Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
2326-9865

Accuracy Assessment of SGP4 and TLE Orbital Information

Shashank Baghel
Department of Computer Science and Engineering
Shri Shankaracharya Institute of Professional Management and Technology
Raipur, India
shashank.baghel@ssipmt.com
Debasish Mohanty
Department of Computer Science and Engineering
Shri Shankaracharya Institute of Professional Management and Technology
Raipur, India
debasish.mohanty@ssipmt.com
Anand Tamrakar
Department of Computer Science and Engineering
Shri Shankaracharya Institute of Professional Management and Technology
Raipur, India
a.tamrakar@ssipmt.com
Tulsi Dewangan
Department of Computer Science and Engineering
Shri Shankaracharya Institute of Professional Management and Technology
Raipur, India
debasish.mohanty@ssipmt.com

Article Info
Page Number: 9675 - 9680
Publication Issue:
Vol 71 No. 4 (2022)

Article History
***Article Received**: 15 September 2022*
***Revised:** 25 October 2022*
***Accepted:** 14 November 2022*
***Publication:** 21 December 2022*

Abstract: — The Simplified General Perturbations (SGP) model began development back in the 1960s and the current industry standard relies completely on physics-based orbital mechanics. Because the orbit of the satellites is continuously affected by perturbation and space weather, etc that are difficult to predict, the TLE data needs to be updated regularly. Using the historical data set of TLE for a period of time we aimed to calculate the error and its efficiency of it. We have tested the 3 satellite objects with the corresponding TLE (Two-Line Element) data set which shows the average distance error for 10days out was up to ~100KM.
Keywords: simplified general perturbation, two-line element, hyper-spectral imaging satellite

Introduction

The Two-Line Element set (TLE) is maintained by NORAD and is publicly available and used for orbit information of space objects like satellites, space debris, etc in Earth orbits, accurate satellite orbit prediction is very important for space missions, for space situational awareness and collision avoidance. To predict the orbit of an object we need to implement the orbital propagation through the Simplified General Perturbation Model 4 with a Two-Line Element (TLE) data set.

The first release of source code for the SGP4 propagator was Spacetrack Report Number 3 (Hoots and Roehrich, 1980). [4], The Spacetrack Report Number 3 introduced SGP, SGP4, SDP4, SGP8 and SDP8 to the user community. The current industry standards use SGP4/SDP4. All these are compatible with the TLE data set which is provided by NORAD (North American Aerospace Defense Command).

Two-Line Element Sets are frequently used to determine the orbital trajectories of space debris and spacecraft. The precision of TLEs varies with the age of their issuance and the position of the satellite, and therefore offer somewhat sloppy parameters for fine orbit computation.

When using the SGP, SGP4, SDP4, SGP8, and SDP8 simplified perturbation models for the satellite state vector calculations, the TLEs then become a standard data source [4]. TLE statistics have been made available by the US government since 1970 and are calculated by a Space Surveillance Network (SSN).

The TLE elements are widely used for many purposes, such as steering setup of the antennas for communication with small satellites, space experiment planning, and processing and interpretation of scientific data measured by small satellites.

I. Literature Review

The TLE elements are widely used because the satellites' TLE is publicly available, for example in [11], and because many professional and semi-professional software packages [6] or source codes exist for Matlab, C, FORTRAN, etc. [7]. But we have used the most updated and ported python version of sgp4 [5]. Two-line element sets (TLEs), which are made available to the public by the Joint Space Operations Center (JSpOC), are the main technique of orbit determination for many small satellite operators. A satellite identification, an epoch, six orbital components, and a B* term associated with the ballistic coefficient make up a two-line element. The Standard General Perturbations 4 (SGP4) model, which is also made accessible to the general public 1, 2, is intended for use with TLEs.

II. Methodology

A. *TLE dataset*

Since many years ago, the TLE catalogue has been made available to the public, first via NASA and most recently via the www.space-track.org website. In addition, Celestrak (http://www.celestrak.com) has long maintained a website where users can access the TLE catalogue. Our TLE data set was requested from the celestrak which is from September 2022 to October 2022 and used to calculate the distance error in SGP4 propagation.

For research, we used KALAMSAT (NORAD ID: 43948) and HySIS (Hyper-Spectral Imaging Satellite NORAD ID: 43719) which is an Earth Observation satellite by the Indian space research organisation.

B. *setup*

Now, to calculate the distance error for an object we take the TLE data set for that object for time T_0 with that we predict the position of the object for the next day at time S_0 and then we take a new updated TLE data set of the same day and time T_1 of the object that we are predicting the position of and calculate the position at time S_1 of an object with the updated TLE.

We used the TLE of Sept 1 2022, to predict the position for Sept 2 2022, and the TLE of Sept 2 2022, to predict the position for Sept2, 2022. These calculations are done for the next 10-days for both NORAD ID 43984 and NORAD ID: 43719.

