

Adaptation of gas-dynamic characteristic arrays to automated ballistics support of spacecraft flight

Institute of Technical Mechanics

*of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine
15 Leshko-Popel St., Dnipro 49005, Ukraine; e-mail: office.itm@nas.gov.ua*

The current level of the design and use of new-generation spacecraft calls for a maximally automated ballistics support of engineering developments. An integral part of the solution of this problem is the development of an effective tool to adapt discrete functions of gas-dynamic characteristics to the solution of various problems that arise in the development and use of space complexes. Simplifying the use of bulky information arrays together with improving the accuracy of approximation of key coefficients will significantly improve the ballistics support quality. The aim of this work is to choose an optimum method for the approximation of a discrete function of two variable spacecraft aerodynamic characteristics. Based on the analysis of the advantages and drawbacks of basic methods of approximation by two fitting criteria: the maximum error and the root-mean-square deviation, recommendations on this choice were made. The methods were assessed by the example of the aerodynamic coefficients of the Sich-2M spacecraft's simplified geometrical model tabulated as a function of the spacecraft orientation angles relative to the incident flow velocity. Multiparameter numerical studies were conducted for different approximation methods with varying the parameters of the approximation types under consideration and the approximation grid density. It was found that increasing the number of nodes of an input array does not always improve the accuracy of approximation. The node arrangement exerts a greater effect on the approximation quality. It was established that the most easily implementable method among those considered is a step interpolation, whose advantages are simplicity, quickness, and limitless possibilities in accuracy improvement, while its significant drawbacks are the lack of an analytical description and the dependence of the accuracy on the grid density. It was shown that spline functions feature the best approximating properties in comparison with other mathematical models. A polynomial approximation or any approximation by a general form function provide an analytical description with a single approximating function, but their accuracy of approximation is not so high as that provided by splines. It was found that there exists no approximation method that would be best by all criteria taken together: each method has some advantages, but at the same time, it has significant drawbacks too. An optimum approximation method is chosen according to the features of the problem, the priorities in approximation requirements, the required degree of approximation, and the initial data organization method.

keywords: aerodynamic coefficients, approximation methods, multidimensional approximation, sampling method, polynomials, splines, fitting criteria, maximum and root-mean-square deviation, trigonometric function fitting.

1. Matusevich A. V. Computer-Aided Solid Modeling of Geological Objects. Moscow: Nedra, 1988. 184 pp. (in Russian).
2. Golubinsky A. N. Mathematical model of a speech signal based on spectrum approximation with a set of constant components in corresponding frequency bands. IT Security. 2009. No. 2. Pp. 12-18. (in Russian).
3. Demin A. V., Ivanov A. I., Orlov O. I. Guide on Mathematical Physiology. Fourier Series Approximation of Measurement Data. Part 4. Moscow: Slovo, 2012. 24 pp. (in Russian).
4. Lapshin E. V. Approximation methods for multivariable functions of aviation complexes. Reliability & Quality of Complex Systems. 2013. No. 4. Pp. 14-20. (in Russian).

5. Saleev D. V. Study of the possibility of experimental data approximation for the ion implantation of boron into silicon. *Fundamental Research*. 2014. No. 9-12. Pp. 2672-2676. (in Russian).
6. Kasheutov A. V., Boklag T. A. Informative properties of self-commutated inverter. Choice of a method of approximation of the phase current curve of a self-commutated inverter. *Electromechanical Energy Converters: proceedings of the VIIIth Scientific and Technical Conference*. October 14-16, 2015, Tomsk, Russian Federation. Tomsk: Tomsk Polytechnic University, 2015. Pp. 140-143. (in Russian).
7. Tsybulnik S. O., Lysikova K. O. Least-square function approximation. *Bulletin of Engineering Academy of Ukraine*. 2017. No. 1. Pp. 106-110. (in Ukrainian).
8. Lapshin E. V., Grishko A. K., Rybakov I. M. Multivariable function approximation methods as applied to flight simulators. *Reliability & Quality of Complex Systems*. 2018. No. 1 (21). Pp. 3-9. (in Russian).
9. Mustafina D. A., Burakova A. E., Mustafin A. I., Aleksandrova A. S. Generalized multidimensional least-square interpolation. *Bulletin of Perm National Research Polytechnic University. Electrotechnics, Informational Technologies, Control Systems*. 2018. No. 27. Pp. 30-48. (in Russian).
10. Ispulov A. A., Suntsov E. V., Ivanov S. L., Trushchinsky A. Yu. Choice of an experimental data approximation method. *Izvestiya TulGU. Tekhnicheskiye Nauki*. 2019. Iss. 3. Pp. 122-129. (in Russian).
11. Kataeva L. I., Maslennikov D. A., Mikhalev S. V., Kiseleva N. N. Search for optimum body flight regimes based on the approximation of CFD-simulation results. *Trudy NGTU im. R. E. Alekseeva*. 2019. No. 4 (127). Pp. 27-35. (in Russian).
12. Akant'ev M. S. Experimental data approximation by interpolation and extrapolation. *Smolenski Meditsinski Almanakh*. 2020. No. 1. Pp. 4-8. (in Russian).
13. *Radio Circuits and Signals. Problems*. Moscow: INFRA-M, 2003. 348 pp. (in Russian).
14. Popov V. P. *Circuit Theory Fundamentals*. Moscow: Vysshaya Shkola, 2003. 575 pp. (in Russian).

