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IMPROVING SGP4 ORBIT PROPAGATION

Annatation. The review reflects a comparison between several studies on improving the orbit propagataion accuracy using space objects' TLE-elements. The study is done to identify a technique that can be applied to enhance the SGP4 model despite increasing the propagation span. The method used in this study is by comparing the techniques that have been used by other researchers for the orbit propagation model. From the review that has been done, a beta regression technique is found to be a suitable technique.

Introduction. The problem of improving the accuracy of satellite motion prediction is relevant for the tasks of determining their lifetime, predicting satellite collisions, cataloging small space debris, navigation, etc.

To solve this problem, physical approaches are mainly used, but they require complete information about the space object at the beginning of the trajectory and environment calculations, as well as data on the maneuvers of the object under study [1]. In all cases, such data is not complete or is not updated regularly, and current observational capabilities are limited or costly.

The need for accurate orbit propagation is identified to maintain the growth of catalogue objects, conducting assessments for collision prevention, handling of ongoing satellite missions that requiring orbital transmission which includes a wide range of accuracy and computational requirements.

Thus, the new solution of the orbit propagation needs to be derived to improve the current implementation despite its various challenges.

Major part. Several studies which represents different approaches to orbit propagation using TLE elements are investigated.

The mathematical approaches presented by the Taylor and Gauss series, polynomial chaos, transition tensors (STT) are not resistant to the influence of perturbations of Earth's gravity, atmospheric resistance and are not suitable for long-term forecasting [2]. In this regard, analytical and semi-analytical approaches are more promising in the description of uncertainties and perturbations [2].

In turn, machine learning methods make it possible to make predictions without explicit modeling of space objects and the space environment. Instead, models are trained based on observable data. There are three types of machine learning: un/supervised learning and reinforcement learning. Among these types, the best one in improving the quality of forecasting is supervised learning, as it allows you to use statistics and information about measurement errors, etc.

Hybrid methods combine classical integration with forecasting techniques based on statistical models of time series or training methods. They allow you to see the difference between the integrated approximate solution and the real picture. They can also be used to refine the analytical approach or optimize the use of computing resources [2].

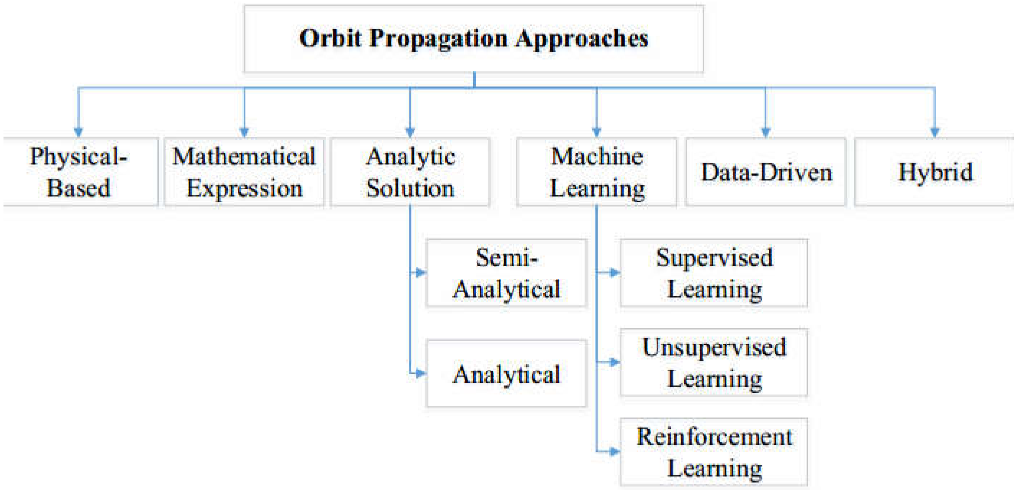

Figure 1 - Various methods for orbit determination

The only open source of initial orbital data for solving the problem under consideration are double-row elements (TLE), regularly and quickly updated on the site of the American Outer Space Control System (SCSC) [3]. The values of the orbit parameters contained in TLE files are calculated using averaging within the framework of specific SGP4 or SDP4 models. TLE elements and the SGP4 model are widely used to predict the trajectories of space objects with an approximate accuracy of several tens of kilometers for a period of 2-3 days. The trajectories constructed in SGP4 are defined in the TEME coordinate system and include the Earth's gravitational potential up to 5 orders of magnitude, a neutral exponential atmosphere, and partially simulated effects of the third body [3].

In some works, the Runge-Kutta method is used to solve nonlinear equations. In [4], a fixed step was applied in the case of a highly elliptical orbit. This method reduces the amount of computation for large time steps, but is complex and rarely used. To combat these shortcomings, Gauss-Legendre quadratures are used, which offer a various time step and improve resistance to disturbances compared to the classical method. However, they require the setting of certain user parameters [5].

