Accuracy Assessment of Azimuth, Elevation, and Time data resulted from using actual TLE and simulated-outdated TLE for tracking LAPAN-A2 Satellite

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Abstract

This study aims to assess the pointing accuracy of a directional antenna at a ground station using outdated Two-Line Element sets (TLEs) to track an equatorial Low-Earth Orbit (LEO) satellite, LAPAN-A2, using AGI System Tool Kit (STK) software by analyzing the Azimuth, Elevation, and Time-lapse (AET). Simulations were performed using 1, 3, 6, and 12-month outdated TLEs. Validation was successfully conducted at the initial work by comparing the orbital parameter data extracted from n2yo.com to the STK simulation results using an updated TLE. It was found that maximum pointing errors using 1, 3, 6, and 12-month outdated TLEs, respectively, were: for the Azimuth 32º, 38º, 167º, and greater than 173º; for the Elevation: 5º, 8º, 7º, and greater than 73º; for the Time-lapse: 24, 35, 488, and 1052 seconds. It can be argued that the maximum pointing errors for up to the three-month outdated TLE are considered small such that a good communication quality between the ground station with a standard directional antenna could still be feasible. However the results of this study is limited only for a selected location in Central Java province in Indonesia. These findings have important implications for real-time satellite tracking when the ground station location becomes remote and disconnected from the internet network due to certain circumstances, such as natural disasters or other kinds of disruption, in which updating TLEs is not possible for a while.

Keywords: leo satellite; lapan-a2; stk; tle; tracking antenna

Abstrak

Penelitian ini bertujuan untuk menilai akurasi antena penjejak di stasiun bumi menggunakan Two-Line Element set (TLEs) yang tidak diperbaharui untuk melacak satelit ekuatorial Low-Earth Orbit (LEO), LAPAN-A2, menggunakan AGI Systems Tool Kit (STK) perangkat lunak dengan menganalisis Azimuth, Elevation, dan Time-lapse (AET). Simulasi dilakukan dengan menggunakan TLE yang sudah kadaluarsa 1, 3, 6, dan 12 bulan. Validasi berhasil dilakukan pada pekerjaan awal dengan membandingkan data parameter orbital yang diekstraksi dari n2yo.com dengan hasil simulasi STK menggunakan TLE yang diperbarui. Ditemukan bahwa kesalahan penunjuk maksimum yang masing-masing menggunakan TLE kadaluwarsa 1, 3, 6, dan 12 bulan adalah: untuk Azimuth 32º, 38º, 167º, dan lebih besar dari 173º; untuk Ketinggian: 5º, 8º, 7º, dan lebih besar dari 73º; untuk Time-lapse: 24, 35, 488, dan 1052 detik. Dapat dikatakan bahwa kesalahan maksimum penjejakan untuk TLE yang sudah tidak diperbaharui hingga tiga bulan dianggap kecil sehingga kualitas komunikasi yang baik antara stasiun bumi dengan antena pengarah standar masih dapat dilakukan. Namun hasil penelitian ini terbatas hanya pada lokasi terpilih di provinsi Jawa Tengah di Indonesia. Temuan ini memiliki implikasi penting bagi pelacakan satelit real-time ketika lokasi stasiun bumi menjadi jauh dan terputus dari jaringan internet karena keadaan tertentu, seperti bencana alam atau gangguan lainnya, sehingga pembaruan TLE tidak dapat dilakukan untuk sementara waktu.

Kata kunci: satelit leo; lapan-a2; stk; tle; antena penjejak

1. Introduction

Indonesia, located off the coast of mainland Southeast Asia, is an archipelagic country with geographical and topographical conditions, consisting of many islands with plains and mountains [1]. This geography creates rural and remote areas within the country, making it difficult for all Indonesian areas to have good and equivalent access to the internet and communications. Many rural and remote regions within developed areas lack reliable, high-quality internet connectivity. Deficiencies of internet use in rural and remote regions severely affect well-being, education, information, and communication in those areas [2] . The use of radio networks in Indonesia is more straightforward and accessible in some regions [1]. In this paper, research is carried out to solve those problems using a Low-Earth Orbit (LEO) Satellite as a liaison for communication in rural and remote areas [1] [3].

A satellite is a natural sky object or artificial man-made machine that revolves around a planet. Artificial satellites are machines launched into Earth orbit for surveillance, remote sensing, communication, and many more. The altitude at which satellites revolve around Earth allows them to cover more area on Earth's ground and collect more data at the same time. Based on orbit altitude, satellites can be classified into three types: Geostationary Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO) [4]. LEO satellites have circular (or elliptical) orbits at an altitude of 250–2000 km from the Earth's surface. Depending mainly on the satellite's altitude, the orbital period varies in the 90-120-minute range. Due to the low altitude of the LEO satellites, their speed is very high (>25,000 km/h), and they can circle the Earth in 12–16 revolutions per day. LEO satellites experience at least 12 to 16 periods of sunlight and nighttime in 24 hours. As a result, in LEO orbit, the maximum in-view period the satellite is above the local horizon for an observer on Earth is up to 20 minutes. This visibility time is used to transfer data and images to selected ground stations positioned at strategic locations [5] [6].