Figure 1 demonstrates the distance error of 1 day out for the next 10 days of time period for kalamsat (NORAD ID: 43984)

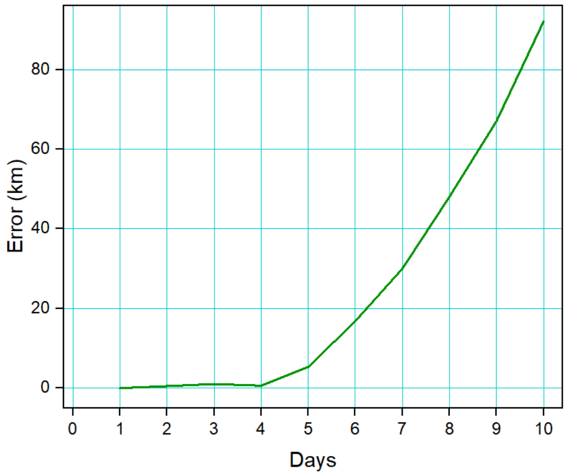

Fig. 1.10 days distance error of KALAMSAT (NORAD ID: 43719)

Figure 2 demonstrates the distance error of 1 day out for the next 10 days of the period for kalamsat (NORAD ID: 43984)

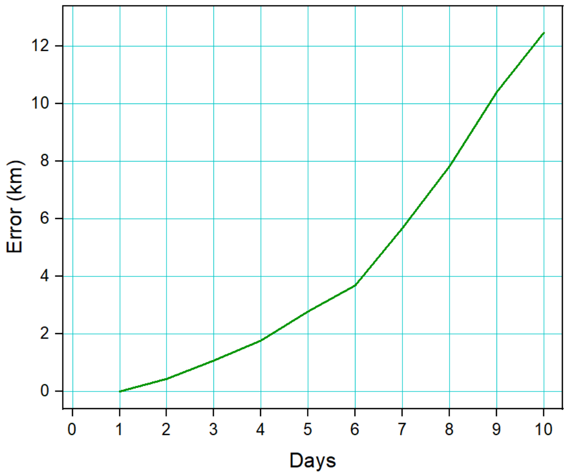

Fig. 2.10 days distance error of HySIS (NORAD ID: 43719)

We also calculated the average distance error for 10 days out error for both objects. We used the data from Sept 1 2022 to Oct 1 2022 for 1 day out to 10 days out.

Figure 2 demonstrates the distance error of 1 day to 10 days out from Sept 1 2022 to Oct 1, 2022, of the period for kalamsat (NORAD ID: 43984)

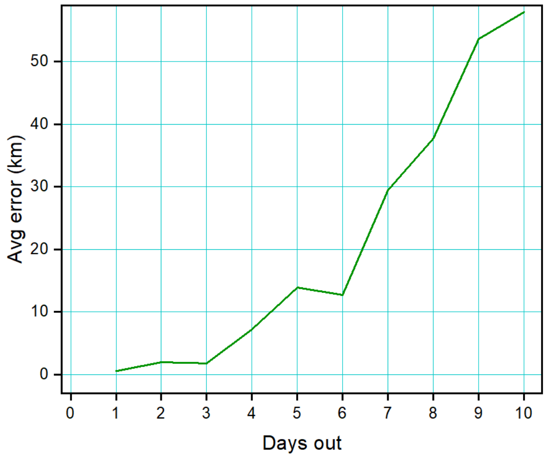

Fig. 3. Average distance error from 1 day out to 10 days of KALAMSAT (NORAD ID: 43984)

Figure 2 demonstrates the distance error of 1 day to 10 days out from Sept 1 2022 to Oct 1, 2022, of the period for kalamsat (NORAD ID: 43984)

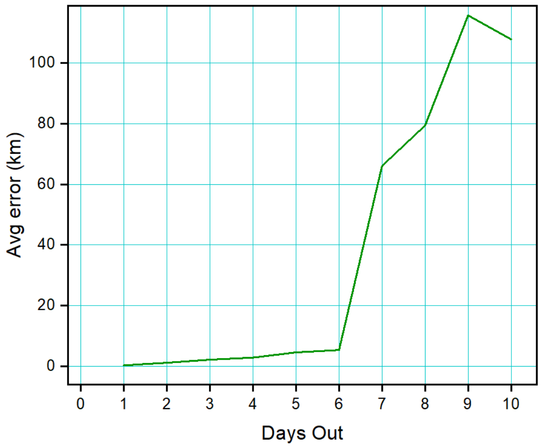

Fig. 4. Average distance error from 1 day out to 10 days of HySIS (NORAD ID: 43719)

Fig. 5.

