided the intermittent highly revisiting. Furthermore, the study of [19] showed that the revisit time for SSO was 4-5 time per day, whereas the revisiting for 30 degrees inclination was taken place up to 8-9 times per day. If the angle of inclination was decreased, the number of revisiting was increased.

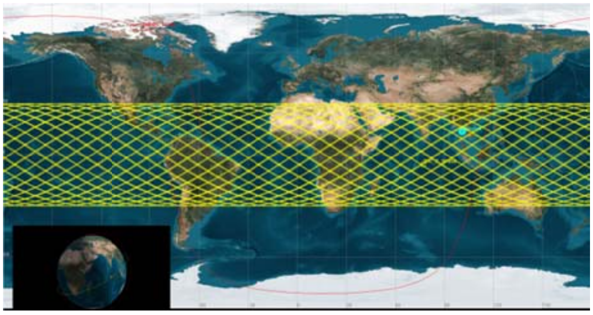

Fig. 5 *An approach for combination of satellites in low inclination orbit and SSO*

For scenario 2, the target was in the Northern part of Thailand at 30 degrees latitude. The simulated results showed that the satellite-2 provided the high rate of revisiting time when compared to the case of low latitude target. However, the revisiting was intermittent and stretched out more than the case of low latitude target.

From simulated results, therefore the combination of low orbital inclination and SSO provided the revisiting regularly. The low orbital inclination provided the high rate of revisiting, whereas the SSO filled the gap of disappearing.

<u>Extensive Considerations</u> :

The flight dynamics for SSO and low inclined orbit satellites can be adapted from the implemented system for Thaichote [20], and THEOS-2 [19]. In order to maintain the orbit accuracy in between the eclipse points, the technique of solving the ephemerid at the entrance and exit point of eclipse can be used to readjust the orbit propagator [21]. In order to compute the revisit time, the new technique for designing the desired revisit time and minimum tilt angle was introduced [22]. This new technique was based on the Bezout equation and taken the gravitational second zonal harmonic into account. In addition, the small offset was replaced by a multiple of the minimum interval on equator when analysing the revisit time of remote sensing satellites. The advantage of this technique was that the relationships between altitude and minimum tilt angle can be quickly obtained when the revisit time was determined. Furthermore, this technique also calculated the side-lap and the range of altitude for providing the orbit solutions which met the mission requirements.

Power generation is another technical issue that has to be considered. Since the inclined orbit configuration, the power generated will be reduced by inclination angle and Earth tilted at 23.5 degrees. In addition, the pointing of solar panels will effect to the overall of generated power. For designing the VRH (very high resolution) of optical satellite system, several issues have to be considered. The reference [23] presented several characteristics of VHR optical satellites for topographic mapping such as orbit type (altitude and inclination), payload performance (GSD, spectral band, swath, ratio of panchromatic and multispectral), AODCS performance (pointing accuracy, attitude determination accuracy, ground location accuracy) and propulsion performance etc. The linkage of all analysed data of the power budget, communication link budget, AODCS characteristics and payload characteristics was very important for NEO mission.

The reference [19] has been extensive studied in detail of space environment effects to satellite subsystems, particularly over the region of South Atlantic Ocean. Another source for space environment in the near-equatorial low earth orbit was the result from the experimental onboard the RazakSAT-1 satellite [24]. It was pre-concluded that the estimated monthly fluxes of GCR (Galactic Cosmic Rays) and trapped particles from the SPENVIS (Space Environment Information System) models did not experience any anomalies during Razaksat-1 three-year mission. However, the further study on the satellite materials was presented by [25]. Three materials of aluminum (Al), gallium arsenide (GaAs) and silicon (Si) were used in the sophisticated simulation. The total ionizing dose (TID) and non-ionizing dose (NIEL) were calculated for a three-year period. The results showed that GCR traveled at longer tracks and produced more secondary radiation than trapped protons. Al turned out to receive the lowest total dose, while GaAs showed to be susceptible toward GCR than Si. The research on environmental concerns associated with material was the new approach to study the effect of space environment to spacecraft.

5. CONCLUSIONS

This paper reviewed the previous researches on the utilisation of low orbital inclination. As shown in Table 1, 2 and 3, in last 15 years, more than 20 missions have been flown in low orbital inclination. In addition, the key characteristics in the context of orbit type, flight dynamics, AODCS performance, power budget and space environment were reviewed. These pointed out that Near Equatorial Orbit (NEO) was plausible for observing the region close to Earth equator. The different approaches in such ways of single satellite or constellation satellites were reviewed and analysed in both academic and management views. The combination of low orbital inclination and SSO would be one of the plausible approaches for Earth observation satellite based system. This approach provides high revisiting regularly under the reasonable and realistic considering issues on the orbit design, power budget, space environment, ground operation concern, and program budget etc. Nevertheless, in the near future, this can verify the concept of the approach with real practical operation of THEOS-2 program.

6. ACKNOWLEDGMENT

An author would like to thank GISTDA for providing information of Thailand space program.

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