UDC 519.25:681.5

O. P. Sarychev

Detection of changes in the motion of Earth-orbiting objects by autoregressive models in conditions of non-equidistant observations

Institute of Technical Mechanics
of the National Academy of Ukraine and the State Space Agency of Ukraine
15 Leshko-Popel St., Dnipro 49005; e-mail: alexsar2021@gmail.com

The problem of increasing prediction accuracy for the motion of Earth-orbiting objects (EOOs) and detecting changes therein is topical for the tasks of spacecraft life prediction, space debris cataloguing, and navigation. Therefore, the problem of detecting changes in dynamic systems characterized by non-equidistant observations is topical. The purpose of this work is the development of autoregressive models with observations non-equidistant in time to detect changes in EOO motion.

The methods employed are multivariate statistical analysis, time series prediction, and complex-system simulation under structural uncertainty. Data generated by NORAD (USA) were used as initial observations to describe EOO motion. They are actual, constantly updated, and freely available via the Internet. These data are presented in the Two-Line Element (TLE) format, which is a data format encoding a list of orbital elements of an EOO for a given point in time. This paper presents a method for constructing autoregressive models to describe the dynamics of EOOs represented by time series of TLE elements with values non-equidistant in time. On its basis, autoregressive models of the Sich-2 spacecraft's dynamics were constructed. The standard errors of the models were analysed on examination samples, and significant deviations of the standard errors for the basic variables (apogee, perigee, eccentricity, longitude of ascending node, perigee argument, and average anomaly) were found, thus demonstrating changes in the Sich-2 motion from its basic regime.

The novelty of this work lies in that the problem of detecting changes in EOO motion characteristics based on the proposed type of autoregressive models has not been considered before. Its practical value lies in that the simulation of the Sich-2 motion using time series of TLE elements allows one to detect changes in motion regimes; the method may be used in detecting in-service changes in EOO properties.

Keywords: time series of TLE elements, non-equidistant observations, autoregressive models, Sich-2 spacecraft.

1. Gondelach D., Lidtke A., Armellin R., Colombo C., Lewis H., Funke Q., Flohrer T. Re-entry prediction of spent rocket bodies in GTO. URL: https://www.degruyter.com/document/doi/10.1515/astro-2020-0006/pdf

2. Kelecy T., Hall D., Hamada K., Stocker D. Satellite maneuver detection using two-line element (TLE) data. URL: https://amostech.com/TechnicalPapers/2007/Modeling_Analysis_Simulation/Kelecy.pdf

3. Nazarenko A. I. Errors in the Prediction of Satellite Motion in the Earth's Gravitational Field. Moscow: Space Research Institute of the Russian Academy of Sciences, 2010. 226 pp. URL: http://www.iki.rssi.ru/books/2010nazarenko.pdf . (in Russian).

4. Levit C., Marshall W. Improved orbit predictions using two-line elements. Advances in Space Research. 2011. V. 47. Pp. 1107-1115. https://doi.org/10.1016/j.asr.2010.10.017

5. Wen-yang Duan et al A hybrid AR-EMD-SVR model for the short-term prediction of nonlinear and non-stationary ship motion. Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering). 2015. V. 16(7). Pp. 562-576. https://doi.org/10.1631/jzus.A1500040

6. Nazarenko A. I. Space Debris Modeling. Moscow: Space Research Institute of the Russian Academy of Sciences, 2013. 216 pp.

7. Basseville M, Wilsky A., Benventiste A. et al. Detection of Changes in the Properties of Signals and Dynamic Systems. M. Basseville, A. Benveniste (Eds.). Moscow: Mir, 1989. 278 pp. (in Russian).

8. Lemmens S., Krag H. Two-line-elements-based maneuver detection methods for satellites in low Earth orbit. Journal of Guidance Control Dynamics. 2014. V. 37. Pp. 860-868.
https://doi.org/10.2514/1.61300

9. Nazarenko A. I. Application of the method for optimum filtering of measurements for determination and prediction of spacecraft orbits. Solar System Research. 2013, V. 47. No. 7. Pp. 564-568.
https://doi.org/10.1134/S0038094613070113

10. Borodkin L.I., Mottl' V. V. Algorithm for detecting instants of changes in random process equation parameters. Avtomatika i Telemekhanika. 1976. No. 6. Pp. 23-31. (in Russian).

11. Kartashev V. Ya., Novosel'tseva M. A. Dedection of structural-parametric changes in stochastic systems in real time using algorithms of continued fractions and structural analysis. Upravlenie Bolshimi Sistemami. 2011. No. 34. Pp. 62-91. (in Russian).

12. Blasques F., Koopman J., Lucas A. Nonlinear autoregressive models with optimality properties. URL: https://www.tandfonline.com/doi/pdf/10.1080/07474938.2019.1701807

13. Ding X., Zhou Z. Auto-regressive approximations to non-stationary time series, with inference and applications. URL: https://arxiv.org/pdf/2112.00693.pdf

14. Mirgorod V. F. Mathematical Models of Control of the Properties of Power Plants. D.Sc. Thesis. Dnipropetrovsk, 2012. 344 pp. (in Russian).

15. Sarychev A. P. Parameter identification of systems of autoregressive equations at known covariance matrices. Problemy Upravleniya i Informatiki. 2012. No. 3. Pp. 14-30. (in Russian).

16. Sarychev A. P. Monte Carlo study of an iterative procedure for the parameter identification of a system of autoregressive equations. System Technologies. 2014. No. 3 (92). Pp. 77-89 (in Russian).

17. Sarychev A. P. Linear autoregression based on the group method of data handling in conditions of quasirepeated observations. Artificial Intelligence. 2015. No. 3-4 (69-70). Pp. 105-123. (in Russian).

18. Sarychev A. P. Simulation in the class of systems of autoregressive equations under structural uncertainty. Problemy Upravleniya i Informatiki. 2015. No. 4. Pp. 79-103. (in Russian).

19. Sarychev A. P. Simulation of Complex Systems Under Structural Uncertainty: Regressive and Autoregressive Models. Saarbrücken: LAP LAMBERT Academic Publishing RU, 2016. 274 pp. (in Russian).

20. Sarychev O. P., Perviy V. A. Optimal regressors search subjected to vector autoregression of unevenly spaced TLE series. System Technologies. 2019. No. 2 (121). Pp. 95-110.

21. Sarychev O. P., Perviy B. A. Models of space object motion based on time series of TLE-elements. Teh. Meh. 2021. No. 1. Pp. 16-24. (in Ukrainian).
https://doi.org/10.15407/itm2021.01.051

22. NORAD Two-Line Element Set Format. URL: http://celestrak.com/NORAD/documentation/tle-fmt.asp

23. SICH 2 Satellite details 2011-044G NORAD 37794. URL: https://www.n2yo.com/satellite/?s=37794

24. Seber G. Linear Regression Analysis. Moscow: Mir, 1980. 456 pp. (in Russian).