III. Results

The following are the result data that we obtained from our research

TABLE I. Result

	KALAMSAT NORAD ID: 43984	HySIS NORAD ID: 43719
2 day out avg distance error	1.9546666666667	1.1416666666667
4 day out avg distance error	7.2113333333333	2.8363333333333
6 day out avg distance error	12.694133333333	5.3653333333333
8 day out avg distance error	37.693333333333	79.466666666667

10 day out avg distance error	57.903333 333333	107.86666 666667

IV. Accuracy

According to Hartman (1993) [9], "trust" in SGP4 propagation could only be assured for a short period of time. This result was reached after looking at a number of satellites in various orbital classes. When the propagation error was greater than 25 kilometers, TLEs were used to make the determination (compared to future TLE values).

A comparable investigation using GPS satellites was carried out by Kelso (2007) [10]. He specifically addressed consistency and abutment checks of the ephemeris information, using the exact GPS ephemerides as a baseline. He discovered that the TLE data include potentially large biases and that different satellites' backwards and forwards propagation accuracies frequently vary.

Of course, the overall accuracy is constrained by the mathematical implementation. The precision is additionally constrained by the generation of TLEs (Orbit Determination).

V. Conclusion And Discussion

In this study, we showed that the orbital error of SGP4 with the TLE data set can increase drastically if not updated regularly. This is why the TLE data sets need to be regularly calculated and updated. The mathematics and source code used to forecast satellite positions were made public by the US Department of Defense (DoD) in SpaceTrack Report Number 3 more than 25 years ago [1].

The DoD's two-line element sets, which were readily accessible through NORAD and other agencies, were the only source of orbital data, therefore this code spread among customers that need precise results.

However, end users altered the code to fix how the equations were implemented and deal with uncommon situations that came up during operations. Numerous new versions and generated programmes outside the DoD incorporated these changes [1].

The publically accessible version of the original STR#3 code no longer corresponds to the version used by DoD to create the TLEs since the modifications made to it have not been made available to the public in their entirety. Fortunately, we were able to create a non-proprietary version that is, in our opinion, current and correct thanks to independent initiatives, technical publications, and source code [1].

References

[1] Vallado, David A., Paul Crawford, Richard Hujsak, and T.S. Kelso, “Revisiting Spacetrack Report #3,” presented at the AIAA/AAS Astrodynamics Specialist Conference, Keystone, CO, 2006 August 21–24

[2] Vallado, David A. and Paul Crawford, “SGP4 Orbit Determination,” presented at the AIAA/AAS Astrodynamics Specialist Conference, Honolulu, HI, 2008 August 18–21.

[3] Vallado, David A., and Paul J. Cefola. "Two-line element sets–practice and use." 63rd International Astronautical Congress, Naples, Italy. 2012

[4] Sherje, N. P., Agrawal, S. A., Umbarkar, A. M., Kharche, P. P., & Dhabliya, D. (2021). Machinability study and optimization of CNC drilling process parameters for HSLA steel with coated and uncoated drill bit. Materials Today: Proceedings, doi:10.1016/j.matpr.2020.12.1070

[5] Hoots, F. R. & Roehrich, R. L. (1980). Spacetrack Report No. 3: Models for propagation of NORAD element sets (). Aerospace Defense Center, Peterson Air Force Base.

[6] Brandon Rhodes and contributors (2012) python-sgp4 2.1. Retrieved from https://pypi.org/sgp4/

[7] Kelso, Vallado TLE Libraries: https://celestrak.com/software/vallado-sw.php/ (accessed on 31 October 2022).

[8] Kovář, P., Puričer, P., & Kovářová, K. (2022). Study of the Two-Line Element Accuracy by 1U CubeSat with a GPS Receiver. *Sensors (Basel, Switzerland)*, *22*(8), 2902. https://doi.org/10.3390/s22082902

[9] Riesing, K.M. (2015). Orbit Determination from Two Line Element Sets of ISS-Deployed CubeSats.

[10] Hartman, Paul G. 1993. Long-term SGP4 Performance. Space Control Operations Technical Note, J3SOM-TN-93-01. US Space Command

[11] Kelso, T.S. 2007. Validation of SGP4 and ICD-GPS-200 against GPS Precision Ephemerides. Paper AAS 07 - 127 presented at the AAS/AIAA Spaceflight Mechanics Meeting. January 2007. Sedona AZ.

[12] Kelso, T.S. TLE: https://celestrak.org/NORAD/archives/request.php (accessed on 31 October 2022).

[13] Sai Pandraju, T. K., Samal, S., Saravanakumar, R., Yaseen, S. M., Nandal, R., & Dhabliya, D. (2022). Advanced metering infrastructure for low voltage distribution system in smart grid based monitoring applications. Sustainable Computing: Informatics and Systems, 35 doi:10.1016/j.suscom.2022.100691

[14] Kelso, T.S. TLE Softwares. Available online: https://www.celestrak.com/software/satellite/sat-trak.php/ (accessed on 31 October 2022)