Indonesia has an equatorial LEO satellite called LAPAN-A2, also known as LAPAN-ORARI, a mitigation disaster satellite with a mission purpose for remote sensing, surveillance, and amateur radio communication/voice repeater [7]. Amateur radio communication/voice repeater is used as disaster mitigation and for alternative communication during a disaster because widespread damage can cause an interruption in mobile and fixed phone communication lines [8]. The disruption of communication lines can delay first aid activities, such as medical and relief supplies, to evacuate and rescue the survivor. To be able to use the LAPAN-A2 Satellite for communication, an internet connection is needed to access the recently updated TLE (Two-Line Element set) from the NORAD (North American Aerospace Defense Command) website server [9].

TLE consists of two-row data with a unique format containing an orbital property of the satellite that can be used for predicting orbital satellites in the next period. This TLE data can change daily because it adapts to the evolving data from NORAD radar, whether the TLE changes can be hourly, daily, or three days, etc. The change in the TLE data might be more substantial for LEO satellites compared to MEO and GEO satellites since the atmospheric drag effect is more prominent in lower altitudes. Due to the situation, conditions, and location when a natural disaster makes communication access and internet connection limited to update the latest TLE, it needs to be tested whether the TLE changes affect the accuracy of data from the movement of satellite orbits. In their research, Afgianto et al. [10] experimented with making a satellite tracking control system based on updated TLE calculations. Nugroho et al. [9] studied the impact of outdated TLE for tracking the LAPAN-A2 and LAPAN-A3 satellites by determining the propagated position errors. However, there was no analysis of the consequence of those propagated position errors on the Azimuth and Elevation angles of a tracking antenna at a ground station.

The limited internet access in remote rural areas and during a disaster time causes the TLE not to be updated regularly. It will make the TLE used for tracking and communication expire. In this paper, the study will be conducted for an accuracy assessment of the Azimuth, Elevation, and Time data (AET) of the LAPAN-A2 satellite from actual and simulated results using outdated-TLE of 1, 3, 6, and 12 months to see how worthy these outdated-TLE data. Further, this study investigates how long since the epoch, the outdated are still suitable for use from the point of view of a tracking antenna at a ground station.

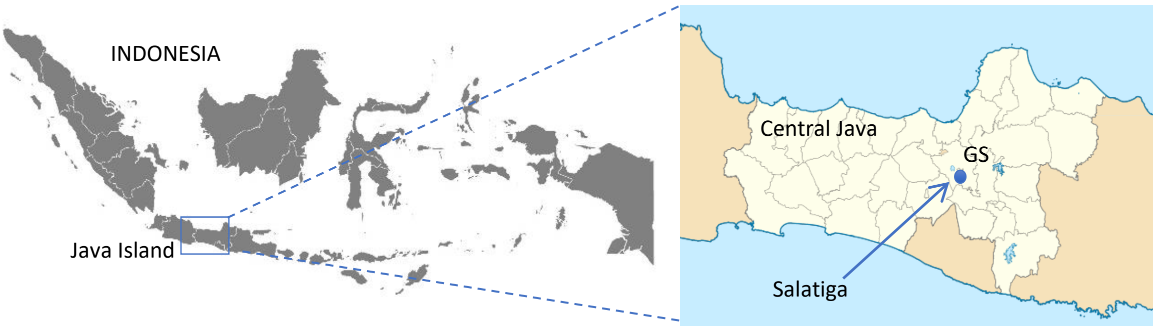


Fig. 1. Ground station (GS) location in Salatiga.

2. Materials and Methods

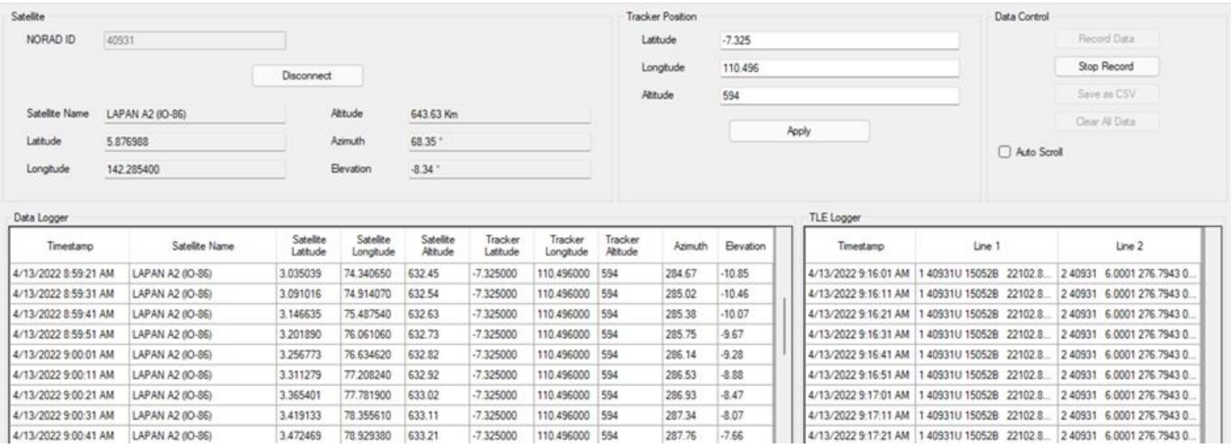
2.1 Satellite Monitoring Data

Having an equatorial orbit, LAPAN-A2 rises from the west and moves to the east from an observer on Earth. It has an altitude of 642 km above sea level. LAPAN-A2 revolves around Earth 14-15 times a day with intervals of 97.5 minutes, and each interval lasts for 700-800 seconds [11]. This study focused on the LAPAN-A2 Satellite being tracked by a ground station (GS) in Salatiga City, Central Java Province, Indonesia, as shown in Fig. 1.