Kamel’s theory and Draper’s semi-analytic satellite theory (DSST) were also used to improve orbit determination [6]. These theories are used to compare the accuracy of certain propagators with the "true", calculated numerically, trajectory. In 2016, DSS theory was used as a propagator for a catalog of space objects [7]. The simulation results show that the DSS theory provides a balance between the accuracy of the prediction and the time spent on the calculation, reducing the latter by 70-90% while maintaining the necessary forecast accuracy. However, this approach is rather complicated and is suitable only for certain types of orbits [7].

Various machine learning methods and hybrid methods are quite successfully used in solving problems of calculating and predicting the motion space objects, among them neural network methods, Kalman filter and support vector method (SVM). In [8], a neural network was used to increase the accuracy of the analytical propagator. As a result, the combination of both methods reduces the position error and increases the accuracy of prediction. In [9], the main emphasis was placed on data mining and extraction of historical data on unknown disturbances using the extended Kalman filter. The technique has improved filtering and prediction efficiency, but only for spacecraft in low Earth orbits.

An approach based on distributed regression and transitional machine learning underlies the publication [10]. The result shows superiority over the extended Kalman filter. In addition, the method is able to evaluate significantly changing parameters of the orbit.

The support vector method in [11] significantly increases the accuracy of the orbit propagation. Model training with additional information improves model performance. However, its disadvantage lies in the limited time interval for forecasting, the need to update parameters, and the inability to work with huge data arrays [11].

In [12–14], Keplerian orbital elements are used as initial estimates of TLE taking into account differential corrections and nonlinear least squares methods. In [15], a Kalman filter is used to evaluate TLE elements using GPS data. Computational methods, search for values and speeds of initial estimates of TLE elements. Methods such as genetic algorithms [16] and IWO optimization [17] do not require an initial TLE estimate, but they are reported to be computationally expensive because they seek a global optimum. Key error indicators are predicted. objects: in [5] the absolute errors of predictions in the RSW coordinate system are determined to be 7.55, 17.23 and 23.04 km. for a period of 7 days, in [6], the minimum absolute error indicator that a neural network provides is 0.1 km. for a period of 7 days, in [10] the average absolute error indicator predicted for a period of 8 days is 0.5 km.

In [11], models based on the genetic algorithm (GA), particle method (PSO), internal point method (IPM), and Kalman filter (KF) were compared. All methods showed approximately the same standard deviations. 1.

Table 1

Values of standard deviations of models constructed by various methods for the Worldview-3 satellite

	KF		IPM		PSO		GA	
	Est.	Error	Est.	Error	Est.	Error	Est.	Error
n (rev/day)	14.848537	0.1115E-5	14.848187	0.3479E-3	14.833516	0.1502E-1	14.736968	0.1116
e	0.0001217	0.5376E-8	0.0001179	0.3846E-5	0.0054721	0.5350E-2	0.0072093	0.7087E-2
i (deg)	97.8683	0.1051E-5	97.8683	0.2289E-4	97.8938	0.0256	97.8485	0.0198
ω (deg)	78.2273	0.0245	71.4915	6.7111	190.2303	112.0276	315.3991	237.1964
Ω (deg)	293.0619	0.1060E-6	293.0619	0.4106E-5	293.0657	0.3760E-2	293.0568	0.5074E-2
θ (deg)	281.9086	0.0245	288.6433	6.7101	169.8368	112.0964	66.2337	215.6994
B^*	0.1100E-4	0.3703E-5	-0.995E-5	0.1725E-4	0.5383E-2	0.5376E-2	0.9226E-2	0.9219E-2

The data in the table show that forecasting methods based on the filter method provide a more accurate estimate. The SGP4 method uses the average anomaly during the calculation of orbits and the conversion of velocity and position vectors. For the same reason, an error in the assessment.

Conclusion. As a result, there are two main approaches to assessing TLE elements in the literature: machine-expensive methods for searching global optics and methods for searching local optics. The developed autoregressive models [18] provide alternative, less machine-costly methods for improving forecasts, and their expected errors do not exceed the error rates presented above the models.

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Огляд моделей поліпшення якості прогнозування руху космічних об'єктів із застосуванням TLE-елементів

Робота відображає порівняння декількох досліджень щодо пыдвищення точністі прогнозування орбіт із застосуванням TLE-елементів космічних об'єктів. Суть дослідження полягає у визначенні методу, який може бути застосований для вдосконалення моделей прогнозування SGP4 протягом тривалого періоду, шляхом порівняння методів, які були використані іншими дослідниками для моделей прогнозованих орбіт. За результатами проведеного огляду пропонується застосування бета-авторегрессійних моделей в якості альтернативних методів покращення якості прогнозування.

Improving SGP4 propagation

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