

ANNOTATION

Dissertation work of Karymsakova Nurgul on the topic
"Development of controllability criteria for dynamic systems with limited control", submitted for the degree of Doctor of Philosophy (PhD) in the specialty
"6D070100 - Automation and control"

The relevance of the dissertation work. Many models of socio-economic, technical, political and other dynamic processes are described by a system of ordinary differential equations. The study of such systems often leads to problems of identification, controllability, and optimal control. In general, there are well-developed mathematical methods for solving the first and third problems. For example, the dynamic programming method, Pontryagin's method, Krotov's method give excellent results in the study of the problem of determining the optimal control of dynamic systems with limited control. Although, before solving the problem of optimal control, in general, it is first necessary to investigate the controllability of a dynamical system.

It should be noted that for studying the controllability of dynamical systems, there are some approaches based on estimating the reachability domain. But only for linear systems without control restrictions, the Kalman criterion is obtained, which solves the problem under study. Even for linear systems, but with restrictions on controls, there are no similar results that close the problem. Thus, the study of the controllability of dynamical systems with limited control is relevant from the point of view of theory and practical applications.

At the same time, a number of problems arise in the study of robotic systems: 1) obtaining the equations of a mathematical model of the dynamics of robotic systems, 2) automating the verification of controllability criteria conditions. It is known that obtaining a mathematical model of the motion dynamics of an n -link manipulator is based on the study of the Lagrange equation of the second kind. But the derivation of the equations of the mathematical model of the robot itself is a routine work, which consists of a lot of execution of various matrices, their inversions, and various replacements (redefinitions) of variables. All this requires scrupulous and lengthy work, the implementation of which can be performed by a specialized system of analytical calculations. Therefore, automation of obtaining a mathematical model of robotic systems is an urgent task.

The complexity of checking controllability criteria requires good specialized mathematical training for developers of various systems, which hinders the expansion of their application. Therefore, the automation of checking the conditions of the controllability criteria of the mathematical model of robotic systems is also an urgent task.

The purpose of the dissertation is to obtain new controllability criteria for linear and nonlinear dynamic systems described by ordinary differential equations. To achieve this goal, the following tasks are solved in the dissertation work.
1) development of controllability criteria for dynamic systems with limited control, described by linear ordinary differential equations;

- 2) development of controllability criteria for dynamic systems with limited control, described by nonlinear ordinary differential equations;
- 3) development of a library of procedures for automating the study of controllability of dynamic systems;
- 4) development of a library of interval procedures for the analysis of the controllability of robotic systems.

The scientific novelty of the dissertation work consists of:

- in the obtained (on the basis of interval mathematics) controllability criteria for linear dynamic systems with limited control;
- in the obtained (on the basis of interval mathematics) controllability criteria for nonlinear dynamic systems with limited control;
- in the developed system of analytical calculations, which allows to automate the derivation of equations of the mathematical model of robotic systems;
- in the developed library of interval procedures.

Research methods. The study used methods from the following fields of knowledge: mathematical control theory, decision theory, interval analysis, modern systems for designing and developing information systems.

The object of research of the dissertation work are dynamic systems.

The subject of research is mathematical models of the dynamics of dynamical systems.

The practical significance of the work lies in the development of an automation system for the derivation of equations describing the dynamics of robotic systems.

The scientific significance of the work lies, first of all, in automating the construction of mathematical models of robotic systems, the study of their controllability.

The applied value of the results of the work lies in the possibility of using an automation system for building mathematical models and studying their controllability in various industries and transport.

Defense provisions. Based on the results of the study, the following tasks were solved:

- the criterion of controllability of linear dynamic systems is obtained;
- a criterion for controllability of nonlinear dynamic systems has been obtained;
- developed a system for automated construction of mathematical models of robotic systems;
- developed a library of interval procedures.

The validity of the scientific provisions, conclusions and recommendations submitted for defense is confirmed by the correct use of the mathematical apparatus, the correct setting of experiments and their processing; qualitative and quantitative correspondence between the results of theoretical studies and experimental data; practical application of research results. The reliability of the conducted studies is confirmed by the correspondence of theoretical calculations and the results of experimental data obtained on the developed software, as well as their comparison with the results given in the scientific literature.

Connection of the topic with the plans of research programs

The dissertation work was carried out in accordance with the schedule of research grant works on priority: 3. Information, telecommunication and space technologies, scientific research in the field of natural sciences, on subpriority: 3.5 Methods and systems of information security and data protection. Technologies and software and hardware information protection on the project topic: 1.26 "Development of biometric methods and information protection tools" of the Institute of Information and Computing Technologies of the Committee of Science and the Ministry of Education and Science of the Republic of Kazakhstan.

The structure of the dissertation includes an introduction, 4 sections, a conclusion, a list of references and applications.

In the introduction, the substantiation of the relevance of the chosen topic of the dissertation work is given. The purpose, object, subject and tasks of the research work are formulated. The results of the conducted research are described, their scientific novelty and practical significance are shown. The data on approbation of the main results of the dissertation work are given.

The first section analyzes the global flow of scientific work in this area. Domestic and foreign scientists who have made a significant contribution to the development of basic methods for complex analysis are noted. The main tasks of the dissertation work are formulated.

The second section is devoted to the comparison of the new interval mathematics with the classical one, and their application to the study of controllability. On the basis of interval analysis, controllability criteria for linear and nonlinear dynamical systems are obtained.