2.2 Data Analysis

The results of real-time tracking data obtained are in the form of time (with hh:mm: ss format), LLA (Latitude Longitude Altitude) satellite, LLA (Latitude Longitude Altitude) ground station, AER (Azimuth, Elevation, Range) satellite to a ground station, and TLE of the satellite. As for the simulation results obtained from AGI STK (Analytical Graphics Inc. Systems Took Kit), the format is in the form of time (with format hh: mm: ss), LLA (Latitude Longitude Altitude) satellite, and AER (Azimuth, Elevation, Range) satellite to the ground station. Data monitoring in this study was based on real-time tracking satellite movement from www.n2yo.com server using updated TLEs; the data taken from this source will be represented by the label "real-time TLE" in which the data will be acquired for one month with a data recording interval of 10 seconds using API from NORAD and integrated with Python program to track the movement continuously.

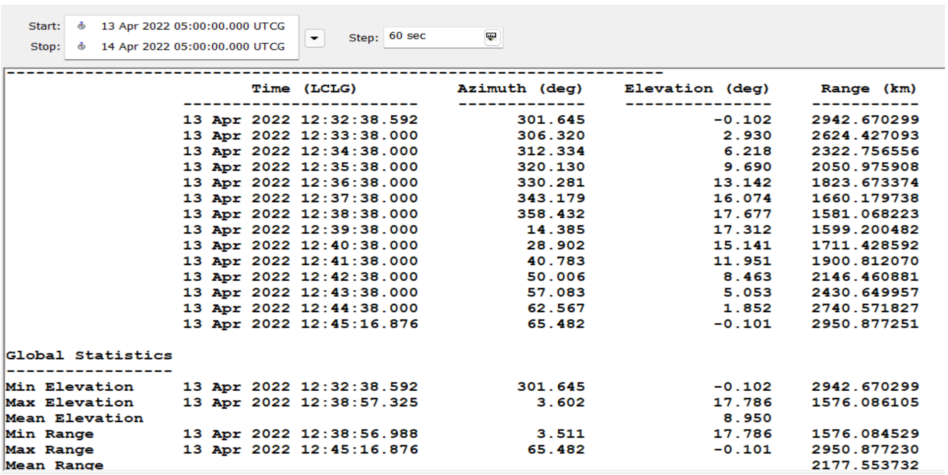
The first step in this study was to validate the AET data from AGI STK simulation using updated TLE to the real-time data given by n2yo.com. Further investigation was performed to quantify the pointing errors on AET data in four cases due to using outdated TLE for 1, 3, 6, and 12 months since the epoch. This study provided plots that compared the orbital tracking parameters, such as the plot of Azimuth and Elevation vs. Time and the plot of Azimuth vs. Elevation, including its polar plot within 24 hours.



Timestamp	Satellite Name	Satellite Latitude	Satellite Longitude	Satellite Altitude	Tracker Latitude	Tracker Longitude	Tracker Altitude	Azimuth	Elevation
4/13/2022 8:59:21 AM	LAPAN A2 (IO-86)	3.035039	74.340650	632.45	-7.325000	110.496000	594	284.67	-10.85
4/13/2022 8:59:31 AM	LAPAN A2 (IO-86)	3.091016	74.914070	632.54	-7.325000	110.496000	594	285.02	-10.46
4/13/2022 8:59:41 AM	LAPAN A2 (IO-86)	3.146635	75.487540	632.63	-7.325000	110.496000	594	285.38	-10.07
4/13/2022 8:59:51 AM	LAPAN A2 (IO-86)	3.201890	76.061060	632.73	-7.325000	110.496000	594	285.75	-9.67
4/13/2022 9:00:01 AM	LAPAN A2 (IO-86)	3.256773	76.634620	632.82	-7.325000	110.496000	594	286.14	-9.28
4/13/2022 9:00:11 AM	LAPAN A2 (IO-86)	3.311279	77.208240	632.92	-7.325000	110.496000	594	286.53	-8.88
4/13/2022 9:00:21 AM	LAPAN A2 (IO-86)	3.365401	77.781900	633.02	-7.325000	110.496000	594	286.93	-8.47
4/13/2022 9:00:31 AM	LAPAN A2 (IO-86)	3.419133	78.355610	633.11	-7.325000	110.496000	594	287.34	-8.07
4/13/2022 9:00:41 AM	LAPAN A2 (IO-86)	3.472469	78.929380	633.21	-7.325000	110.496000	594	287.76	-7.66

Timestamp	Line 1	Line 2
4/13/2022 9:16:01 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:16:11 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:16:21 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:16:31 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:16:41 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:16:51 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:17:01 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:17:11 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...
4/13/2022 9:17:21 AM	1 40931U 15052B 22102.8...	2 40931 6.0001 276.7943 0...

