Observation of GEO Satellite Above Thailand’s Sky

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Abstract. The direct observations of Geostationary Orbit (GEO) satellites above Thailand’s sky by 0.7-meters telescope were proceeded at Inthanon Mt., Chiang Mai, Thailand. The observation took place at night with Sidereal Stare Mode (SSM). With this observing mode, the moving object will appear as a streak. The star identification for image calibration is based on (1) a star catalogue, (2) the streak detection of the satellite using the software and (3) the extraction of the celestial coordinate of the satellite as a predicted position. Finally, the orbital elements for GEO satellites were calculated.

1. Introduction
There are four common categories of satellite’s orbits which are classified by the altitude of satellites [1], as shown in Figure 1. First, the Low-Earth Orbits (LEO) are at altitudes between 200 and 1200 km, with low or moderately low inclination to the equatorial plane, and moderate eccentricity. Second, the Medium-altitude-Earth Orbits (MEO) are at attitudes ~1200-35790 km, with inclinations in the range of 45° to 60°. Third, the Geostationary-earth orbits (GEO) are at the attitude ~35790 km, with zero inclination. Last, the Highly Elliptical Orbits (HEO) are at attitude above 35790 km, which is very near to the earth at closest approach (perigee) and is very far away on the opposite side of the orbit (apogee).

Figure 1. Four type of satellite’s orbits [1]
GEO is the orbit whose orbital period, at certain distance from the centre of the earth, is equal to the time taken by Earth to complete one rotation around its axis [2]. The importance of an artificial satellite in this orbit is to provide intercontinental communication services because the satellite would appear to be stationary with respect to a location on the Earth’s surface. Thus, this satellite makes a possible host of communication services [2], not only as a communication GEO ring, but also as a valuable transport for scientific mission.

There are two common methods for optical satellite tracking system. The first one is Sidereal Stare Mode (SSM), which is used to find unknown satellite, whose position is predicted at the current time. The second mode is Track Rate Mode (TRM), which is used for satellite with Two-Line Element (TLE). Accordingly, the precise celestial coordinate of the satellite can be extracted from acquired images using detection methods. In additions, the new orbital parameters can be generated and the TLE dataset can be updated [3].

In this paper, we chose SSM to observe GEO satellites along the equator above Thailand’s sky by using 0.7 m telescope with CCD camera at Inthanon Mt., Chiang Mai, Thailand.

2. Observation and Data Analysis
Observations were take place in January 2017 with 0.7 m telescope at Inthanon Mt., at 2550 meters above sea level. SSM was used as observational method for satellites orbiting along the equator where most GEO satellites are locating. According to the air condition then, the plan was to start searching from altitude above 30 degree. The sidereal tracking was used in corresponding to the altitude of telescope, where the pointing changes as a function of the time but unchanged with respect to the Right Ascension (RA) and Declination (Dec). As a result, all images are in the same equatorial position and the same background. Furthermore, the image of moving object would appear as a streak line. Each image was taken with only 10 seconds exposure time because satellite moves very fast across the field of view.

Next the astrometry technique; LPSR (Least Square Plate Reduction), was used to obtain object’s coordinate in order to compare with well-known reference stars in catalogues available on astrometry.net. The observed images were analysed on XParallax VIU software, as shown in Figure 2. Next RA and Dec position at the center of streak line and length of streak line (in angular size) were calculated in each frame. In this study, streak lines were found in 254 images.

![Image](image-url)

*Figure 2.* Coordinate identification of streak line (left) with the linear profile (right) of the line’s brightness analyzed by XParallax VIU software.

3. Result and Discussion
The orbital element of satellite was calculated based on following method. Considering the length of streak line, we can calculate the angular velocity ($v_{rad}$) with Equation 3.1, where $\Delta \theta$ is streak line’s length (in radian), and $\Delta t$ is exposure time (in second).
\[
\nu = \frac{\Delta \theta}{\Delta t}
\]  

(3.1)

Mean motion \(n\) can be obtained from \(\nu\) in unit of rev/sec. Next, the period of satellite \(T\) can be expressed in term of angular velocity as Equation 3.2,

\[
T = \frac{2\pi}{\nu}
\]  

(3.2)