The third section is devoted to the analysis of existing methods of solutions and the formulation of tasks for automating the derivation of equations of a mathematical model of robotic systems. The system of analytical calculations is implemented in the C++ language.

The fourth section is devoted to the description of the library of interval functions.

In conclusion, the main results and conclusions of the dissertation are presented.

Approbation of work. The results of the dissertation work were reported at international scientific conferences, annual scientific conferences of the Institute of Computing and Information Technologies, scientific conferences of young scientists and specialists of the Kazakh National University, as well as at scientific seminars of the Department of Artificial Intelligence and Big Data of Al-Farabi Kazakh National University. Conducted a foreign internship (Appendix A). Received 2 certificates of state registration of rights to the object of copyright (Appendix B).

Publications. On the topic of the dissertation, 15 printed works were published, including 9 in publications recommended by the KKSON MES RK, 2 papers in a journal included in the international citation database "SCOPUS"

Scientific publications:

1. Карымсакова Н.Т. Управляемость линейных систем с ограниченным управлением // Материалы международной конференции

студентов и молодых ученых «Фараби әлемі». – Алматы: Қазақ университеті, 2018. – 330 с.

2. Джомартова Ш.А., Карымсакова Н.Т., Исимов Н.Т., Зиятбекова Г.З., Мазакова А.Т. Программа перевода объемных изображений из PLY-формата в регулярную матрицу высот // Вестник Национальной инженерной академии РК. – 2018. – №3(69). – С.34-38.

3. Мазакова А.Т., Зиятбекова Г.З., Амирханов Б.С., Жолмагамбетова Б.Р., Карымсакова Н.Т. Комплекс программ трехмерной графики «3D-MAT» и его приложения // Вестник КазУТБ. – 2019. – № 1. – С.17-23.

4. Jomartova Sh.A., Nikulin V.V., Karymsakova N.T. Research of controllability of dynamical systems with constraints on control using interval mathematics // Вестник КазНУ, серия математика, механика, информатика. – 2019. – № 2(102). – С.63-80.

5. Алиаскар М.С., Айпанов Ш.А., Тусупова С.А., Карымсакова Н.Т., Амирханов Б.С. Биометрическая идентификация человека по отпечаткам пальцев // Материалы научной конференции ИИВ МОН РК «Современные проблемы информатики и вычислительных технологий» 1-4 июля 2019. – С.83-88.

6. Исимов Н.Т., Мазаков Т.Ж., Карымсакова Н.Т., Жолмагамбетова Б.Р., Зиятбекова Г.З. Оптимальное управление эпидобстановкой // Труды 14-й международной азиатской школы-семинара «Проблемы оптимизации сложных систем», Кыргызская Республика, Иссык-Куль. – 20-31 июля, 2018. – С.250-258.

7. Исимов Н.Т., Мазаков Т.Ж., Карымсакова Н.Т. Исследование модели прогнозирования и управления эпидобстановкой с применением нечеткого и интервального анализа // Научно-технический журнал «Вестник АУЭС», спец.выпуск. – 2018. – С.147-155.

8. Мазаков Т.Ж., Исимов Н.Т., Жолмагамбетова Б.Р., Карымсакова Н.Т., Ыдырышбаева М.Б. Об одном методе обработки экспертной информации // Материалы III международной научной конференции «Информатика и прикладная математика», часть 2. – Алматы. – 2018. – С.221-224.

9. Дасибеков Х.А., Дарибаева Г.Д., Карымсакова Н.Т., Жолмагамбетова Б.Р., Джомартова Д.Т., Мазакова А.Т. Применение программно-аппаратного комплекса психофизиологического тестирования для оценки нервно-психической устойчивости // Вестник КазУТБ. – 2019. – № 2. – С.12-21.

10. T. Zh. Mazakov, P. Kisala, Sh. A. Jomartova, G. Z. Ziyatbekova, N. T. Karymsakova. Mathematical modeling forecasting of consequences of damage breakthrough // News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences. – 2020. – Vol. 5, No 443. – pp. 116-124. // <https://doi.org/10.32014/2020.2518-170X.111> (Scopus, процентиль 26)

11. Ш.А. Джомартова, Н.Т. Карымсакова, А.Т. Турсынбай, Б.Р. Жолмагамбетова. Применение интервального анализа для управляемости

химического реактора // Вестник КазННТУ им. К.И. Сатпаева. – Алматы, 2020. – № 2(138). – С. 517-522.

12. Абдиев Б., Карымсакова Н., Сатыбалдина Д. Мақсатты шабуылдардан қорғау жөніндегі сынақ (тестілік) іс-шараларын жүргізу// Вестник КазННТУ им. К.И. Сатпаева. – Алматы, 2020. – № 3(139). – С. 189-198.

13. Джомартова Ш.А., Карымсакова Г.Н., Турсынбай А.С. Применение системы аналитических вычислений для вывода уравнений динамики робототехнических систем // Вестник КазАТК. – Алматы, 2020. – №2. – С. 207-213.

14. Ш. Джомартова, Н. Карымсакова, Б. Абдиев Критерий управляемости для следящей системы автоматического манипулятора// Вестник КазННТУ им. К.И. Сатпаева. – Алматы, 2020. – № 5(141). – С. 615-620.

15. Mazakov T., Wójcik W., Jomartova Sh., Karymsakova N., Ziyatbekova G., Tursynbai A. The Stability Interval of the Set of Linear System // INTL Journal of Electronics and Telecommunications. – 2021. – Vol. 67, N. 2. – P.155-161. DOI: 10.24425/ijet.2021.135958