Fig. 2. Satellite real-time tracking data from n2yo.com



	Time (LCLG)	Azimuth (deg)	Elevation (deg)	Range (km)
	13 Apr 2022 12:32:38.592	301.645	-0.102	2942.670299
	13 Apr 2022 12:33:38.000	306.320	2.930	2624.427093
	13 Apr 2022 12:34:38.000	312.334	6.218	2322.756556
	13 Apr 2022 12:35:38.000	320.130	9.690	2050.975908
	13 Apr 2022 12:36:38.000	330.281	13.142	1823.673374
	13 Apr 2022 12:37:38.000	343.179	16.074	1660.179738
	13 Apr 2022 12:38:38.000	358.432	17.677	1581.068223
	13 Apr 2022 12:39:38.000	14.385	17.312	1599.200482
	13 Apr 2022 12:40:38.000	28.902	15.141	1711.428592
	13 Apr 2022 12:41:38.000	40.783	11.951	1900.812070
	13 Apr 2022 12:42:38.000	50.006	8.463	2146.460881
	13 Apr 2022 12:43:38.000	57.083	5.053	2430.649957
	13 Apr 2022 12:44:38.000	62.567	1.852	2740.571827
	13 Apr 2022 12:45:16.876	65.482	-0.101	2950.877251
Global Statistics				
Min Elevation	13 Apr 2022 12:32:38.592	301.645	-0.102	2942.670299
Max Elevation	13 Apr 2022 12:38:57.325	3.602	17.786	1576.086105
Mean Elevation			8.950	
Min Range	13 Apr 2022 12:38:56.988	3.511	17.786	1576.084529
Max Range	13 Apr 2022 12:45:16.876	65.482	-0.101	2950.877230
Mean Range				2177.553732

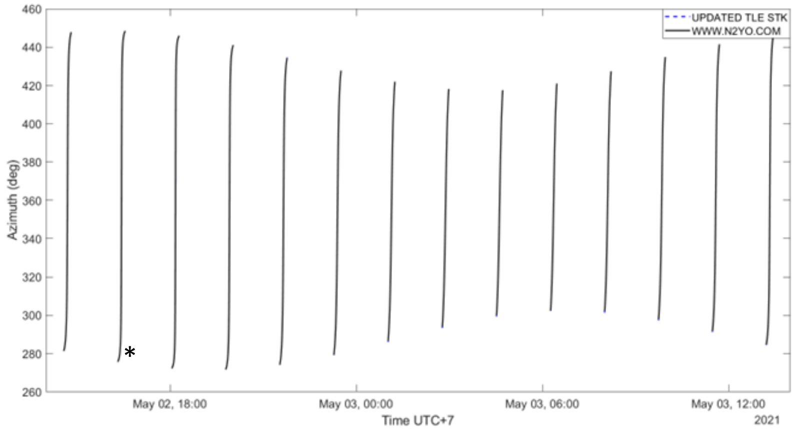
Fig. 3. Satellite tracking data resulting from simulation in AGI STK software.

3. Result and Discussion

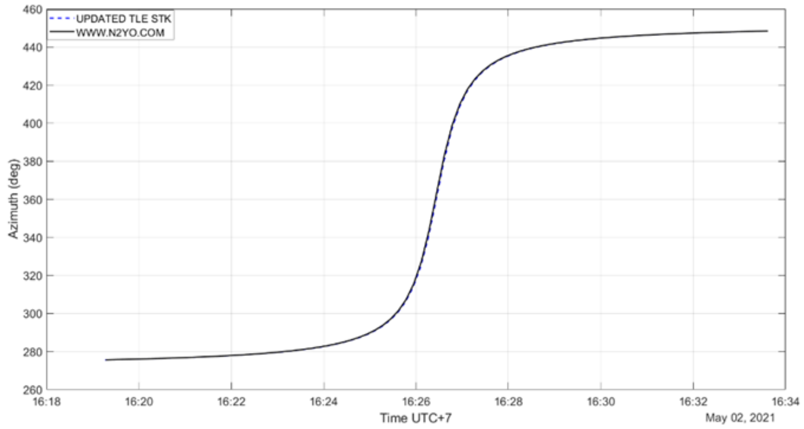
The real-time data acquisition of satellite movements was from May 2, 2021, at 14:34:57 until May 3, 2021, at 13:27:07. All simulation results from AGI STK software were compared to this real-time data acquisition. The simulation for the updated TLE used the data from n2yo.com, while the simulations for the outdated TLE used the data from space-track.com.

3.1 Real-time TLE vs. Simulated-updated TLE

A total of 14 passes were observed and analyzed, as shown in Figs. 4 - 6. Each pass lasts from 12 minutes to 14 minutes. Validation of AGI STK simulation compared to the data from n2yo.com resulted in the maximum propagation error for Azimuth, Elevation, and time of 6.5º, 1.8º, and 2 seconds consecutively. These errors are considered very small, so they can not be observed from the plots in Figs 4 – 7. The Azimuth and Elevation vs. Time for one pass were provided in Figs. 4b and 5b related to the pass noted as "*" in Figs 4.a and 5a. This one pass has a range of Elevation and Azimuth close to the maximum of 74º and 175º, respectively. It can be seen in Figs. 4a and 5a that the range of Azimuth and Elevation fluctuate with a period of nearly 25 hours, in which the smallest range for the Azimuth is around 120º while the smallest range for the Elevation is 16º. Figures 6 and 7 show that from the ground station's tracking antenna, the equatorial LAPAN-A2 satellite rises from the west and sets in the east.