Since GEO satellite can be assumed to have circular orbit (eccentricity; \(e = 0\)), therefore its semi-major axis \(a\) is approximately equal to distance from Earth’s center to the satellite \(r\). Therefore, Kepler’s Third Law can be rewritten as shown in the Equation 3.3, where \(T\) is period (in second), \(G\) is Universal Gravitational Constant \((6.67259 \times 10^{-11} \text{ m}^3 \text{kg}^{-1} \text{s}^{-2})\) and \(M_{\text{earth}}\) is mass of the earth \((5.974 \times 10^{24} \text{ kg})\) [2].

\[
d = \left(\frac{GM_{\text{earth}}T^2}{4\pi^2}\right)^{\frac{1}{3}}
\]  

(3.3)

After the calculation, the orbital elements were matched with satellite database, NORAD, to identify the satellite’s name. In this work, 48 GEO satellites’ names were identified. The results from the calculation of satellites’ orbital elements are shown in Table 1. According to the result, our calculated orbital elements are very close to the satellite database. For one explanation of this slight difference, we assumed those satellites to be perfectly geostationary satellites, whose orbits are expected to be perfectly circular. Therefore the eccentricity \(e\) and inclination \(i\) were considered to be zero. However, the remain orbital elements, RA of ascending node \(\Omega\), argument of perigee \(\omega\) and mean anomaly \(\nu\), are undefined and should be the explanation for the difference of our result from the database.

4. Conclusion

Based on the observation with Sidereal Stare Mode (SSM), based on image calibration, a star catalogue, and the streak detection of the satellite, the star identification discovers 254 images with streak lines. Next, the extraction of the satellite’s celestial coordinate was performed and resulted in predicted position. Finally the orbital elements were calculated. Since GEO satellite is assumed to have circular orbit, therefore the eccentricity \(e\) should approximately be zero and geostationary satellite inclination \(i\) should be zero as well. As a result, RA of ascending node \(\Omega\), argument of perigee \(\omega\) and mean anomaly \(\nu\) are undefined for this work, which can be proceeded for future work. On the other hand, the mean motion \(n\), period \(T\) and semi major axis \(a\) can be calculated as shown in Table 1.

References

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Table 1. Results from the calculation of satellites’ orbital elements.