15. Nefedov V. I., Sigov A. S., Bityukov V. K., Khakhin V. I. Metrology and Radio Measurements. Moscow: Vysshaya Shkola, 2006. 526 pp. (in Russian).
16. Hryshchenko N. V., Semerikov S. O., Kharadzhan O. A., Chernov E. V. Comparative Analysis of Approximation Methods. Kryvyi Rih: KDPI, 1998. 25 pp. (in Ukrainian).
17. Nekrasov O. N., Mirmovich E. G. Data interpolation and approximation by exponential and trigonometric polynomials. Scientific and Educational Tasks of Civil Defense. 2010. No. 4. Pp. 23-32. (in Russian).
18. Markova I. A. Generalization of discrete data set approximation methods. Discrete and Continuous Models and Applied Computational Science. 2014. No. 2. Pp. 404-409. (in Russian).
19. Pakhnutov I. A. Multidimensional interpolation. Interactive Science. 2017. No. 5(15). Pp. 83-87. (in Russian).
<https://doi.org/10.21661/r-130275>
20. Golubinsky A. N. Methods of experimental data approximation and model construction. The Bulletin of Voronezh Institute of the Ministry of Internal Affairs of Russia. 2007. No. 2. Pp. 138-143. (in Russian).
21. Zadorin A. I., Zadorin N. A. Polynomial interpolation of a two-variable function with steep gradients in boundary layers. Uchenye Zapiski Kazanskogo Universiteta. Seriya Fiziko-Matematicheskie Nauki. 2016. V. 158. Book 1. Pp. 40-50. (in Russian).
22. Katrich S. A. Computational features of error minimization for Chebyshev node interpolation function approximation. Vestnik Taganrogskego Instituta imeni A. P. Chekhova. 2015. Pp. 67-72. (in Russian).
23. Petryanin D. L. Analysis of approximation accuracy improvement methods and a new refined model of approximation accuracy improvement. Reliability & Quality of Complex Systems. 2016. No. 3 (15). Pp. 96-102. (in Russian).
24. Tsybulnik S. A., Komenchuk I. E. Approximation of oscillatory processes in diagnostics engineering. International Journal "NDT Days". Bulgarian Society for NDT. 2019. V. II. Iss. 1. Pp. 48-57. (in Russian).
25. Dyakonov V. P. MATLAB 6.5 SP1/7+Simulink 5/6®. Basics of Application: Expert's Library. Moscow: SOLON-Press, 2005. 800 pp. (in Russian).
26. Dyakonov V. P., Abramenkova I. V. LAB. Signal and Image Processing: Handbook. Saint Petersburg: PITER, 2002. 564 pp. (in Russian).

27. Dyakonov V. P. MATLAB 6.5 SP1/7+Simulink 5/6 ® in Mathematics and Simulation. Basics of Application: Expert's Library. Moscow: SOLON-Press, 2005. 576 pp. (in Russian).
28. Porshnev S. V. Computer Simulation of Physical Processes in MathCad. Moscow: Goryachaya Liniya-Telekom. 2002. 252 pp. (in Russian).
29. Dyakonov V. P. Maple 9,5/10 in Mathematics, Physics, and Education: Library. Moscow: SOLON-Press, 2006. 720 pp. (in Russian).
30. Barten'ev O. V. FORTRAN for Experts. Mathematical Library IMSL (Part. 1). Moscow: DIALOG-MIFI., 2000. 448 pp. (in Russian).
31. Barten'ev O. V. FORTRAN for Experts. Mathematical Library IMSL (Part. 2). Moscow: DIALOG-MIFI, 2001. 320 pp. (in Russian).
32. Shumikhin A. G., Kondrashov S. N., Melkov D. A., Zorin M. P. Analytical review of works on problems in mathematical simulation, identification, and process control in the formalin production. PNRPU Bulletin. Chemical Technology and Biotechnology. 2017. No. 1. Pp. 7-36. (in Russian).
<https://doi.org/10.15593/2224-9400/2017.1.01>
33. Terekhin A. A., Dadenkov D. A. Review of asynchronous drive parameter identification methods. Bulletin of Perm National Research Polytechnic University. Electrotechnics, Informational Technologies, Control Systems. 2017. No. 22. Pp. 55-66. (in Russian).
34. Zhmako O. A., Golikov K. A., Chuprin E. N. Application of the least-squares method to physical-chemical analysis methods, Innovatsionnye Tekhnologii v Nauke i Obrazovanii. 2015. No. 3. Pp. 20-22. (in Russian).
35. Uteshev A. Yu., Tamaskin G. Sh. On the problem of polynomial interpolation with multiple nodes. Vestnik Sankt-Peterburgskogo Universiteta. Prikladnaya Matematika. Informatika. Protsessy Upravleniya. 2010. No. 3. Pp. 76-85. (in Russian).
36. Wen D. S., Wen H., Shi Y. G., Su B., Li Z. C., Fan G. Z. Use B-spline interpolation fitting baseline for low concentration 2, 6-di-tertbutyl p-cresol determination in jet fuels by differential pulse voltammetry. 2nd International Conference on New Material and Chemical Industry (NMC12017); 18-20 November, Sanya, 2017.
<https://doi.org/10.1088/1757-899X/292/1/012071>
37. Krepkogorsky V. L. On multidimensional interpolation methods. Izvestiya Vysshikh Uchebnykh Zavedenii. Matematika. 1999. No. 11. Pp. 41-49. (in

Russian).

38. Kalitkin N. N. Numerical Methods. Moscow: Nauka, 1978. 512 pp. (in Russian).

Received on October 21, 2021,
in final form on November 26, 2021