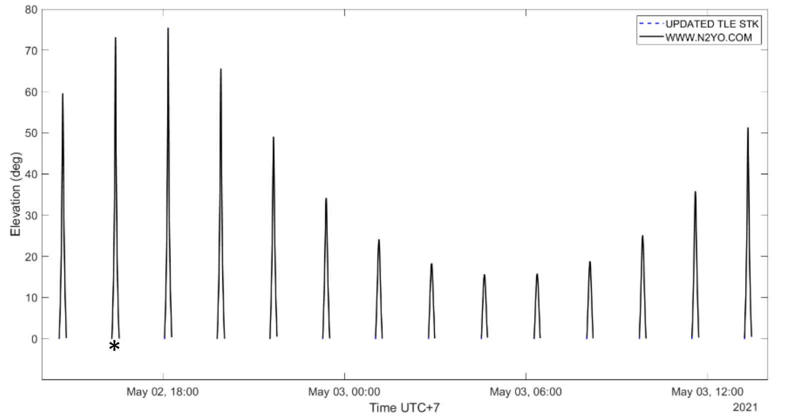


(a)

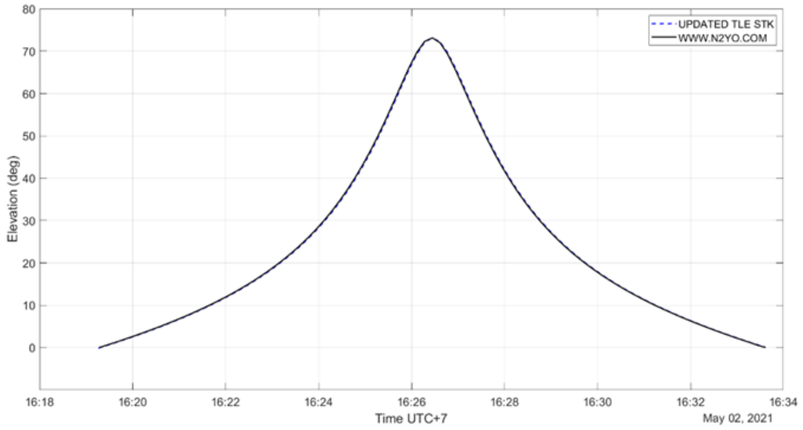


(b)

Fig. 4. Azimuth vs. Time plot data for real-time TLE and Simulated-updated TLE: (a) 14 passes, (b) one pass "*".



(a)



(b)

Fig. 5. Elevation vs. Time plot data for real-time TLE and Simulated-updated TLE: (a) 14 passes, (b) one pass "*."

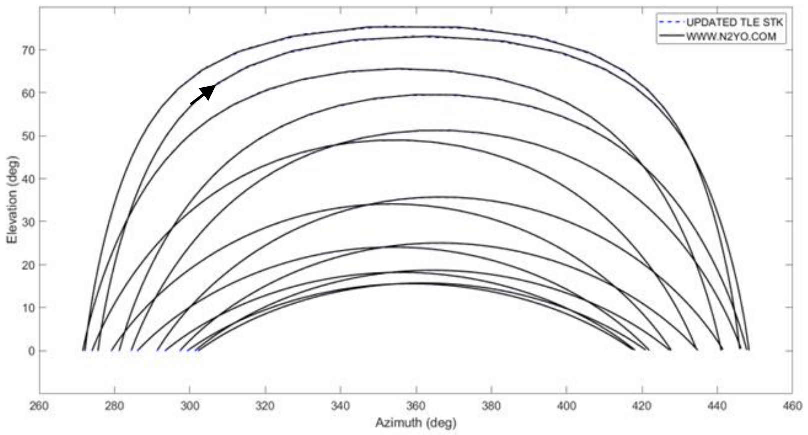
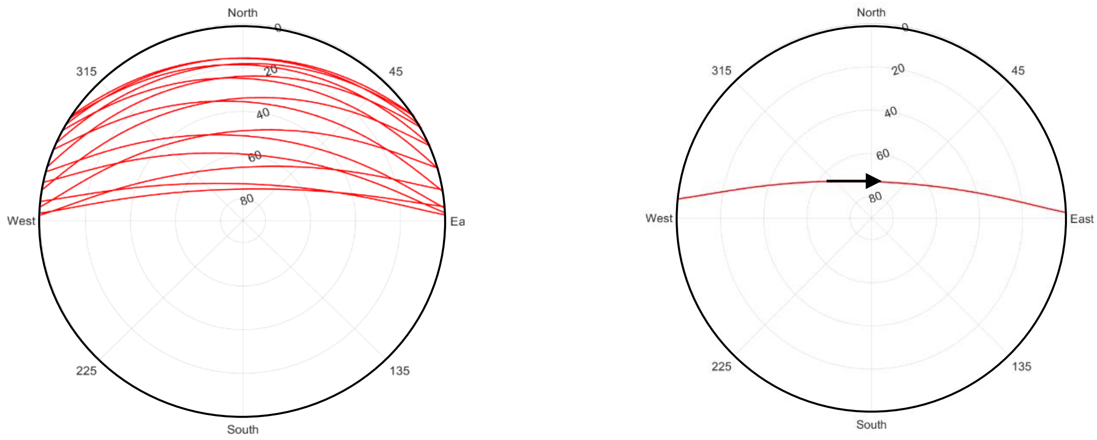


Fig. 6. Azimuth-Elevation plot data for real-time TLE and Simulated-updated TLE for 14 passes.
Note: " ➚ " shows the tracking antenna trajectory and direction for one pass "*" in Figs. 5b and 6.b