| Satellite’s name | Mean motion (rev/day) | %err | Period (day) | %err | Semi major axis (km) | %err |
|------------------|-----------------------|------|--------------|------|----------------------|------|
| HIMA WARI-7      | 0.98618328            | 1.65 | 1.01425      | 1.70 | 42640.38             | 1.13 |
| SKYMUSTER II     | 0.99880798            | 0.38 | 1.00121      | 0.39 | 42275.12             | 0.26 |
| SUPERBIRD-C2     | 0.98996720            | 1.27 | 1.01020      | 1.30 | 42527.44             | 0.86 |
| APSTAR-9         | 0.99435960            | 0.84 | 1.00572      | 0.85 | 42401.68             | 0.56 |
| HIMA WARI-9      | 0.98666014            | 1.60 | 1.01367      | 1.64 | 42624.37             | 1.09 |
| HIMA WARI-8      | 0.99488873            | 0.78 | 1.00523      | 0.80 | 42387.81             | 0.53 |
| SKYMUSTER        | 1.00340356            | 0.07 | 0.99665      | 0.06 | 42146.41             | 0.04 |
| EXPRESS-AM5      | 1.00148449            | 0.12 | 0.99855      | 0.13 | 42200.01             | 0.08 |
| EXPRESS-AT2      | 0.99314366            | 0.95 | 1.00692      | 0.97 | 42435.77             | 0.64 |
| APSTAR-5         | 0.99370605            | 0.90 | 1.00641      | 0.91 | 42421.13             | 0.61 |
| JCSAT-2A         | 1.00299617            | 0.03 | 0.99702      | 0.02 | 42157.15             | 0.02 |
| APSTAR-6         | 1.00043378            | 0.23 | 0.99960      | 0.23 | 42229.66             | 0.15 |
| JCSAT-5A         | 1.00366082            | 0.09 | 0.99636      | 0.09 | 42138.43             | 0.06 |
| VINASAT-1        | 1.00410690            | 0.14 | 0.99592      | 0.14 | 42126.03             | 0.09 |
| VINASAT-2        | 1.00157232            | 0.11 | 0.99844      | 0.12 | 42197.09             | 0.08 |
| ZHONGXING-20A    | 0.99482311            | 0.79 | 1.00522      | 0.79 | 42387.86             | 0.53 |
| CHINASAT-1A      | 1.00060433            | 0.21 | 0.99940      | 0.21 | 42224.11             | 0.14 |
| LAOSAT 1         | 1.00225042            | 0.05 | 0.99777      | 0.05 | 42178.22             | 0.03 |
| COMS 1           | 0.99301334            | 0.97 | 1.00706      | 0.98 | 42439.46             | 0.65 |
| JCSAT-3A         | 1.00323377            | 0.05 | 0.99680      | 0.05 | 42150.72             | 0.03 |
| JCSAT-RA         | 1.00331995            | 0.06 | 0.99672      | 0.06 | 42148.56             | 0.04 |
| CHINASAT-6A      | 1.00225791            | 0.05 | 0.99776      | 0.05 | 42177.85             | 0.03 |
| JCSAT-13         | 1.00133186            | 0.14 | 0.99868      | 0.14 | 42203.76             | 0.09 |
| ASIASAT 4        | 0.99759382            | 0.51 | 1.00241      | 0.52 | 42309.06             | 0.34 |
| ASIASAT 6        | 0.99779560            | 0.49 | 1.00221      | 0.49 | 42303.29             | 0.33 |
| THAICOM 4        | 1.00167342            | 0.10 | 0.99834      | 0.11 | 42194.28             | 0.07 |
| TELKOM 2         | 0.99952783            | 0.32 | 1.00048      | 0.32 | 42254.65             | 0.21 |
| ABS-7            | 0.99994116            | 0.28 | 1.00007      | 0.28 | 42243.07             | 0.19 |
| KOREASAT 6       | 0.99935113            | 0.34 | 1.00067      | 0.34 | 42259.90             | 0.23 |
| ZHONGXING-6B     | 1.00145331            | 0.13 | 0.99855      | 0.13 | 42200.35             | 0.09 |
| KOREASAT 5       | 1.00051583            | 0.22 | 0.99950      | 0.22 | 42226.88             | 0.15 |
| PALAPA D         | 1.00309481            | 0.04 | 0.99693      | 0.04 | 42154.41             | 0.02 |
| CHINASAT 10      | 1.00652304            | 0.38 | 0.99352      | 0.38 | 42058.40             | 0.25 |
| N-SAT-110        | 1.00038364            | 0.23 | 0.99963      | 0.23 | 42330.71             | 0.16 |
| BSAT-3C          | 1.00049994            | 0.22 | 0.99951      | 0.22 | 42227.14             | 0.15 |
| BSAT-3B          | 1.00696621            | 0.42 | 0.99308      | 0.42 | 42046.05             | 0.28 |
| NSS-11           | 0.99953692            | 0.32 | 1.00046      | 0.32 | 42254.14             | 0.21 |
| SES-7            | 1.00309042            | 0.03 | 0.99700      | 0.03 | 42156.66             | 0.02 |
| TELKOM 1         | 1.00190612            | 0.08 | 0.99810      | 0.08 | 42187.50             | 0.05 |
| GAOFEN 4         | 1.00194791            | 0.08 | 0.99808      | 0.08 | 42186.86             | 0.05 |
| EXPRESS-AM3      | 1.00406824            | 0.14 | 0.99595      | 0.14 | 42126.93             | 0.09 |
| ASIASAT 5        | 0.99768831            | 0.50 | 1.00233      | 0.50 | 42306.51             | 0.34 |
| CHINASAT 11      | 1.00484000            | 0.21 | 0.99518      | 0.21 | 42105.18             | 0.14 |
| EXPRESS-AM33     | 0.99901267            | 0.36 | 1.00099      | 0.37 | 42268.92             | 0.25 |
| SKYNET 5A        | 0.99976862            | 0.29 | 1.00026      | 0.30 | 42248.22             | 0.20 |
| NSS-6            | 1.00198793            | 0.07 | 0.99802      | 0.07 | 42185.40             | 0.05 |
| SES-8            | 1.00456704            | 0.18 | 0.99545      | 0.18 | 42112.97             | 0.12 |