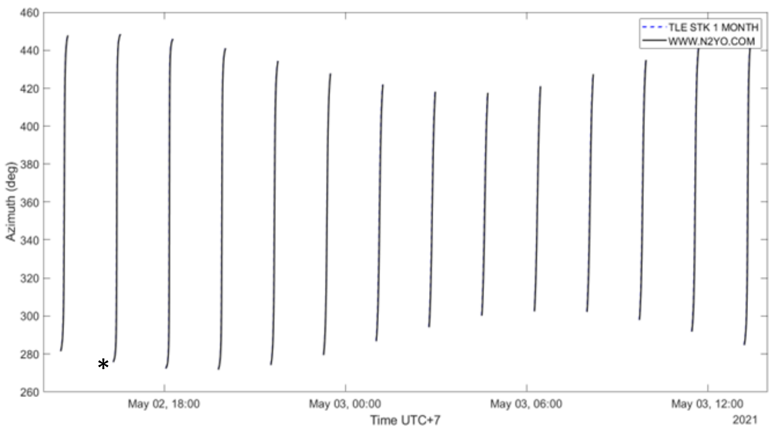


(a) (b)

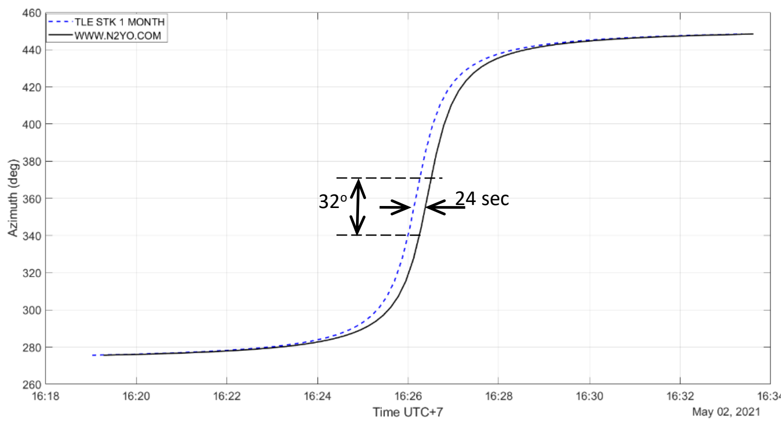
Fig. 7. Polar plot trajectory data for updated TLE: (a) 14 passes, (b) one pass "*".

3.2 Real-time TLE vs. Simulated one-month outdated TLE

Similar to the results of the simulated updated TLE, the simulated one-month outdated TLE has 14 passes, each lasting 12 minutes to 14 minutes, as shown in Figs. 8a and 9a. The pointing error of the Azimuth and Elevation can be seen in the one-pass plots shown in Figs. 8b and 9b. From the analysis, the maximum error for the Azimuth is 32º, the maximum error for the Elevation is 8º, and the error for time-lapse is 24 seconds. It can be seen that the pattern of satellite motion in all views of the Simulated one-month outdated TLE case, shown in Figs. 8-11 is the same as the pattern in the simulated-updated TLE case shown previously in Figs. 4-7.

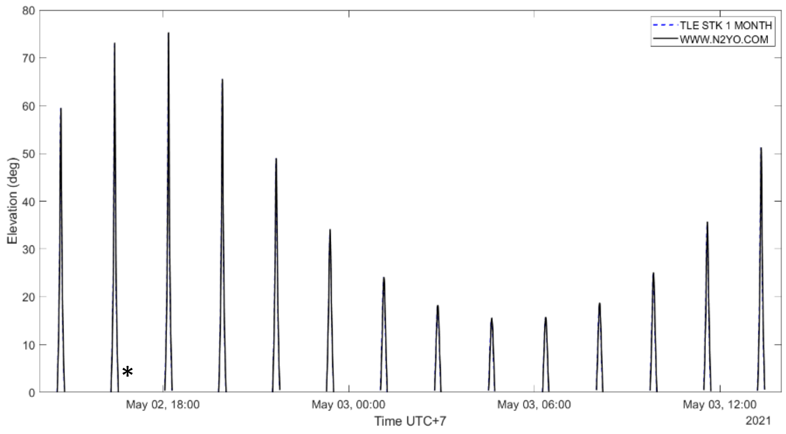


(a)

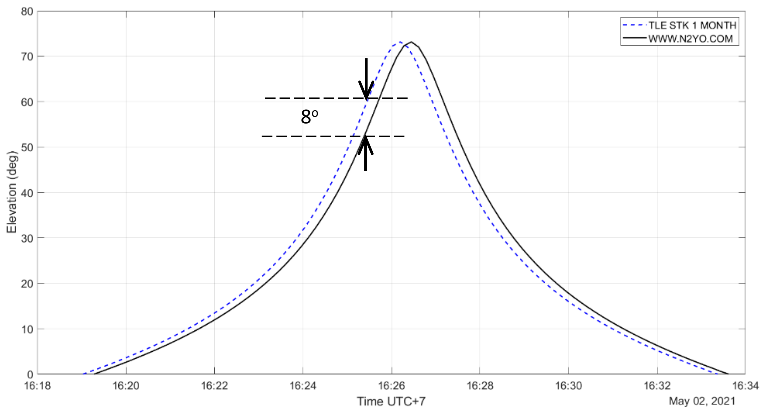


(b)

Fig. 8. Azimuth vs. Time plot data for real-time TLE and Simulated one-month outdated TLE:
(a) 14 passes, (b) one pass.



(a)



(b)

Fig. 9. Elevation vs. Time plot data for real-time TLE and Simulated one-month outdated TLE: (a) 14 passes, (b) one pass.

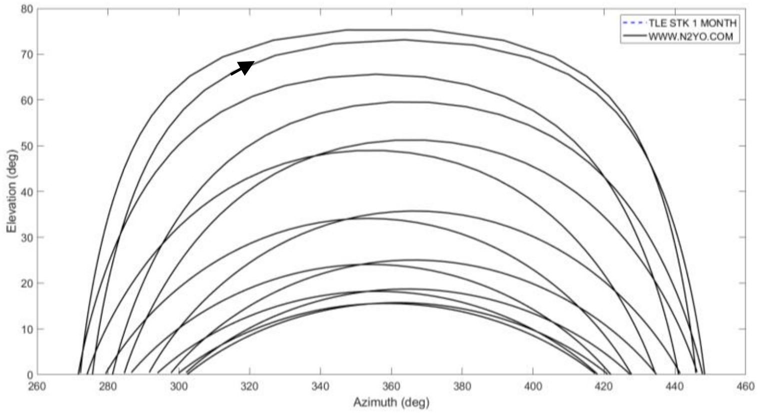
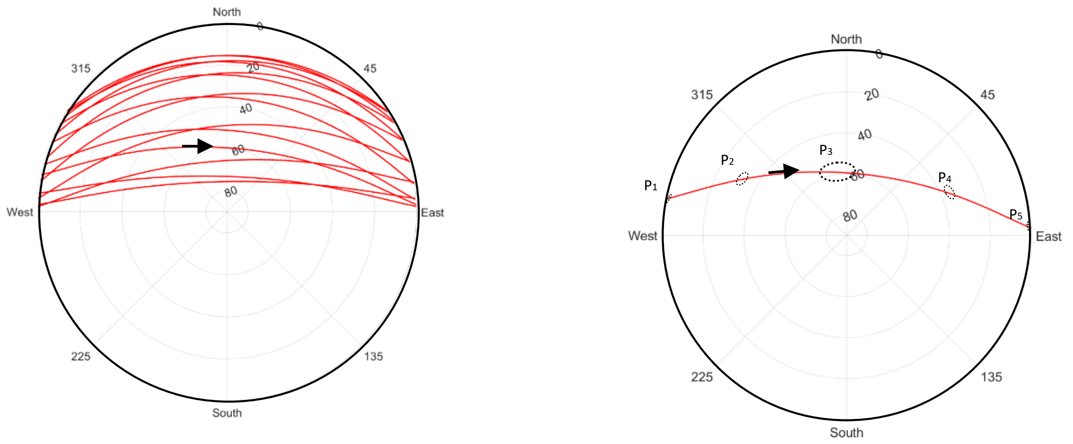


Fig. 10. Azimuth-Elevation plot data for real-time TLE and Simulated one-month outdated TLE for 14 passes. Note: " ➚ " shows the tracking antenna trajectory for one pass in Figs. 8b and 9b



(a) (b)

Fig. 11. Polar plot trajectory data for real-time TLE-Simulated one-month expired TLE: (a) 14 passes, (b) one pass.

The pointing errors of AET reach maximum when the Elevation approaches its peak, as shown in Figs. 8b and 9b. These propagation errors of AET can be viewed as a potential deviation from its actual trajectory, depicted as the size of ellipses P_1 to P_5 on the polar plot shown in Fig. 11b. This pointing error might not be significant enough to degrade the quality of communication between a ground station to the LAPAN-A2 satellite since it is still much less than the typical Half Power Beam Width (HPBW) angle of 50º to 70º for a directional antenna[8].

3.3 Real-time TLE - Simulated six-month outdated TLE

A procedure similar to that in section 3.2 was performed here to determine the propagation error of AET. The maximum errors for Azimuth, Elevation, and Time data are 167º, 7º, and 488 seconds, consecutively as shown in Figs. 12 and 13. The pattern of the Azimuth and Elevation trajectories here is still the same as the pattern for the updated simulated TLE. The propagation error of the Azimuth is considered significant. The pointing error will be much bigger than the typical HPBW angle; thus, the strength of the communication signal will be significantly reduced.

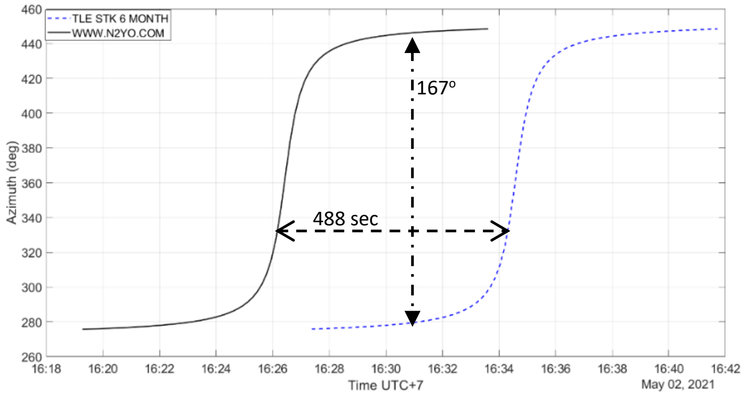


Fig. 12. Azimuth vs. Time plot data for real-time TLE-Simulated six-month outdated TLE for one pass.

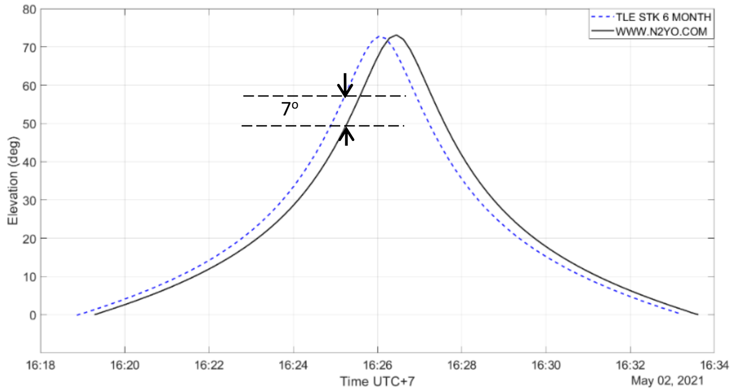
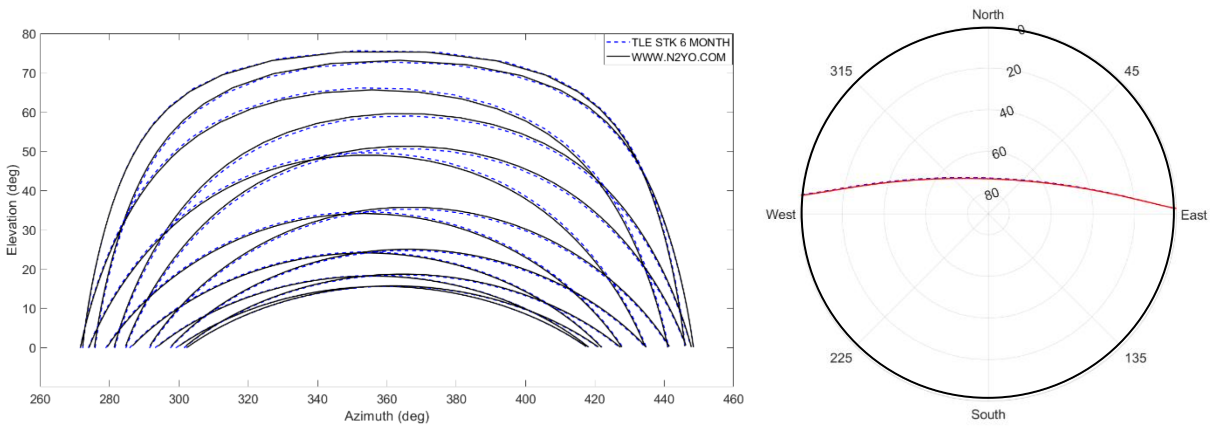


Fig. 13. Elevation vs. Time plot data for real-time TLE-Simulated six-month outdated TLE for one pass.



(a) (b)

(b)

Fig. 14. Data for real-time TLE vs. Simulated six-month outdated TLE: a) Time-Elevation plot for 14 passes, b) Polar plot for one pass

3.4 Discussion

The same procedure in sections 3.2 and 3.3 was further performed to investigate the maximum possible pointing errors for using three-month and twelve-month outdated TLEs. The results of the investigation are summarized in Table 2. It can be observed that the Azimuth error is dominant and keeps increasing as the TLE gets more outdated. The Elevation error does not vary much until the six-month outdated TLE compared to the Azimuth Error. The time-lapse error consistently becomes higher as the TLE gets more outdated. A further experimental study is needed to prove that the communication quality using a three-month outdated TLE is still good since its pointing error is still in the range of a typical HPBW angle. It can be concluded that TLE older than six months should not be used for tracking the LAPAN-A2 satellite. It should be noted that this study is limited only to the case of having a specific location of the ground station in Central Java province. Further analysis should be done for other areas in Indonesia.

Table 2. Pointing errors of tracking antenna using simulation results in AGI STK.

Evaluated parameter	**Updated TLE**	**Outdated TLE**			
		One-month	Three-month	Six-month	Twelve-month
Azimuth (deg)	6	32	38	167	>173
Elevation (deg)	2	5	8	7	> 73
Time-lapse (s)	2	24	35	488	1052

4. Conclusion

As demonstrated by this study, the reliability and precision of tracking LEO satellites, such as LAPAN-A2, greatly hinge upon the age and accuracy of the Two-Line Elements (TLE) being used. The various investigations conducted, spanning from an updated TLE to a twelve-month outdated TLE, elucidated a clear pattern: as the age of the TLE increases, so does the pointing error for satellite tracking or deviation in satellite orbital properties, including Azimuth, Elevation, and Time-lapse. On the other hand, the outdated one- to three-month TLE offers a promising substitute for real-time tracking in pressing scenarios. Its results, bearing only slight deviations from the updated TLE, indicate that it could serve as an interim solution in emergencies or when access to the latest TLE data is unavailable. However, as the TLE age extends to three or six months, the growing gaps in accuracy become progressively evident. In essence, relying on the most recent TLEs is imperative for satellite tracking applications demanding high precision. When situations necessitate the use of older TLEs, it becomes a trade-off between immediacy and accuracy, where the one-month TLE appears to strike a reasonable balance.

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